TESTING SIX WET SNOW MODELS BY 30 YEARS OF OBSERVATIONS IN BULGARIA

Dimitar Nikolov[1], Lasse Makkonen[2]
[1] National Institute of Meteorology and Hydrology – Bulgarian Academy of Sciences, [2] VTT - Finland
dimitar.nikolov@meteo.bg

***Abstract*: Six simple wet snow accretion models are applied for simulations of well documented historical severe wet snow events in Bulgaria for the period 1969-1998. The data base consists of information about the diameters and masses, and thereof about the densities, of wet snow depositions in cases of damages on power lines. These measurements were taken soon after each of the damage. For all cases is checked if the meteorological conditions correspond to the wet snow accretion criterion of Makkonen. The models used in this study are: the model of Admirat and Sakamoto (Admirat et al., 1986a,b, Admirat and Sakamoto, 1988a), the model of Finstad et al. (1988), two model suggestions of Sakamoto and Miura (1993), the model of Makkonen (1989) and its improvement (Makkonen and Wichura, 2010) and one with the latest suggestion for the sticking efficiency by Nygaard et al. (2013).**

The estimated density of the wet snow depositions varied between 700 and 400 kg/m^3 and these measured values are used in the calculations instead of the experimental relationships proposed in some of the models. Working with known densities allows us to make conclusions for the approximations of the sticking efficiency and the snow concentration in air. The models are tested with two data sets – the original one consisting of standard three and six hourly synoptic measurements and its transformation into hourly values.

The sensitivity of some of the models to the meteorological parameters is also demonstrated.

Keywords: wet snow accumulation and model assesments, sticking efficiency and fall velocities of snowflakes

ABBREVIATIONS OF THE USED WET SNOW MODLES

AS	*Admirat and Sakamoto*
Finstad	*Finstad, Fikke and Ervik)*
SM	*Sakamoto and Miura*
LM	*Makkonen*
BEN	*Nygaard et al.*
α_2	*sticking efficiency*

INTRODUCTION

Wet snow accretion affects many regions located not only in cold climates. The phenomenon is common in France [3, 5, and 8], Japan [3, 15, and 16], Norway and Iceland [6] but also in parts of Central or South Europe [4]. Severe wet-snow storms are common even in Southeast Europe, e.g. the central south and southeast regions of Bulgaria. In this area, especially in the mountainous regions (the mountain Rodopes), wet snow causes damage almost every year [11 and 12]. In winter 2011-2012 alone four damages happened there. The most recent case is that from 6 to 7 January 2012 but now the affected regions were not limited only to the Rodophes - they encompassed almost the whole country. More than 200 poles collapsed and several overhead conductors were broken, more than 500 000 residents were affected, some of them for up to 6 days. Some reports of wet snow depositions with diameter up to 20 cm appeared in the public, but no official information is still available, except few photos at the disposal of the Electricity System Operator. No quantitative measurements from that event are available.

The models used in this study are: the model of Admirat and Sakamoto [1-3], the model of Finstad et al. [7], two model suggestions of Sakamoto and Miura [14] for the sticking efficiency, one with the latest suggestion of Nygaard et al. [13] and the model of Makkonen [9] and its improvement [10].

The models have been applied to 10 past severe wet snow events so far. The estimated density of the wet snow depositions varied between 700 and 400 kg/m^3 and these measured values have been used in the calculations instead of the experimental relationships proposed in the models. In the few cases, where no density measurements were available or they were not trustworthy, we have estimated the density indirectly. Working with known densities has allowed us to make conclusions for the approximations of the sticking efficiency and the snow concentration in air. The proposed density formulas have been also roughly evaluated.

I. SHORT DESCRIPTION OF THE USED MODELS

The above mentioned six simple wet snow accretion models have been used in this study. These models use only the available meteorological data as input information and some theoretical or experimental assumptions and relationships. The six models could be divided into two groups according to the method utilized for parameterization of the mass concentration of snow in air. The first group estimates this quantity using the precipitation rate and the assumption that the fall velocity of the snow particles is 1 m/s – the first five of the used models belong to this group. Actually they differ from each other only in the approximation of the sticking efficiency.

In the second group is only the model of Makkonen (the first version and its improvement). This model uses the horizontal visibility during snowfall for estimation of the snow concentration in air. It was utilized in a case study simulation of the severe wet snow event in Münsterland, Germany in 2005, showing good results [10].

All of the models have the following same assumptions, which are true in a wet snow process: cylindrical form of the depositions and unity collision efficiency. All calculations have been made for diameter of the conductor 2 cm. For determination of the beginning and ending of wet snow accretion process the criterion of Makkonen [9, 10], namely the web bulb temperature to be above - 0.1 ^{o}C, has been applied.

A. The sticking efficiency in the different models

Admirat et al. [1] proposed the sticking efficiency to be approximated by the inverse value of the wind speed, assuming that the fall velocity of the snowflakes is 1 m/s. Finstad et al. [7] suggested the following formula for the sticking efficiency, trying to reflect its dependency on the air temperature (T_a) and the diameter of the obstacle (D):

$$\alpha_2 = \frac{0.038\, T_a}{VD} \qquad (1)$$

They also set up ranges of validity, which are $0^oC \leq Ta \leq 4\ ^oC$, $5 \leq V \leq 15$ m/s, and $0.01 \leq D \leq 0.04$ m and all values of α_2 above 1 are taken to be just 1. According to this expression this coefficient will increase with the temperature and will have its maxima at the end of the accepted temperature range.

Sakamoto and Miura [14] emphasized the reasonable dependence of α_2 on the conductor diameter, but criticized its constant increasing with the air temperature. They pointed out, that according to their observations, there should be a temperature point where the coefficient achieves its maximum and decreases in both sides and proposed the following approximations, which are based on wind tunnel experiments and observations of few natural wet snow events:

$$\alpha_2 = \exp(-1.01 + 4.37\, T_r - 6.89\, T_r^2 - 0.0168\, P\, V\, t), \qquad (2)$$

where t is the time step, V is the wind speed, P is the precipitation rate, $T_r = T/T_d$, T is the air temperature and T_d is the upper temperature limit above which snow turns into rain. In our calculations with this model the value of 4^oC is used. The proposed expression for this coefficient possess the expected behaviour with a maximum at certain temperature point, which depends also on the chosen upper temperature limit. At fixed other conditions the maximums are shifting into direction of the positive temperatures, the curves are becoming wider and more flat at the top but the maximum values are almost the same. This is presented on the figure 1.

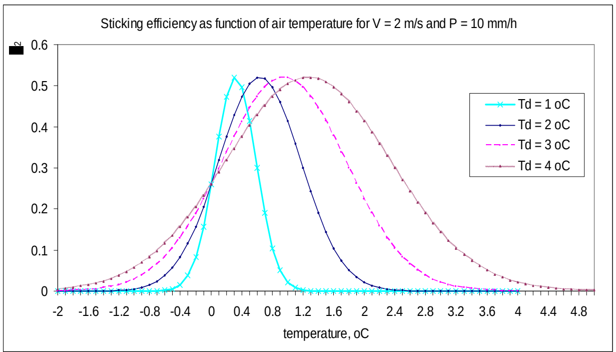

Figure 1: The curves for α_2 according to equation (11) for four different upper temperature limits

The accretion efficiency according to equation (2) decreases with increasing wind speed and precipitation rate but it is independent of the diameter of the obstacle. It has its absolute maximum in the corresponding temperature points for low precipitation rates and low wind speeds. However high wind speeds and/or precipitation rates may compensate the decreasing of the efficiency and may lead to an increase of the total ice load with increasing the values of these both parameters up to a certain level before decreasing. This was pointed out by the authors themselves, who stated that according to their calculations the estimated snow mass begins to decrease when the total precipitation exceeds 30 and 60 mm for wind speed 16 and 8 m/s correspondingly. It should be noted that for very small precipitation rate i.e. 1 mm/h the maximum values of α_2 are very high even for strong wind speeds – they remain above 0.5 up to 23 m/s – see figure 2.

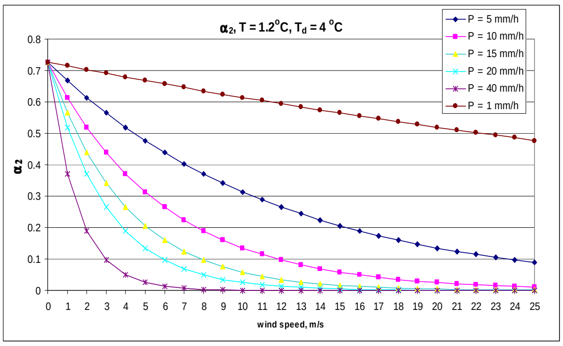

Figure 2: Change of α_2 according to equation (2) with the wind speed for different precipitation rates, Td = 4 ^oC and fixed air temperature T = 1.2 ^oC

The whole behaviour of $\alpha_{2,}$ proposed by the authors, seems quite reasonable except the independence of the diameter of the conductor. In order to overcome this Sakamoto and Miura [14] joined the advantages of their model with the model of Finstad et al. and recommended for α_2:

$$\alpha_2 = 4.5 \frac{\exp\left[-6(T/T_d - 0.320)^2\right]}{V^{0.2} D} \qquad (3)$$

According to this formula α_2 has its maximum always at the same temperature as equation (2) but are much lower. Certainly this underestimation of α_2 results also in lower ice loads and diameters of the depositions as will be shown in the next paragraph. It should be also noted that although the dependence on the diameter is now included in the formula, the dependency on the precipitation rate is excluded.

Recently Nygaard et al [13] proposed for the sticking efficiency an expression based again only on wind speed:

$$\alpha_2 = V^{-0.5} \qquad (4).$$

The model of Makkonen uses for the sticking efficiency the approximation of Admirat and Sakamoto. Description of this model and its improvement can be find in Makkonen [9] and Makkonen and Wichura [10].

II. DATA TRANSORMATIONS AND INPUT CHANGES

In order to better investigate and compare the selected models in regard to all their peculiarities the following transformations and transitions of the input data and quantities have been made:

1. *Time scale transformation of the input data (transformation of the short data set into long data set)*

This transformation is determined by the fact that the measurements in the used stations are the standard surface meteorological observations, which means that most of them are three hourly and those of the precipitation amounts three or six hourly, and it is reasonable to expect that hourly intervals should represent an event better. For the assessment of the hourly values the following simple assumption has been made – the values of the air temperature, the wind speed and the visibility have been assumed to be the same in the hours before and after the SYNOP observations, except in cases where rapid changes occurred – then additional adjustments have been made. The precipitation amounts have been divided equally in the measurement intervals. In addition to the described transformation some corrections concerning the precipitation data have been also performed - when simultaneous snow and rain was observed, appropriate reduction of the total precipitation amount has been made in order to derive the part only from snow.

2. *Change of the upper temperature limits*

This transformation concerns only both models of Sakamoto and Miura (1993) because only they possess such dependence. Four different upper temperature limits have been tested in this study - Td = 1, 2, 3, and 4 ^{o}C.

III. Model Results

In figure 3 an example of the results from the model simulations for the case 2 are shown. It can be seen that in this case the models of Admirat and Sakamoto (AS) and of Makkonen show the best fit to the measured data (given as a box plot). The second model of Sakamoto and Miura (S-M-2) and the model of Finstad underestimate significantly, while the models of Björn Egil Nygaard et al (BEN) and the first one of Sakamoto and Miura (S-M-1) overestimate very much the measured values of the radius of the depositions. This pattern is similar in all the cases investigated.

All results, except those for the model of Finstad, are summarized graphically in the following six scatter plots (Figures 4 – 8). This concerns mostly the results with the long data set. Only the results for S-M-1 model are presented with two graphics and this will be explained later. The results for the Finstad model are similar to those of S-M-2.

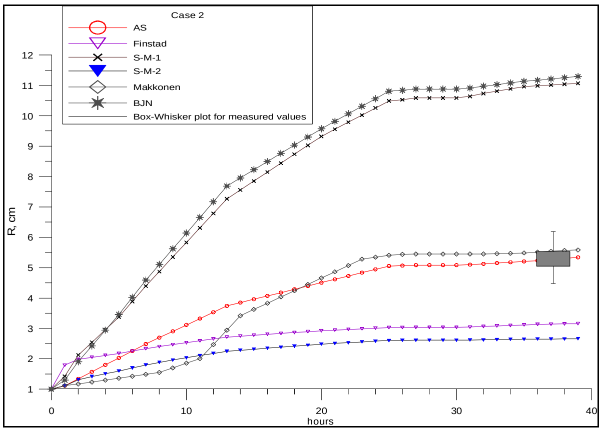

Figure 3: Model results for case 2, 06-07.03.1984

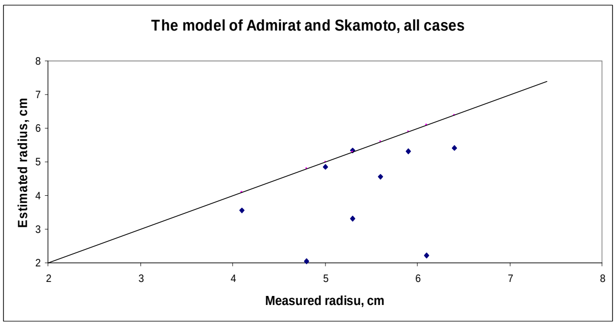

Figure 4: Scatter plot for the results of the model of Admirat and Sakamoto (the black solid line represents the true values)

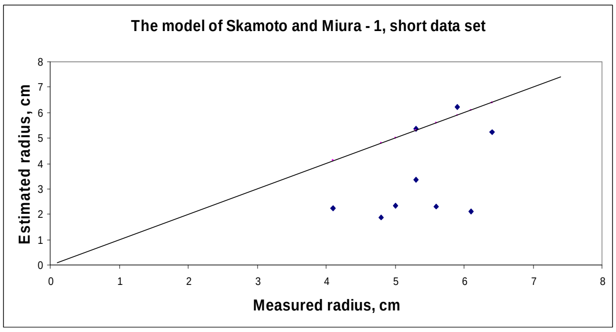

Figure 5a: Scatter plot for the S-M-1 model, short data set

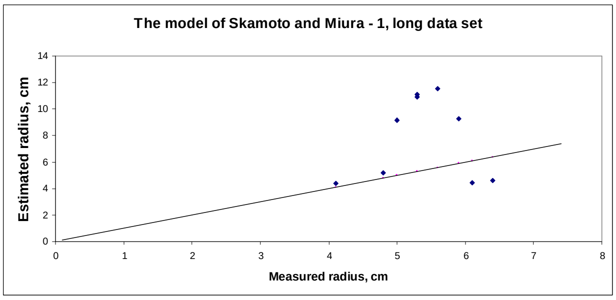

Figure 5b: Scatter plot for S-M-1 model, long data set

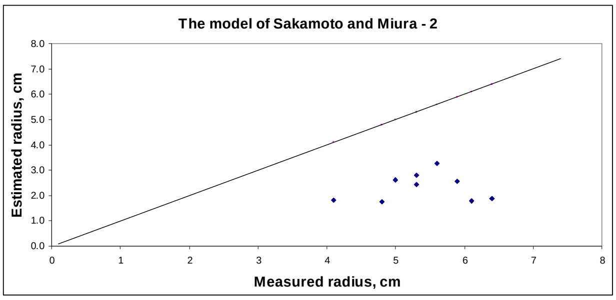

Figure 6: Scatter plot for S-M-2 model

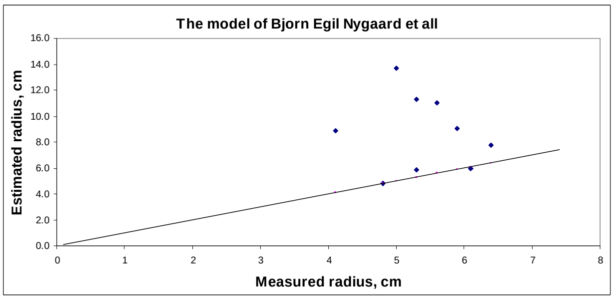

Fig. 7: Scatter plot for the BEN model

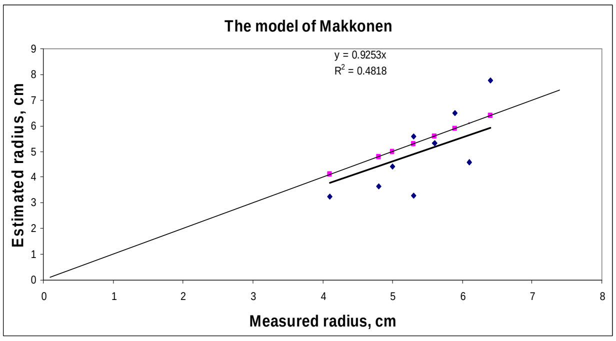

Fig. 8: Scatter plot for the model of Makkonen

At first sight it seems that all models, but that of Makkonen, either underestimate or overestimate the measured values. Indeed only the LM model shows narrow spread of the points close to the true values (Fig. 8). The S-M-2 model (Fig. 6), as well as the Finstad model, always vastly underestimates the true values with both data sets. The S-M-1 model shows change of front when changing the time scale of the input data. The usage of short data set leads to significant underestimation with exception of three cases (Fig. 5a). The transformation of the short data set into a long one (hourly input data) always results in serious increase of the model estimations (Fig. 5b). The BEN model demonstrates significant overestimation in more than the half of the cases but fits well to the measured values in three of them (Fig. 7). Figure 4 for the AS model also depicts low underestimation. However, it has been found that this underestimation is mainly connected with the cases with high wind speeds (above 10 m/s). When we remove these cases, the following picture appears – Fig. 9.

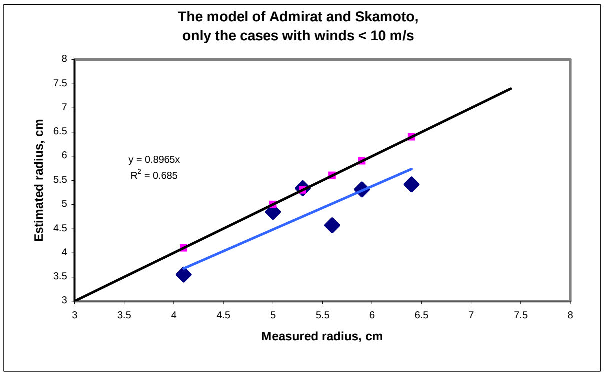

Figure 9: Scatter plot for the results for the model of Admirat and Sakamoto only for the cases with wind speed below 10 m/s.

Because the AS and BEN models are very similar, we have investigated closer the BEN results and we reveal that its three good estimations describe cases with high wind speeds. This was most evident in the last calculated case – the event from 02-03.02.1986 in Southeast Bulgaria - one of the most severe cases ever happened. The mean measured value for the radius of the deposition was 6.1 cm and the mean ice load 6.5 kg/m. The BEN model has estimated 5.8 cm and 6.1 kg/m. No one from all other models approaches so close to these values. The LM and AS yield 4.63 and 4.43 cm correspondingly.

On the next two figures are presented two pictures from that event, which illustrate the situation, as well as the measuring procedure.

Figure 10: Sampling and measuring procedure from the event on 02-03.02.1986

Figure 11: Sampling and measuring procedure form the event on 02-03.02

Table 1 summarizes the results from the investigation of the influence of the data transformation. It can be seen that all models, except for the S-M-1, undergo very low change with this transformation and the AS model even not any. This means that these models could be used directly with the three or six hourly measurements. The strong increase (in the first case up to 100%) in the results of the S-M-1 model is due to the sensitivity of the sticking efficiency and hence the model itself to the meteorological variables. As mentioned above α_2 has very high values when the precipitation rates are small and the air temperature is close to the points of extrema.

Table 1 Relative changes between the short and long data sets for the first four cases (values in %)

AS	Finst.	S-M-1	S-M-2	BEN	LM
0.0	- 3.9	48.1	- 3.4	- 0.9	2.3

Moreover – the model of SM1 features high dependence not only in regards to the transformation of the time scale of the input data but also on the choice of the upper temperature limit. This is shown on Fig. 12a representing the increasing of the calculated with four different upper temperature limits radiuses of the wet snow depositions from the first event. The used temperature limits are 1, 2, 3 and 4 ^{o}C and the corresponding curves reveal significant differences. The greatest results are yielded with Td = 4 ^{o}C and this is determined mostly by the favourable combination of low precipitation rate (mean value of 0.8 mm/h) and air temperature around 1.3 ^{o}C, which is exactly the point where the sticking efficiency has its absolute maximum for Td = 4^{o}C (see Fig. 1).

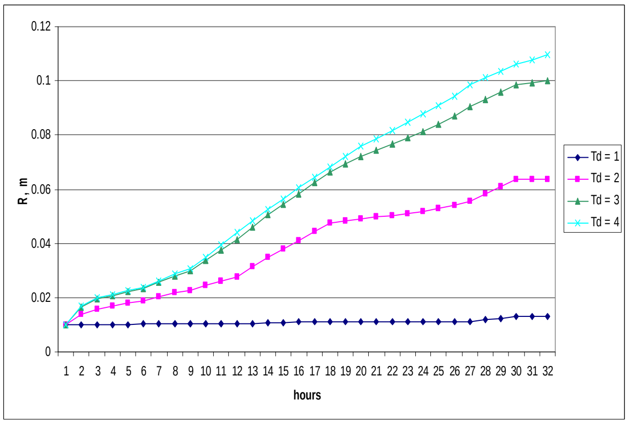

Figure 12a: Estimated radiuses of the deposited wet snow in case 1 with the SM1 model for different upper temperature limits – Td = 1, 2, 3 and 4 ^{o}C; long data set

Figures 12b and 12c compare the radii for the four selected temperature limits and their relative change in regards to the data transformation from short to long data set for the first case. As mentioned above the greatest values of the radii are obtained for Td = 4^{o}C for both data sets. The data transformation yields to an increment in the radii of more than 100 % for all temperature limits except for the lowest one. For Td = 1 ^{o}C the increase is only 24.3 %.

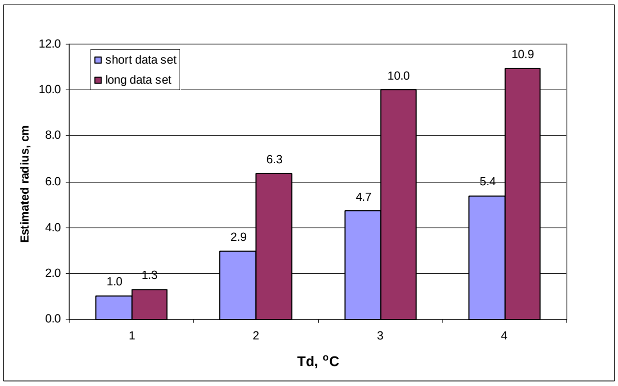

Figure 12b: Comparison of the estimated radiuses after the S-M-1 model by the transformation from the short to the long data set for the different upper temperature limits

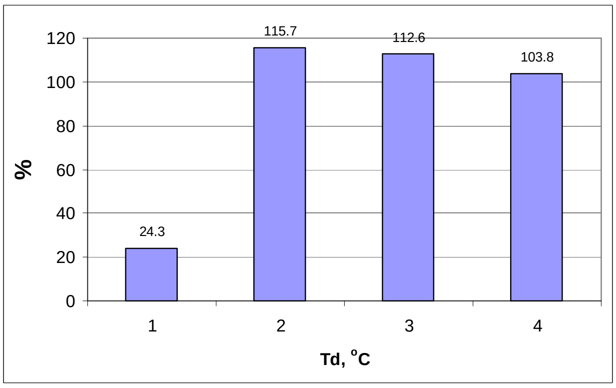

Fig. 12c: Relative change in the estimated radiuses by the transformation from the short to the long data set for the different upper temperature limits

The same investigation for the influence of the temperature limits has been done also for the sticking efficiency α_2. In summary, the S-M-1 model is very sensitive to transformation of the input data, because, on the one hand, this transformation divides the 3 or 6 hourly precipitation amount into low one hourly quantities and on the other hand it most often retains the high wind speeds for the hours between the observations (were there is no significant change in the wind speed between the three-hourly observations). These both operations act in direction of common enhancement of the sticking efficiency, especially when the air temperature is close to the point of the maximum for the selected Td. The location of these points depends on the chosen upper temperature limit, and this is another important sensitivity of the model.

IV. Conclusions

The models with best performance seem to be AS and LM – they both have relative good estimations of the measured values; both ate not sensitive to the data transformation and they always have close results. However, they have their own limitations. It may be assumed that the AS model gives not so good results for high wind speed cases. Above 10 m/s it underestimates the depositions – for such wind speeds the BEN models seems more appropriate. The LM should be used carefully when fog is presented together with the snowfall. However such combination seems to be rare except for the mountain regions.

The BEN model usually gives overestimation but yields very good results for wet snow conditions accompanied by high wind speed. Actually a combination of the two parameterisations – the one of AS for wind speed up to about 10 m/s and the one from BEN for wind speeds above – might be the best way.

The S-M-1 model sometimes gives good results but is very sensitive to the meteorological input information and to the chosen temperature limit.

The other two models (S-M-2 and Finstad) always underestimate the depositions, probably due to the very high assumed dependency on the wet snow radius.

References

[1] Admirat, P., Sakamoto, Y., De Goncourt, B., 1986a. Calibration of a Snow Accumulation Model Based on Actual Cases in Japan and France. Proc. Fourth Int. Workshop on Atmospheric Icing of Structure. IWAIS, Paris, France, pp. 129-133.

[2] Admirat, P., Sakamoto, Y., Lapeyre, J.L. and Maccagnan, M., 1986b. Quantitative results and proposed mechanisms on wet snow accretion in the Ishiuchi wind tunnel facilities. Third Int. Workshop Atmospheric Icing of Structures, Vancouver, B.C.

[3] Admirat, P. and Y. Sakamoto, 1988a. Calibration of a wet-snow model on real cases in Japan and France. Proc. Fourth Int. Workshop on Atmospheric Icing of Structures. IWAIS, Paris, France.

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

[5] Dalle, B. and P. Admirat, 2011. Wet snow accretion on overhead lines with French report of experience, Cold Regions Science and Technology 65: 43-51.

[6] Eliasson, A.-J., Thorsteins, E., Olafsson, H., 2000. Study of Wet Snow Events on the South Coast of Iceland. Proc. IX Int. Workshop on Atmospheric Icing of Structure. IWAIS, Chester, U.K.

[7] Finstad K., S. Fikke and E. Magnar, 1988. A comprehensive deterministic model for transmission line icing applied to laboratory and field observations. Proc. IV Int. Workshop on Atmospheric Icing of Structures. IWAIS, Paris, France

[8] Gland, H. and Admirat, P., 1986. Meteorological conditions for wet snow occurrence in France, Calculated and measured results in a recent case study on March 5th, 1985, Proc. Third Int. Workshop on Atmospheric icing of Structures. IWAIS, Vancouver, Canada.

[9] Makkonen, L., 1989. Estimation of wet snow accretion on structures. Cold Regions Science and Technology, 17(1): 83-88.

[10] Makkonen L. and B. Wichura, 2010: Simulating wet snow loads on power line cables by a simple model. Cold Regions Science and Technology, 61: 73-81.

[11] Moraliiski, E. and A. Gocheva, 1991. Estimation of the conductor icing in Bulgaria, Energetic, vol. 3-4 (in Bulgarian).

[12] Nikolov, D. and E. Moraliiski, 1999. Icing and damages on technical equipment on the territory of Bulgaria, Proc. of IV ECAM, Norrköping, Sweden.

[13] 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. Meteorol. Climatol. 52 (10), 2189–2203.

[14] Sakamoto, Y. and A. Miura, 1993. Comparative study of wet snow models for estimating snow load on power lines based on general meteorological parameters. Proc. Sixth Int. Workshop on Atmospheric Icing of Structures. IWAIS, Budapest, Hugary.

[15] Shoda, M. 1953. Studies on snow accretion. Res. Snow and Ice, 1:50-72 (in Japanese).

[16] Wakahama, G., Kuroiwa, D. and Goto, K., 1977. Snow accretion on electric wires and its prevention. J. Glaciol., 19(81): 479-487