P6.5 SIGMA : System of Icing Geographic identification in Meteorology for Aviation

Christine Le Bot *
Météo France,Toulouse, France

1 INTRODUCTION

Icing is one of the major meteorological hazards pilots wish to avoid. In order to diagnose accurately the extension of the icing areas, to limit the number of false alerts and to quantify the intensity of icing, a system was developed at Météo France.

SIGMA (System of Icing Geographic identification in Meteorology for Aviation) has been developed at Météo-France since 1996. This tool is aimed at helping forecasters to identify the icing areas from a representation in 2D of the icing potential of the atmosphere. SIGMA uses a combination of data from three different operational networks operated 24 hours a day : the numerical model (ARPEGE), the IR satellite imagery (METEOSAT) and the radar imagery (ARAMIS). Each set of data can confirm or infirm the information deduced from the others.

The principle of SIGMA and the data used are described in the first part. Then a comparative study of SIGMA with pilots reports is shown, and also a confrontation to the forecasters' judgement through the use of operational soundings. Finally, a climatology based on the SIGMA results during two winters is presented.

2 PRESENTATION OF SIGMA

SIGMA is based on the combination of three different sources of data, each of them already used separately in an operational way. Each kind of data can confirm or infirm the information deduced from the others.

First an icing index is derived from the French numerical model ARPEGE. This index determines icing areas, by combining humidity and temperature fields calculated at each grid point. However, as it has been shown by experience, the numerical model has a tendency to overestimate the humidity and thus the extent of forecasted icing areas.

Then the results obtained with the icing index are filtered, using the observation of cloudy areas derived from an IR Meteosat image. The IR image allows to determine cloudy areas with clouds tops temperatures under 0°C and above –15°C. This first category of clouds is called "warm clouds". But what about cloudy areas where clouds tops temperatures are below –15°C? These areas cannot be forgotten as the risk of icing exists under the colder layer of the clouds seen by the satellite. They belong to a second category named "cold top clouds".

Finally, to keep on improving the results obtained with the icing index and the IR imagery, the operational radar imagery (from the French operational weather radar network in centimetric waves) is used. It gives an information on the quantity of water contained in the areas selected by the previous criteria. Areas with icing rain into cloud can be highlighted, corresponding to areas with rain echoes (however, icing rain in cloud does not automatically mean icing rain on the ground).

In fact, there are two icing indices calculated with the numerical model. One index integrates vertical upward velocities, the other index does not. The images issued using the index without vertical velocity are named SIGMA images, the other ones SIGMA-VV images.

The output of these different treatments is a bi-dimensional image, which shows cloudy areas with humidity and temperature conditions favourable to icing. The SIGMA and SIGMA-VV images are calculated every ¼ of an hour with a geographical coverage from the north of Spain to the south of Scotland, and from Ireland to Germany, and with a 1.5km resolution grid.

3 VERIFICATION WITH PIREPS

Due to the very low number of civil Pireps issued in France and in order to obtain icing observations, a collaboration with the French Air Force was initiated. A questionnaire was filled in by pilots mentioning the day, hours of the flight and if icing was encountered. 167 observations were made during 58 days (1997-1998 wintertime). They are shown in Table 1.

Icing intensity	null	trace	light	moderate	severe
Number of cases	116	2	18	20	11

Table 1: *Distribution of the icing intensities in pilots observations sample*

The SIGMA images, using either the index without or with vertical ascendant velocity, were calculated at each time a pilot observation was available. Pilots' observations did not mention the temperature of the clouds. Then it was not possible to test what kind of clouds (warm or cold tops) were associated with observed icing conditions. SIGMA results corresponding to the observations are detailed in Table 2.

	SIGMA		SIGMAVV	
	icing	mod/sev	icing	mod/sev
Cold top clouds	17	12	7	6
Warm top clouds	28	16	20	12

Table2 : Number of cases according to the icing intensity and the clouds tops temperature

Table 2 shows that icing (particularly moderate to severe icing) is more often encountered in warm top clouds.

Different statistical indices were calculated: the percent of good forecasts or hit rate (%HR), the probability of detection of icing (POD), the probability of detection of no-icing (PODNO)and the false alarm rate (FAR).

To have an idea of the improvement due to SIGMA, the statistic scores are calculated both on index and SIGMA results. The different statistical scores are shown in Table3.

No icing/icing	Index	Index VV	SIGMA	SIGMA VV
%HR	71,26	71,86	76,65	73,65
POD	0,882	0,490	0,882	0,529
FAR	0,483	0,456	0,423	0,425
PODNO	0,638	0,8190	0,716	0,828

Table3: *« no icing/icing » repartition, scores*

Index behaviour

The percentage of good forecast is 71%. The probability to detect icing from the index alone is 88%, which is a good result. On the other hand, the false alarm rate is 48%, which is quite high. These results can be explained by the way icing is defined. Any kind of aircraft entering a forecasted icing area (even with real icing conditions) will not systematically experienced icing. Icing does depend on the speed and on the characteristics of each aircraft. Icing results of an unstable equilibrium state of water that can be easily broken. One aircraft may then experience icing while the following may not.

Moreover, icing is forecasted regardless of its level, in a 2D approach. One level is not representative of the whole column of the atmosphere. This may explain the high false alarm rate not.

With the index using the upward vertical velocity, the percentage of correct forecast is 72%. The probability to detect icing is 49%, with a false alarm rate at 46%. These last results are not very satisfying. The VV index shows better results in detecting non icing areas than in detecting icing areas. This is confirmed by the detection probability of non-icing conditions which is 82%.

SIGMA behaviour

The percentage of correct forecast is 77%. The probability of detecting icing is 88%, very close to the icing detection probability based upon the single icing index. This shows the great role played by the index in the SIGMA algorithm. On the other hand, the false alarm rate is lower when using SIGMA than when using the index alone, because SIGMA brings useful information on the nature of the icing areas. The PODNO is also logically higher, the use of the IR imagery limiting the forecasted icing areas to cloudy areas with tops below 0°C.

Using SIGMA with the VV index, the percentage of good forecasts is 74%. The probability of detecting icing is quite low, 53%. But, the percentage of detection of the non icing conditions is about 83% which shows the great ability of SIGMA VV to detect the areas free of icing.

4 VERIFICATION WITH RADIOSOUNDINGS

During the 2002-2003 winter, SIGMA images were analysed by the French National Meteorological Center forecasters of the Aviation Division. Every day, the 1130 UTC SIGMA and SIGMA-VV images were compared with the twenty-three 1200UTC radiosoundings located in the SIGMA geographical domain. This slight difference of hour between SIGMA and the radiosounding takes into account the duration of a sounding which begins around 11 UTC to be available on the Global Telecommunication System at 12 UTC. The forecaster's expertise leads to an evaluation of the icing intensity and of the icing area extension horizontally and vertically on each radiosounding site.

Between mid December 2002 and the end of April 2003, 86 days of analysis helped to build a 1926 sample data bank, with 591 cases of icing observations against 1335 cases of non icing observations.

Table 4 shows contingency table between the forecasters' observations and SIGMA, and the forecasters' observations and SIGMA-VV.

Observed	SIGMA		TOTAL	SIGMA-VV	
	Icing	No Icing		Icing	No Icing
Icing	463	128	591	213	378
No icing	139	1196	1335	31	1304
TOTAL	602	1324	1926	244	1682

Table 4: *Contingency table between observations and SIGMA and SIGMA-VV*

It can be noticed as previously that the number of icing forecasts is greater with SIGMA than with SIGMA-VV. The use of the upward vertical velocity lowers the number of icing forecasts.

	SIGMA	SIGMA-VV
%Hit rate	86	79
POD	0,78	0,36
PODNO	0,90	0,98
FAR	0,10	0,02

Table 5: *Statistical scores*

The usual statistical scores are calculated in Table 5. They are comparable to those obtained previously when comparing SIGMA with pilots' reports. SIGMA performs correctly with a POD of 78% and a PODNO of 90%. SIGMA "sees" quite well the different icing areas as diagnosed by the forecaster using the radiosounding data. The false alarm rate, 10%, is quite reasonable keeping in mind the transient nature of icing and the way of comparing the data. A 1.5 km area on SIGMA (one pixel) is compared to a sounding which may, depending on the wind, concerns several km^2 area.

Observed	SIGMA		SIGMA VV	
	Cold top cloud	Warm top cloud	Cold top cloud	Warm top cloud
Icing	216	247	122	91
No icing	46	93	18	13

Table 6: *Forecasters validation of SIGMA icing prediction depending on cold top clouds and warm top clouds*

When having a look at Table 6 where icing is classified according to the temperature of the cloud top, one can deduct that SIGMA has a tendency to predict overestimated icing occurrences in warm top clouds. The wrong behaviour of SIGMA, in this case, is strongly influenced by the wrong behaviour of the index.

Another conclusion derived from Table 6 is that warm top clouds are more favourable to icing than cold top clouds as it has been already noticed previously.

When the upward vertical velocity is used, results are not convincing. Even if the SIGMA-VV PODNO and false alarm rate are quite good, the POD is too low. A reasonable use of SIGMA-VV could be therefore the prediction of non icing areas.

5 CLIMATOLOGY

A climatology has been established by using the results of SIGMA. During two winters (from November 2000 to February 2001 and from November 2001 to February 2002) SIGMA images have been computed twice a day using 0UTC and 12UTC model runs. The icing occurrences are calculated at each pixel of the SIGMA images by dividing the number of cases when the pixels is classified as "icing" by the total number of images.

Results

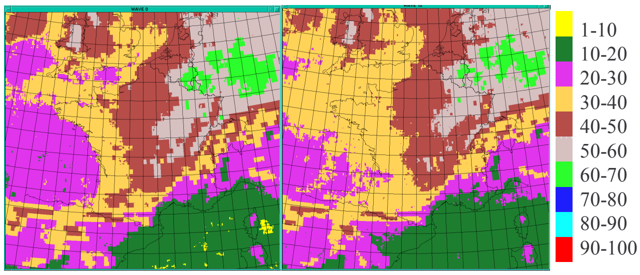

Figure 1: *Icing areas in percentage of cases by pixels with SIGMA at 0 UTC on the left, and at 12UTC on the right.*

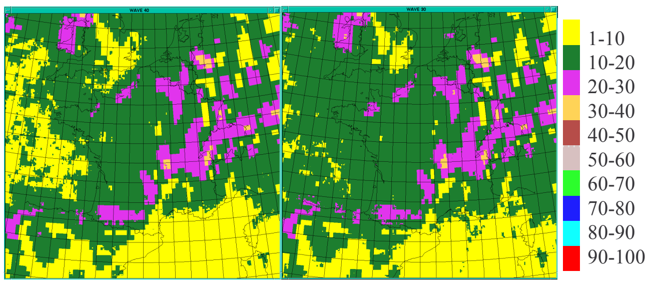

Figure 2: *Icing areas in percentage of cases by pixels with SIGMA_VV at 0 UTC on the left, and at 12UTC on the right.*

It should be noticed that on the SIGMA-VV images, the number of cases with "no icing" is, expectedly, more important that on the SIGMA images. The use of vertical velocities in the icing index calculation reduces drastically the number of classes with icing.

What is discernable at first sight on Figure 1 is the contrast between land and sea along the Atlantic coast at 00 UTC. 30% of icing conditions are found over the ocean. At 12 UTC the limit between land and sea becomes blurred and the percentage of cases of icing conditions increases to reach 40% even over the ocean.

The link between continental regions and icing conditions appears distinctly on these two maps (Figure 1). Up to 60 to 70% of cases of icing conditions are obtained over Germany and eastern Europe. On the other hand, 30 to 50% of cases of icing conditions are observed over France, England and less than 20% over Spain and over the areas submitted to a maritime influence.

The risk of icing conditions is very limited over the south of Europe, particularly over the Mediterranean sea and its coasts. 80 to 100% of cases are free of icing.

Mountainous areas are very well represented on these two maps (Figure 1). As it could be expected, the mountainous areas present a more important risk of icing conditions (between 60 and 70% of icing conditions in the continental part and between 40 and 50% for the places less favourable to icing conditions). These mountainous areas present in average 10 to 20% more cases of icing conditions than the areas in their surroundings.

Looking at the two maps Figure 2, it appears that the dimensions of the icing free areas are more important on the maps using SIGMA-VV than on the map using SIGMA (Figure1) This is in agreement with results of a previous study on SIGMA (Le Bot, 2000).

The impact of the use of upward vertical velocities is well shown on these maps (Figure 2). In fact the areas with most cases of icing conditions are not only situated on the orography (as shown previously) but also slightly upstream ahead of the orography.

On the other side it is surprising to notice that the results do not seem to be particularly biased by the distinction between "warm top clouds" and "cold top clouds". The number of cases of icing conditions under clouds with cold tops is lower than under the clouds with warm tops, even if the SIGMA method could let one think the contrary. Icing is more often predicted when the cloud top temperature is above –15°C.

The results obtained so far, were compared with another climatological study (Carriere and al 2000) based on observations messages, and results were similar.

6 CONCLUSION

From the previous studies, it can be concluded that :

– Icing areas diagnosed with SIGMA seem to be too large. This default is inherited from the use of the numerical index. However the use of the IR imagery helps to correctly reduce the size of icing areas. The error is difficult to quantify and to be careful, it sounds reasonable to stay on the pessimistic side of the forecast.

– SIGMA improves the detection of icing areas, but a problem remains on the determination of the intensity. The intensity strongly depends on the characteristics of the aircraft. SIGMA can correctly diagnose the icing potential of the atmosphere, inaccuracy persists in the prediction of the phenomenon intensity.

– Even if the study would have benefited from a higher number of observations, it can be understood that icing is more often encountered in warm tops clouds, with more cases of moderate or severe icing in this kind of clouds. This confirms the study by Pobanz and al (1994).

– Comparison between SIGMA and pilots' reports gives similar results as comparison between SIGMA and radiosoundings through forecasters' expertise. Therefore, it can be concluded that SIGMA can be a valuable tool to forecasters in areas where no radiosoundings are available. Once again, SIGMA could benefit from the integration of pilots' reports if they were to be available over France and most of Europe.

ACKNOWLEDGMENTS

Special thanks to Pascale Dupuy for her precious help.

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* *Corresponding author address:* Christine Le Bot
Dprévi/Aéro , MétéoFrance 42 Avenue G Coriolis
31057 Toulouse Cedex1 ;
e-mail: Christine.lebot@meteo.fr