Tests on adjustment laws of wet snow and rime loads in France

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***Abstract*— Extreme weather events like rime or wet snow events are not regular phenomena in France. But when they happen, accretion overloads can impact and damage in particular electrical transmission and distribution lines. Electricité de France is involved in accretion risk maps by estimating T-return-period rime and wet snow overloads. Because of the irregularity of the phenomenon, asymptotic extreme value theory must be reviewed. At French meteorological stations, observations of daily meteorological situations are used to extract the right parameters values inducing rime and wet snow. Then overloads are estimated with accretion models (see another presentation on rime models by S.Parey). The T-return-period overloads are assessed with a sort of threshold method (keeping the 15% highest values) at available Météo-France stations. Results from an empirical law fit (a polynomial form) and an extreme distribution fit (an exponential law) are compared. The polynomial law describes precisely the data but, by construction, is very sensitive to isolated values.**

I. Introduction

Rime and wet snow events are not regular phenomena in France. Some winters don't present the right meteorological conditions to induce overloads on electrical lines. Therefore, overloads data do not correspond to "extreme values" in a statistical meaning, and the asymptotic hypothesis of extreme value theory is not verified yet. The question of using an a priori distribution law and not an extreme value distribution law, is asked [6][7]. 15% of the highest overloads, estimated with an accretion model from meteorological data, are kept to use a threshold method [10], and two types of adjustment laws (exponential and polynomial, the latter recommended in [6]) are compared in different areas in France.

Meteorological conditions inducing consequent rime and wet snow on electrical lines, and the methods used in the paper, corresponding to both modeling and statistics, are described in a first part. Then, comparison between the two adjustments and results are given in a next part. At the end, a discussion is given.

II. Data and Methods Used

The studied areas in France are the following : Alpes du Sud, Pyrénées-Roussillon and Loire for wet snow (which correspond respectively to 2 high risk areas and a low risk area), and Nantes-Atlantique and Nice-Alpes d'Azur for rime (for which data were available, following an update of risk maps for EDF distribution centers in 2002).

A. Meteorological conditions

A wet snow overload on electrical wires can occur when the snow is "wet", corresponding to a snow with a liquid water content high enough to create an overload by contact. To obtain a consequent overload, the snow fall must be important and long enough. Meteorological conditions required are then a strong event of precipitations with temperatures around 0°C (see the meteorological criterion below). Wind speed can also influence the load formation.

For each studied area, we select 10 to 15 Météo-France stations with about 30 years of daily minimum and maximum temperatures (noted Tmin and Tmax respectively) and daily amount of precipitations (noted P) recorded. Then the potential wet snow days are selected from the following criteria: $T_{min} \leq +1°C$, $T_{max} \geq +1°C$ and $P \geq 20mm$ from the first November to the end of March. An example of the selection of wet snow episodes is given in Appendix A for a station named Arvieux in Alpes du Sud.

In-cloud icing occurs when an electrical wire stays within an icing cloud for at least two consecutive days.

As for wet snow, we select 10 to 15 Météo-France stations on the studied area with about 30 years of daily maximum temperatures recorded. First, some days are selected from the following criteria: $T_{max} \leq -3°C$ during 24h between the first November and the end of March. Then, the potential rime days are selected from the following criteria : $T_{max} \leq 0°C$ during 24h and more ; $\left|T_{min} - T_{max}\right| \leq 4°C$, with rime observed at the nearest meteorological station, with a positive wind speed and relative humidity exceeding 95% (or daily amount of precipitations < 5 mm). An example of the selection of rime episodes is given in Appendix B for a station named Ancenis in Nantes-Atlantique.

B. Accretion models

In addition to temperature and precipitations, wind speed data is needed as input of the accretion model to evaluate a wet snow overload. The nearest meteorological station from the climatological station (which does not measure this parameter) is used. Then an overload is calculated for each day by the "GERIKO-Neige" model for wet snow and "GERIKO-Givre" model for rime (see Appendix C and D for a short description of principles of the models and references at the end of the paper).

C. Statistical methods

From these overloads data (sometimes very occasional), we look for a cumulative distribution function (CDF) which fits the data the best, to estimate a T-return-period value. By definition, a CDF noted F(x)=P(X<x), is defined from $\Re$ to [0;1], and is a monotonous increasing and continuous (on left side) function (from [9]). This reminder will be important for discussion.

Firstly, the fit on overloads is done on the 15% highest values (with a minimum of 10 values for wet snow) with an exponential law. The probability of not exceeding X but exceeding the threshold S is then given by $F(X)=1-\exp[-(X-S)/\alpha]$ where α is the exponential coefficient. So, the probability of exceeding X is given by $F'(X)=\exp[-(X-S)/\alpha]$ and $\ln[F'(X)])=-(X-S)/\alpha$ with F'(X) estimated from the empirical annual frequency given by $FA(X_i)=(k+1-i)/N$ (where k is the number of values exceeding the threshold, i the rank of the ordered values ($x_1 \leq \ldots \leq x_N$), and N the years number of observations). In a semi-logarithmic graph, X as a function of ($-\ln[F'(X)]$), which is ln(T) with T the time period, is then a straight line (see Figs.1 and 2 in Appendix). The CDF F(X) is in this case a monotonous increasing function of X, varying between [0;1[when X varies from 0 to $+\infty$.

In a second step, this fit is compared with a polynomial adjustment [6] (where $-\ln[F'(X)]$ follows a polynomial form): this curve is not always a monotonous increasing function (see Fig.2). Comparisons between fits are presented in terms of correlation with the original data and in terms of 20-year-return-period values. Two examples of adjustments (one for wet snow and one for rime) are given in Appendix A and B.

III. Comparison and Results

For each EDF distribution center studied, a table is given, including a 20-year-return-period value (in kg/m) for exponential adjustment (noted Exp.) and for a 3-order polynomial adjustment (noted Polyn.), which is the order corresponding to the best fit in term of correlation with data, for each meteorological station of the area, followed by the correlation coefficients between original data and each kind of adjustment.

A. Wet snow

1) Alpes du Sud

This EDF distribution center contains 21 meteorological stations, with data from 17 to 57 years. For each station, 2 adjustments are done (exponential and polynomial) as shown in an example in Appendix A. Then, the following table (Table 1) presents the results as 20-year-return-period values and as correlation.

We can see that 20-year-return-period values are quite similar between the two kinds of adjustments (except for Castellane and St Etienne en D., for which 2 and 1 values respectively influence the polynomial distribution shape towards high values). A 3-order polynomial adjustment describes well the data (see the high correlation coefficient values with the original data) but in return, is very sensitive to isolated values, which has important consequences for extrapolation.

TABLE I

By column : station name of Alpes du Sud, 20-year-return-period value (in kg/m) with exponential fit and polynomial fit, correlation coefficient between original data and exponential fit then polynomial fit.

station	20-year-return-period value (kg/m)		correlation / obs	
	Exp.	Polyn.	Exp.	Polyn.
Allos	8.7	8.3	0.9466	0.9773
Arvieux	6.5	6.8	0.9706	0.9731
Barcelonnette	3.9	4.0	0.9410	0.9741
Briançon	6.5	6.7	0.9907	0.9947
Castellane	5.9	6.6	0.7752	0.8606
Ceillac	4.9	5.1	0.9565	0.9800
Ch Ar St Auban	2.5	2.6	0.9654	0.9731
Embrun	6.0	6.3	0.9750	0.9897
Gap	5.2	5.3	0.9712	0.9882
Lamotte	1.7	1.8	0.8769	0.9245
Laragne	5.3	5.4	0.8814	0.9741
Les Orres	3.2	3.4	0.9151	0.9832
Lus la Croix hte	3.4	3.5	0.9486	0.9447
Marcoux	5.1	5.4	0.9709	0.9851
Le Monetier	6.2	6.3	0.9221	0.9774
Nevache	6.1	6.4	0.9739	0.9845
Orcières	7.6	7.6	0.9080	0.9846
Rosans	2.2	2.0	0.9533	0.9875
St Etienne en D.	7.2	8.2	0.8842	0.9668
St Paul	7.1	7.2	0.9747	0.9777
Tallard	3.7	3.8	0.9644	0.9756

2) Pyrénées Roussillon

This EDF distribution center contains 28 meteorological stations, with data from 9 to 78 years. The results, presented as above, are given in the following table (Table 2).

As for Alpes du Sud, the 20-year-return-period values are quite similar between the two adjustments (except for Perpignan where polynomial adjustment is distorted towards high values). Correlation coefficients are high (>0.7) and polynomial adjustment is better (by construction) to describe data (correlation coefficients > 0.9).

TABLE II
AS TABLE I BUT FOR PYRÉNÉES-ROUSSILLON.

station	20-year-return-period value (kg/m)		correlation / obs	
	Exp.	Polyn.	Exp.	Polyn.
Alenya	5.6	5.9	0.9544	0.9731
Amélie les Bains	5.9	6.5	0.9167	0.97
Banyuls sur mer	4.1	4.3	0.9686	0.9742
Canet en Roussillon	5.3	5.6	0.9596	0.9812
Codalet	6.4	6.5	0.9726	0.9674
Eus	Not enough episodes			
Formiguères	4.1	4.3	0.8902	0.9069
Le Barcarès	Not enough episodes			
Le Boulou	4.8	4.8	0.9272	0.9801
Le Perthuis	Not enough episodes			
Le Tech	5.7	6	0.9642	0.9731
Le Tech-la-Lau	5.7	5.9	0.9456	0.9703
Millas	7.4	7.8	0.8207	0.9553
Mont-Louis	5.5	5.4	0.8101	0.9319
Nohedes	6.3	6.5	0.9109	0.9216
Olette	4.3	3.7	0.8706	0.9787
Perpignan	6.2	7.5	0.7473	0.9839
Porte-Puymorens	7.9	8	0.9713	0.9805
Port-Vendres	2.8	2.7	0.9357	0.9172
Sournia	7.7	7.9	0.8426	0.9519
Ste Léocardie	1.8	1.8	0.9795	0.9737
St Laurent de Cerdans	8.0*	8.9	0.8787	0.9391
St Paul de Fenouillet	Not enough episodes			
Thuir	Not enough episodes			
Torreilles	8.0*	8.8	0.8545	0.9184
Tuchan	7.7	8	0.8511	0.9455
Valcebollère	8.0*	8	0.872	0.9764
Vernet les Bains	6.8	7.2	0.9472	0.9837
* values at 8 kg/m because of short series				

3) Loire

This EDF distribution center contains 16 meteorological stations, with data from 10 to 71 years. The results, presented as previously, are given in the following table (Table 3).

As for Pyrénées Roussillon, the 20-year-return-period values are quite similar between the two adjustments. Correlation coefficients are high (>0.8) and polynomial adjustment is better (by construction).

TABLE III
AS TABLE I BUT FOR LOIRE.

station	20-year-return-period value (kg/m)		correlation / obs	
	Exp.	Polyn.	Exp.	Polyn.
Andrézieux-B.	2	1.7	0.8885	0.933
Boen sur L.	Not enough episodes			
Chalmazel	2.8	2	0.8941	0.9667
Chazelles sur L.	0.7	0.8	0.9504	0.9503
Feurs	1.2	1.2	0.9313	0.9263
Fourneaux	1.1	1	0.8996	0.9488
La Pacaudière	2.1	2	0.8521	0.9595
Nandax	1.1	1.2	0.8402	0.9891
Riorges	1.8	1.7	0.9685	0.9932
Savigneux	1	1	0.9184	0.9811
St Denis de C.	1.2	1.2	0.8994	0.9864
St Etienne	1.3	1.3	0.9865	0.986
St Germain L.	Not enough episodes			
Sauvages	2	1.5	0.8513	0.9678
Tarentaise	3.1	3.7	0.7221	0.8603
Verrirères en F.	2.5	2.6	0.9741	0.9809

B. *Rime*

1) Nantes-Atlantique

This EDF distribution center contains 20 meteorological stations, with data from 4 to 57 years. The results, obtained as previously for wet snow, are given in Table 4 for rime.

TABLE IV
SAME TABLE THAN TABLE I BUT FOR RIME IN NANTES-ATLANTIQUE.

station	20-year-return-period value (kg/m)		correlation / obs	
	Exp.	Polyn.	Exp.	Polyn.
ANCENIS (20 m)	1	0.7	0.7266	0.9722
BAULE-ESCOUBLAC (6 m)	1.2	1.3	0.8927	0.9728
BLAIN (14 m)	0.4	0.5	0.7763	1
BSE-GOULAINE (6 m)	Not enough episodes			
DERVAL (43 m)	0.9	1	0.8203	0.9167
GUERANDE (3 m)	Not enough episodes			
HERBIGNAC (22 m)	Not enough episodes			
LA HAIE-FOUASSIERE (30 m)	1.2	0.7	0.6052	0.8967
LANDREAU (40 m)	Not enough episodes			
MACHECOUL (5 m)	2.9	3.8	0.7763	1
NANTES-BOUGUENAIS (26 m)	0.8	0.7	0.743	0.9634
NORT-SUR-ERDRE (14 m)	1.3	1	0.8092	0.962
PALLET (30 m)	Not enough episodes			
PELLERIN(LE) (7 m)	Not enough episodes			
PORNIC (8 m)	1.6	1.5	0.8648	0.9136
SAINT-JOACHIM (2 m)	1.6	1.3	0.7763	1
SAINT-NAZAIRE (23 m)	1.4	1.1	0.9094	0.9679
SOUDAN (64 m)	4 episodes with 0.2 kg/m			
SOUDAN (79 m)	Not enough episodes			
ST NAZAIRE-MONTOIR (3 m)	0.6	0.6	0.8337	0.9419

The meteorological data for rime are sometimes too short to obtain more than a few episodes per station. So adjustment is not possible in these cases. As for wet snow, the 20-year-return-period values are quite similar between the two adjustments. Correlation coefficients are relatively medium (>0.6) and polynomial adjustment is better (by construction), but in return, is very sensitive to isolated values (see Machecoul example where a 3 kg/m episode distorts polynomial distribution towards high values).

2) Nice-Alpes d'Azur

This EDF distribution center contains 32 meteorological stations, with data from 8 to 44 years. The results, presented as above, are given in the following table (Table 5).

TABLE V

AS TABLE IV BUT FOR NICE-ALPES D'AZUR.

station	20-year-return-period value (kg/m)		correlation / obs	
	Exp.	Polyn.	Exp.	Polyn.
ANDON (1160 m)	0.3	0.2	0.8863	1
ASCROS (1180 m)	0.0*	too weak values (0.2 or 0.3 kg/m)		
BOUYON-OBS (745 m)	0.2	only 2 episodes		
BOUYON (720 m)	0.4	only 2 episodes		
CAUSSOLS (1265 m)	1	1.0	0.9358	1
COLOMARS (334 m)	0.4	only 2 episodes		
ISOLA (870 m)	0.7	0.8	0.9316	1
ISOLA (2035 m)	6.1	5.7	0.8962	0.938
ISOLA 2000 (1910 m)	2.3	2.2	0.9406	0.9854
LUCERAM-OBS (1420 m)	1	1.0	0.8306	0.9401
LUCERAM (1480 m)	0.8	1.0	0.8218	0.9979
MOULINET (780 m)	0.5	0.8	0.7714	1
PEILLE (1103 m)	0.3	only 2 episodes		
PEONE (1659 m)	1.3	1.4	0.9119	0.9701
SAINT-AUBAN (1050 m)	0.4	only 3 episodes		
ST-DALMAS-LE-SE	1.6	1.4	0.7245	0.8451
SAINT-ETIENNE-DE-TINEE (1610 m)	1.4	1.4	0.9197	0.9005
SAINT-MARTIN-VESUBIE (1000 m)	0.6	0.8	0.8577	1
VALDEBLORE-OBS (1000 m)	0.4	only 3 episodes		
TENDE (650 m)	0.6	0.7	0.8739	0.9478
CASTERINO (1550 m)	2.9	3.0	0.8023	0.7985
* value at 0 kg/m because only 3 episodes of too weak values (0.2 or 0.3 kg/m)				

The conclusions are the same as for Nantes-Atlantique.

IV. CONCLUSION AND DISCUSSION

Rime and wet snow events are rare and not regular phenomena in France, so the asymptotic hypothesis of extreme value theory is not verified yet. This study tests the use of an a priori distribution law on the 15% of the highest overloads estimated with an accretion model from meteorological data. As a conclusion, we can say that adjusting a 3-order polynomial distribution instead of an extreme value distribution (a simple exponential law was tested here) does not modify, in a significant manner, the 20-year-return-period overload, whatever the risk is (different areas were tested here). Correlation with original data is better with polynomial adjustment but in return, it is very sensitive to high isolated values, and cannot be used to extrapolate reasonably data in future. Furthermore, a 3-order polynomial, which was the polynomial order which fitted the data the best, is not in all cases a monotonous and increasing function, and statistical hypothesis have to be checked before using it as a CDF. So, the choice of the kind of adjustment law depends on what it is done for (description of past events, extrapolation towards future, etc…) but above all, statistical definitions must be kept in mind and verified.

V. APPENDIX

A. Example of wet snow episodes at Arvieux station (Alpes du Sud) : data and adjustments

The station presented in this Appendix is named Arvieux in Alpes du Sud area. 52 years (from 1951 to 2002) of data are used to extract the days following the wet snow criterion given in the main text (Part II), corresponding to 21 days on this period of time. From these data, a maximum and a mean overloads (noted Sx and Sm respectively, given in kg/m) were then calculated by the accretion "GERIKO-Neige" model and given in the table below (Table 6).

TABLE VI

BY COLUMN : THE DATES (IN YYYYMMDD) SELECTED AS WET SNOW DAYS, DAILY MINIMUM AND MAXIMUM TEMPERATURES (TMIN AND TMAX IN °C), DAILY AMOUNT OF PRECIPITATIONS (P IN MM), DAILY MEAN WIND SPEED (VM IN M/S), MAXIMUM AND MEAN OVERLOADS CALCULATED (SX AND SM IN KG/M), EMPIRICAL ANNUAL FREQUENCY (FA IN 1/YEARS) AND THE ASSOCIATED RETURN PERIOD (PR IN YEARS).

Date	Tmin	Tmax	P	Vm	Sx	Sm	FA	PR
19850122	-2.1	1.7	65.9	2.6	10.0	8.0	0.02	52.0
19790127	-4.4	1.8	65.3	3.0	9.8	7.9	0.04	26.0
19961111	-0.8	1.7	57.6	3.0	7.7	6.2	0.06	17.3
19631115	-3.0	11.0	58.0	4.3	6.5	5.2	0.08	13.0
19701113	-1.5	4.8	53.5	3.4	6.3	5.0	0.10	10.4
19691112	-1.0	14.9	50.8	3.0	6.1	4.8	0.12	8.7
19511118	-2.0	4.0	49.8	3.0	5.8	4.7	0.13	7.4
19541209	-6.0	1.0	49.1	3.0	5.7	4.6	0.15	6.5
19961113	0.2	2.9	43.6	3.0	4.5	3.6	0.17	5.8
19710321	-2.3	3.2	43.2	3.0	4.5	3.6	0.19	5.2
19821208	-1.6	2.9	41.2	3.0	4.1	3.3	0.21	4.7
19601217	-2.0	5.0	55.0	8.6	4.0	3.2	0.23	4.3
19711108	0.0	7.0	38.4	3.0	3.6	2.9	0.25	4.0
19761201	-3.5	2.6	37.1	2.6	3.6	2.9	0.27	3.7
20010106	-0.9	7.2	36.0	3.0	3.2	2.5	0.29	3.5
19640325	0.5	2.5	40.5	5.0	3.0	2.4	0.31	3.3
19510218	0.0	3.0	35.3	3.0	3.0	2.4	0.33	3.1
19590306	-0.3	10.8	35.6	3.3	2.9	2.4	0.35	2.9
19971106	0.6	6.6	34.4	3.0	2.9	2.3	0.37	2.7
19790325	-5.9	6.4	34.3	3.0	2.9	2.3	0.38	2.6
19660221	0.0	4.8	35.5	3.6	2.8	2.3	0.40	2.5

According to these data, whose loads were classified in a decreasing order, two fits on mean overloads (Sm) are tested: a simple exponential law (which is the simplest extreme value distribution) and a 3-order polynomial law, as shown on Fig. 1.

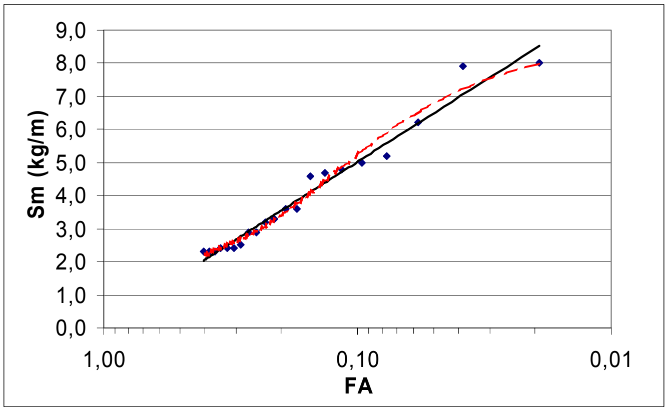

Fig. 1. Arvieux (Alpes du Sud). Mean wet snow overload (in kg/m) as a function of empirical frequency (in 1/years, in a decreasing order) in a semi-logarithmic graph, with two fits on data : an exponential law (straight line) and a 3-order polynomial adjustment (dashed curve).

A 20-year-return-period overload corresponds, by definition, to a 0.05 empirical frequency (PR=1/FA). That is to say, on Fig.1, an overload of 6.5 kg/m with exponential law and 6.8 kg/m with polynomial law.

The same types of table and graph are obtained for each station of each area studied in this article for wet snow.

B. Example of rime episodes at Ancenis station (Nantes-Atlantique) : data and adjustments

As for wet snow, the same types of results (see Table VII and Fig. 2 below) are presented here for rime, at Ancenis station in Nantes-Atlantique, which is a low risk area. 39 years (from 1964 to 2002) of data are used to extract the days following the rime criterion given in the main text (Part II), that is to say only 7 days, hence the difficulty of fitting a law to these data.

TABLE VII

BY COLUMN : THE EPISODE BEGINNING AND ENDING DATES (IN DD/MM/YYYY) SELECTED AS RIME EPISODES, MINIMUM AND MAXIMUM OF DAILY MINIMUM AND MAXIMUM TEMPERATURES (IN °C), DAILY MEAN WIND SPEED (VM IN M/S), MAXIMUM OVERLOAD (SX IN KG/M), EMPIRICAL ANNUAL FREQUENCY (FA IN 1/YEARS) AND THE ASSOCIATED RETURN PERIOD (PR IN YEARS).

Beginning date	Ending date	Min. Tmin	Max. Tmax	Vm	Sx	FA	PR
12/01/1987	13/01/1987	-11.0	-7.0	7.3	2.0	0.03	39.0
01/01/1997	01/01/1997	-9.0	-6.5	4.0	0.5	0.05	19.5
18/01/1966	18/01/1966	-7.3	-4.5	5.6	0.2	0.08	13.0
13/12/1968	13/12/1968	-5.9	-4.0	5.1	0.2	0.10	9.8
07/01/1997	07/01/1997	-7.4	-3.5	4.5	0.2	0.13	7.8
16/01/1987	16/01/1987	-6.5	-4.0	3.5	0.2	0.15	6.5
19/01/1987	19/01/1987	-6.8	-4.3	2.5	0.2	0.18	5.6

We can see on Fig. 2 that the 20-year-return-period overload corresponds to a value of 1 kg/m with exponential law and 0.7 kg/m with polynomial law.

The same types of table and graph are obtained for each station of each area studied in this article for rime.

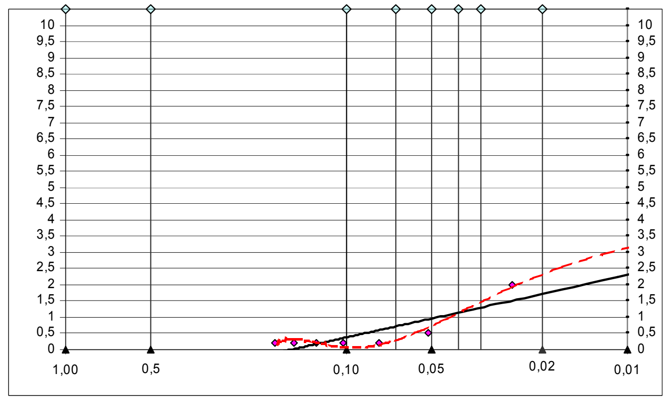

Fig. 2. Ancenis (Nantes-Atlantique). Mean rime overload (in kg/m) as a function of empirical frequency (in 1/years, in a decreasing order) in a semi-logarithmic graph, with two adjustments laws : an exponential law (straight line), and a 3-order polynomial fit (dashed curve).

C. Wet snow model

The forecast of wet-snow risk at EDF is done using a model called "GERIKO-Neige", designed by Mr Admirat. This model uses meteorological information to evaluate the overloads caused by wet-snow events. A technical report describes the principle of the model (see [1] for details).

To evaluate a snow load, the model needs as inputs the forecasted maximal precipitation amount for the event, the duration of the event, the height of 0°C isotherm at the beginning of the event and at its end, the wind speed at the beginning of the event and at its end.

Then, the evaluation is conducted over the event duration with a one hour time step and for heights between 0 and 1500m with a 100m step. Precipitation amount is distributed each hour following a Gauss distribution. Temperature and wind speed are interpolated both temporally and spatially. Temporal interpolation is linear. For interpolation with height, a linear formulation is used for wind speed, and temperature is evaluated from 0°C isotherm height using a calculated temperature gradient. Beforehand, duration is corrected by a 0.8 factor.

D. Rime model

In the 1980's, the rime model basis came from a collaboration with a laboratory of the University of Clermont-Ferrand (LAMP, Laboratoire Associé de Météorologie Physique) and its principle [8] could have been identified and coded by EDF R&D last year. This version is used in the weather alarm service at EDF (called "GERIKO-Givre" model). Then, another model, based on an approach proposed by Lasse Makkonen since 1984 ([4], [5]) and recommended in the ISO 12494 standard [3], was developed (this version is not used in this study). The two versions of the "GERIKO-Givre" model are described in a technical report [2] and are now available for use (see another presentation on this theme, by S.Parey).

VI. ACKNOWLEDGMENT

We would like to thank Lasse Makkonen for his instructive discussions with Sylvie Parey at the Tenth IWAIS in 2002 [6], and Marc Le Du for constructive discussions on this paper.

VII. References

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