A Heat Wave Forecast System for Europe

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***Abstract*—We introduce a Heat Wave Forecast System (EHWP) useful for detecting incoming heat waves in Europe at a high-medium spatial-temporal resolution. Historical and forecast temperatures feed a heat wave detection algorithm whose outcomes on duration and intensity of incoming heat waves within the next 14 days. The model has been empirically validated with numerous official sources on the hottest European heat wave in 2017 ('Lucifer'). The EHWP is a novel tool for emergency alert warnings both for local and European scale.**

***Keywords*-heat waves; emergency management; natural hazard; European heat waves; extreme temperatures**

I. Introduction

Extreme weather conditions are consistently more frequent due to climate change. Observing and forecasting extreme weather is crucial to face the problems they cause. As a major example, heat waves are a natural hazard causing growing concern. In the last century heat waves have increasingly grown as a problem affecting the public health [1]–[4] and they are likely to become more frequent and more intense due to climate change [5], [6]. As heat waves are basically periods of intense high temperatures (considered to be "higher than usual"), their interpretation is still open, starting from intensity and duration pattern for comparative analysis of different time and location. Assessment of heat wave quantitative indices still needs a more common global definition, a multi-aspect approach (considering the assessment of heat wave trends) and an approach applicable to different climates/regions and sectors [7].

Here we introduce a Europe-wide system for predicting and mapping heat waves, which could be used both on a local (regional, country) and on a broader (European) level. We also aim to use a common methodology and definition of heat waves that can be adopted to compare heat waves between different locations, thus taking in consideration historical/local variability of the climate for an efficient natural disaster management. In this short paper we show the first application of the European Heat Wave pipeline (EHWP), which is demonstrated on the heat wave 'Lucifer' that struck Europe the summer of 2017, with extreme temperatures causing death, wildfires, damaged crops and more.

II. Methods

The Heat Wave Magnitude Index daily (HWMId) [8] was implemented for the detection of heat waves in Europe. HWMId index is developed using a percentile-based threshold considering local climates, thus is transformable and comparable across different regions. Furthermore, HWMId takes into account both magnitude and duration of a heat wave, as far as we know no other method implements all these features [7], [9]. Following the definition in [8], a heat wave is considered if the measured maximum daily temperature is above threshold for three or more consecutive days. The threshold for a selected day and a selected grid point (in a chosen reference period of 30 years daily maximum temperatures) is defined as the 90th percentile of daily maximum temperatures in a 30-day-window centered in the selected day. As the model is grid point specific, the threshold and the defined heat wave is uniquely dependent on its grid point maximum temperature, which makes the prediction usable for comparison between different regions or countries and through different time periods.

The EHWP pipeline, summarized in Figure 1, was applied to investigate the presence of heat waves in Europe for the year 2017 in a short-medium window time (14 consecutive days of forecast maximum temperature). The Finnish Meteorological Institute (FMI) provided daily a medium-high resolution raster map containing the maximum temperature forecast for the whole Europe for the next two weeks (12 UTC analysis time). Maximum temperature forecasts are calculated in EHWP by using ECMWF (European Centre for Medium-Range Weather Forecasts) ensemble prediction system, which is based on 51 models. The ECMWF model has 0.2×0.2 deg (ca. 18 km) spatial resolution, and forecast lead times up to 360 hours. The ECMWF model is preferred to the ensemble model for European area called GLAMEPS (Grand Limited Area Model Ensemble Prediction System) which has a higher spatial resolution (0.075 x 0.075 deg), but is available for short term forecasts ranging from few hours to only two days, thus not covering the heat wave definition.

ECMWF ensemble forecasting is used to account for inherent uncertainty of weather forecasts, especially useful when considering the rare and high-impact weather events. Even a minor inaccurate description of the current state of the atmosphere tends to increase uncertainty in time due to the complex nature of the atmosphere. Therefore, all members in the ensemble prediction system have slightly different initial conditions providing the distribution of possible outcomes instead of one value.

Since raw ECMWF ensemble forecasts tend to be under dispersive and biased, they need calibration to produce more reliable and useful forecasts of adverse weather events. Calibration is based on statistical models, and, in particular, for temperature forecasts, the Gaussian regression model is used. Calibration coefficients are calculated by feeding into the model the information from historical observations and forecasts. Finally, these coefficients are applied to the raw model output in every forecast cycle. The calibration of weather forecasts increases forecast skill at different time scales including lead times from few hours to two weeks.

For heat wave calculation the 25th, 50th, and 75th percentile of ECMWF ensemble distribution are sent to IREACT Data Interface (the IREACT data collector, generated by all partners in the project) in netCDF format. In addition, the maximum temperature analysis for the previous day is sent with the same spatial resolution as ECMWF (0.2 x 0.2 deg). The analysis is calculated using gridded maximum temperature observations from SYNOP stations (at 18 UTC), and the latest forecast (50th percentile) as a background field.

As a heat wave is defined as three consecutive days of over-threshold maximum temperature and since we aim to take in consideration the complete duration of a heat wave, the implemented solution extends the 14 days forecast temperatures with the analysis of temperatures from previous days (provided by FMI daily). Hence, the model enhances the forecast data in order to better highlight a possible ongoing heat wave in the first days of the prediction.

III. Implementation and data details

The implemented heat wave model used in EHWP is an adaptation of the **HWMId** function in the **extRemes** R-package [10], modified for short term predictions. According to [8], 30 years of daily temperature have been selected as the reference period. In practice, the model needs 32 years of observed data since the moving average is computed over a window of 30 days. In order to improve the performance, the thresholds described above have been pre-calculated using the last 32 years of maximum temperature from European Climate Assessment and Dataset, E-OBS gridded dataset, Version 15[1] adopting the same procedure as described in [8].

The E-OBS dataset is provided as a netCDF file with a resolution of 0.25 x 0.25 deg, starting from 1950. The daily maximum temperatures, from year 1985 until 2016, have been extracted and uploaded into a PostgreSQL database table (using a standard laptop the E-OBS import process takes 5 hours). Each row of the table contains a particular grid point (lat-long), a year, and the relative vector of 365 (or 366) daily maximum temperatures observed. For a given year, in our case 2017, a PLR routine (R Procedural Language for PostgreSQL, an extension to run R scripts in the database [2]) computes the relative vector of thresholds for each lat-long, the 75-th percentile and the interquartile range (IQR), used in the HWMId function (using a standard laptop the computation of thresholds takes approximately one day and it is done once per year). This DB-structure adapts to year shifting analysis: the E-OBS temperature dataset must be updated one time per year in order to recompute correctly the relevant thresholds for the previous year. Equivalently, it is possible to compute a threshold analysis for the previous years to assess the model for past heat wave events (e.g. for a possible validation test with documented heat waves).

Forecast temperatures obtained from FMI are provided as netCDF files with a resolution of 0.2 x 0.2 deg for the whole Europe (using a standard laptop the HWMId computation takes less than one hour). The heat wave forecast is predicted on the daily threshold (0.25 x 0.25 deg). It is possible to apply any grid resolution finer than 0.25 deg in the EHWP, since the proposed implementation uses the closest (within a maximum fixed distance) cell data threshold for the computation of the HWMId model.

The output of the EHWP is a set of 14 rasters (one for each day of prediction), covering Europe with the same resolution as the FMI forecast (ca 18 km). Each grid point displaying a heat wave is called h_{cell} and for each cell: the HWMId value, the relative threshold value, the predicted duration, the start day and the end day, are generated.

To increase usability possibilities of such a system, and to be able to reference the output for the end user, each h_{cell} has been converted to LAU (Local Administrative Units) using the spatial database GADM (Global Administrative Areas), v.2.8 [3]. This rescaling procedure has been developed in PostgreSQL. A particular LAU is considered affected by a heat wave if more than 50% of its area is covered by one or more h_{cell} grid points. In the case of multiple h_{cells} covering one area, the HWMId and the duration value are obtained by weighted average for each intersecting h_{cell}. The difference between h_{cell} representation and LAU scaling is shown in Figure 2a vs. Figure 2b-2c .

The Heat Wave Magnitude Scale proposed in [9] is characterized by the occurrences of heat waves in a global

[1] http://www.ecad.eu/download/ensembles/download.php.

[2] http://www.joeconway.com/plr/

[3] http://www.gadm.org/version2

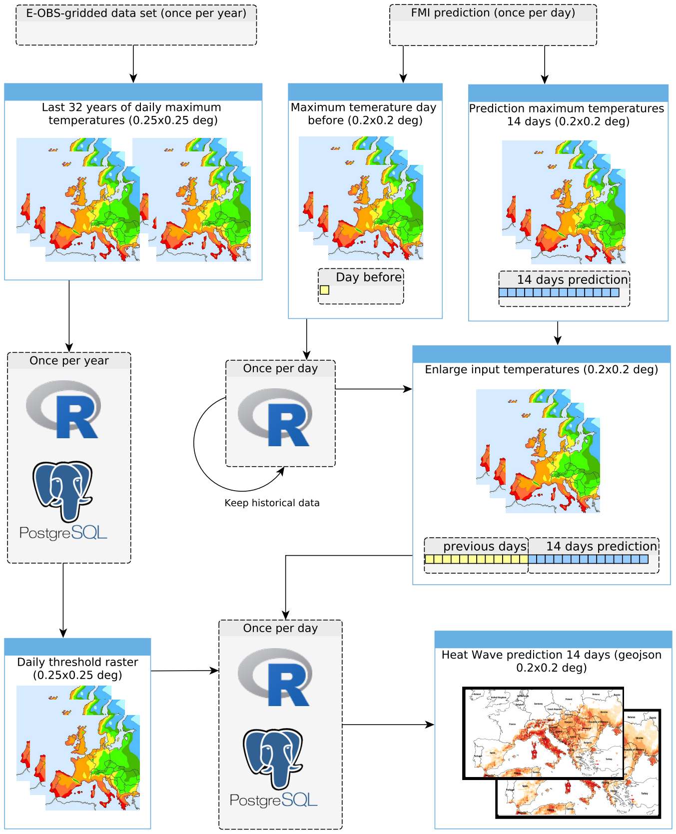

Figure 1: The Heat Wave Forecast System pipeline.

area, during a time period of 33 years. It was generated by taking in consideration the amount of occurring heat waves for specific magnitudes, e.g. Normal: at least one heat wave on this level has occurred for all the global grid points. Note that a European scale has not been calculated here because it would limit a possible comparison with a global-scale Heat Wave Forecast System.

IV. Results

The results presented were generated on 02-08-2017 (12.00 h) with a forecast of 14 days. The first day of forecast starts at +33 hours, which corresponds to the day 03-08-2017. In what follows, the generated heat waves are compared with the coverage of the 'Lucifer' heat wave, which struck Europe in summer of 2017. Corresponding temperatures, heat wave maps and duration of the heat wave, for the dates of 3/08, 5/08 and 7/08, are shown in Figures 3 to 5.

For a detailed validation procedure of HWMId model see [8]. Here we present an empirical validation on 'Lucifer' heat wave. Multiple sources, like the European forecast network Meteoalarm and local meteo providers[4], reported the 'Lucifer' heat wave to begin around 31/7-1/8 and last until around 9/8. Our prediction exactly reproduces the duration of 'Lucifer' around Europe. Since our approach covers 14 days of forecast and integrates the temperatures of previous days, heat waves which have extended duration are captured through the whole period of time.

Meteoalarm, the European weather warning operation, members of the World Meteorological Organization (WMO) issued high danger warnings in Italy, Hungary, Romania and Croatia during this period. For the corresponding regions the EHWP result in the magnitude scale of extreme/super extreme levels. As follows, the Meteoalarm issued danger warnings in Spain, France, and parts of Italy, which correspond to EHWPs moderated-severe levels, and potential dangers in Greece and Spain which correspond to moderate-normal in the magnitude scale used in EHWP. Thus our prediction agree with the observed intensity of 'Lucifer' and the magnitude scale used.

V. Discussion and Conclusion

The EHWP framework is a valid tool for emergency alert warnings, hence it takes in consideration the complete duration and the intensity of heat waves with a valid forecast of 14 days. It is also applicable on a local level, which is especially useful for emergency warning alerts and for adaptive strategies through risk analysis. The flexibility of updating threshold temperatures yearly keeps the prediction up to date in a long time prospective. The whole pipeline can easily be reproduced in any spatial resolution, geographical location or time period if both historical data and forecast temperature are available. Note that FMI provides a finer grid (0.075x0.075 deg) of forecast temperature but only for 57 hours, which does not fulfill the minimum of 3 days heat wave definition.

The model can be integrated with other parameters such as humidity [11]. That could be particularly relevant to define perceived humidity. The EHWP extendibility and adaptability is significant and as such useful as a forecast system for heat waves, thus makes it also feasible to be applied for risk impact assessment for natural disaster management.

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[4]A non-exhaustive list of sources: https://www.theguardian.com/world/2017/aug/04/extreme-heat-warnings-issued-europe-temperatures-pass-40c, https://www.meteoalarm.eu/, http://www.meteo.it, https://weather.com/news/news/europe-heat-wave-lucifer-italy-france-spain

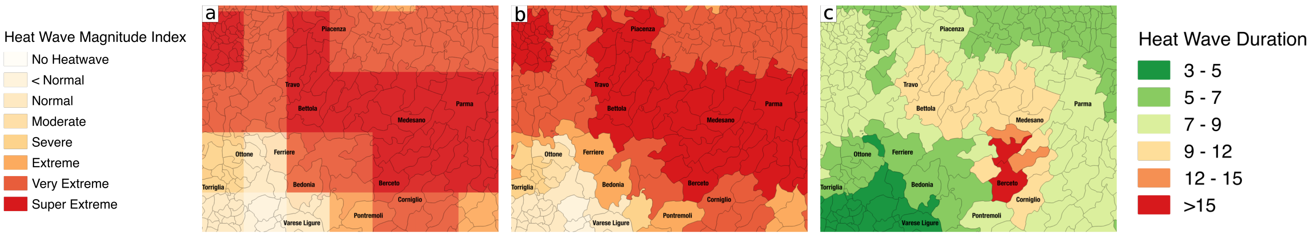

Figure 2: Heat waves forecast of 02-08-2017, +1 day: a) h_{cell} representation, b) LAU scaling, c) duration per LAU.

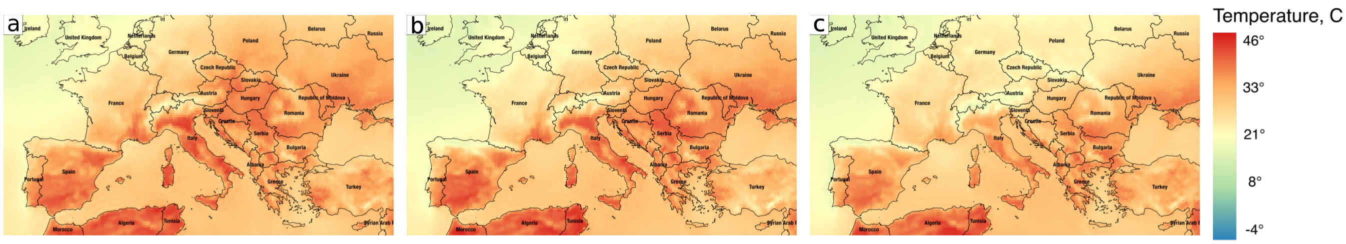

Figure 3: Maximum temperatures, Ensemble forecast of 02-08-2017: a) +1 day, b) +3 days, c) +5 days.

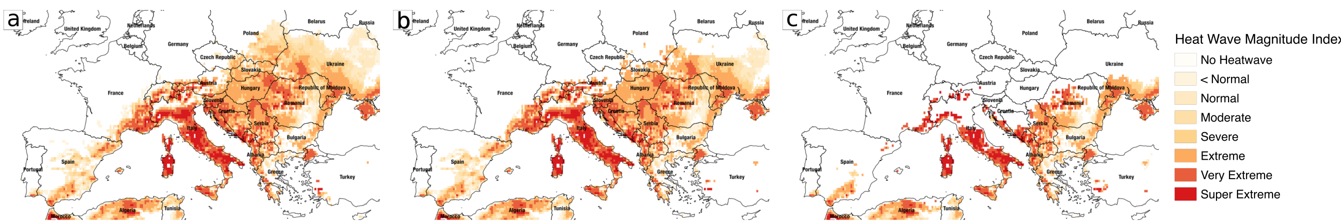

Figure 4: Heat wave prediction, Ensemble forecast of 02-08-2017: a) +1 day, b) +3 days, c) +5 days.

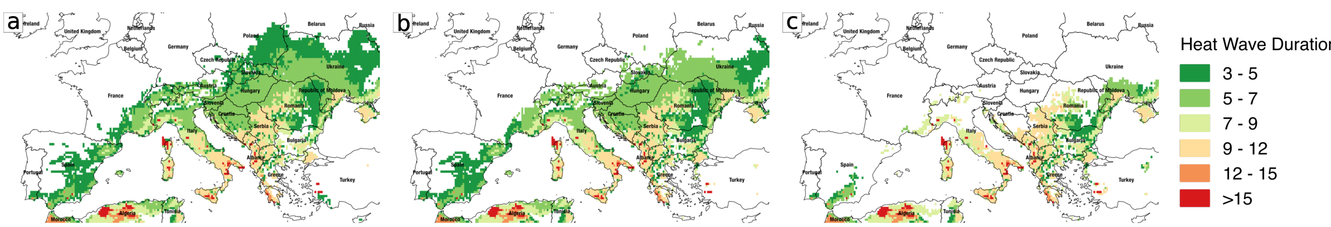

Figure 5: Heat wave duration, Ensemble forecast of 02-08-2017: a) +1 day, b) +3 days, c) +5 days.

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