A revision of wet snow load map for the Italian power lines with a new high resolution reanalysis dataset

M.Lacavalla[1], S.Sperati[1], R.Bonanno[1], P.Marcacci[1]

[1] RSE, Energetic System Research
Milan, Italy
matteo.lacavalla@rse-web.it

Abstract— **In recent years, the intensity and frequency of wet snowfall has increased over Italy. Often these snow events cause prolonged electrical disruptions due to snow sleeves on overhead lines that, in some cases, led to the breakage of conductors and ground wires or even the fall of the lattice tower. In this work we introduce a new meteorological reanalysis dataset called MERIDA - MEteorological Reanalysis Italian DAtaset - able to respond to the energy sector stakeholders who need high spatial and temporal resolution meteorological data to reconstruct the most critical weather conditions that impact the electric system such as wet snow. First of all, the snow load series has been simulated for the period 2000-2018 by using hourly temperature, wind intensity and precipitation of MERIDA with a spatial resolution of 4 km. The wet snow sleeve loads have been calculated through the cylindrical sleeve accretion model for wet snow (Makkonen ISO 12494:2001) for each point of the Italian domain. Some relevant wet snow case studies of the last 15 years have been analyzed and compared with electrical disruptions. Finally, the procedure to reconstruct the expected values of sleeve loads has been developed with the purpose of updating the current regulation. The reconstruction is carried out through the Generalized Extreme Value over the test period 2000-2018 using two methods to calculate the 50-year return times, i.e. the Block Maxima (BM) and Peak Over Threshold (POT), obtaining comparable results. These reconstructions are still under examination and refinement by the working group established by the Italian Electrotechnical Committee. The goal of this group is to verify the expected snow loads provided in the CEI EN 50341-2-13 "Overhead electric lines with voltage higher than 1 kV in AC. Part 2-13: National Normative Aspects (NNA)" with the aim of updating the wet snow load map for Italy.**

Keywords—***reanalysis, resilience, electric system disruptions, wet snow load map***

I. INTRODUCTION

This work has been developed following the indications emerged from the "Resilience Working Table" set up by the Italian Regulatory Authority for Energy, Networks and the Environment (ARERA) in February 2016 (*Deliberation 6/2016 - DIUC*). ARERA underlines that, in the last 15 years, a notable increase in long-term disruptions has occurred mainly due to extreme meteorological events of wide extension and exceptional for intensity and duration over the Italian territory. The resilience of the electric system has become a crucial and current topic in the research activities of RSE due to the relevant meteorological events that have caused major electrical disruptions on both the medium and high voltage power lines.

This paper has two main objectives. The first is to synthetically present a new high resolution MEteorological Reanalysis Italian DAtaset (MERIDA) entirely realized by RSE [1], now available from 2000 to 2018 and updated continuously. This meets the needs of the stakeholders of the electric system, for which it is nowadays essential to have an extensive high-resolution meteorological dataset, reliable and continuously updatable, in order to improve the resilience of the system with regard to the more and more frequent extreme weather events.

The second objective of this activity is the reconstruction of snow sleeve loads over the Italian domain for the period 2000-2018. MERIDA is used to estimate the snow loads (kg/m) on different type of conductors by using the Makkonen model ([2],[3]) expressed in a simplified version ([4]-[6]).

Some relevant wet snow case studies of the last 15 years with associated faults on the medium and high voltage lines have been analyzed. Finally, a preliminary calculation of the expected values of sleeve loads over Italy for different conductors has been developed with the purpose of updating the relevant legislation. The reconstruction is carried out through the Generalized Extreme Value Analysis [7] over the test period 2000-2018 using two methods to calculate the 50-year return times, i.e. the Block Maxima (BM) and Peak Over Threshold (POT) [8]. These reconstructions are still under examination and refinement by the Working Group established by Italian Electrotechnical Committee (CEI).

Fig. 1 Curious wet snow formation on medium voltage line near the town of Dobbiaco in the Dolomites. 5 January 2018.

II. MERIDA

MERIDA consists of a dynamical downscaling of the ERA5 global reanalysis dataset [9] using the mesoscale model WRF-ARW v3.9 [10]. The computational domain of MERIDA is defined using two grids with a spatial resolution of 21 km and 7 km respectively, with the internal grid centered over Italy as shown in Fig.2.

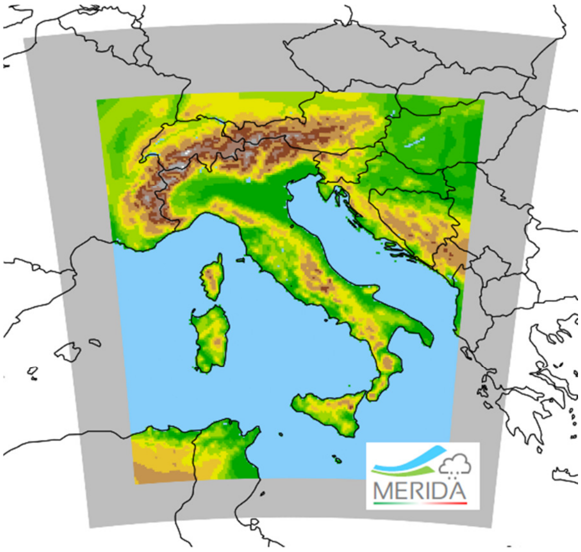

Fig. 2 MERIDA domain. The inner grid has a horizontal resolution of 7 km [1].

The main physical parameterizations that derive from an in-depth study conducted on real cases of different weather events over the whole Italian territory are summarized in Table I. Spectral nudging is applied on the geopotential field, temperature, u and v wind components on all 40 vertical model levels. In addition, temperature, u and v are nudged within the Planetary Boundary Layer (PBL).

TABLE I. WRF-ARW PHYSICAL PARAMETERIZATION

Physics options	**Parameterization scheme**
Microphysics	*Thompson*
Longwave radiation	*RRTMG*
Shortwave radiation	*RRTMG*
Surface layer	*Mellor-Yamada -Janjic*
PBL	*Mellor-Yamada -Janjic*
Land Surface	*Noah*
Land Use	*USGS 24 category*
Soil categories	*FAO/UNESCO Soil Type*
Cumulus parameterization	*New Tiedtke*

Temperature data from the SYNOP stations are retrieved to be assimilated in the WRF simulations at 3-hourly temporal increments. The WRF run is initialized at 1200 UTC of a day and covers the following 84 hours. Each new run is initialized after 72 hours from the start of the previous one, while the first 12 hours are considered as spin-up time and thus discarded. Therefore, each run is connected to the following one at 0000 UTC. The numerical simulations are carried out for the period 2000-2018 and updated regularly.

A. *Post processing of MERIDA*

2-m temperature and precipitation validated data from the Regional Agencies for Environmental Protection (ARPA) stations are used to apply the Optimal Interpolation (OI) technique ([11],[12]) to MERIDA in order to create a precipitation and temperature dataset on a regular grid of 4 km remodelled on the basis of the observations available on the ground. The OI applied on 2-m temperature is more complex than for precipitation because it takes into account both the horizontal and orographic differences between each station and model grid point. The first step for 2-m temperature consists in the OI of the model temperature on a regular 7 km grid using the validated temperature values. Thereafter, the 2-m temperature field is downscaled on a 4 km regular grid with a correspondent orography field extracted by the upscaling of a Digital Elevation Model (SRTM-90m). The motivation of this choice is related to a better description of the 2-m temperature field with an underlying higher resolution orography. The downscaling of 2-m temperature from the 7 km orography to the 4 km one is performed considering the orographic differences between grid points at the two different resolutions and the lapse rate obtained from the model itself. The lapse rate is calculated at each hour as an average value in the first 400 m of atmosphere above each grid point at 7 km resolution. The OI is only applied for the period 2010-2018, according with the availability of stations data. From 2000 to 2009, 2-m temperature data are post-processed with a Quantile Mapping (QM [13]) technique based on the use of the OI data to reduce model bias, while precipitation and wind speed data are only regridded at 4 km, the latter also for the period 2010-2018. Hereinafter, the 4 km 2-m temperature, precipitation and wind fields for the whole 2000-2018 period are identified as MERIDA.

III. SNOW ACCRETION MODEL

The MERIDA 2-m temperature, precipitation and 10-m wind fields have been used for the reconstruction of the wet snow loads in the period 2000-2018. Therefore, the growth conditions of the snow sleeve on overhead power lines depend on the meteorological variables derived from MERIDA with hourly frequency. The scheme of the weather conditions identified by MERIDA for wet/dry snow accretion, snow sleeve maintenance and shedding are shown in Fig.3.

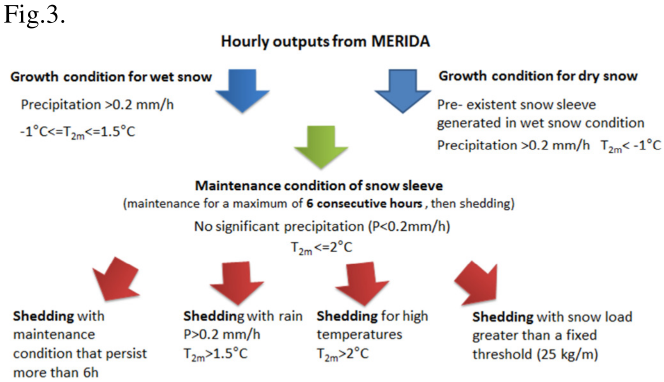

Fig. 3 Scheme of weather condition assumptions for snow sleeve accretion, conservation and shedding implemented in the wet snow model.

A simplified version of wet snow sleeve accretion model on overhead conductors ([4]-[6]) has been applied for the reconstruction of wet snow loads. The model foresees a cylindrical growth of the sleeve on the conductor and essentially depends on the sticking coefficient to the cable (β), the density of the snow sleeve (ρ) and the snowfall precipitation flux over the cable (I). The (I) flux corresponds to the hourly total precipitation of MERIDA in wet snow conditions. The main snow model parameterizations are summarized in Table II.

TABLE II. SNOW MODEL PARAMETERIZATIONS

Snow model coefficients	Expressions
Sleeve density (ρ)	ρ = 300+20*V ; if 1m/s <V<10m/s ρ = 500 kg/m^3 ; if V>10m/s ρ = 200 kg/m^3 ; if dry snow
Sticking coefficient (β)	β = 1/V$^{1/2}$ for wet snow β = 0.3 for dry snow

The evolution of snow mass (M) accreted during a time step i in the interval Δt (*i=hour*) on a conductor is given by the following equation (1)

$$M_i = M_{i-1} + \beta I_i D_{i-1} \Delta t \qquad (1)$$

Considering a cylindrical wet-snow accretion on conductor, the corresponding snow sleeve diameter (D) is given by (2):

$$D_i = \left[\frac{4(M_i - M_{i-1})}{\pi \rho} + D_{i-1}^2 \right]^{1/2} \qquad (2)$$

The total mass (M_r) is the resultant of the mass of the snow sleeve combined with action of wind on the snow-covered conductor and is given by (3):

$$M_r = \sqrt{M_i^{\,2} + S_{vc}^{\,2}} \qquad (3)$$

The wind force action (S_{vc}) over snow-covered conductor is calculated as (4):

$$S_{vc} = \frac{1}{2} * \frac{1}{g} * \rho_{air} V^2 * D_i \qquad (4)$$

where:

V is the wind speed (km/h);
g =9.81 m/s^2;
ρ_{air} is the air density at 0°C (1.292 kg/m^3).

IV. WET SNOW CASE STUDY

From the meteorological point of view, in Italy there is a recrudescence of extreme weather events caused by exchanges along the meridians of air masses with very different thermal and hygrometric characteristics. In winter season there are frequent outbreaks of cold air from north eastern Europe with the formation of low pressures over the central Mediterranean region, which cause heavy snowfalls on the orographic slopes exposed to the flow due to the stau effect, as it often happens along the northern-central Apennine ridge. A typical synoptic configuration for wet snow condition in Italy is represented in Fig.4, which corresponds to the event of 6 February 2015. The formation of a deep low pressure over Italy is evident from the geopotential height and temperature at 500 hPa and 850 hPa obtained from ERA5.

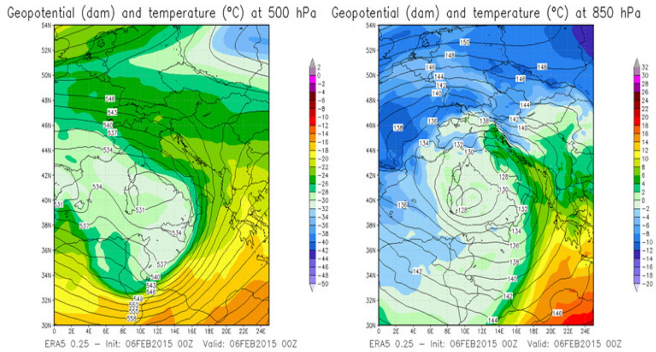

Fig. 4 Map of the geopotential height and temperature at 500 hPa (on the left) and at 850 hPa (on the right) for the event of 6 February 2015. Source: ERA5.

At the end of a heavy snowfall event in February 2015, ARERA started a fact-finding investigation in relation to the interruptions of the electricity service for the abundant wet snowfalls that affected large areas of Emilia Romagna and Lombardy (*Deliberation 96/2015/E/eel*). The map of total snow load estimated with Makkonen model by using MERIDA and the reported power lines failures is represented in Fig.5. The failures actually occurred in areas with the most significant estimated snow load.

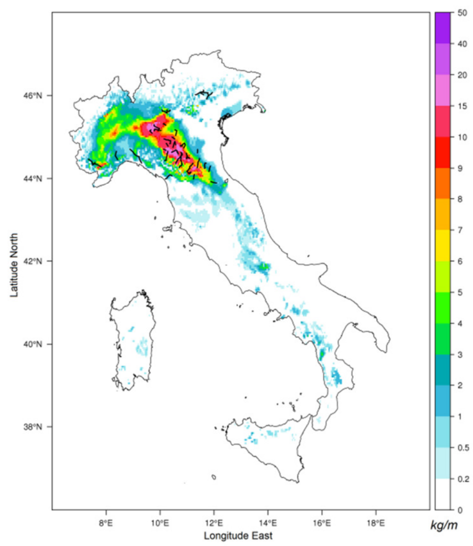

Fig. 5 Map of total snow loads (kg/m) for ACSR-585 mm^2 conductor and the reported lines failures (black lines) for the event of 6 February 2015 [1].

As an example, Fig.6 shows the 2-m temperature, the wind speed, the accumulated and the intensity of precipitation extracted from MERIDA relative to the town of Reggio Emilia, in the area of Emilian plain from 5 to 7

February 2015. The weather conditions are typical of a wet snow and the total mass estimated with the snow model for the CU25 mm^2 conductor at the end of the event, is close to 5 kg/m. The grid point of MERIDA is near the distribution power line failures.

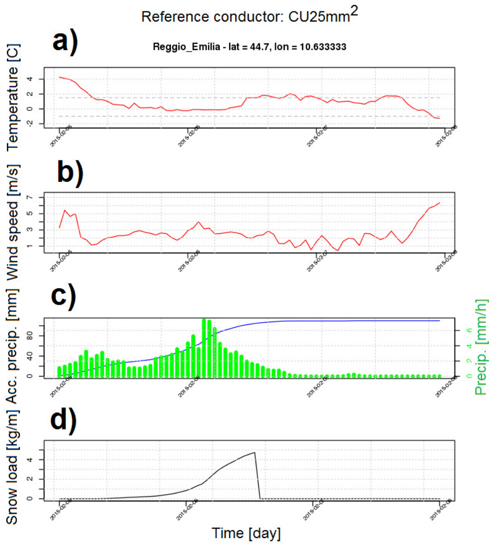

Fig. 6 Meteogram: 2-m temperature (a), wind speed (b), cumulative and intensity of precipitation (c), snow load (d) for the reference conductor CU25 mm^2 . The grid point of MERIDA is near the distribution power line failures in the municipality of Reggio Emilia.

The survey pointed out that the energy not provided to the users was 990 MWh, i.e. 20% of the energy not supplied in a year. In just one day, the automatic refunds for protracted outages over 8 hours were quantified in the order of 33 million euros, net of structural damage and restoration costs. At the end of the same survey, the Authority had resolved that the distribution companies updated their emergency and intervention plans, thus increasing the level of safety and reliability of the electricity service (*Deliberation 644/2015/E/eel*).

V. WET SNOW LOAD MAPS

The preliminary mapping of the expected sleeve loads with a 50-year return time was obtained through two different statistical methods referring to the Extreme Value Analysis (EVA) theory [7], i.e., the Block Maxima (BM) and the Peak Over Threshold (POT) [8]. The first is based on extracting the maximum annual snow loads, while the latter consists of extracting from a continuous record the peak values reached for any period during which a certain threshold is exceeded.

Both methods were tested on the series of sleeve loads data for the 2000-2018 period and the reference ACSR 585 mm^2 conductor of the transmission network. In summary, the Generalized Extreme Values (GEV) is a family of continuous probability distributions developed within the theory of extreme values, which provides the statistical framework to calculate the probability of very rare or extreme events where it is necessary to assess their risk of occurrence. Therefore, the GEV distribution was used as an approximation to model the values of the series of sleeve loads data. On the basis of the extreme values theory deriving from the GEV distribution, it is possible to reconstruct the parameters that best explain the probability distribution of extreme events and, from it, to derive the expected values at different return times. There are several criteria to evaluate the model through proper estimators such as the maximum likelihood (MLE) or the l-moments estimator.

For both the BM and the POT, the *l-moments* was used to fit the distribution of sleeve loads because it best reproduces the derived probability distribution. The POT method collects all the "relevant" load values, while the BM takes into account only the maximum annual values of the series. Hence the POT seems to better use the information available in the dataset of loads reconstructed with MERIDA. The BM mainly focuses on the queues of the distribution of the annual maximum load values through a proper combination of the probability distributions of Gumbel, Fréchet and Weibull ([14]-[17]), but the POT method is more complex because it requires the identification of threshold values above which to perform the statistical analysis. In particular, it can be shown that for large enough thresholds, the distribution of values that exceed a certain threshold is approximated to a Generalized Pareto Distribution (GPD [18]) with its own parameters of shape and scale. The maximum values that constitute the threshold to fit the series with the GPD are extracted within a monthly mobile window that runs along the series of loads. For each model grid point and identified threshold the fit is made with the GPD, obtaining the scale and shape values. Through these, it is possible to reconstruct the cumulative distribution function (CDF) starting from the GPD for each identified threshold. Similarly, the empirical cumulative distribution function (ECDF) is reconstructed from the sleeve load series.

A Goodness of Fit (GOF [19]) test is then introduced to identify between the used thresholds the one that produces the best fit with the GPD distribution. The Anderson-Darling test allows to compare the fitting of an ECDF with an estimated CDF. This test gives more weight to the queues than the Kolmogorov-Smirnov one [20], and is therefore more suitable to investigate the snow load series. The threshold value that minimizes the *p-value* of the test is the one used to fit the entire series of sleeve loads through the GPD. Fig.7 shows the two maps of the expected loads at 50 years over Italy for ACSR 585 mm^2, obtained with the BM method (on the left) and the POT (on the right).

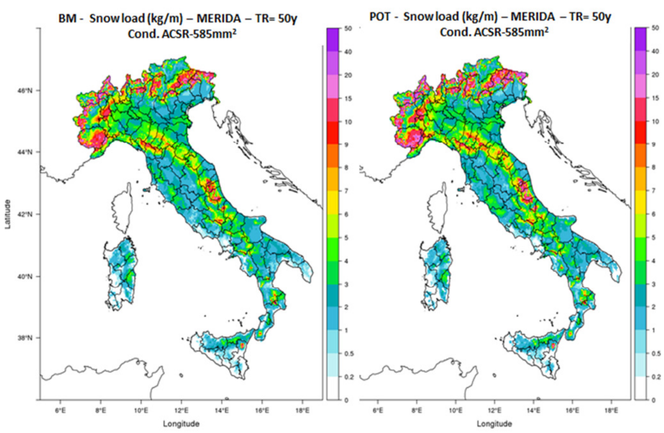

Fig. 7 Preliminary maps of expected values of total snow loads (kg/m) at 50 years return time for ACSR-585 mm^2 conductor with BM (on the left) and POT (on the right).

In general, a rather similar mapping of expected loads at 50 years-return time is observed over the Alpine sectors and along the Adriatic side, however with slightly higher snow loads for the POT, especially in the western part of the Alps. Along the northern Tyrrhenian side the POT shows a bit more expected snow loads than the BM, while for the two major islands the methods indicate similar results.

It is recalled that these reconstructions are only preliminary and the authors intend to test another new approach proposed by Makkonen and Tikanmäki in a recent article [21] based on *VWLS method* and compare the results with BM and POT estimations over Italy.

VI. Conclusions

The first part of this work is dedicated to the presentation of a new high resolution reanalysis dataset (MERIDA) entirely realized by RSE. MERIDA uses the WRF-ARW model to dynamically downscale 3-hourly ERA5 global reanalysis data for the period 2000-2018, with a spatial resolution of 7 km and hourly temporal increments. The Optimal Interpolation (OI) technique combined with the lapse rate obtained from the model has been applied order to create a precipitation and temperature dataset on a regular grid of 4 km remodelled on the basis of the observations available on the ground. A simplified version of the Makkonen model for wet snow has been applied in order to reconstruct the snow loads for the period 2000-2018 by using the MERIDA and some case studies related to prolonged disruption like those caused by the wet snow of February 2015, have been analyzed .

The second part of this work focuses on the creation of a new mapping of the return level of sleeve loads over a fixed return period of 50 years on the Italian territory, as required by the National Normative Aspects (NNA) for Italy (CEI-EN 50341-2-13:2017), in order to update the design criteria of overhead transmission lines (IEC 60826:2017), which specifies their loads and strength requirements. The preliminary estimation of the snow loads is carried out using the Generalized Extreme Values (GEV) analysis following two different approaches, the Block Maxima (BM) and the Peak Over Threshold (POT) over the period 2000-2018. In general, a rather similar mapping of expected loads at 50 years return times has been reproduced over Italy with the two methods, with slightly higher snow loads for the POT. Other approaches will be tested to estimate the snow loads over Italy, first of all the *VWLS method* proposed in a recent article by Makkonen and Tikanmäki.

MERIDA is thus produced to deepen information about the most relevant weather events especially for wet snow that represent the most critical risk factor for transmission and distribution of energy. The electric operators can derive from MERIDA the necessary information for both strengthening the power network and restoring the energy supply service in areas subject to relevant phenomena in order to increase the resilience of the electrical system.

Acknowledgments

This work has been financed by the Research Fund for the Italian Electrical System in compliance with the Decree of Minister of Economic Development April 16, 2018.

References

[1] Bonanno, R., Lacavalla, M., Sperati, S. (2019). A new high‐resolution MEteorological Reanalysis Italian DAtaset: MERIDA. Accepted Article published online on 25 March, 2019. , Quarterly Journal of the Royal Meteorological Society. https://doi.org/10.1002/qj.3530

[2] Makkonen, L. (2000). Models for the growth of rime, glaze, icicles and wet snow on structures. Phil. Trans. R. Soc. Lond. A, 358, 2913-2939. https://doi.org/10.1098/rsta.2000.0690.

[3] Fikke, S.M., Ronsten, G., Heimo, A., Kunz, S., Ostrozlik, M., Person, … Makkonen, L. (2007). COST 727: Atmospheric Icing on structures, Measurements and data collection on icing: State of the Art. Veröffentlichung MeteoSchweiz, 75.

[4] Bonelli, P., Lacavalla, M., Marcacci, P., Mariani, G., Stella, G. (2011). Wet snow hazard for power lines: a forecast and alert system applied in Italy. Nat. Hazards Earth Syst. Sci., 11, 2419-2431. https://doi.org/10.5194/nhess-11-2419-2011.

[5] Nygaard, B.E.K., Ágústsson, H., Somfalvi-Tóth, K. (2013). Modeling Wet Snow Accretion on Power Lines: Improvements to Previous Methods Using 50 Years of Observations. J. Appl. Meteor. Climatol., 52, 2189-2203. https://doi.org/10.1175/JAMC-D-12-0332.1.

[6] Somfalvi-Tóth, K., Lakatos, M., Kollath, K. Fulop R, Simon A. (2009). Climatology and forecasting of severe wet snow icing in Hungary. Proc. 13th International Workshop on Atmospheric Icing of Structures. Andermatt.

[7] D. Benstock e F. Cegla, «Extreme value analysis (EVA) of inspection data and its uncertainties,» NDT & E International, vol. 87, n. ISSN 0963-8695, pp. 60-77, 2017.

[8] Rivas, F. Caley, A. Valor e J. Hallen, «Extreme value analysis applied to pitting corrosion experiments in low carbon steel: Comparison of block maxima and peak over threshold approaches,» Corrosion Science, vol. 50, n. ISSN 0010-938X, pp. 3193-3204, 2008.

[9] Hersbach, H., Dee, D.P. (2016). ERA5 reanalysis is in production. ECMWF Newsletter, 147, 1-11.

[10] Skamarock, W., Klemp, J., Dudhia, J. (2008). A Description of the Advanced Research WRF Version 3. Tech. Note NCAR/TN-475+STR.

[11] Kalnay, E. (2003). Atmospheric modeling, data assimilation and predictability. Cambridge Univ. Press.

[12] Uboldi, F., Lussana, C., Salvati, M. (2008). Three-dimensional spatial interpolation of surface meteorological observations from high-resolution local networks. Met. Apps., 15, 331-345. https://doi.org/10.1002/met.76.

[13] Maraun, D. (2013). Bias Correction, Quantile Mapping, and Downscaling: Revisiting the Inflation Issue. J. Climate, 26, 2137–2143. https://doi.org/10.1175/JCLI-D-12-00821.1

[14] E. Gumbel, «Statistics of Extremes,» Columbia University Press, 1958.

[15] W. Weibull, «A statistical distribution function of wide applicability,» J. Appl. Mech.-Trans., pp. 293-297, 1951.

[16] R. Fisher e L. Tippett, «Limiting forms of the frequency distribution of the largest and smallest member of a sample,» in Proc. Cambridge Philosophical Society, 1928.

[17] S. Kotz e S. Nadarajah, «Extreme Value Distributions: Theory and Applications,» London: Imperial College Press, 2000.

[18] C. Barry, «Pareto Distribution,» Wiley Stats Ref: Statistics Reference Online, pp. 1-10, 2015.

[19] T. Anderson e D. Darling, «A Test of Goodness-of-Fit,» Journal of the American Statistical Association, vol. 49, p. 765–769, 1954.

[20] Springer, «Kolmogorov–Smirnov Test,» The Concise Encyclopedia of Statistics, 2008.

[21] Makkonen, L. (2019). An improved method of extreme value analysis. Journal of Hydrology X. Volume 2, January 2019, 100012. Elsevier.