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ICS Inside Climate Service

Missione 4 Istruzione e Ricerca

PROGETTO "ICSC" "National Centre for HPC, Big Data and Quantum Computing (HPC)" Codice progetto CN00000013, CUP C83C22000560007

ENGAGEMENT - ENHANCING CLIMATE CHANGE INFORMATION FOR INFRASTRUCTURE RISKS AND LAND SUITABILITY IN ITALY

Energy Systems and Extreme Weather Risk Assessment: lessons from the ENGAGEMENT project

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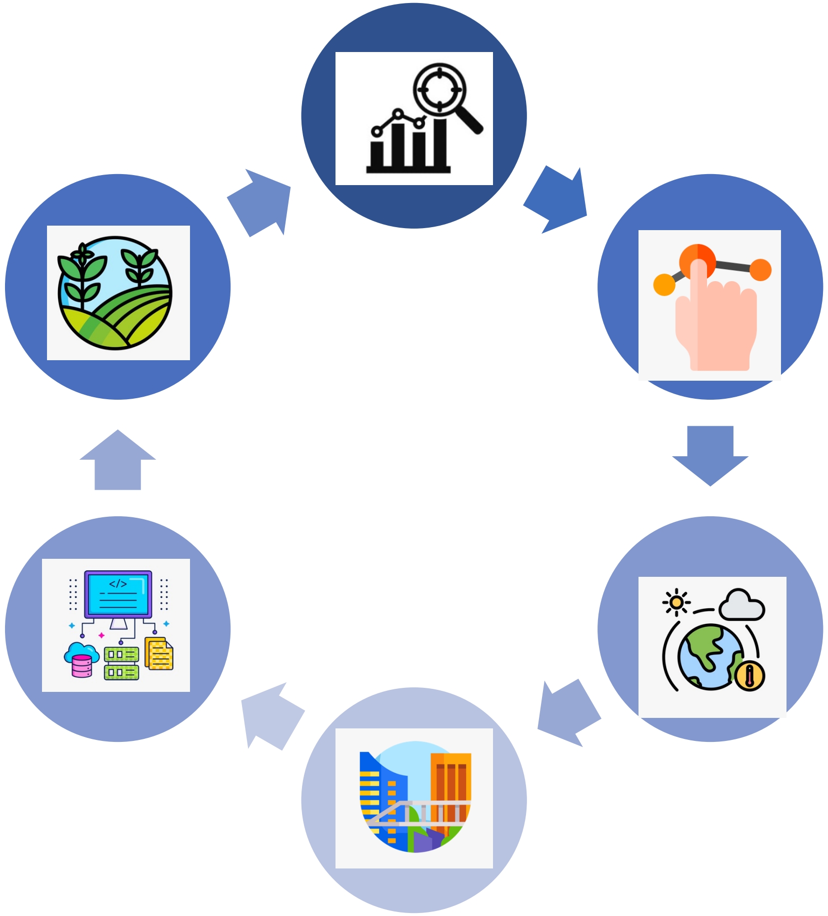
Project Overview

The ENGAGEMENT project aims to improve the accuracy and usability of climate data for assessing infrastructure risks and agricultural land suitability in Italy



Objectives and Activities

1. Improving the accuracy of climate models through advanced bias adjustments and downscaling techniques
2. Systematic assessment of climate change risks in relation to infrastructure
3. Evaluation of present and future land suitability conditions for agriculture
4. Development and implementation of an interactive web visualization tool
5. Promote collaboration and integration between disciplines and sectors

PROJ stream

Bias Adjustment of High-Resolution Climate Projections (RCPs 4.5 and 8.5)

Infrastructure Risk Analysis

Indicators based on matrix multiplication approach combining future extreme weather conditions (hazards) with infrastructure stress thresholds (exposure + vulnerability)

Land Suitability Analysis

Vulnerability curves for corn, wheat, soybeans, rice and grapes

Visualisation

Aggregated data by province for Northern Italy

Development of replicable and scalable methodological tools

SEAS stream

Downscaling and bias-adjustment of ECMWF and CMCC Seasonal Forecast Systems

Optimisation of Seasonal Forecast System through ML techniques

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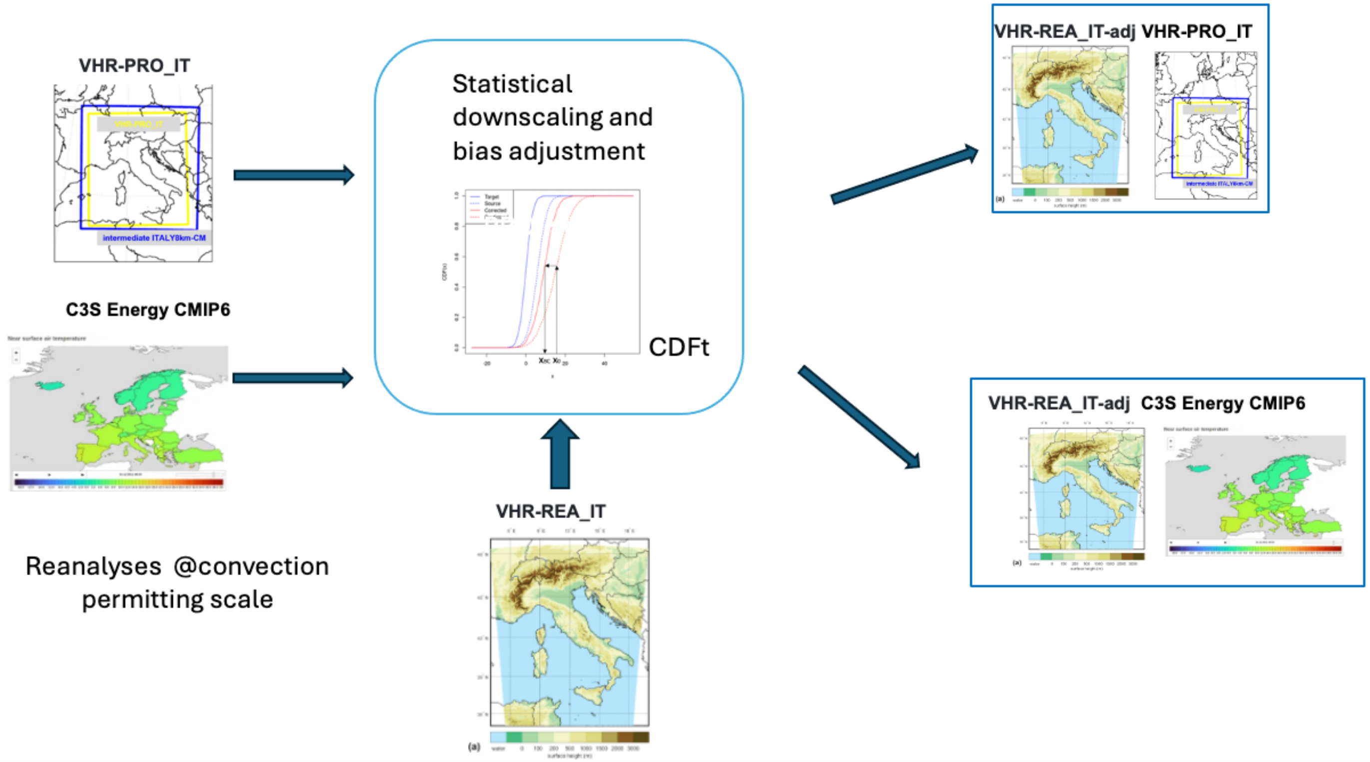
Workflow PROJ: statistical downscaling and bias-adjustment of climate projections for the infrastructure climate change risk assessment and future land suitability



Workflow PROJ: statistical downscaling and bias-adjustment of climate projections for the infrastructure climate change risk assessment and future land suitability

PROJ STREAM						
	Dataset	**Models**	**Spatial Resolution**	**Spatial Coverage**	**Temporal Resolution**	**Temporal Coverage**
Input datasets (projections)	VHR-PRO_IT	CMCC-CM+COSMO	2.2 km	Italy + surrounding	1 h	1981-2005 (historical) 2006-2070 (projection)
	CMIP6 C3S-Energy	various RCMs, ERA5-bias adjusted	25 km	Global	1h	1985-2005 (historical) 2015-2100 (projection)
Input datasets (reanalyses)	VHR-REA_IT	COSMO+ ERA5	2.2 km	Italy + surrounding	1 h	1989-2020
Methodology	Cumulative Distribution Function transform (CDFt)					
Output	Bias-adjusted VHR-PRO_IT methodology: CDFt; reference: VHR-REA_IT				1 h	2006-2070
	Downscaled bias-adjusted CMIP6 C3S-Energy; methodology: CDFt; reference: VHR-REA_IT				1 h	2015-2100

Raffa, M., Reder, A., Marras, G. F., Mancini, M., Scipione, G., Santini, M., & Mercogliano, P. (2021). VHR-REA_IT Dataset: Very High Resolution Dynamical Downscaling of ERA5 Reanalysis over Italy by COSMO-CLM. *Data*, *6*(8), 88. https://doi.org/10.3390/data6080088

Raffa, M., Adinolfi, M., Reder, A. *et al.* Very High Resolution Projections over Italy under different CMIP5 IPCC scenarios. *Sci Data* **10**, 238 (2023). https://doi.org/10.1038/s41597-023-02144-9

Michelangeli, P.-A., M. Vrac, and H. Loukos (2009), Probabilistic downscaling approaches: Application to wind cumulative distribution functions, *Geophys. Res. Lett.*, 36, L11708, doi:10.1029/2009GL038401.

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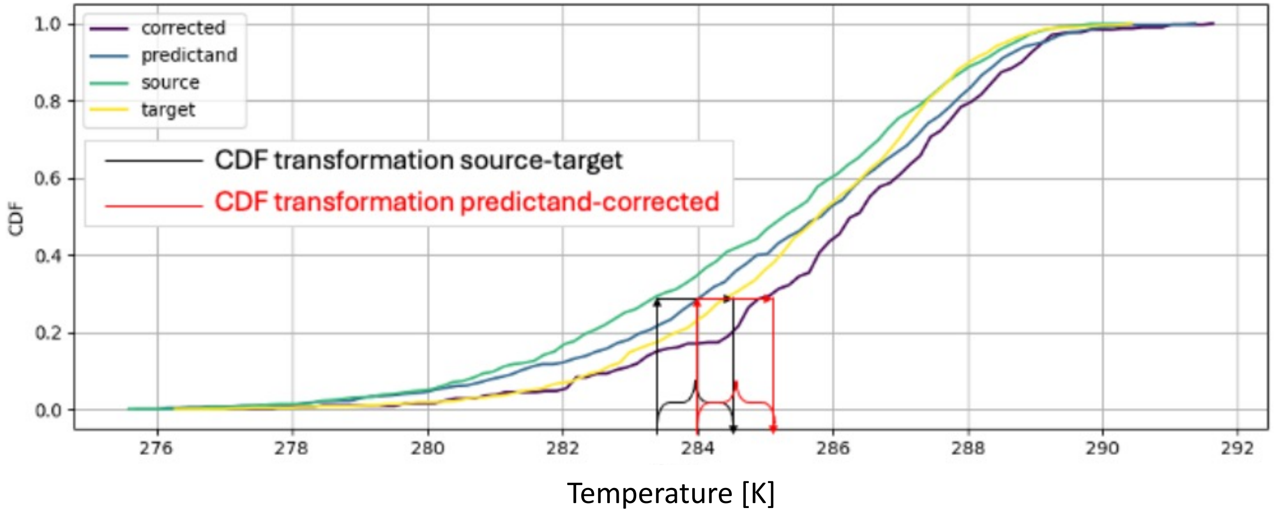
BIAS ADJUSTMENT: CDFt

Cumulative Distribution Function transform: a probabilistic downscaling method that models the statistical relationships in the CDFs between a target dataset and a biased projection model (GCMs); these transfer functions, or non-parametric correspondences are applied to a predictor CDFs, resulting in the output adjusted CDFs. The method **uses the CDF of the target and source for a historical period to model the future period's CDFs, assuming the future predictor CDF is known**.

PRO: it's more accurate compared to the delta method, can capture nonlinear behaviours and climate change signal (trend) with moving averages

LIMITS: complex and time-consuming



$F_{Sh}(x)$ the CDF of the target for the calibration (h, historical) period and $F_{Gh}(x)$ the CDF of the source/to-be-adjusted for the calibration period. Thus, T can be used to model the relationship between $F_{Sf}(x)$ and $F_{Gf}(x)$, i.e., same CDFs but for a future (different) period, assuming that $F_{Gf}(x)$ is known.

$$T\left(F_{Gh}(x)\right) = F_{Sh}(x) \qquad F_{Sf}(x) = T\left(F_{Gf}(x)\right)$$

$$T(u) = F_{Sh}\left(F_{Gh}^{-1}(u)\right) \qquad F_{Sf}(x) = F_{Sh}\left(F_{Gh}^{-1}\left(F_{Gf}(x)\right)\right)$$

Michelangeli, Vrac, Loukos (2009) Probabilistic downscaling approaches: Application to wind cumulative distribution functions. Geo. Res. Letters, 36, L11708, <doi:10.1029/2009GL038401>

Vrac, Drobinski, Merlo, Herrmann, Lavaysse, Li, Somot (2012) Dynamical and statistical downscaling of the French Mediterranean climate: uncertainty assessment. Nat. Hazards Earth Syst. Sci., 12, 2769-2784<doi:10.5194/nhess-12-2769-2012>.

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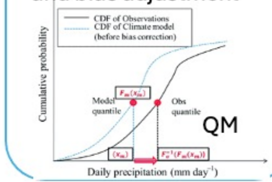
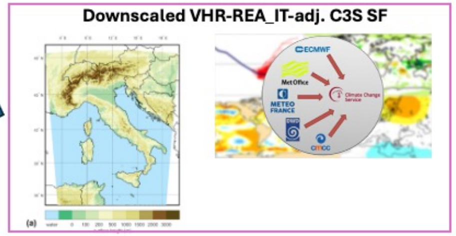
Workflow SEAS: statistical downscaling and bias-adjustment and optimisation based on ML

Downscaling and bias-adjustment of ECMWF and CMCC Seasonal Forecast Systems

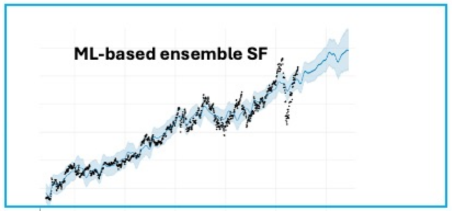
Seasonal Forecast (SF) Systems from C3S

Statistical downscaling and bias adjustment





Reanalyses @convection permitting scale



Optimisation of Seasonal Forecast System through ML techniques

Workflow SEAS: statistical downscaling and bias-adjustment and optimisation based on ML

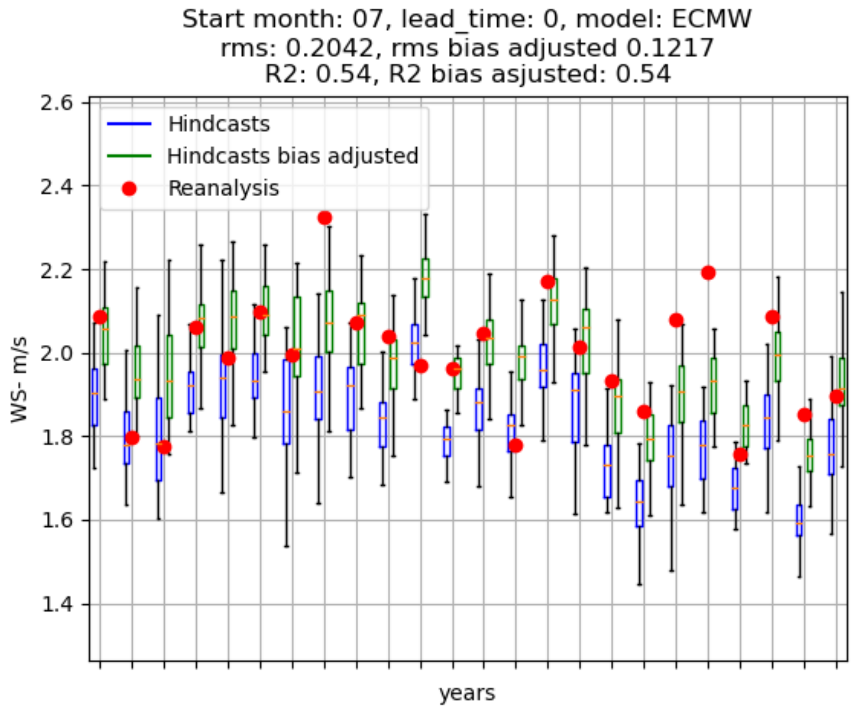
SEAS STREAM						
	Dataset	**Models**	**Spatial Resolution**	**Spatial Coverage**	**Temporal Resolution**	**Temporal Coverage**
Input datasets (seasonal forecasts)	C3S Seasonal Forecasts	CMCC, ECMWF, DWD	1°x1°	Global	6 or 24 h (depending on variable)	1993-2016 (hindcasts) 2017-now (forecasts)
Input datasets (reanalyses)	VHR-REA_IT	COSMO+ ERA5	2.2 km	Italy + surrounding	1 h	1989-2020
	ERA5 (for ML)	ERA5	ca. 30 km	Global	1 h	1940-now
Methodology	Quantile mapping with moving window (QMW)					
Output	Downscaled bias-adjusted C3S seasonal forecasts; methodology: QMW; reference: VHR-REA_IT				daily	1993-2016/ 2017-now
	ML seasonal forecast				monthly	1993-2016/ 2017-now

Raffa, M., Reder, A., Marras, G. F., Mancini, M., Scipione, G., Santini, M., & Mercogliano, P. (2021). VHR-REA_IT Dataset: Very High Resolution Dynamical Downscaling of ERA5 Reanalysis over Italy by COSMO-CLM. *Data*, *6*(8), 88. https://doi.org/10.3390/data6080088

Sanna, A., A. Borrelli, P. Athanasiadis, S. Materia, A. Storto, S. Tibaldi, S. Gualdi (2017). CMCC-SPS3: CMCC-SPS3: The CMCC Seasonal Prediction System 3. Centro Euro-Mediterraneo sui Cambiamenti Climatici. CMCC Tech. Rep. RP0285, 61pp. Available at adress: https://www.cmcc.it/it/publications/rp0285-cmcc-sps3-the-cmcc-seasonal-prediction-system-3/

BIAS ADJUSTMENT: QM

Quantile Mapping (QM): a statistical bias correction method that aligns the CDF of a forecast model with the CDF of a high-resolution reference dataset.
Methodology:
- Uses cumulative distribution functions (CDFs) of model data and reference data
- Adjusts each forecast value to the corresponding quantile in the reference distribution
- Applied independently to each ensemble member, forecast lead time, and spatial grid point
- Uses a 31-day moving window centered on each calendar day
- Ensures seasonally relevant, robust sample sizes for each quantile correction
- Adjustments performed across 20 equally spaced quantiles



Gudmundsson, L., Bremnes, J.B., Haugen, J.E., Engen Skaugen, T., 2012. Technical note: downscaling RCM precipitation to the station scale using quantile mapping—a comparison of methods. Hydrol. Earth Syst. Discuss. 9, 6185–6201, http://dx.doi.org/10.5194/hessd-9-6185-2012.

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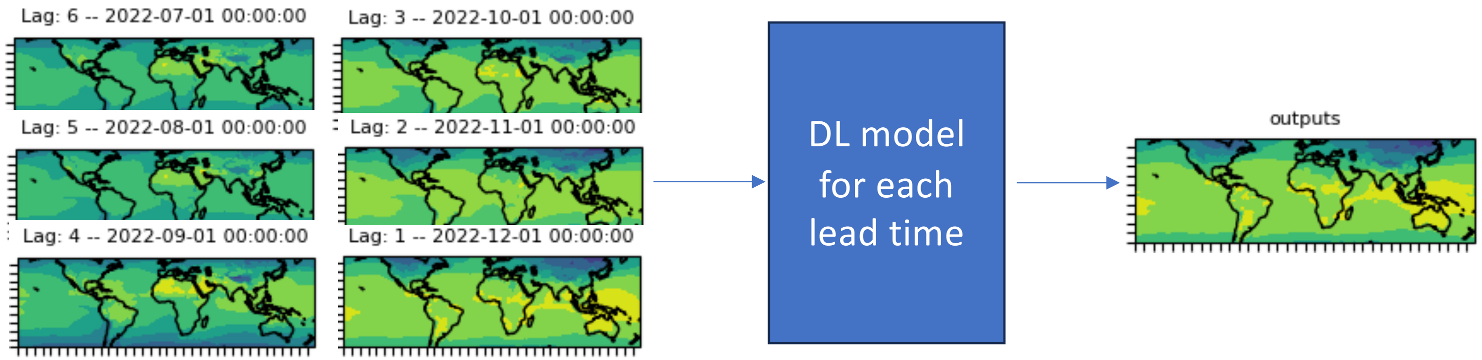
ML for seasonal forecast

- ERA5 monthly data
- Predictors are sequence of lag months (from 3 to 6) among 2m_temperature, mean_sea_level_pressure, geopotential_500, volumetric_soil_water_layer_1, 10m_u_component_of_wind, 10m_v_component_of_wind
- Additional predictors toa_incident_solar_radiation, soil_type, high_vegetation_cover, low_vegetation_cover, land_sea_mask, geopotential_0000m
- Goal is to predict 2m_temperature 0,1,2,3,4,5 months ahead



Month 0 – 2023-01-01
Month 1– 2023-02-01
....
Month 5 - 2023-06-01

Infrastructure-Risk Analysis

Goal: Assess climate-related risks on infrastructure assets — electricity power grid, road and railway networks— under future climate scenarios (Virtuous vs. Business-as-usual emission pathways)

Approach:

1. **Extreme events**: Identify climate-driven events affecting infrastructure, such as floods, heatwaves, cold spells
2. **Climate indices**: Select relevant climate variables and indices to monitor extreme events and their influence on infrastructure assets
3. **Input Data**: Use high-resolution reanalysis data and bias-adjusted climate projections over Italy

Example of some climate indices specific to the infrastructure sector

Climate variables	Climate index	Purpose
Temperature	Heatwave Duration	Measure in days the length of heatwave
Precipitation	Maximum 1-day Precipitation	Characterize flash flood events
Wind Speed	Extreme wind speed days	Characterize extreme storms when wind speed exceeds a threshold identified using the historical time-series

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Land Suitability Analysis

Goal: Assess climate-related risks on key crops in Northern Italy — corn, wheat, soybean, rice and grapes — and evaluate yield changes under future climate scenarios (Virtuous vs. Business-as-usual emission pathways)

Approach: (similar to the Infrastructure-Risk analysis)

1. **Extreme events**: Identify climate-driven events affecting agriculture, such as heatwaves, droughts and flash floods.
2. **Climate indices**: Select relevant climate variables and climate indices to monitor extreme events and their influence on crop productivity
3. **Vulnerability curves**: Apply crop-specific vulnerability curves to quantify yield responses to key climate stressors
4. **Input Data**: Use high-resolution reanalysis data and bias-adjusted climate projections over Italy

Example of some climate indices specific to the agriculture sector

Climate variables	Climate index	Purpose
Temperature	Growing Degree Days	Measure of heat accumulation to predict plant growth rates
Precipitation	Standardized Precipitation Index (SPI)	Characterize droughts on different timescales
Temperature and Precipitation	Standardized Precipitation Evapotranspiration Index (SPEI)	Characterize drought on different timescales also accounting for the impact of increased temperatures on water demand

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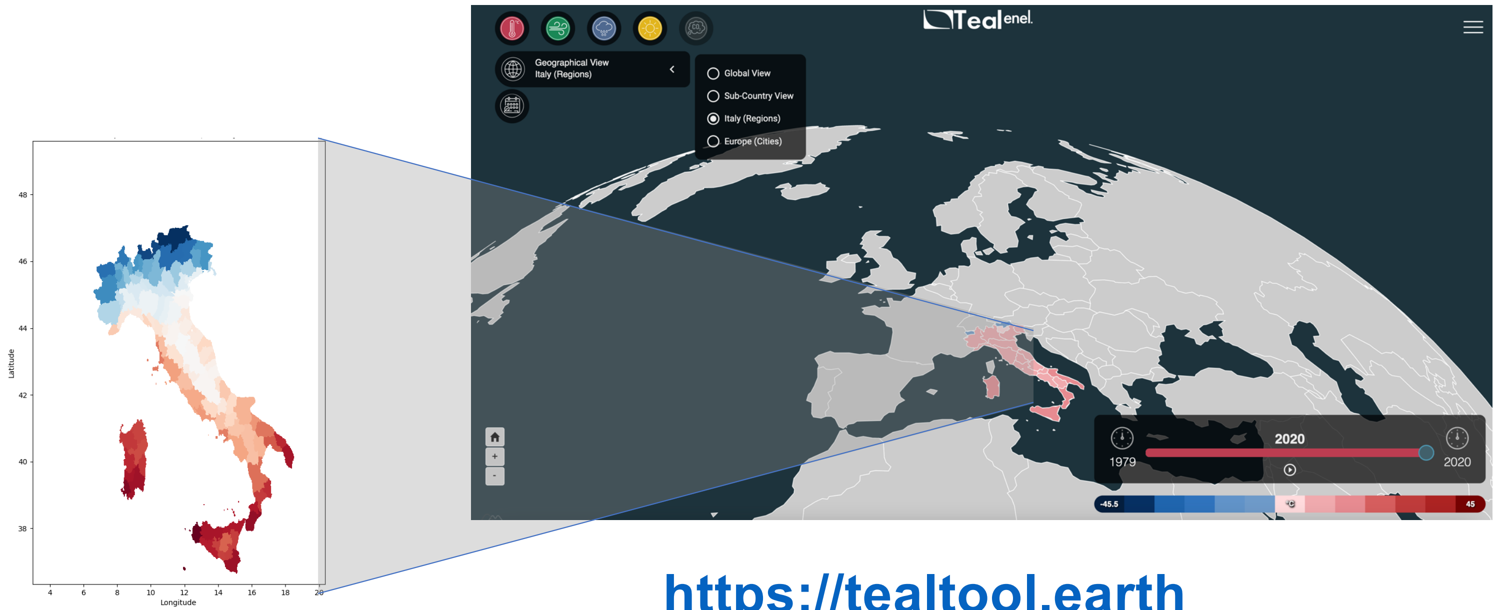
Data Access and Visualization

The TEAL tool



https://tealtool.earth

This is the (simplified) public version. No need to be an expert to operate.

Conclusions

- The ENGAGEMENT project aims at significantly enhancing the availability and usability ***of high-resolution climate data in Italy***, supporting better assessments of infrastructure risks and land suitability under climate change conditions.
- Through advanced bias adjustment techniques, statistical downscaling, and integration of machine learning models, ENGAGEMENT is developing climate datasets and application-specific indicators that are vital tools for ***infrastructure and agricultural decision-making***. The Teal platform will ensure this data is accessible and actionable for a wide range of stakeholders.
- ENGAGEMENT is part of a network of initiatives focused on ***applying climate information to real-world infrastructure and planning challenges in Italy***.

Future Outlook

- Broader ***dissemination*** of methodologies and high-resolution climate datasets to support replication and uptake by other regions and projects.
- Strengthening partnerships with public institutions and private stakeholders to ***co-design*** effective climate adaptation tools.
- Continued efforts in dissemination and ***capacity building***, including thematic workshops and training initiatives.
- ENGAGEMENT stands as an example of a strategic initiative to ***transform climate science into operational solutions***, contributing directly to territorial resilience and sustainability.

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