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Ice cloud climatology and NWP model evaluation from a Doppler Cloud Radar

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1 Introduction

Ice Clouds must be correctly represented in the NWP (Numerical Weather Prediction) and GCM (Global Climate Model) models in order to better estimate cloud feedbacks on climate projections and improve the weather forecast at different lead times. In the present paper we propose to build an ice cloud climatology in order to validate and improve the skill of these models. Taking advantage of the existence of the European CLOUDNET project (Illingworth et al. 2006), we built and analyzed a climatology using a new Doppler radar method (Delanoë et al. 2006) over three instrumented sites (Cabauw NL, Chilbolton UK, Palaiseau F). This climatology of the cloud properties has been constructed as follows: the parameters of interest are the morphological properties (mean cloud depth, mean cloud altitude/temperature, mean cloud top height), microphysical and radiative properties (ice water content IWC, effective radius R_e, visible extinction α, terminal fall velocity of crystals V_T), and the layer-mean microphysical and radiative properties of clouds (ice water path IWP, visible optical depth τ). Histograms and mean vertical profiles have been computed both for the two years over the three sites and at seasonal scale using the Cabauw site and within different altitude slices (section 2). Histograms and mean vertical profiles have then been produced as a function of cloud height over the three sites. This cloud climatology is finally used in section 3 to evaluate the representation of ice clouds in the four NWP models involved in CloudNet (ECMWF, RACMO, Met-Office and Météo-France models).

2 A climatology of the ice cloud properties using RadOn over the three CloudNet sites

From the outputs of the IPSL radar-only method (RadOn, Delanoë et al., 2006) for retrieval of the dynamical / microphysical / radiative properties of ice clouds, histograms and mean vertical profiles (as a function of altitude / altitude below cloud top) have been computed both for the two years over the three sites, at seasonal scale using the Cabauw site (which is the only one for which the radar sampling was homogeneous enough over the CloudNet period and its seasons) and within different altitude slices (0-3 km, 3-8 km, 8-12 km for cloud thicknesses less than 4 km, and a special category for the clouds thicker than 4 km).

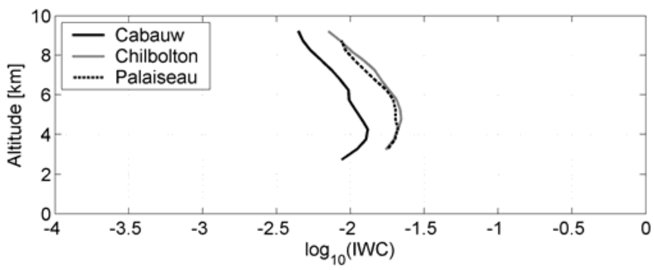

Fig. 1. Mean IWC profiles for a 2 year over the three sites

As it is shown by the mean IWC profiles reported in fig.1 it appears clearly that the statistics over Chilbolton and Palaiseau is similar, while over Cabauw the statistics of IWC is shifted towards smaller IWCs (same conclusion for extinction and terminal fall velocity). This can be explained either by a true meteorological difference between the sites or by several instrumental effects: the Cabauw radar is not at the same frequency as the Chilbolton and Palaiseau radars, it was 5 to 10 dB more sensitive during the CloudNet period, it experienced no power loss over the CloudNet period, and it has operated more continuously than the two other radars. To address this problem and separate the effect of potential sources of errors, we have first used model outputs to mimic the sampling and instrumental effects and evaluate their impact on the statistics. This study has undoubtedly shown that the difference could not be explained by a partial temporal sampling (not shown), but could be explained by

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the radar sensitivity. We have therefore computed again from the radar observations the mean profiles of the microphysical properties but after degrading the sensitivity of the Cabauw radar at that of the Palaiseau radar over the two years (Fig.2).

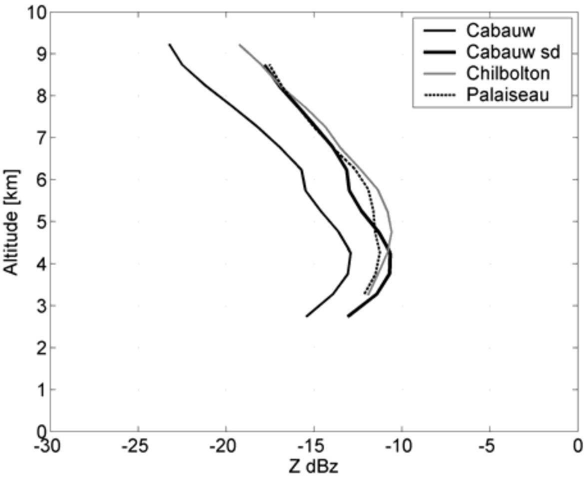

Fig. 2. Mean reflectivity profiles for a 2 year over the three sites and after degrading the sensitivity of the Cabauw radar

This plot clearly shows that the statistics derived from the less sensitive radars is significantly biased towards larger IWCs. It is therefore believed that the effect of radar sensitivity is the reason for the differences, rather than a true meteorological difference between clouds at the three sites.

Using the model we have further evaluated the potential for remaining biases due to radar sensitivity (not shown). Depending on the model, the part that is still missed by the very sensitive Cabauw radar is different. Using the Met-Office model, it appears that only above 8 km the statistics may still be biased, while according to the RACMO model there is still a potential bias at all heights.

As a result, the cloud climatology has then been constructed as follows: a reference climatology is developed using only the Cabauw radar with full sensitivity, while the regional variability of this climatology is studied using the Palaiseau / Chilbolton radars and the Cabauw radar with degraded sensitivity (called Cabauw sd in the next).

In terms of cloud macrophysics (fig. 3a, b c), the Cabauw site seems to be different from the two others, with a larger proportion of low-level ice clouds, and a clear trend for thinner clouds (500 m thick clouds are two times more likely at Cabauw, while 2-3 km thick clouds are two times less likely) than at the two other locations. The effect of radar sensitivity is here essentially observed on the cloud top height statistics, with a larger amount of higher cloud tops (8-12 km) with the full radar sensitivity, which is not surprising.

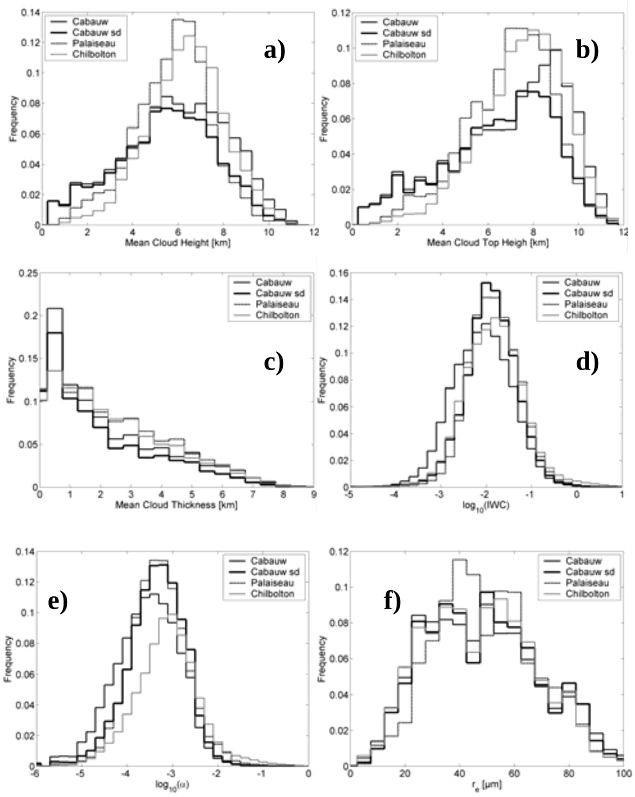

Fig. 3. The cloud microphysics and macrophysics statistics over the three sites

The cloud microphysics statistics is presented in the fig.3d, e f. Some regional variability is found, essentially in the extinction and IWC at Chilbolton, which are both shifted towards larger values, with a clearly skewed distribution. The effect of radar sensitivity is again clearly visible on IWC, extinction and terminal fall velocity (not shown).

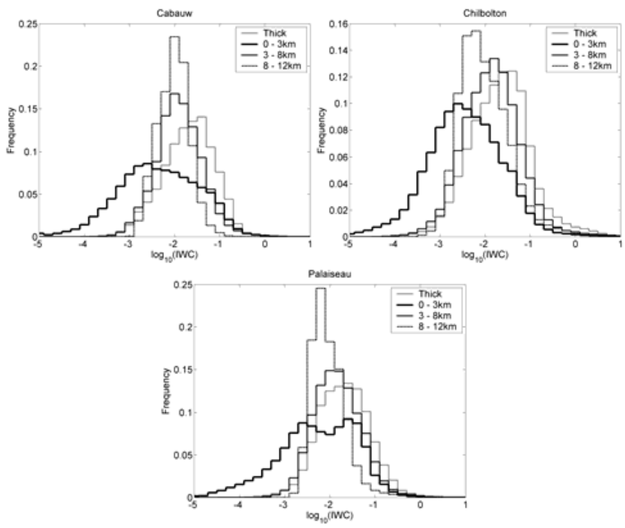

Fig. 4. Statistic of IWC for different altitude slices (0-3 km, 3-8 km, 8-12 km and thick clouds)

Histograms and mean vertical profiles have then been produced as a function of cloud height over the three sites, showing a clear distinction of the cloud microphysics statistics in low-level, mid-level, high-altitude, and thickest ice clouds, which is roughly the same for the three sites (see illustration for IWC Fig.4):

In terms of global statistics, the interannual and intraseasonal variabilities are not very large, generally speaking, as revealed by the Cabauw observations (not shown). However inside each cloud category above, the intraseasonal variability sometimes becomes significant, especially for the low-level and high-altitude ice clouds as it is shown by the fig. 5.

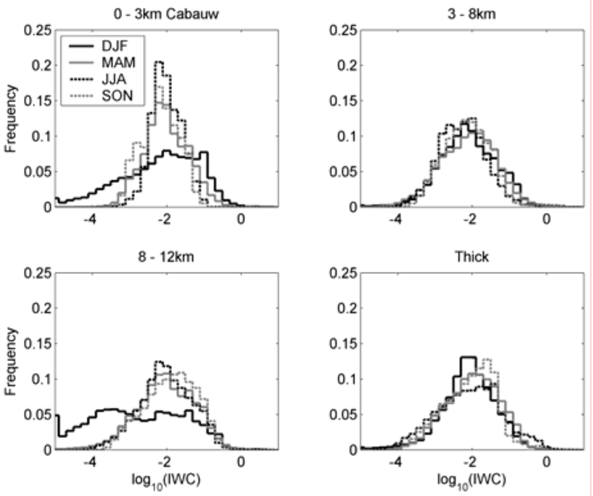

Fig. 5. Intraseasonal statistic of IWC for different altitude slices (0-3 km, 3-8 km, 8-12 km and thick clouds)

From the mean vertical profiles and in-cloud mean profiles, the interannual variability is also not very large for all parameters (not shown), but the intraseasonal variability (fig. 6.) seems to be larger, with the largest mean IWCs in autumn, and the smallest mean IWCs in spring, with differences of around 0.3 in log(IWC) (corresponding roughly to a factor 2 in IWC).

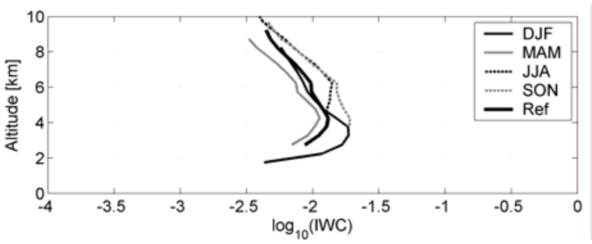

Fig. 6. Intraseasonal variability

3 Comparison of model and observed ice water content including sampling and instrumental effects

The cloud statistics previously shown has been used to evaluate the performances of the four NWP models involved in CloudNet. The IWCs from the models have been selected carefully in order to account for three effects: the fact that the IWC statistics from radar does not include the ice clouds above precipitating systems (too much attenuation by liquid water to process the ice part above), the effect of radar sensitivity (which is different over the three sites), and the effect of incomplete sampling of the two-years period. The resulting comparisons are shown for the three sites in the fig. 7 as normalized histograms and mean vertical profiles.

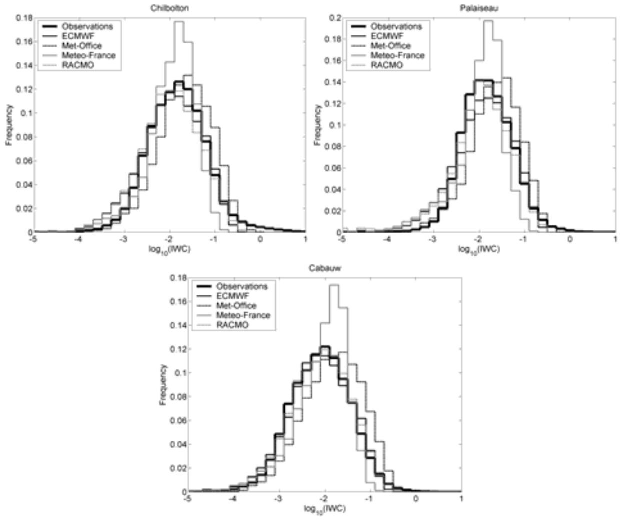

Fig. 7. IWC comparisons Models/Observation over the three sites

In terms of histograms represented by the fig.7, it is first observed that the ECMWF, Met-Office, and RACMO models relatively well represent the IWC variability. The agreement is particularly spectacular for ECMWF and RACMO over the Cabauw site. It is however observed that the Met-Office model has a systematic shift towards large IWCs, despite a very good shape of the histogram. The Meteo-France model, which is the only model out of the four to have diagnostic IWC, seems to produce a much narrower IWC distribution (positively skewed). During the CloudNet project, Meteo-France has changed its cloud scheme, and the present statistics mixes both, which may explain partly this departure. ECMWF and RACMO seem to be the models that have the smallest differences with respect to the observations.

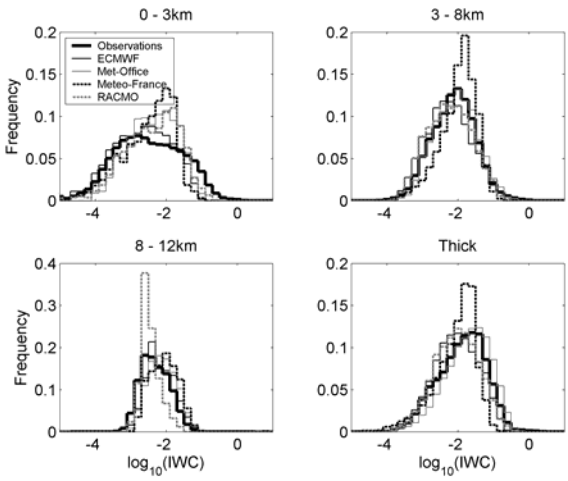

fig. 8. IWC comparisons Models/Observation over the three sites for different altitude slices (0-3 km, 3-8 km, 8-12 km and thick clouds)

These histograms have also been calculated as a function of cloud height over Cabauw (represented by fig. 8). The skills of the models are different for each type of clouds. For the low-level ice clouds (clouds below 3 km), the ECMWF is the best fit to the observations, while the other models tend to have a narrower distribution and to overestimate IWC. For midlevel ice clouds (clouds between 3 and 8 km, depth < 4 km), the Met-Office model is almost perfect, while ECMF and RACMO well represent the histogram structure, with however a slight shift towards the smaller IWCs. The largest differences between observations and models are found for the high-altitude clouds (cloud above 8 km, depth < 4 km). ECMWF is this time the best match to the observations, but tends to underestimate the small IWCs. RACMO seems to well represent the left part of the observed distribution, but its distribution is too narrow (significant underestimation of the large IWCs in high clouds). The Met-Office and Meteo-France models well capture the histogram characteristics, with however a systematic shift towards larger IWCs. Finally for the thick clouds the Met-Office model seems to best match the observations, as was the case for the clouds between 3 and 8 km, with a slight shift towards larger IWCs. ECMWF and RACMO do a reasonable job, despite a general underestimation of the intermediate IWCs.

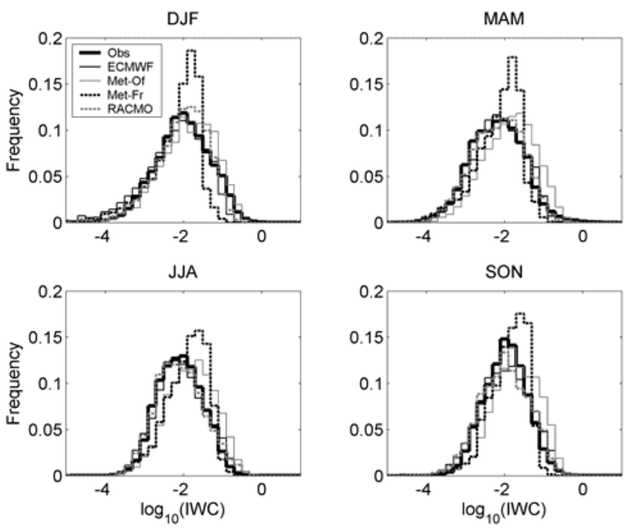

Fig. 9. IWC comparisons Models/Observation over Cabauw for each season.

The fig9. shows the differences in model skills as a function of the season. Overall there does not seem to be a large seasonal difference in skills for all models. ECMWF and RACMO are in good agreement with the observations for all seasons. Meteo-France has a too narrow distribution whatever the season, and the Met-Office model is systematically shifted towards larger IWCs (less in winter).

From the mean vertical profiles by model and by site represented by fig.10, we obtain a clear difference between the Cabauw site and the two others. As shown previously, this is essentially due to the higher sensitivity of the Cabauw radar, which is able to detect smaller particles and therefore has the effect of shifting the mean profile towards smaller mean IWCs. It is obtained that ECMWF and RACMO do a reasonably good job at representing the mean IWC profile over two years at Chilbolton and Palaiseau, while only RACMO seems to reasonably well reproduce the Cabauw observations. This suggests a least accurate representation of the smallest IWCs in ECMWF than in RACMO. The Met-Office model seems to very well represent the vertical structure of the mean IWC profile, with however a general overestimation throughout the troposphere.

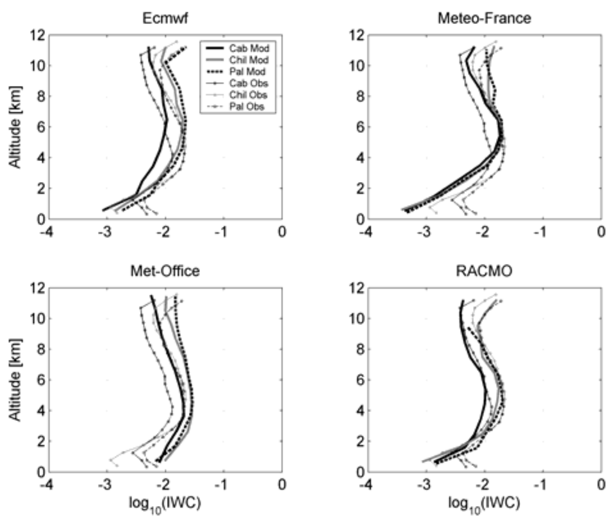

Fig. 10. Mean vertical profiles of IWC by model and by site

4 Conclusion

In the present paper we built an ice cloud climatology in order to validate and improve the skill of NWP models. In terms of cloud macrophysics, the Cabauw site seems to be different from the two others, with a larger proportion of low-level ice clouds, and a clear trend for thinner clouds than at the two other locations. Concerning the cloud microphysics statistics, some regional variability is found, essentially in the extinction and IWC at Chilbolton. In terms of global statistics, the interannual and intraseasonal variabilities are not very large, except inside each cloud category.

The skills of the models are different for each type of clouds, but there does not seem to be a large seasonal difference in skills for all models. ECMWF and RACMO are in good agreement with the observations for all seasons. The Met-Office model well captures the observed histogram characteristics, with however a systematic shift towards larger IWCs.

References

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