COMPARISON OF TWO RIME-MODELS AGAINST AN OBSERVED EVENT IN FRANCE

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***Abstract*— EDF has a weather alarm service for its distribution network, regarding wind, wet-snow and rime accretions, and lighting. For dimensioning and event severity estimation, risk maps for each parameter are produced, based on 20-year return levels (see the other presentation by C. Laurent). For forecasting as for risk maps, it is necessary to convert meteorological forecasted parameters into rime or wet-snow loads for the wires. This paper refers to rime accretion calculation, for which two modelling approaches have been tested and compared to a real rime event in France. The two models are based on the same principle but differ in the way of evaluating collection efficiency, rime density and mass losses. One is a French model, written by Pezard, Gayet and Admirat and the other one is the Makkonen model. The comparison shows that Makkonen model gives realistic results both for diameter and for overload, when the other one is better for overload than for diameter evaluation, but for different values for liquid water content and droplet diameter. Thus once again the importance of these non routinely measured parameters on the model results is shown, and the two approaches are considered for the evaluations devoted to the weather alarm service.**

I. INTRODUCTION

Rime overloads occur when a wire stays inside an icing cloud for a long time. They are evaluated from meteorological conditions using mathematical modelling. The approach used for EDF weather alarm service was based on a model previously developed by Pezard, Gayet and Admirat [3]. This approach has been compared to the one proposed by Makkonen since 1984 [6,7]. The two models will be compared on observed data measured for a real rime event in France. Firstly, the two models will be described, then the observed data will be presented and finally the results will be compared, before coming to discussion and conclusion.

II. RIME OVERLOAD MODELLING

Ice loads form due to particle in the air colliding with an object, here an electrical wire. The maximum rate of icing per unit area of the wire is determined by the flux density of these particles, which is expressed as the product of their mass concentration, w (liquid water content of the air, kg/m^3), and their velocity relative to the wire, Vi (m/s). Then, the rate of icing due to any icing phenomena (rime, freezing rain or wet snow) may be expressed as:

$$\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 w V_i A \qquad (1)$$

where A is the cross-sectional area relative to the direction of the particle velocity (m^2) [7]. Coefficients α_ι represent different phenomena which may reduce this rate and they vary between 0 and 1.

Coefficient α_1 represents the collision efficiency, that is the ratio of the flux density that hits the wire to the maximum flux density. Small particles tend to follow the streamlines and may then be deflected from the wire, so for rime loads, α_1 is smaller than 1.

Coefficient α_2 represents the sticking efficiency, that is the ratio off sticking particles to the hitting ones. It is reduced when the particles bounce from the surface. For rime, α_2 can reasonably be set to 1 [7].

Coefficient α_3 represents the accretion efficiency, and is one if the particle freezes immediately on the object (dry growth icing) and reduced from 1 otherwise (wet growth icing). In this latter case, α_3 is determined from the heat balance.

Then, for rime icing, equation (1) becomes:

$$\frac{dM}{dt} = \alpha_1 \alpha_3 w V A \qquad (2)$$

where V is the wind velocity (m/s) considered as perpendicular to the wire at any time, which maximises the calculated overload.

The ice deposit diameter D (m) is thus evaluated at each time-step i by:

$$D_i = \sqrt{\frac{4\Delta M}{\pi\rho} + D_{i-1}^2} \qquad (3)$$

where ρ is the ice density (kg/m^3) and M the mass per meter wire (kg/m).

The two models used here differ in their evaluation of α_i coefficients and of ice density, as detailed below.

A. *Pezart et al. model*

This model represents only the dry growth icing conditions, and thus, <u>α_3 is 1</u>.

1) *Calculation of α_1*

Coefficient α_1 is considered as the sum of a dynamical part α_{1dyn}, due to the streamlines around the wire, on one hand, and of a roughness part α_{1rug} on the other hand. The dynamical part is evaluated from Langmuir and Blodgett theory [5] : if it is assumed that the icing object is cylindrical, an analytical solution exists for the airflow around the object and α_1 can be parameterized using two dimensionless parameters:

$$K = \frac{\rho_w V d_m^{\ 2}}{9\mu_a D} \qquad (4)$$

where ρ_w (kg/m^3) is the water density, d_m (m) the median volume diameter of the particles, μ_a (kg/m/s) the absolute air viscosity and D (m) the cylinder diameter;

and

$$\mathrm{Re} = \rho_a \frac{V d_m}{\mu_a} \qquad (5)$$

the droplet Reynolds number, with ρ_a (kg/m^3) the air density.

Then, the dynamical part is evaluated as follows:

$$K_0 = 0.125 + (K - 0.125)\frac{1}{1 + 0.0967\,\mathrm{Re}^{0.6367}}$$

and

if $0 \le K_0 \le 0.125$ then $\alpha_{1dyn} = 0$

if $0.125 < K_0 \le 0.9$ then $\alpha_{1dyn} = 0.489(\log 8K_0)^{1.978}$

if $0.9 < K_0$ then $\alpha_{1dyn} = \frac{K_0}{K_0 + 1}$

The roughness part α_{1rug} is added to still allow accretion growth when wind speed is low and ice diameter is of a few centimeters [3]. It is calculated as:

$\alpha_{1rug} = (1 - \alpha_{1dyn})\alpha D$, with

$\alpha = \frac{-7.135}{V^2} + \frac{21.49}{V} + 0.12$, and a limitation at 0.11 for α_{1rug}.

Finally, $\alpha_1 = \alpha_{1dyn} + \alpha_{1rug}$

2) Rime density calculation

Rime density is evaluated from the Macklin parameter

$$R = \frac{-v_0 d_m}{2t_s} \qquad (6)$$

(v_0 (m/s) being the droplet impact speed and t_s (°C) the surface temperature), but using V, the wind speed, instead of v_0 and air temperature T_a for t_s as follows:

$R = \frac{-V d_m}{2T_a}$ and if $R \le 10$ $\rho = 110R^{0.76}$ (kg/m^3)

if $10 < R \le 60$ $\rho = R(R + 5.61)^{-1}$ (kg/m^3)

if $R > 60$ $\rho = 917$ (kg/m^3)

The model includes then a term for mass loss, considering a linear and constant part, so that finally:

$$dM = \alpha_1 VwDdt + M(1 - k_{expo}dt) + k_{lin}dt$$

with $k_{expo}=4.10^{-16}s^{-1}$ and $k_{lin}=4.10^{-4}gs^{-1}$.

B. Makkonen model

The model is designed both for dry- and wet-growth.

1) Calculation of α_1

α_1 is also evaluated from Langmuir and Blodgett theory [5], but using more recent numerical solutions provided by Finstad et al. [9]. With K and Re defined as previously (equations 4 and 5):

$$\Phi = \frac{\mathrm{Re}^2}{K} \qquad (7)$$

$$\left.\begin{array}{l} A = 1.066K^{-0.00616}\exp(-1.103K^{-0.688}) \\ B = 3.641K^{-0.498}\exp(-1.497K^{-0.694}) \\ C = 0.00637(\Phi - 100)^{0.381} \end{array}\right\} \qquad (8)$$

and finally:

$$\alpha_1 = A - 0.028 - C(B - 0.0454)$$

These formulae are available when $10^2 \le \Phi \le 10^4$ and $0.17 \le K \le 10^3$.

For K<0.18, $\alpha_1 = 0.01$ and for $K>10^3$, $\alpha_1 = 0.99$. When Φ is out of range, Makkonen 1984 [6] formulae are used.

2) Calculation of α_3

α_3 is evaluated in wet-growth condition by resolving the heat balance equation for the surface temperature t_s being 0°C. It leads to:

$$\alpha_3 = \frac{\pi}{2\alpha_1 VwL_f}\left[\frac{-2}{\pi}\alpha_1 VwC_w t_a - ht_a + \frac{hkL_e}{CpP_a}(e_0 - e_a) - \sigma a t_a - \frac{hrV^2}{2Cp}\right]$$

where h, the convective heat transfer coefficient, is calculated as $h = \frac{k_a Nu}{D}$, k_a being the heat conductivity of air (W/m/K) and Nu the Nusselt number, estimated from the cylinder Reynolds number as $Nu = 0.032\,\mathrm{Re}^{0.85}$ ($\mathrm{Re} = \frac{\rho_a DV}{\mu_a}$)

The calculation is not detailed since the simulated case here is dry growth.

3) Rime density calculation

Rime density is also evaluated using Macklin parameter R (equation 6), but v_0 is now calculated from the numerical solution of Langmuir and Blodgett theory [5] proposed by Finstad et al. [9], for the same range for K and Φ as above:

$$\left.\begin{array}{l} A = 1.030K^{-0.00168}\exp(-0.796K^{-0.780}) \\ B = 2.657K^{-0.519}\exp(-1.060K^{-0.842}) \\ C = 0.00944(\Phi - 100)^{0.344} \end{array}\right\} \qquad (9)$$

and then

$$v_0 = A - 0.04 - C(B - 0.029)V \qquad (10)$$

For K<0.18, $v_0 = 0.01V$ and for $K>10^3$, $v_0 = 0.99V$. As previously, Makkonen 1984 [6] formulae are used when parameters K and Φ are out of range

For t_s, cylinder surface temperature, two calculations have been tested : once, t_s has been evaluated in resolving the heat balance with α_1=1, and then, t_s has been taken as the air temperature T_a. Both values lead to similar results, so it seems reasonable to take the air temperature value for the surface temperature, which avoid a quite sophisticated calculation.

Finally:

$$\rho = 0.378 + 0.425(\log R) - 0.0823(\log R)^2 \quad (\text{g/cm}^3)$$

III. OBSERVATIONAL DATA

Measurements concerning real rime cases are rare. An event occurred in the center of France between the 1st and the 7th of December 1990. The meteorological parameters have been measured in Champclause, where a line broke, and it was used by Pezard et al to calibrate their model [3]. The 3-hourly reconstituted evolutions for temperature and wind speed during the first 5 days of the event, which were the most important for the ice load, are the following:

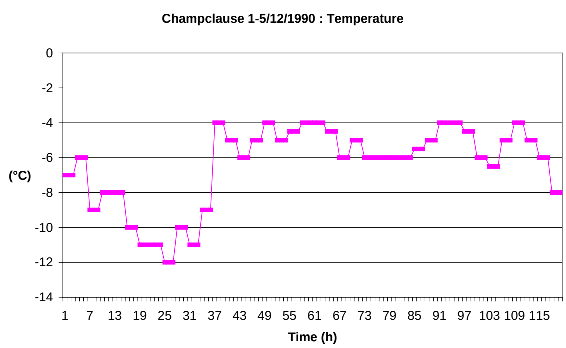

Fig. 1. 3-hourly temperature evolution during the event

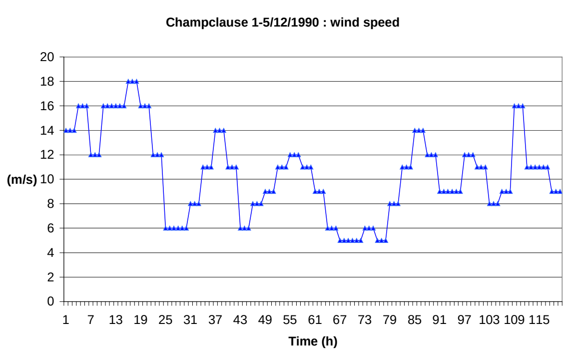

Fig. 2. 3-hourly wind speed evolution during the event

Observations conducted when the ice load was maximal mention ice deposit diameters of 12cm with a mass of 3.1kg/m. Locally, ice deposit of 18cm were seen, for wires particularly exposed to wind. The ice density is found around 300 kg/m^3.

IV. MODEL RESULTS FOR THIS CASE

The calculations were conducted with a wire diameter of 1cm.

A. *Pezard et al. model*

Liquid water content and median volume diameter of droplets were unfortunately not measured during the event. Pezard et al. tested a large number of combinations for these parameters, taken in the range measured in center of France during previous studies, and finally retained w=0.22g/m^3 for liquid water content and d_m = 11µm for droplet diameter, for which they obtained the best fit [3]. Using these values and the observed evolutions of temperature and wind speed previously mentioned, the model calculates an ice deposit of diameter 8,3cm for a mass of 3,3kg. Compared to observed ice load dimensions, the mass is correctly simulated, while the diameter is under-estimated. One must mention that Pezard et al. have calibrated their model so that the simulation of the mass is correct, even if diameter is less correct, because for risk issues, mass in more important than diameter.

B. *Makkonen model*

When using the same values for liquid water content and droplet diameter, Makkonen model leads to a diameter of 9.3cm for a mass of 1.2kg/m. If diameter is better simulated than above, ice load is really underestimated.
As liquid water content and droplet diameter were not measured but chosen in a range measured in center of France ($0.11 g/m^3 \le w \le 0.72 g/m^3$ and $7.3\mu m \le dm \le 16.2\mu m$) [3], other values for these parameters were tested and the best fit (in terms of minimized gap between simulated and observed values) was found for w = 0.30g/m^3 and d_m = 15µm : the obtained diameter and mass are respectively 12.4cm and 3kg/m. The following figures show the ice deposit diameter and mass evolution calculated with both models with their "best fit" input parameters:

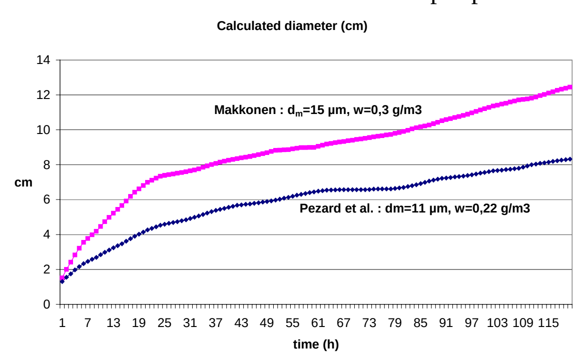

Fig. 3. Ice deposit diameter evolution computed with Makkonen model and with Pezard et al. model

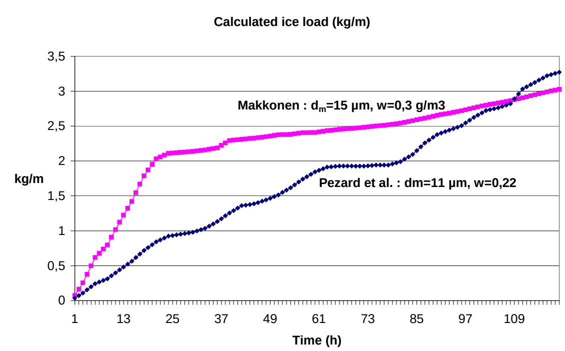

Fig. 4. Ice load evolution computed with Makkonen model and with Pezard et al. model

The calculated mean ice density is 250 kg/m^3 with Makkonen model, and 610 kg/m^3 with Pezard et al. model. This may be compared with the measured value of 300 kg/m^3.
The main learning from this study is then the great sensitivity of the models to rarely measured parameters like liquid water content and droplet diameter.

V. CONCLUSION AND DISCUSSION

Ice loads form on wires when the lines stay in an icing cloud. The evaluation of their mass and diameter can be made through mathematical modelling of icing. This has been done using two approaches based on the same principle, but differing in some hypotheses. The comparison of these two approaches to one documented case in France showed that the best fit is obtained for different values of liquid water content and median volume droplet for each model. Using ranges measured in France for these parameters, it has been possible to determine conditions likely to lead to a correct evaluation of ice loads, but regarding only one documented situation. Nevertheless, until better, it has been decided to keep the two approaches for real time estimation with d_m = 11µm and w = 0.22g/m^3 for Pezard et al. model and d_m = 15µm and w = 0.30g/m^3 for Makkonen model.

VI. ACKNOWLEDGMENT

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