WEMC World Energy & Meteorology Council

Advanced meteorological forecast model and applications in energy market

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Background

Weather is a major driver of energy supply and demand, considering the evolution of technology, extensive adoption of renewable energy sources, producer-consumer relationships, and future management of energy systems which will be more challenging. Therefore, **operational and planning decisions in energy systems** have to be guided by efficiency and reliability. **Weather forecasts**, including accurate uncertainty estimates **are fundamental tools**. In the short-medium range, the appropriate time and space resolutions necessary for an effective decision-making may vary, in principle, from minutes to days, while, on the long-range scales, planning activities and supplies of energy commodities should involve sub-seasonal and seasonal projections of weather and climate. Uncertainty modelling techniques should be used in order to quantify and minimize forecast errors as well as target variables which mostly impact the decision-making process.

eni-Kassandra Meteo Forecast

In the last decade, **Eni company has developed a technique to forecast atmospheric variables, especially temperatures, precipitation, and wind**. The weather model, named **e-kmf® (eni-Kassandra Meteo Forecast)**, is **global forecast system** which uses a **multi-model and ensemble approach to develop meteorological predictions from the short-medium term to the sub-seasonal and seasonal range**. Short- and medium-term forecasts are provided by using regional and Limited Area Models (LAMs) with a grid size ranging from 1.25 km to 7 km, while long-term forecasts are carried out using two global models with 20 perturbed initial conditions (plus one control member) each, to obtain a multi-model with 40 ensemble forecasts (plus two control members). The output of the global models is on a regular mesh grid size covering the whole world.

Research activity

Here, we show **recent achievements** where the model has been used both at local and large scales, particularly over Italy, and Europe. These applications are focused on managing the trade sale, transport, and storage steps of energy resources, estimating the production of electric energy obtained using natural gas in combined cycle power plants, improving efficiency and reducing environmental impact by early warning systems for geo-hazards, forecasting of the industrial and civil consumptions as well as renewable power plants energy productions, optimizing the supply of oils and the industrial refining processes lead by market trends. **Benchmark analyses** by using observations and climate data have been evaluated, considering both the short-range and the medium-long range predictions; even the analysis of daily forecast performances is routinely performed. Main results have shown **high reliability of this forecast system and its great capability to support operative decisions in energy market**.

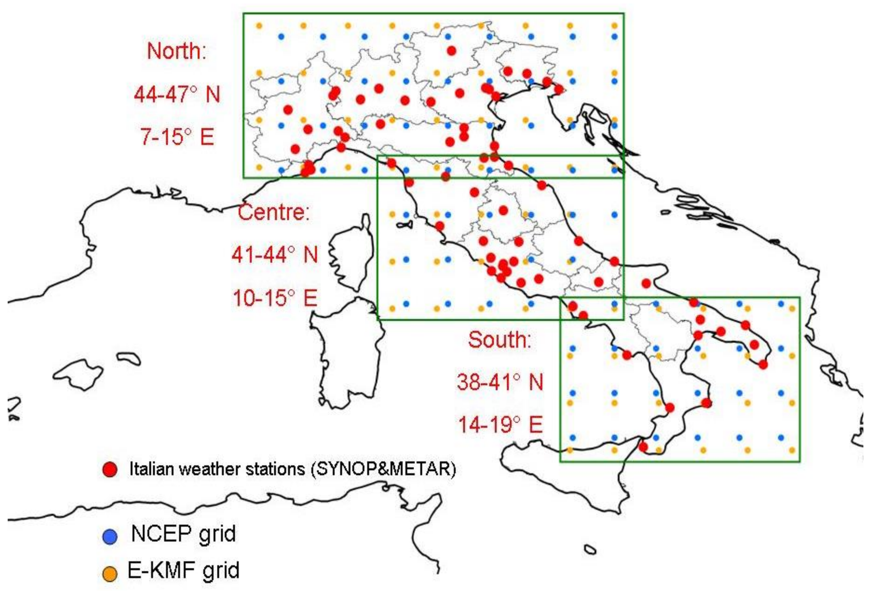
Benchmark analysis of forecasted seasonal temperature over different climatic areas

Giunta, G., Salerno, R., Ceppi, A., Ercolani, G., Mancini, M.. (2015). *Geoscience letters*, 2(1).

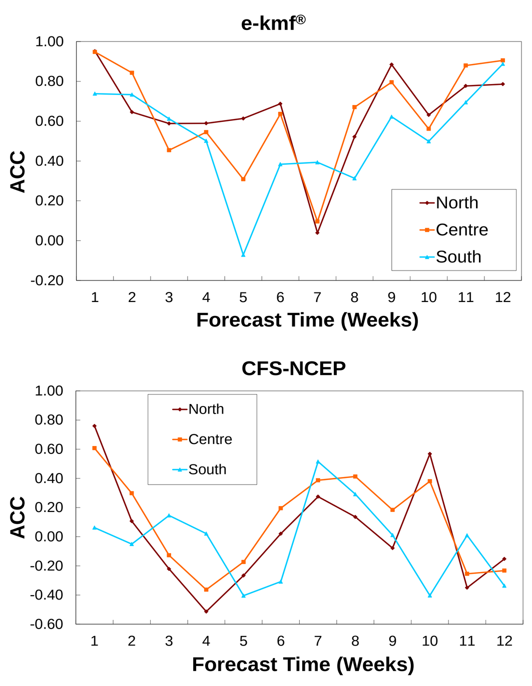
Benchmark analysis for long-term temperature forecasts in Italy in the year 2010, comparing the e-kmf and CFS-NCEP meteorological models to be verified against climatology and observed data.

The SSclim (Skill Score) index shows how **the e-kmf® model has an average improvement of 35% compared with climatology** (used as a reference) for the year 2010, while the performance of the CFS-NCEP is worse.

The ACC (Anomaly Correlation Coefficient) provides information which is very useful for understanding the reliability of the forecast from the 1st to the 12th week for each forecast initialization month. In particular, **the e-kmf® model shows a good correlation between forecasted and observed temperature data in the 1st and 3rd month of the forecast**, while a worsening of the model's performance was observed between the 5th and 8th week of prediction.



Grid points of the two climate models for the three areas of Italy (north, centre and south) represented by *green rectangles*; the e-kmf® model grid is shown with *orange dots*, while the CFS-NCEP model grid with *blue dots*; geographical location of Italian weather stations (68 in total) below 500 m a.s.l. used for observed data of the year 2010 and for computing the climatological mean (1984–2008) in the three reference areas are shown with *red dots*. The horizontal grid point for both models are on a regular latitude–longitude grid spaced by 1° .



$$ACC=\frac{\sum_{i=1}^{n}\left((F_i-C_i)-\overline{(F-C)}\right)\left((O_i-C_i)-\overline{(O-C)}\right)}{\sqrt{\sum_{i=1}^{n}\left((F_i-C_i)-\overline{(F-C)}\right)^2}\sqrt{\sum_{i=1}^{n}\left((O_i-C_i)-\overline{(O-C)}\right)^2}}$$

$$SS_{clim}=\frac{MSE_{forecast}-MSE_{clim}}{MSE_{obs}-MSE_{clim}}=1-\frac{MSE_{forecast}}{MSE_{clim}}$$

$$MSE=\frac{1}{n}\sum_{i=1}^{n}(F_i-O_i)^2$$

Climatological Skill Scores for the two models (e-kmf®, CFS-NCEP) and for each area and month

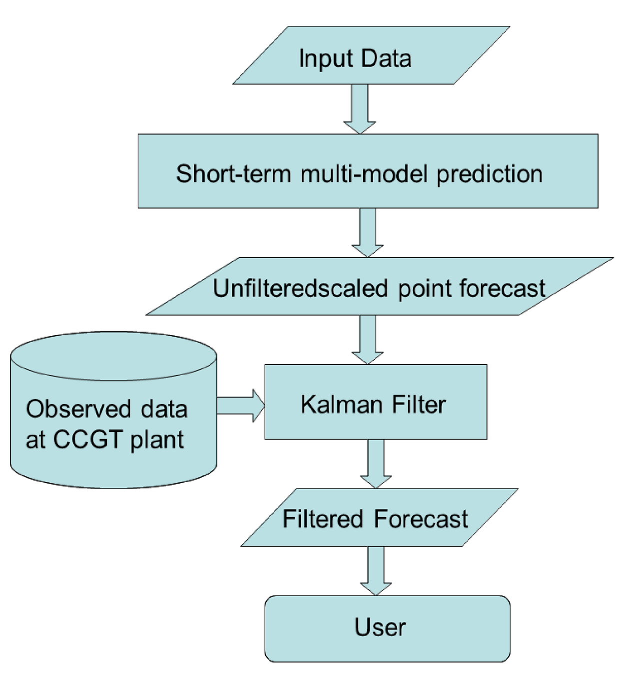
Initialization month	e-kmf® North	e-kmf® Center	e-kmf® South	CFS-NCEP North	CFS-NCEP Center	CFS-NCEP South
January	0.55	0.70	0.78	-3.02	-0.91	-1.97
February	0.04	0.14	-0.18	-4.45	-0.62	-0.15
March	0.43	0.41	0.51	-5.18	-0.89	-0.06
April	0.69	0.78	0.79	-7.17	-1.18	-0.39
May	0.13	0.00	-0.37	-5.63	-0.73	-0.35
June	0.76	0.89	0.69	-4.10	-0.51	-0.32
July	0.17	0.26	-0.38	-5.88	-0.69	-0.69
August	0.62	0.75	0.83	-5.62	-1.12	-0.59
September	0.50	0.75	0.84	-9.57	-2.77	-0.10
October	0.13	0.04	0.11	-1.14	-0.21	-0.95
November	0.21	0.12	0.13	-0.42	0.15	-1.42
December	0.21	0.05	-0.53	-1.59	0.40	-1.26
Mean	**0.37**	**0.41**	**0.27**	**-4.48**	**-0.76**	**-0.69**

Hourly weather forecasts for gas turbine power generation

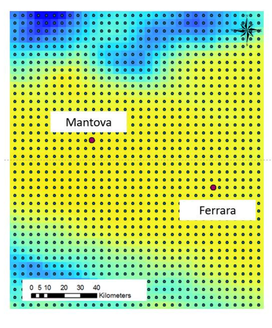
Giunta, G., Vernazza, R., Salerno, R., Ceppi, A., Ercolani, G., Mancini, M. (2017). *Meteorologische zeitschrift*, 26, 307–317.

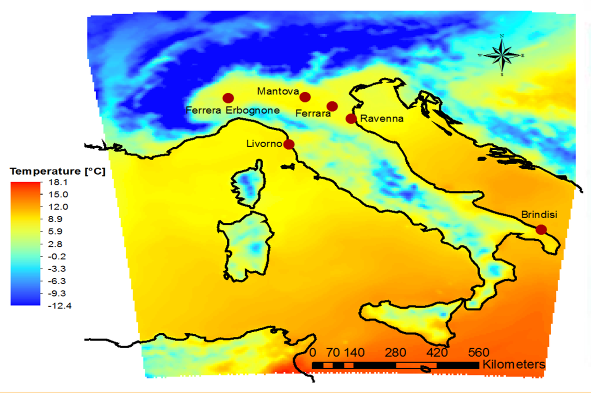
Application of short-term temperature forecasts and their sensitivity to specific errors which may have impacts on energy predictions for power plants. Forecast analysis has been performed on **six Enipower CCGT plants of 390 MW power each**, in particular 260 MW from the **gas turbine** and 130 MW from the **steam turbine** (placed to Mantova, Brindisi, Livorno, Ravenna, Ferrara, and Ferrera Erbognone), and it has been carried out over thirteen months, from 1 August 2012 to 31 August 2013. This work analysed different phenomena among climate areas, and the **model capability to forecast temperatures.** The obtained results point out the performances of the e-kmf™ model on **a forecast horizon of 48 hours, which is the target in the gas-to-power production planning**, the **forecast errors occurring during significant changes of weather conditions** (i.e., variations in daily temperatures higher than ±4 ° C in two consecutive days), and local scale phenomena such as fog, thunderstorms and orographic winds.

Flowchart of the e-kmf™model



The map of the Italian CCGT Enipower plants (purple dots) used for carrying out the analysis for short-term temperature forecasts: the colored map shows the e-kmf™ temperature field with boundaries of the weather model domain (right), while a zoom over two plants (Mantova and Ferrara) shows the detail of the high-resolution e-kmf™ grid (bottom).





Ferrera Erbognone

	Day + 1	Day + 2
R² [-]	0.93	0.92
MAE [K]	1.80	1.98
RMSE [K]	2.34	2.58
Fct-Obs [K]	0.17	0.30
MRE [-]	-0.18	0.01

Mantova

	Day + 1	Day + 2
R² [-]	0.95	0.94
MAE [K]	1.63	1.79
RMSE [K]	2.16	2.33
Fct-Obs [K]	0.22	0.33
MRE [-]	0.03	0.10

Ferrara

	Day + 1	Day + 2
R² [-]	0.94	0.93
MAE [K]	1.67	1.90
RMSE [K]	2.19	2.46
Fct-Obs [K]	0.10	0.21
MRE [-]	0.06	0.06

Ravenna

	Day + 1	Day + 2
R² [-]	0.94	0.93
MAE [K]	1.74	1.85
RMSE [K]	2.31	2.44
Fct-Obs [K]	0.16	0.26
MRE [-]	0.07	0.08

Livorno

	Day + 1	Day + 2
R² [-]	0.91	0.90
MAE [K]	1.72	1.77
RMSE [K]	2.23	2.30
Fct-Obs [K]	0.19	0.22
MRE [-]	0.03	0.03

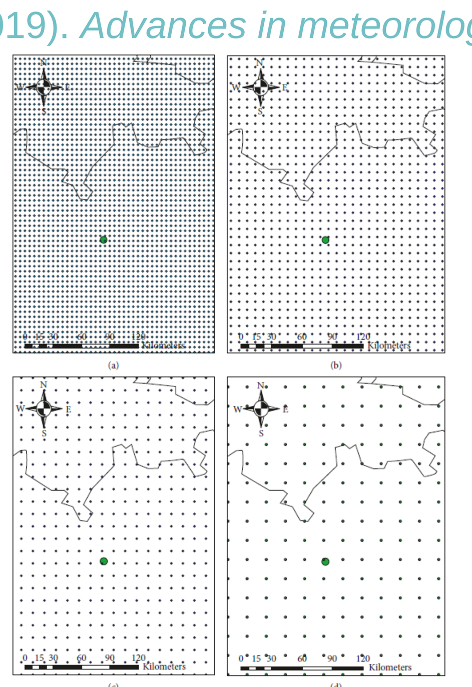
Brindisi

	Day + 1	Day + 2
R² [-]	0.93	0.92
MAE [K]	1.37	1.44
RMSE [K]	1.76	1.86
Fct-Obs [K]	-0.16	-0.17
MRE [-]	0.00	0.00

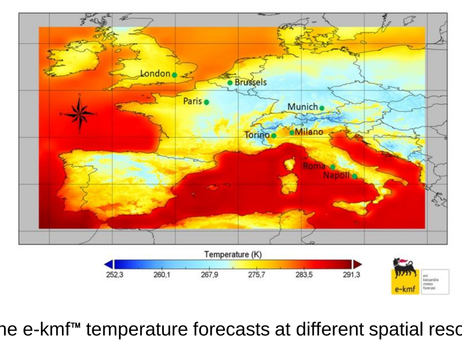
Effects of model horizontal grid resolution on short- and medium-term daily temperature forecasts for energy consumption application in European cities

Giunta, G., Salerno, R., Ceppi, A., Ercolani, G., Mancini, M. (2019). *Advances in meteorology*, 1–12.

Several simulations across 2013-2014 have been performed with the e-kmf™ model by changing its horizontal resolution and quantifying its impact in terms of computational cost and time running the e-kmf™ model with different spatial grids. **To assess the impacts of horizontal grid on the forecast results in the selected areas**, vertical resolution and physics have been maintained the same for all simulations (as **the daily operative 5.5 km model**), with a **forecast horizon up to day + 11**. Temperature forecasts scaled on selected cities in Italy (Milano, Torino, Roma, and Napoli), Germany (Munich), Belgium (Brussels), France (Paris), and UK (London) have been compared against observations coming from SYNOP (surface synoptic observations) and METAR (meteorological aerodrome report) stations for a dataset of two years, and then, for particular periods of two weeks with stable and unstable situations. **For an operative application over both Italian and European cities by minimizing the computational costs, a proper grid size might be 8 km.**



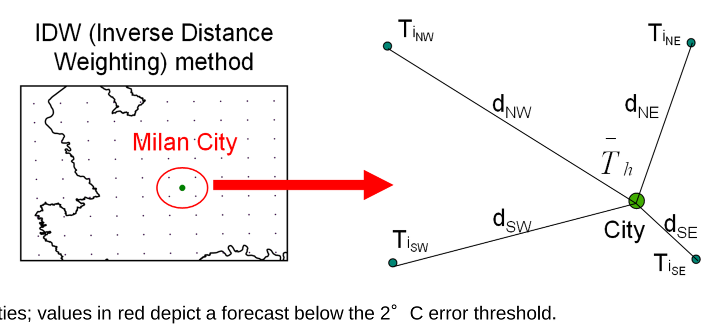
Example of the four grid domains: 5.5 km (a), 8 km (b), 13 km (c), and 18 km (d) of the e-kmf™ model; the green dot shows the city centre of Milano in the north of Italy.



$$\overline{T}_h=\frac{T_{i_{nw}}/d_{nw}^2+T_{i_{ne}}/d_{ne}^2+T_{i_{sw}}/d_{sw}^2+T_{i_{se}}/d_{se}^2}{1/d_{nw}^2+1/d_{ne}^2+1/d_{sw}^2+1/d_{se}^2},$$

$$\left(\overline{T}_{\text{daily forecast}}\right)=\frac{1}{n}\sum_{h=1}^{n}\overline{T}_h,$$

IDW (Inverse Distance Weighting) method



MAE of the e-kmf™ temperature forecasts at different spatial resolutions and lead times over Italian and European cities; values in red depict a forecast below the 2° C error threshold.

MAE [°C]	d+0	d+1	d+2	d+3	d+4	d+5	d+6	d+7	d+8	d+9	d+10	d+11
Milano (5.5 km)	0.45	0.56	0.59	0.75	0.79	1.29	1.76	2.03	2.21	2.16	2.43	2.72
Milano (8 km)	0.46	0.58	0.58	0.76	0.83	1.30	1.79	2.06	2.25	2.24	2.47	2.76
Milano (13 km)	0.63	0.76	0.77	1.01	1.07	1.66	2.27	2.58	2.80	2.77	3.04	3.38
Milano (18 km)	1.12	1.25	1.26	1.55	1.63	2.43	3.21	3.46	3.69	3.57	3.88	4.24
Torino (5.5 km)	0.59	0.74	0.85	0.80	0.83	1.19	1.78	2.28	2.28	2.42	2.39	2.61
Torino (8 km)	0.40	0.62	0.69	0.87	0.89	1.27	1.92	2.48	2.65	2.84	2.80	3.06
Torino (13 km)	0.55	0.84	0.94	1.16	1.19	1.65	2.46	3.14	3.31	3.55	3.51	3.78
Torino (18 km)	0.96	1.37	1.52	1.77	1.79	2.37	3.41	4.17	4.29	4.48	4.44	4.66
Roma (5.5 km)	0.33	0.45	0.55	0.54	0.59	1.15	1.55	1.93	1.98	1.90	2.24	2.37
Roma (8 km)	0.34	0.46	0.54	0.55	0.61	1.16	1.57	1.96	2.00	1.98	2.27	2.40
Roma (13 km)	0.47	0.63	0.73	0.76	0.81	1.55	2.05	2.52	2.55	2.49	2.87	3.03
Roma (18 km)	0.78	1.02	1.19	1.15	1.19	2.23	2.79	3.30	3.26	3.11	3.55	3.74
Napoli (5.5 km)	0.22	0.39	0.47	0.47	0.59	0.98	1.41	1.68	1.87	1.93	2.11	2.21
Napoli (8 km)	0.24	0.40	0.47	0.49	0.63	1.01	1.43	1.73	1.96	2.07	2.18	2.27
Napoli (13 km)	0.33	0.56	0.67	0.68	0.86	1.39	1.96	2.31	2.58	2.69	2.87	2.92
Napoli (18 km)	0.51	0.85	1.01	0.97	1.19	1.90	2.57	2.88	3.11	3.16	3.36	3.44

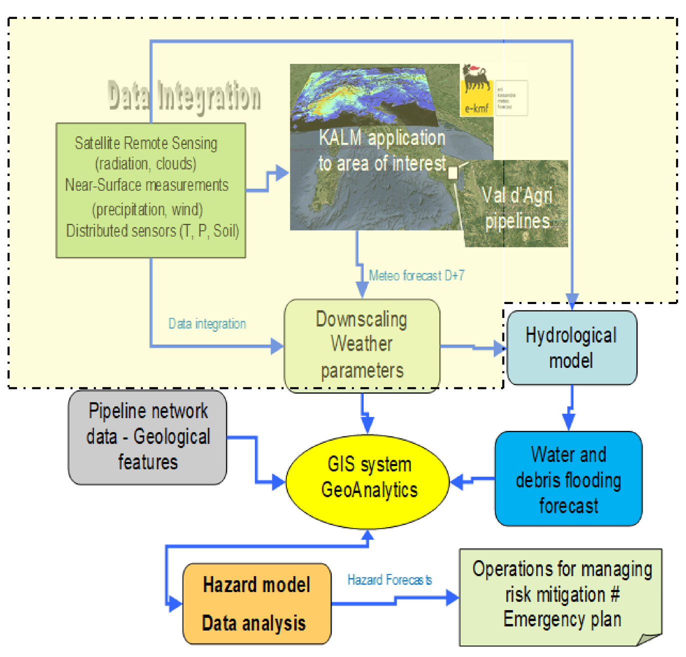
MAE [°C]	d+0	d+1	d+2	d+3	d+4	d+5	d+6	d+7	d+8	d+9	d+10	d+11
Brussels (5.5 km)	0.83	0.87	0.91	1.07	1.25	1.52	1.48	1.34	1.33	1.51	1.76	1.88
Brussels (8 km)	0.88	0.94	0.94	1.12	1.29	1.58	1.54	1.38	1.38	1.58	1.84	1.95
Brussels (13 km)	0.94	0.98	0.96	1.17	1.36	1.67	1.62	1.46	1.48	1.69	1.96	2.09
Brussels (18 km)	0.97	1.01	1.01	1.21	1.40	1.73	1.66	1.50	1.49	1.71	1.96	2.09
London (5.5 km)	0.51	0.57	0.66	0.92	1.09	1.32	1.43	1.04	1.14	1.38	1.56	1.64
London (8 km)	0.57	0.62	0.69	0.97	1.15	1.38	1.49	1.08	1.19	1.44	1.62	1.71
London (13 km)	0.61	0.64	0.70	0.99	1.18	1.43	1.55	1.13	1.25	1.52	1.69	1.78
London (18 km)	0.62	0.65	0.71	1.01	1.21	1.48	1.59	1.15	1.28	1.54	1.71	1.81
Paris (5.5 km)	0.77	0.86	0.79	1.08	1.27	1.56	1.61	1.26	1.48	1.63	1.83	2.00
Paris (8 km)	0.86	0.95	0.84	1.12	1.33	1.63	1.67	1.30	1.55	1.71	1.92	2.09
Paris (13 km)	0.93	0.99	0.86	1.17	1.38	1.72	1.74	1.37	1.65	1.82	2.02	2.20
Paris (18 km)	0.95	1.01	0.88	1.20	1.43	1.79	1.79	1.40	1.67	1.85	2.04	2.23
Munich (5.5 km)	0.79	1.06	1.16	1.17	1.17	1.48	1.35	1.56	1.67	1.89	2.17	2.38
Munich (8 km)	0.88	1.16	1.24	1.22	1.23	1.55	1.39	1.63	1.73	1.98	2.25	2.49
Munich (13 km)	0.95	1.22	1.28	1.30	1.30	1.66	1.50	1.74	1.87	2.14	2.41	2.66
Munich (18 km)	1.00	1.30	1.36	1.36	1.37	1.75	1.55	1.80	1.91	2.19	2.47	2.72

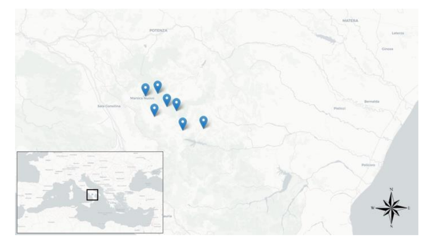
Local-scale weather forecasts over a complex terrain in an early warning framework: performance analysis for the Val d'Agri (southern Italy) case study

Giunta, G., Ceppi, A., Salerno, R.. (2022). Advances in meteorology.

In the framework of an EWS, the **KALM-HD model**, based on a local ensemble prediction system, has been applied to investigate the forecast performance in the Val d'Agri area, Basilicata region, in Southern Italy. This study compared two years of hourly and daily predicted and observed data, from December 1st, 2018, to November 30th, 2020, at day +1 as a lead time of forecast in six places, where weather stations are installed and forecast values are scaled to these points. The **benchmark analysis** is made by using different skill scores and **considering two different model horizontal resolutions: 1.25 km and 5 km**. Results show how the **best scores** are achieved for the **1.25 km horizontal resolution** model in comparison with the 5 km one, concerning **temperature** and **wind forecasts**, mostly affected by the interaction of synoptic patterns, which are generally more predictable, while an overestimation in drizzle or light **precipitation** events slightly **worse the performance at 1.25 km**.

The Early Warning System workflow diagram. The light-yellow box highlights meteorological components as data integration in the project.





Mean Absolute Errors for precipitation thresholds in the two-years of observation period over the six weather stations at day +1 as lead time for the KALM-HD model with 1.25 km (left) and 5 km (right). Values in red are referred to as the percentage of analyzed events in each bin.