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VISIBILITY VERSUS PRECIPITATION RATE AND RELATIVE HUMIDITY

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1. INTRODUCTION

The purpose of this work is to analyze the relationships between visibility and precipitation rate (PR), and visibility and relative humidity with respect to water (RHw), obtained from surface measurements.

Presently, visibility parameterizations related to precipitation type in forecast models are not adequate because they represent mid-latitude cloud systems (Stoelinga, 1999). Some previous works have shown that particle phase is an important factor in the visibility calculation but usually it is ignored (Rasmussen et al., 1999). The relative humidity with respect to water in forecast models is used for visibility parameterization but changes have been continuously made because of the uncertainty in accurate RHw measurements (Smirnova et al., 2000). The earlier works suggested that significant differences exist among the various parameterizations of visibility and that their application to forecasting models should be carefully addressed.

In this work, the visibility (vis) versus RHw relationships were obtained using surface observations, and compared with those of the Rapid Update Cycle (RUC) model. Also, vis versus droplet number concentration (N_d) and ice particle number concentrations (N_i) were derived for non-precipitating boundary layer conditions, and it is suggested that both N_d and N_i should be included in the fog parameterizations. Finally, vis versus precipitation rate relationships, using previous studies, were evaluated to enable better predictions of vis from the forecast models.

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2. OBSERVATIONS

The main observations used in the analysis were the precipitation rates for rain and snow from the Desert Research Institute (DRI) manufactured hot plates (Rasmussen et al., 2002), the Precipitation Occurrence Sensor System (POSS) (Sheppard, 1990), and from the Visalia FD12P, ice and liquid particle characteristics from the optical probes, visibility from the Belfort visibility meter, the Vaisala FD12P and from the fog measuring device (FMD), and relative humidity and temperature from the Campbell Scientific instruments. Details on these instruments can be found in Isaac et al. (2005) and Gultepe et al. (2006).

3. ANALYSIS AND RESULTS

The data were collected during the Alliance Icing Research Study (AIRS 2) which was conducted in the Ottawa-Mirabel area from 3 November 2003 to 12 February 2004 (Isaac et al., 2005) and during the Fog Remote Sensing And Modeling (FRAM) field project that took place at the Center for Atmospheric Research Experiment (CARE) site for the winter of 2005-2006 (Gultepe et al., 2006).

In this work, the vis values averaged over 1 minute intervals were plotted against RHw, and PR for snow and rain. Also, the N_d and N_i measurements from the FMD and York University ice particle counters (IPC, Savelyev et al., 2003), respectively, were plotted against vis that represented liquid and ice fog conditions. The vis and PR measurements from the Vaisala probe were used in the analysis. The vis values from the DRI hot plates and POSS were not used in the relationships for the FRAM project because of the large variability in PR measurements.

a. Visibility versus RHw

The vis-RHw parameterizations used in the RUC model is preset such that vis reaches 5 km at 95% RHw. Fig. 1 shows the vis-RHw relationships used in the RUC model (Smirnova et al., 2000) and is given as

$$vis_{RUC} = 60\exp(-2.5*(RHw-15)/80) . \quad (1)$$

Using the vis and RHw surface observations obtained from the Toronto Pearson International Airport, the vis-RHw relationship obtained for hourly data is shown on Fig. 1 (black solid line). Then, observations from the AIRS2 Mirabel site are overlaid on the plot for 1) all the data points, 2) T<-1°C, and 3) PR>0.1 mm h^{-1}. A fit to data representing snow conditions (#2) is also shown in Fig. 1. The relationships for both vis values from the present work, representing the Pearson Airport (FRAM) and AIRS2 data, are derived, respectively, as

$$vis_{FRAM} = -41.5\ln(RHw) + 192.3 , \quad (2)$$

and

$$vis_{AIRS} = -0.0177 RHw^2 + 1.462 RHw + 30.8 \quad (3)$$

where RHw is given between 30 and 100, representing percentage values. Differences among the 3 fits given above are found to be very distinct. In general, vis_{RUC} near 100% RHw results in about 2 times larger than vis values obtained from the other data sets. Note that total visibility in a numerical model is obtained using both vis-RHw and the vis-PR relationships. In the RUC model, for snow and rain visibility calculations, the parameterizations given by Stallabrass (1985) and Kunkel (1984) have been used, respectively.

b) Visibility versus N_d and N_i

Visibility versus particle number concentration for a fog type (e.g. particle phase) has always been ignored in forecast models (Gultepe et al., 2006; Stoelinga et al., 1999). Using the state of art observations of N_d and N_i from the new optical probes, e.g. Droplet Measurement Technologies (DMT) FMD and York University IPC (Gultepe et al., 2006; and Savelyev et al., 2003), correspondingly), vis versus N_i, and vis versus N_d together with their fits are shown in Fig. 2a and 2b, respectively. These relationships are obtained as

$$vis_{Ni} = 18 N_i^{-0.56} , \quad (4)$$

and

$$vis_{Nd} = 238 N_d^{-1.31} . \quad (5)$$

where vis is given in km, N_i in number per liter, and N_d in number per centimeter cubed. The vis values >50 km obtained from Eq. 5 should not be considered significant because of uncertainties in the counting of particles at small sizes.

It should be noted that, based on the nature of log-log plots, the variability in vis obtained from Eq. 4 can be very large for a given N_i value; therefore, these results should be used cautiously.

c. Vis versus PR from AIRS2 and FRAM

The results from both the AIRS2 and FRAM projects are presented here. Some of the earlier fits are also shown over the observed data points in Fig. 3a. This figure shows the values from the hot plates and POSS for T<-1°C and T>-1°C, respectively. Overall, two regions of data points are seen. It should be noted that there is no sharp separation between them but, when T>-1°C (mostly green points), vis values become larger as compared to those of T<-1°C that represents the snow conditions. Overall, a trend for snow conditions exists with decreasing vis for higher precipitation rates. Fig. 3b shows a similar plot but it uses only the T criteria and the fits from previous studies. The two solid black lines indicate the regions for snow and wet snow conditions based on relationships given by Rasmussen et al. (1999). The variability is large and none of the earlier fits represent the results entirely. This indicates that some other parameters need to be considered for vis-PR relationships.

An experimental test bed site at CARE during FRAM was setup as a part of Airport Vicinity and Icing Studies Applications (AVISA) project (Isaac et al., 2006). Based on the availability of both vis and PR_V from the VAISALA FD12P, a relationship between vis and PR_V is obtained. Fig. 4 shows that a trend exists when T<-1°C, representing snow conditions. Some accumulation of data points just above the data points, representing snow conditions, shows that wet snow conditions were present similar to the AIRS2 data (Fig. 3), but this needs to be further researched. It should also be stated that PR less than 0.1 mm h^{-1} are not reliable due to sampling issues.

4. DISCUSSION AND CONCLUSIONS

In the present work, surface observations from the various instruments, measuring N_d, N_i, PR, vis, RHw, and T, were used in the analysis. The relationships between vis and a related parameter (e.g. PR) were evaluated and compared with previous works. Based on the results, the following conclusions can be drawn:

- The use of the previous relationships in the forecast models especially for RHw cannot be acceptable because of an underestimation of vis at values close to saturation. Eq. 3 can be used for replacing the previous relationship used in the forecasting models.

- Although a fit is not given for vis versus PR, the results are found to be comparable with earlier works and the theoretical calculations of Rasmussen et al (1999). Overall, a large variability in the relationships suggests that vis-PR relationships need to be improved.

- The relationships between vis versus N_d and N_i clearly indicated that number concentration of the particles needs to be considered for parameterizations. Although Gultepe et al (2006) developed a parameterization based on both N_d and LWC, there is no unique relationship for ice fog conditions.

- The turbulence and wind shear at the surface need to be considered for the analysis, as they can easily affect Vis-PR relationships.

In the future, additional observations from field programs that represent cold atmospheric conditions will also be used to define limitations for the suggested relationships. These conclusions suggest that the new visibility parameterizations can significantly improve visibility estimates but additional tests utilizing the forecasting models (e.g. US Rapid Update Cycle (RUC) and the Canadian Meteorological Center (CMC) Global Multi-scale Model (GEM)) are required.

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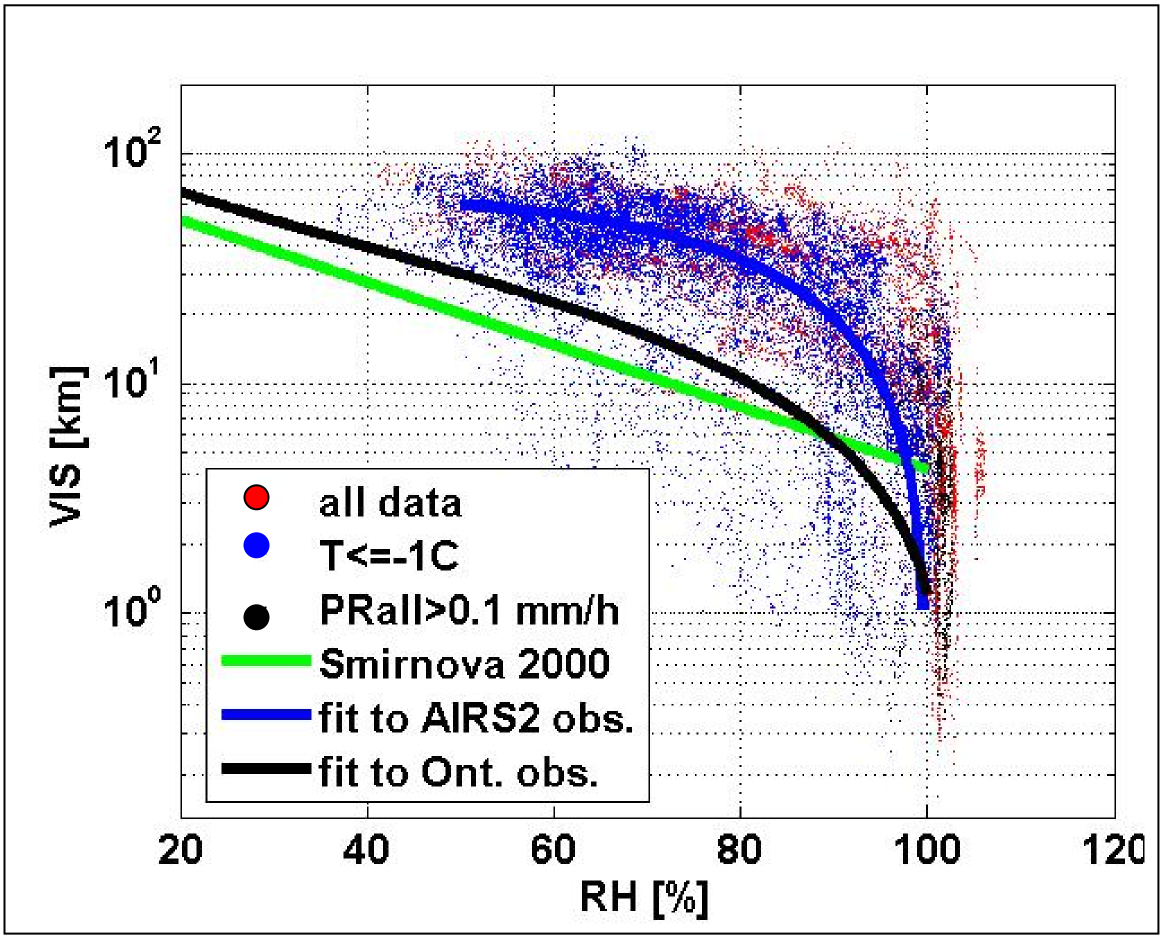

Fig. 1: Visibility (vis) versus relative humidity with respect to water (RHw) for AIRS2 measurements as dots, and a fit to observations is given with solid blue line. The black solid line is for the hourly observations from the Pearson Airport site. The green line represents the RUC model parameterization.

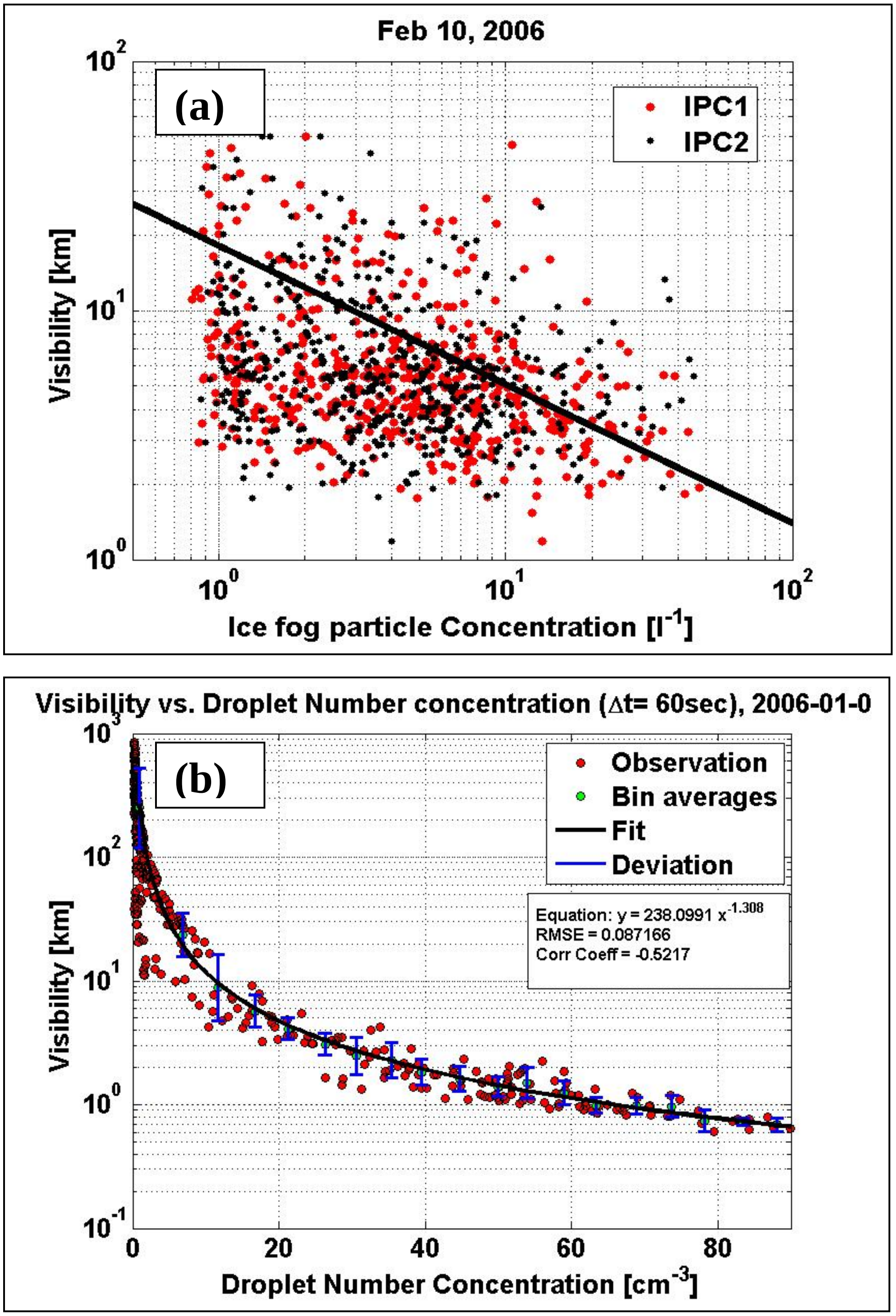

Fig. 2: Visibility (vis) versus ice crystal number concentration obtained from the YU ice particle counters (at 0.75 m and 2.5 m heights) for an ice fog case (a) and vis versus droplet number concentration obtained from the FMD (b) where blue lines are for standard deviations.

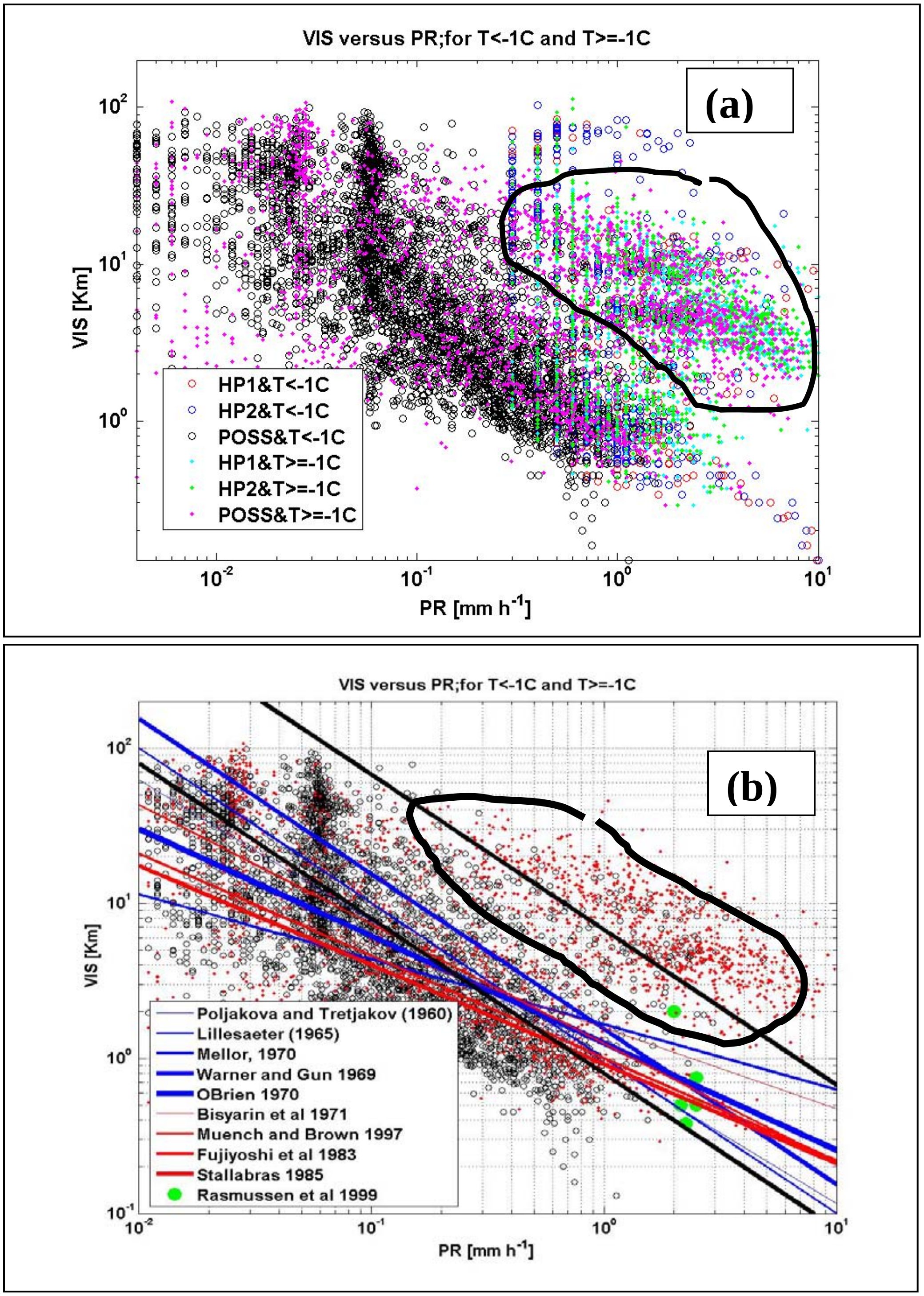

Fig. 3: Visibility (vis) versus precipitation rates from the POSS and DRI hot plates with a temperature criteria (T=-1°C) representing the boundary between rain and snow conditions. The area bordered with a black curved line is for the wet snow/rain conditions a). The data set segregated using the condition outlined above. b) the same data set with fits from previous works for snow PR. The black lines represent the results of the Rasmussen et al. (1999) together with vis values from the aircraft accidents (green filled circles) described in the same paper. The fits in (b) are the same as in Rasmussen et al. (1999).

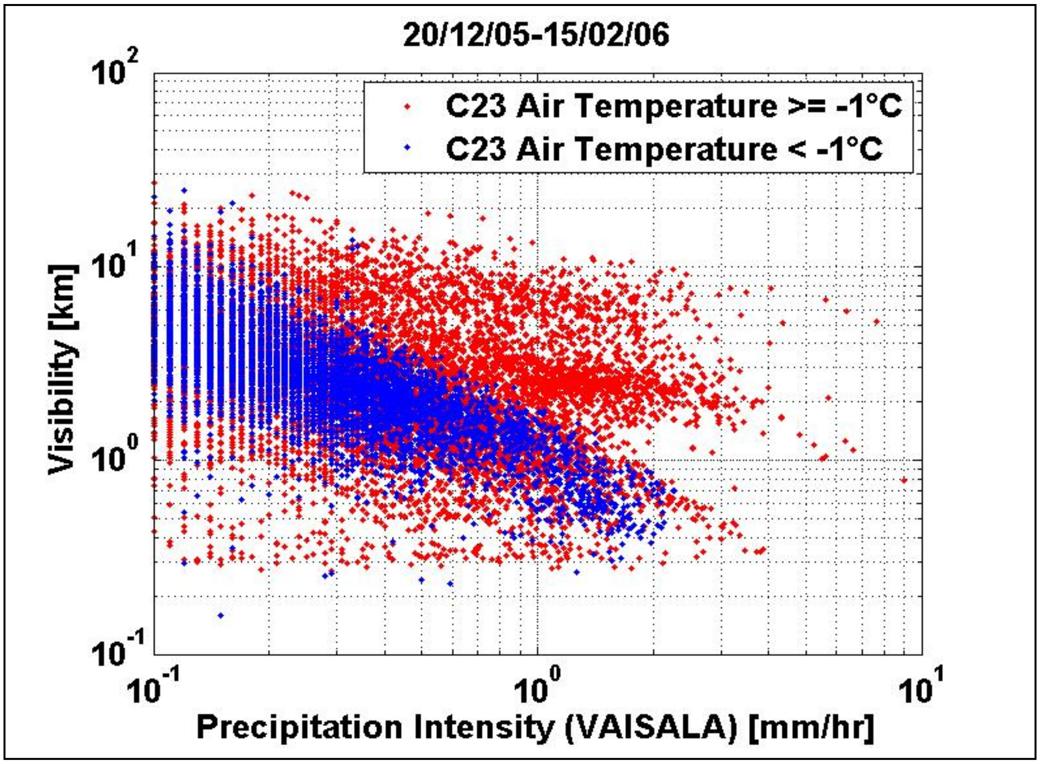

Fig. 4: Visibility versus precipitation rate (PR) using the Vaisala F12P measurements at CARE during the winter of 05/06 for T< -1°C and T>-1°C.