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Sensitivity studies on difficult cloud and fog situations for weather model

Axel Stigborg

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Supervised by Kristian Pagh Nielsen and Elna Heimdal Nilsson

Department of Physics
Danish Meteorological Institute
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Abstract

Fog and clouds are difficult to predict for meteorologist today. Models have a tendency to show either too much or too little clouds or fog, which can be a problem for people and industries that depend on the weather conditions. Improvements are being done, but errors still occur. One of the problems is that when an improvement is attained, it might only work for one specific season. This happens, for instance, due to winter causing colder air temperature, while water, which is a poor heat conductor, remains fairly warm relative to the air. Consequently, warmer air near the surface of water rises, and thereby creates clouds when the air has cooled down to the point of saturation. Using MUSC (Modèle Unifié Simple Colonne), which is a 1D-model of the weather model HARMONIE-AROME (Hirlam Aladin Research for Mesoscale Operational Numerical Weather Prediction in Euromed)-(Application of Research to Operations at Mesoscale), different cases are evaluated for specific parameters to see improvements can be made. To check the consistency of the improvement, the cases are not bound to one single season.

Acknowledgements

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Abbreviations

MUSC	Modèle Unifié Simple Colonne
HARMONIE	HIRLAM ALADIN Research for Mesoscale Operational Numerical Weather Prediction in Euromed
HIRLAM	High Resolution Limited Area Model
ALADIN	Aire Limitée Adaptation dynamique Développement InterNational
AROME	Application of Research to Operations at Mesoscale
DMI	Danmarks Meteorologiske Institut (Danish Meteorological Institute)
nm	nanometer
µm	micrometer
CCN	Cloud Condensation Nuclei
CC	Cloud Cover fraction
TKE-1	Turbulent Kinetic Energy - lenght
LINUX	Linus Torvald's UNIX
UTC	Universal Time Coordinated
N	North
E	East

1 Introduction

Today's weather forecasting is phenomenal. Weather can be predicted days ahead and actions can be taken for severe conditions if necessary. However, problem arises when the weather models are not showing the correct weather situation. There have been many cases where the weather models have been showing the incorrect cloud cover ¹.

Predicting false cloud cover will not only influence the sunshine but also, for instance, radiation fluxes in the atmosphere of the weather models, which, by interacting with different factors, could influence the thickness and lifetime of the clouds ². Predicting false properties of clouds could also affect the forecasted precipitation, which might add to the total error of the weather prediction.

Since this is a well-known concern for meteorologist around the globe, some speculations have been made of what might cause this error ³. Suggestions have been made to investigate the impact aerosols have in the weather models ². Aerosols are liquid or solid particles in the atmosphere, in mixtures of particles and gases ⁴. These aerosols vary from 1 nm to 100 µm in diameter in different size bins gases ⁴. Moreover, water is able to attach to some of these aerosols, and aerosols, which are able to form cloud droplets from the water uptake, are called Cloud Condensation Nuclei (CCN) gases ⁴. In the HARMONIE-AROME model, for example, the CCNs are set to two default values for model runs, where one default value, 400.0, is set over land and 50.0 is set over sea. These values are further used to calculate the effective radius of the cloud liquid. The cloud liquid effective radius is then used to calculate the liquid cloud optical properties. This might cause some problems since the number of CCNs are not constant everywhere and big cities near seas might increase the number of CCNs over the water. However, CCNs are not the only parameter set to a default value. Cloud overlap is set to represent a specific state of how clouds at different heights interact with each other. This parameter can be set to four different modes. However, it is by default set to one mode which uses interaction between clouds both vertical and horizontal. Furthermore, one of the options was implemented as a test from a person at Meteo France ³. Consequently, not much information can be found about how this option differ from the default mode commonly used ³.

In this project, the focus is to investigate how the CCN and cloud overlap affects the results on two different cases. These cases are real errors produced by the HARMONIE-AROME model at DMI (Danish Meteorological Institute). The cases are from different seasons in order to get a better perspective and make improvements for the whole year.

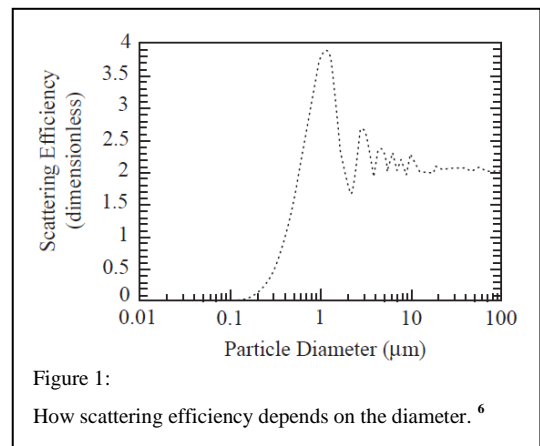
2 Background

2.1 Aerosols

Aerosols are usually divided into groups called modes⁴. These modes consists of nucleation mode, Aitken mode, accumulation mode and coarse mode gases⁴. However, Aitken mode contains two different groups, which are dependent on the diameter of the aerosol⁴. Aerosols with a diameter of less than 30 nm are usually placed in the nucleation mode⁴. These can be created by, for instance, a sulphuric acid molecule activating a Non-activated cluster of molecules which does not contain a sulphuric acid molecule⁴. However, growth by for instance coagulation, which occurs when two particles collide with each other⁴, the aerosols in the nucleation mode decreases while the diameter of the aerosols might increase to above 30 nm, to the Aitken mode⁴. Furthermore, aerosols in the Aitken mode might also be created during combustion processes and vehicle exhaust. By condensation, or if the aerosols in the Aitken mode act and grow as CCNs, the aerosols could grow into the accumulation mode, which are particles larger than 100 nm⁴. Mechanically generated particles with a diameter larger than 1 μm are often placed in the coarse mode⁴. The mechanically generated particles are generated for instance from wave-breaking and abrasion of tires⁴. The combustion processes might contain more sulfate particles, while the jet-drops from wave-breaking contain more ions, such as chlorine, magnesium and potassium⁴. Aerosols affect weather both direct and indirect, and therefore must be in consideration while modelling the weather³.

2.1.1 Direct effect

The direct effect includes the absorption and scattering of incoming solar radiation⁵. However, this effect is dependent on the radius of the aerosols, which can be seen in Figure 1⁶. Scattering aerosols in the atmosphere scatters incoming solar radiation and, consequently, less radiation reaches the surface⁵. However, due to atmospheric circulations, the cool ground spreads out in the atmosphere⁵. Furthermore, absorbing aerosols in the atmosphere instead absorbs incoming solar radiation⁵. This leads to, as before, a cooler surface⁵. However, due to the absorption, the layer of aerosols heats up⁵. Furthermore, the atmospheric circulations spread out the heat which in net difference leads to a warming of the atmosphere⁵.



2.1.2 Indirect effect

The indirect effect affects the lifetime of clouds, clouds and cloud cover⁵. The CCN is used as a core of a water droplet, which allows water to attach to the CCN in order to grow⁷. Consequently, a higher concentration of CCNs gives an increased amount of cloud droplets⁵. Due to the increased amount of cloud droplets, the cloud would receive an increased albedo, thereby leading to an increased scattering of incoming solar radiation⁸. This is called the Twomey effect⁵. However, more CCN in a cloud could further lead to a smaller size of the cloud droplets⁵. Consequently, this decreases the efficiency of the precipitation and thereby extends the lifetime of the clouds⁹. This is called the Albrecht effect⁵.

2.2 Cloud Development

Clouds can be developed in different ways. The most common way clouds develop is through rising air which reaches saturation¹⁰. Convection, movement up obstacles, convergence of air near surface and fronts are a few mechanics which are responsible for rising air and which might be connected to this project¹⁰. Convection occurs when the surface gets heated and becomes warmer than the surrounding air¹⁰. Air near the heated surface then becomes warmer, which creates a lifting force to make the rising air reach saturation¹⁰. However, this mechanic can also occur during winters when the water usually is warmer than the air¹⁰.

If moving air collides with larger obstacles, for instance mountains, which are wide enough to not let air pass on the side, air is forced to rise above the obstacle¹⁰. The rising air then becomes cooler and eventually reaches saturation which develops clouds¹⁰. Furthermore, moving air near surface might also collide with each other¹⁰. Since the surface prevents the air to descend, the air is forced upwards where it reaches saturation and develops clouds¹⁰.

Fronts occur when a warm air mass moves into a cooler air mass or a cold air mass moves into a warmer air mass¹⁰. When a warm air mass moves into a cooler air mass the warmer air rises on top of the cooler air mass and thereby develops clouds¹⁰. However, when instead a cold air mass moves into a warmer air mass, the warmer air mass gets forced upwards which develops clouds¹⁰.

2.3 Cloud overlap

Cloud overlap in models is used to describe the overlapping of vertical cloud cover fraction between different layers. The cloud overlap in the HARMONIE-AROME model is divided into four different modes, where each is assigned a different value³. The modes are random, maximum-random, maximum and maximum-random, and they are assigned the values 5, 6, 7 and 8 respectively in the model³. Note, in this section, chapter 2.2, the cloud cover fraction defines the vertical cloud cover fraction, where the cloud cover fraction is how much the cloud covers on a scale from 0 to 1, where 0 is no clouds and 1 is overcast.

The maximum overlap places all cloud layers on top of each other and uses the cloud layer with the most cloud cover fraction as the predicted cloud cover¹¹. For instance, if two points, j and k , represents two different levels in the atmosphere, then the total cloud cover fraction would be calculated as

$$CC_{tot} = \max(CC_j, CC_{j+1}, \dots, CC_{k-1})$$

where CC is defined as the cloud cover fraction, and CC_j is the cloud cover fraction between j and $j + 1$, CC_{j+1} is the cloud cover fraction between $j + 1$ and $j + 2$ and so on¹². Due to the clouds being represented as a column with a cloud cover fraction of the cloud with the largest value, the model produces reasonable results for clouds which are close vertically¹¹. However, since the model assumes that all clouds are placed vertically over each other, the maximum overlap assumption has a tendency to underestimate the cloud cover fraction for clouds which are separated vertically by a clear layer¹³. The random overlap mode, however, instead assumes that each layer are different and have no relation with other cloud layers, even if they are vertically adjacent¹¹. Furthermore, to calculate the random overlap assumption, the following equation is used¹¹.

$$CC_{tot} = 1 - \prod_{n=j}^{k-1} (1 - CC_n)$$

Since this method assumes no relation between two cloud layers, there would be a notable error for deep convective clouds¹². However, in areas where clouds are not adjacent, the random overlap assumption can give realistic results of the cloud cover fraction¹³.

The final mode is the maximum-random overlap. This mode combines the maximum overlap assumption with the random overlap assumption¹¹. Consequently, if two cloud layers are connected vertically, it is seen as a maximum cloud overlap¹². However, if two cloud layers are separated by a clear layer, it is seen as a random cloud overlap¹². To calculate the cloud cover fraction from the maximum-random overlap assumption, the following equation is used¹².

$$CC_{tot} = 1 - \prod_{n=j}^{j-1} \left(\frac{1 - \max(C_n, C_{n-1})}{1 - C_{n-1}} \right)$$

However, as addressed in the introduction, no further information was found on how the alternative maximum-random specifically differed from the default maximum-random other than the alternative maximum-random overlap assumption uses a maximum-random assumption.

3 Methodology

HARMONIE-AROME cycle 38 was used in order to produce the model forecast as seen in chapter 4.1 and 4.2. The HARMONIE-AROME model is a non-hydrostatic, convection permitting model, which has been developed by the teams of ALADIN and HIRLAM¹⁴. The grid spacing of the HARMONIE-AROME model is usually set to 2.5 km in the horizontal plane, while the atmosphere is divided into 65 different layers¹⁴. However, to investigate CCN and cloud overlap in this thesis, MUSC, a one dimensional column model of the HARMONIE-AROME model was used. The MUSC model use four grid points in the horizontal plane and produce a column based on the initial conditions given³. Consequently, instead of running the HARMONIE-AROME model with approximately 100000 grid points, the MUSC model runs significantly faster than the HARMONIE-AROME model³. However, the MUSC model used was cycle 40 which differs from HARMONIE-AROME cycle 38³. For instance, the MUSC cycle 40 implements a new turbulence scheme, which improves the mixing of air in the model³. The new turbulence scheme introduces a new formulation of the length-scale in a TKE-l (Turbulent Kinetic Energy)-(length) scheme, where a TKE-l is a computational cheap and simple scheme which is a combination of a prognostic TKE equation and a length scale¹⁵. This TKE-l scheme is then used to calculate the eddy diffusivity¹⁵. However, some restrictions occur for this scheme, where the conditions must be near neutral near the surface, or it has to be convective¹⁵. For conditions where the Richardson number is larger than 0.2, a different length-scale is used¹⁵.

In order to produce the results, a namelist for the MUSC model was needed. The parameters evaluated could be found inside this file. However, for simplification, all was done with the operating system LINUX. Consequently, scripts could be made to simplify changing the value of the parameters, as well as plotting the results. The scripts can be found in appendix A. Furthermore, in order to produce the plottings, Gnuplot was used, since it allowed for the creation of scripts in order to store the color scheme for the plots.

4 Results of model runs and discussion

As stated, two cases were chosen where the HARMONIE-AROME model produced an error in cloud cover. This has been confirmed by comparing the HARMONIE-AROME model output with a satellite picture. However, due to a large amount of plots from the MUSC model, only plots being discussed in the upcoming chapter will be used in the result section. Furthermore, remaining plots will be presented in the appendix B.

4.1 March 17 – 2016 Model run 06 UTC + 06 Hours

The first experiment which was chosen was during the transition from winter to spring in March 2016. As seen on Figure 2.1, the HARMONIE-AROME model predicted, at 06 UTC, an extensive cloud cover in the south eastern part of Sweden, but also over the southern parts of the Baltic Sea at 12 UTC. However, compared to the satellite picture, which can be seen in Figure 2.2 and was taken 12 UTC, this was not the case. Large parts of the predicted cloud cover were not present during the 12 UTC satellite picture. Both the area described above and in the southern part of the North Sea had no cloud cover, although the model predicted a low completely covered cloud layer. Since a clear difference between the modeled cloud cover and the real cloud cover was found in the western part of Scania and the southern parts of the Baltic Sea, two points in this area was chosen in the MUSC model run. The point and the area can be seen in Figure 2.1 as the green markings on the map. The coordinates chosen were 55.56N, 14.05E which were over the water and 55.03N, 13.96E which were over land.

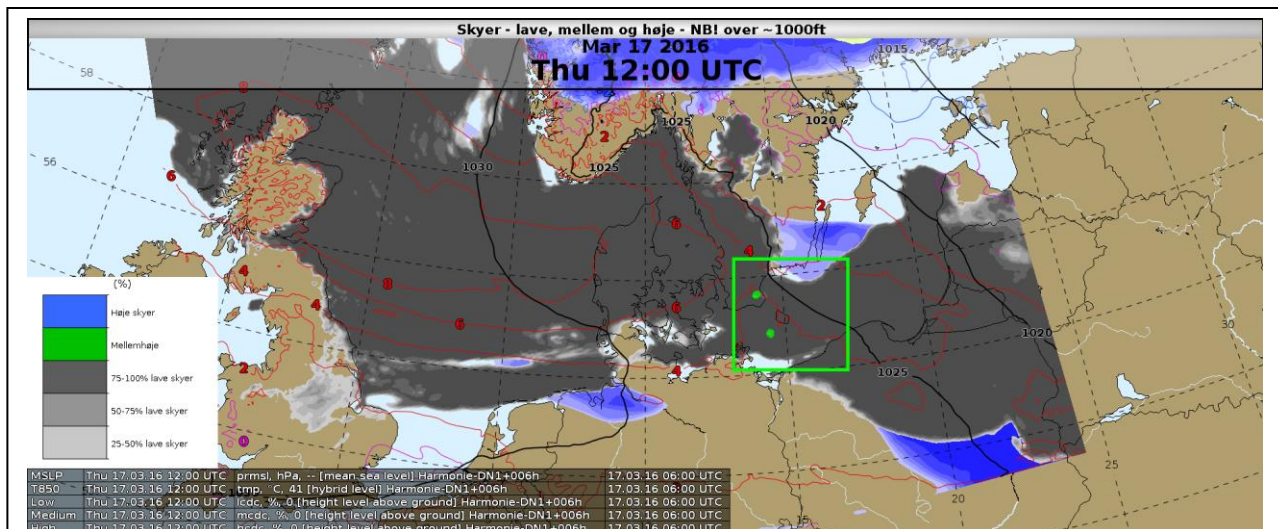


Figure 2.1

Model cloud forecast over Denmark, southern Sweden and the Baltic Sea on the 17th of March 2016. High altitude clouds are depicted as blue, medium altitude clouds are depicted as green and depending on low level cloud cover, the darker the gray, the more the low clouds cover the sky.

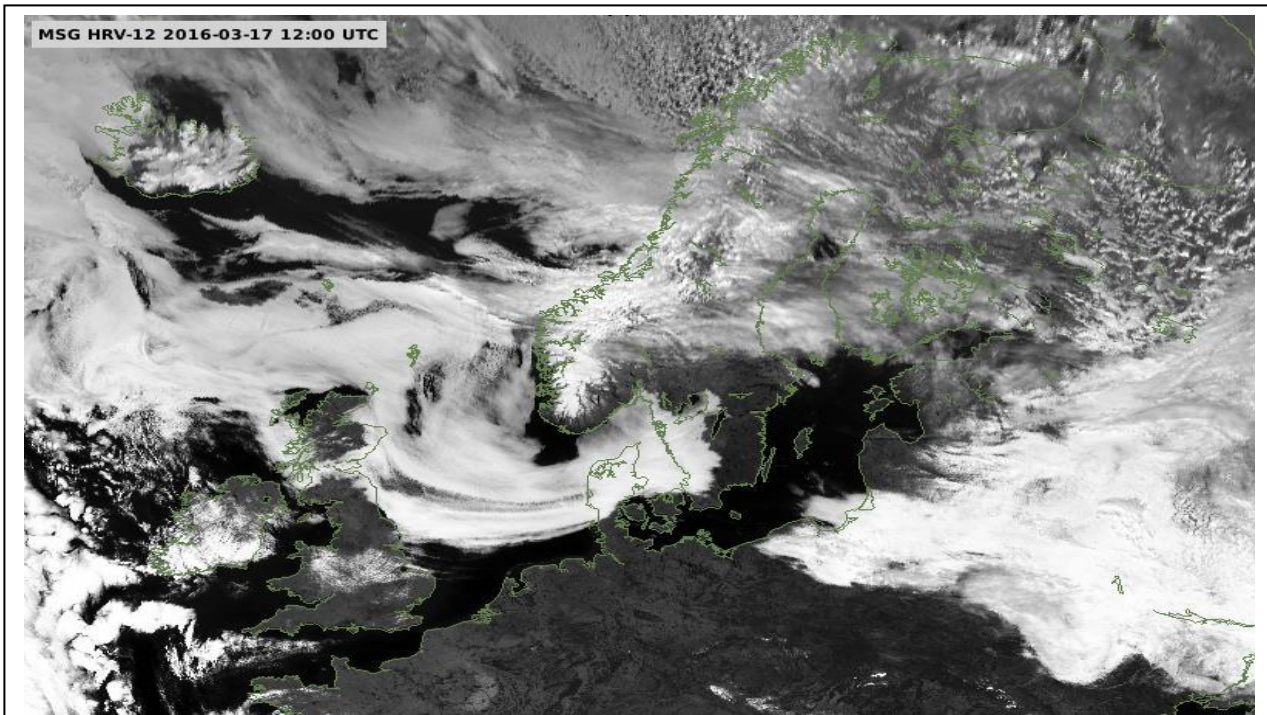


Figure 2.2

Satellite picture of the clouds over the same area as in Figure 2.1, during the 17th of March 2016. The clouds are depicted as white.

4.1.2 Land

As seen in Figure 2.2, there is an area of no clouds in the eastern part of Scania, where a cloud cover is predicted by the model as seen in Figure 2.1. The coordinates chosen over land was put into the MUSC cycle 40 model which was set to run for a period of 12 hours in time steps of 1 minute. The outcome was then transferred from .lfa files to readable files with the chosen parameter and plotted using Gnuplot. The cloud cover ranges from 0 to 1, where 1, depicted as black, is 100% cloud cover and 0, depicted as white, is no clouds. The parameters CCN over land and sea, as well as cloud overlap was changed in order establish the best result,

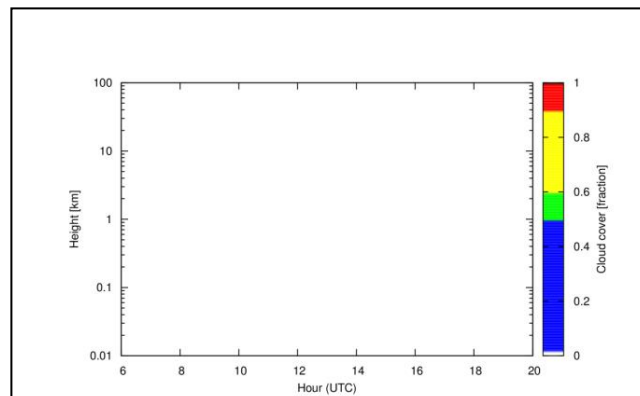


Figure 2.3

Cloud cover which represents all values of CCN with default cloud overlap.

White represents no clouds, blue is a few clouds or scattered clouds, green is scattered clouds or broken clouds, yellow is broken clouds, red is transition between broken clouds to total overcast and black is total overcast.

compared to Figure 2.2. The CCN values which were investigated were 1, 10, 100 and 1000. However, extreme cases were also investigated, where the CCN was set to 0, as well as 100000 to examine if there were a great impact of the CCN in the model. The result can be seen in Figure 2.3, where the standard overlap value of 6 is chosen and the CCN varies between values above.

During most model runs, the CCN had a small to no impact on the model output. During the land case 17th of March 2016, comparing the results, which can be seen in Figure 2.3 as well as the appendix, given from the MUSC model run, to the satellite picture, Figure 2.2, all of the Figures were identical and showed the correct situation, which was no clouds during 12 UTC. Moreover, comparing the results, no significant change was found between different cloud overlaps. To further investigate if the CCN had an impact on the result, two extreme values were chosen to 0 and 100000. Compared with each other, no change was noticed. Furthermore, the version of the HARMONIE-AROME model used for the case was cy38h1.2, where the MUSC model used the version cy40h1. Since the turbulence scheme was not implemented in the HARMONIE-AROME model run during these two test cases, this could have an impact on the result and therefore improving the result by not displaying a cloud cover for the land case. Consequently, since the turbulence scheme might have been the dominant factor during this model run, the CCN and cloud overlap had no impact on the result. Therefore, by this case alone, the preferred value of CCN and cloud overlap cannot be determined.

4.1.3 Sea

The same procedure was then used for the coordinates over water. Furthermore, the same values of CCN and cloud overlap were used to investigate the case, and the results were then compared with Figure 2.2 to determine which values for the CCN and cloud overlap produced the best result. The results produced by the MUSC model can be seen in Figure 2.10 – 2.18. However, Figure 2.10 depicts the model run with CCN and cloud overlap set to default values

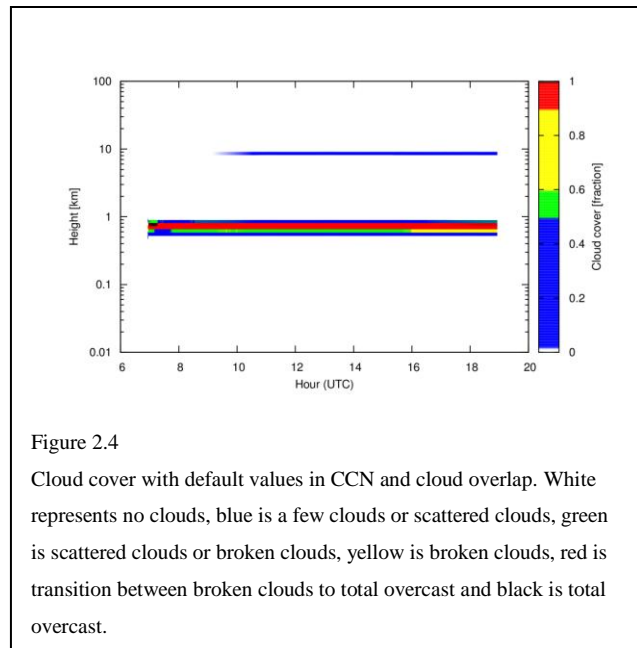


Figure 2.4
Cloud cover with default values in CCN and cloud overlap. White represents no clouds, blue is a few clouds or scattered clouds, green is scattered clouds or broken clouds, yellow is broken clouds, red is transition between broken clouds to total overcast and black is total overcast.

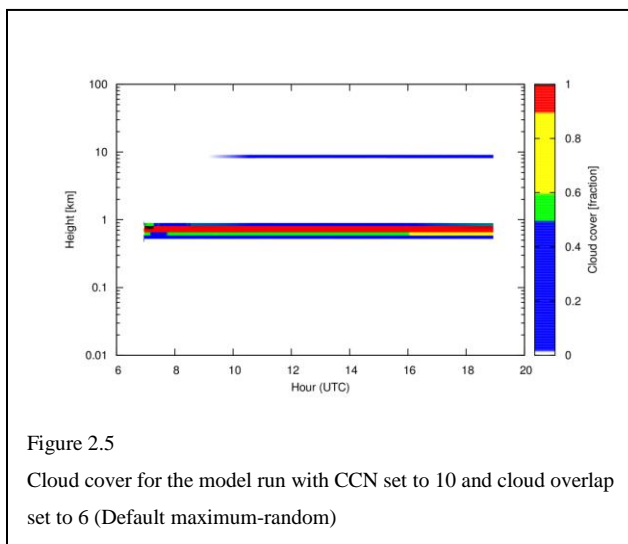


Figure 2.5
Cloud cover for the model run with CCN set to 10 and cloud overlap set to 6 (Default maximum-random)

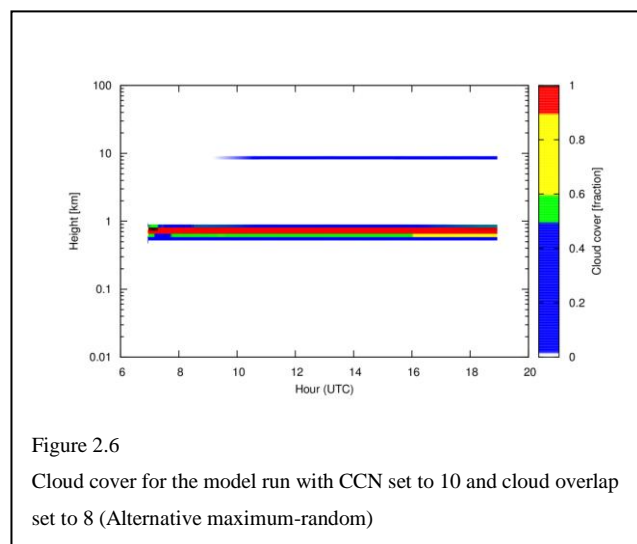


Figure 2.6
Cloud cover for the model run with CCN set to 10 and cloud overlap set to 8 (Alternative maximum-random)

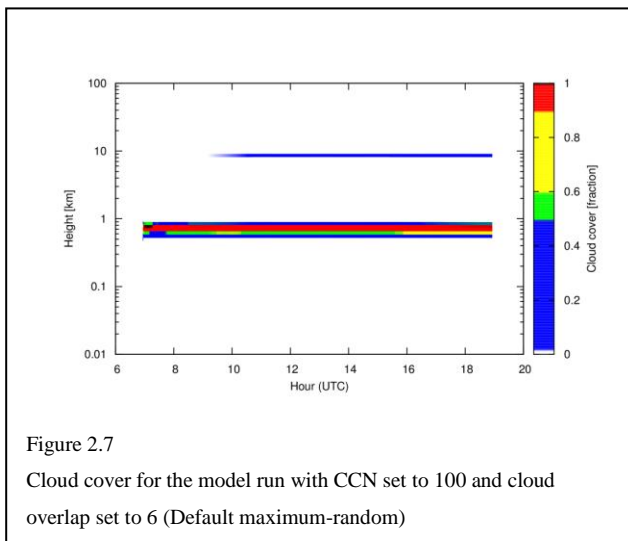


Figure 2.7
Cloud cover for the model run with CCN set to 100 and cloud overlap set to 6 (Default maximum-random)

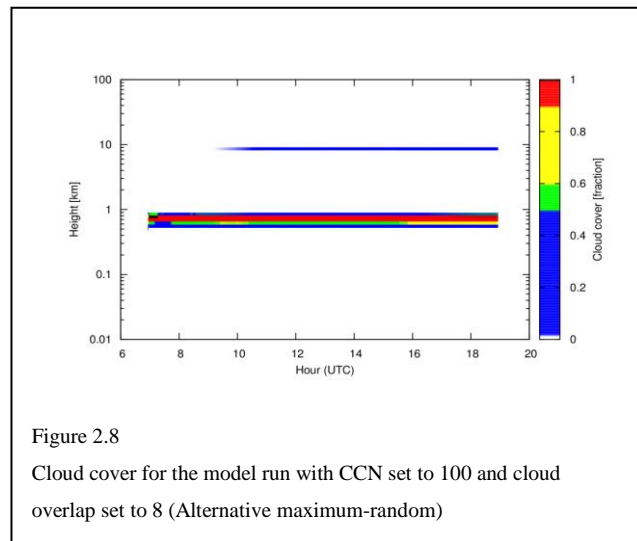
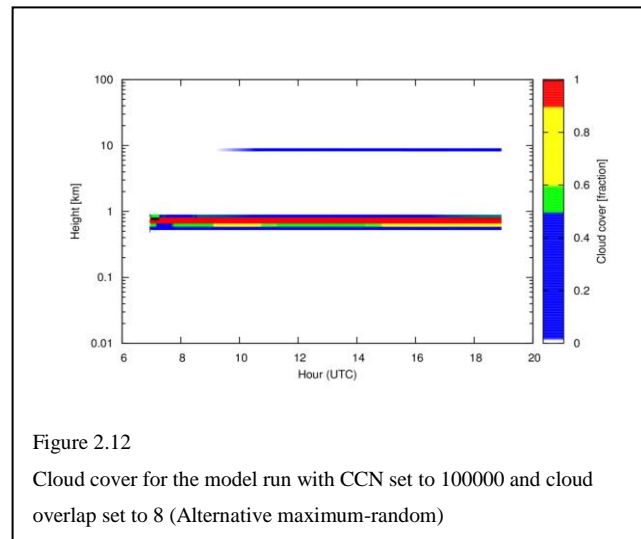
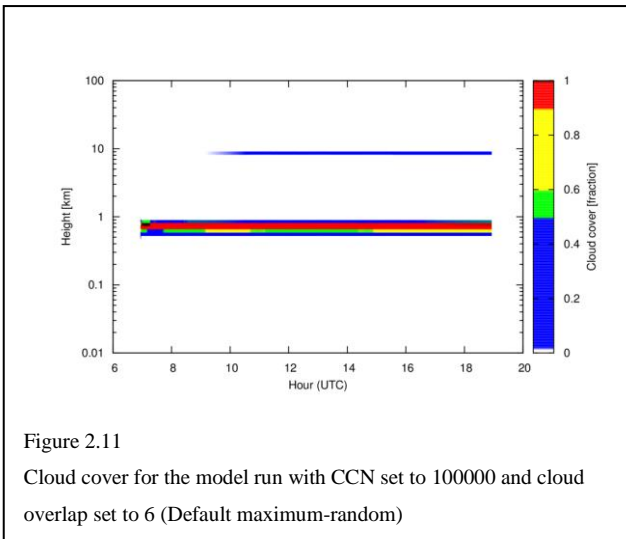
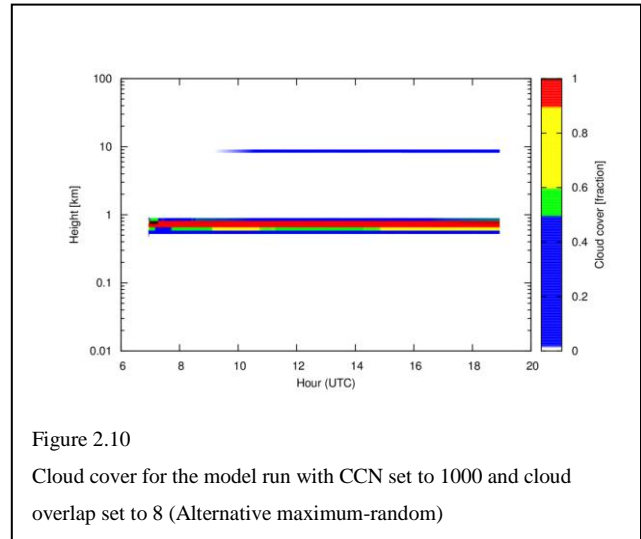
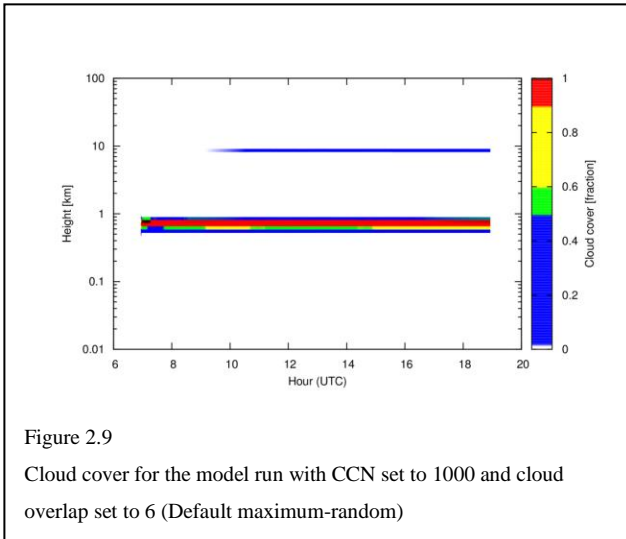


Figure 2.8
Cloud cover for the model run with CCN set to 100 and cloud overlap set to 8 (Alternative maximum-random)



For the sea case during the 17th of March 2016, both the CCN and cloud overlap had an increased impact on the result. While closely studying the difference between Figures 2.10 – 2.18, small differences can be found. The difference between Figure 2.10 and 2.11 seems to be a shorter duration of the green cloud fraction area at approximately 600 meters, where Figure 2.10, which displayed the default values, seemed to increase the cloud cover fraction during the last hours. However, Comparing Figure 2.11 with Figure 2.12, the total cloud cover during the beginning of the model run seems to be prolonged by approximately 1 time step. Furthermore, the green cloud cover fraction, as previously mentioned, seems to get shortened by one time step. The difference between Figure 2.12 and 2.13 seems to be that the green area at 600 meters, as well as the initial full cloud cover is shortened. Furthermore, during approximately 9 to 10 UTC, there seems to be small parts of yellow cloud cover

fraction imbedded into the green area. Both the yellow part and the shortening of the green area are enhanced in Figure 2.14 and 2.15. In Figure 2.15, however, the yellow area is now clearly visible and the green fraction has become significantly shorter. Furthermore, the cloud cover increases in Figure 2.16, only to decrease in Figure 2.17 and finally increase in Figure 2.18. However, the only reference from this case in the report is the satellite picture in Figure 2.2. Therefore, determining the value for which CCN and cloud overlap would be the most optimal would be difficult. If assuming that no significant changes were made to the cloud cover during the period of 10 UTC to 12 UTC, the most optimal value for CCN over sea would be 10 while the cloud overlap should be set to 5, 6, 7 or 8. However, due to maximum cloud overlap, in cases where CCN was set to 100, 1000 or 100000, increased the cloud cover slightly, speculations are made if 5, 6 or 7 might be the most optimal value for cloud overlap.

4.2 November 25 – 2016 Model run 06 UTC + 03 Hours

During the transition between autumn and winter of 2016, the HARMONIE-AROME model predicted cloud overcast in the southern area of Jylland, as well as a large section of the Wadden Sea area, as seen in Figure 3.1. Therefore, the points chosen are marked as pink in Figure 3.1 and have the coordinates, 55.37N 9.07E over land and 54.51N 8.11E over sea. The forecast was modeled on 25th of November at 06 UTC and forecasted the cloud cover for 3 hours later at 09 UTC. However, the satellite picture taken at 09 UTC, Figure 3.2, does not show the low cloud base as seen in the model prediction.

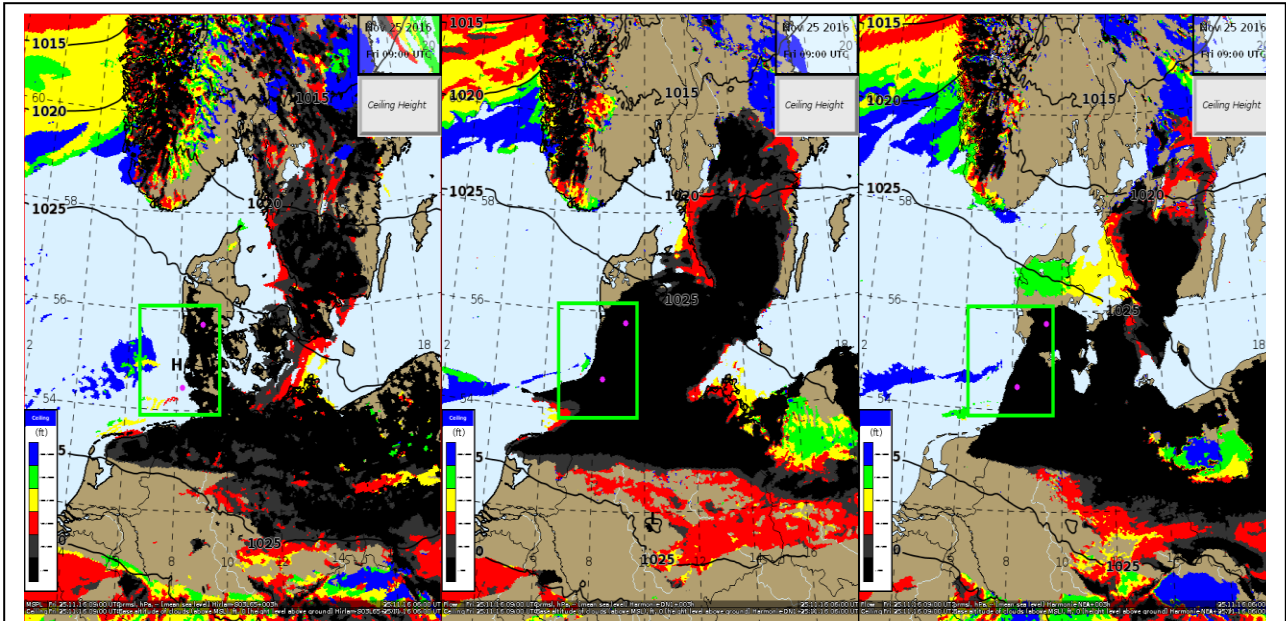
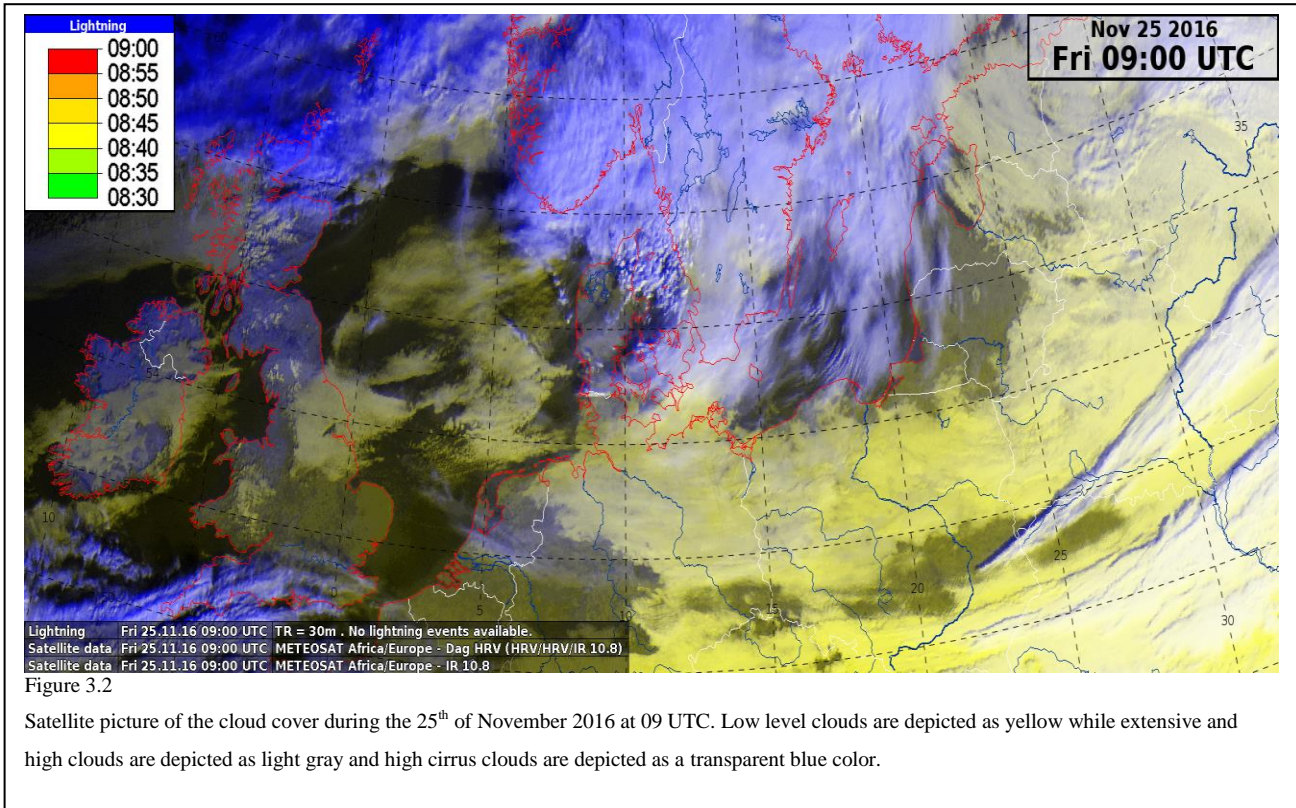


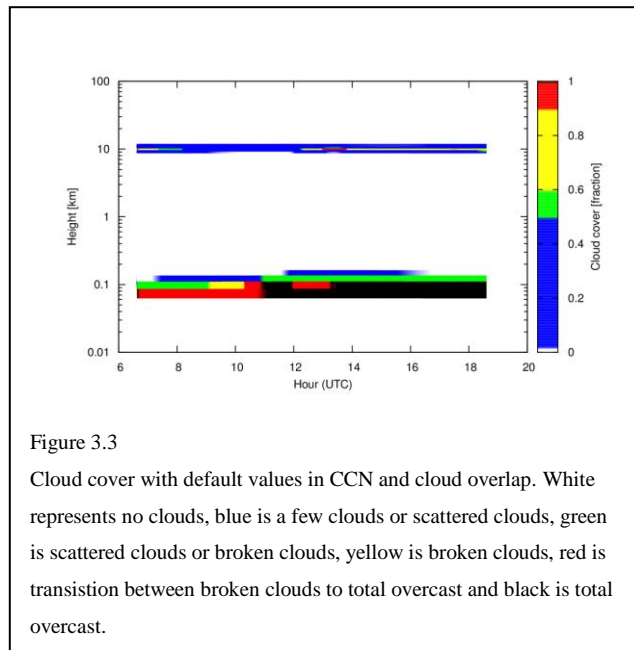
Figure 3.1

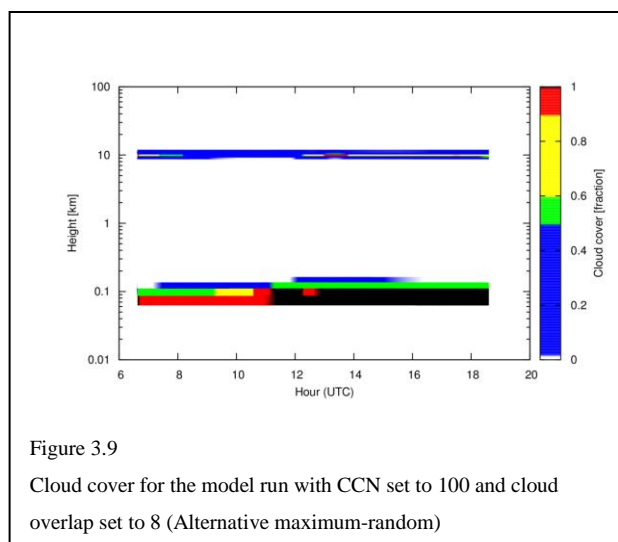
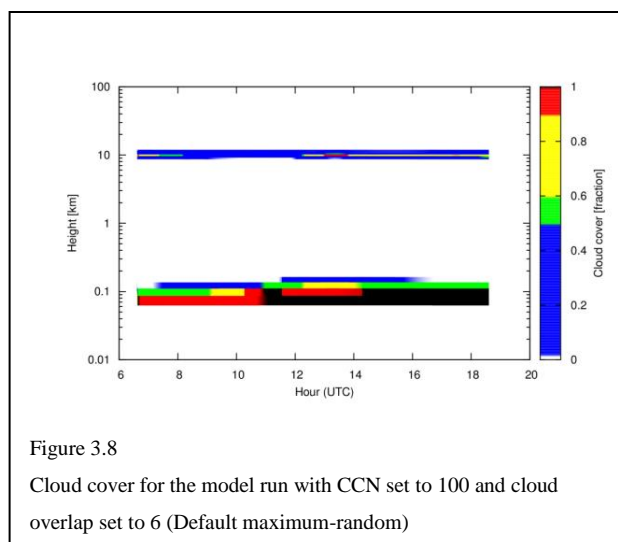
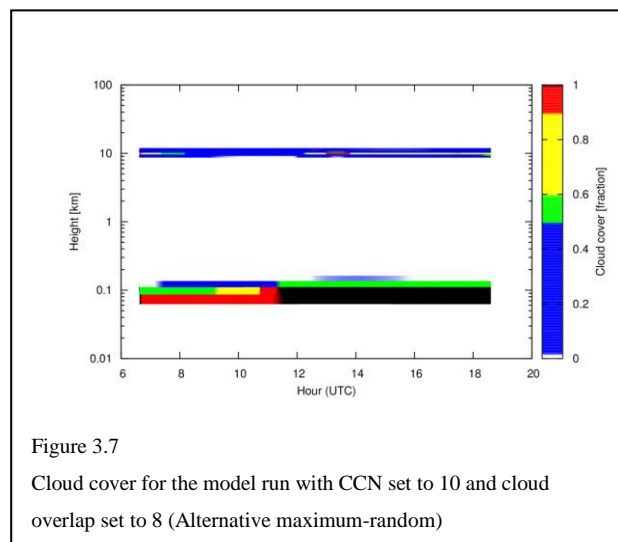
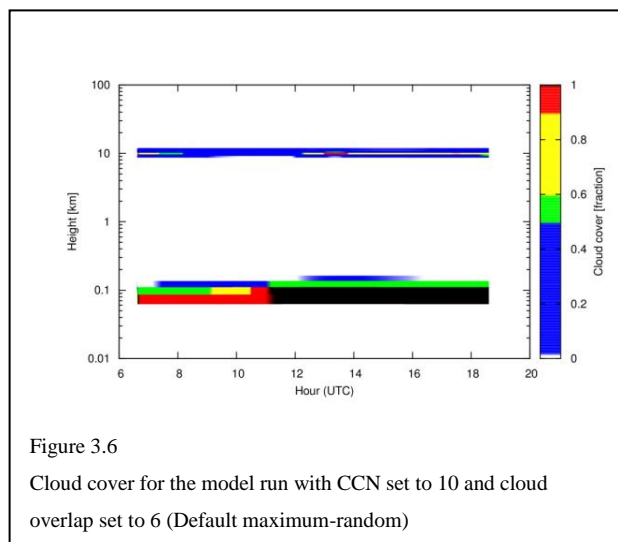
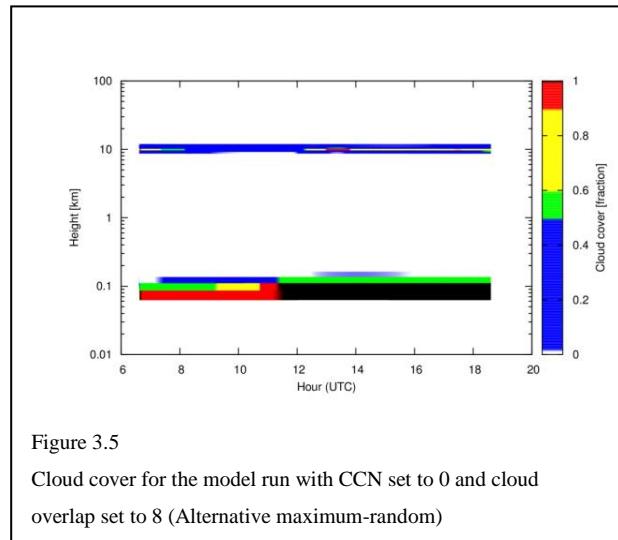
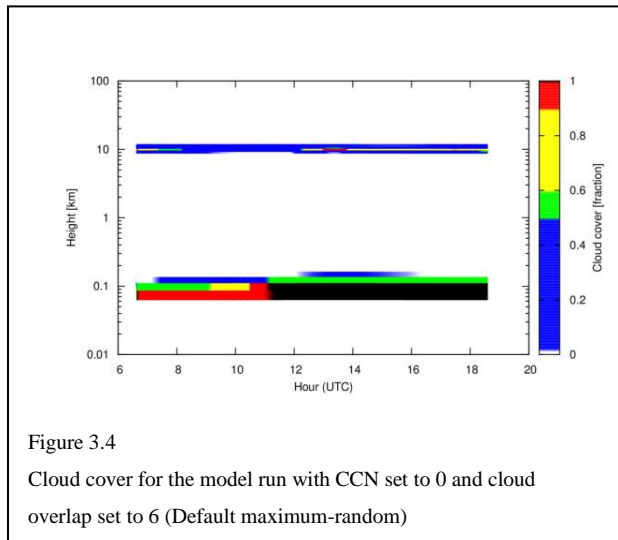
Cloud base as modeled by the HARMONIE model. The lowest cloud base, <200ft, is depicted as black, while the highest cloud bases, 2000-5000ft, are depicted as blue.

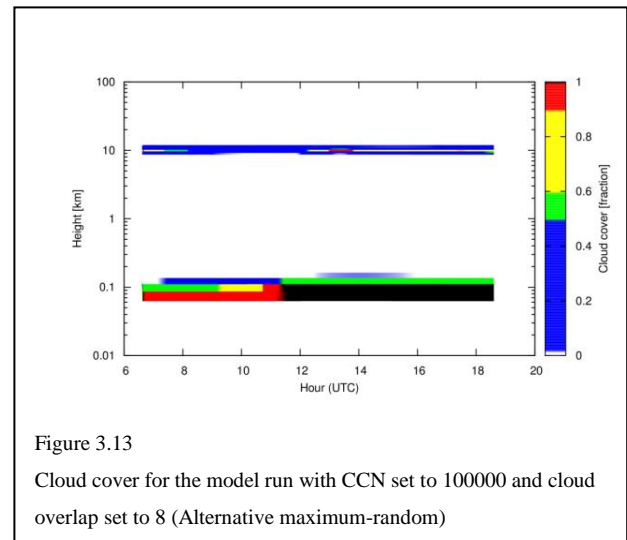
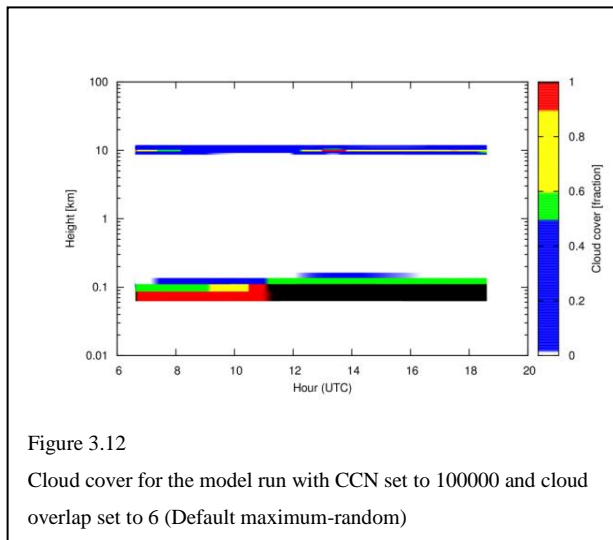
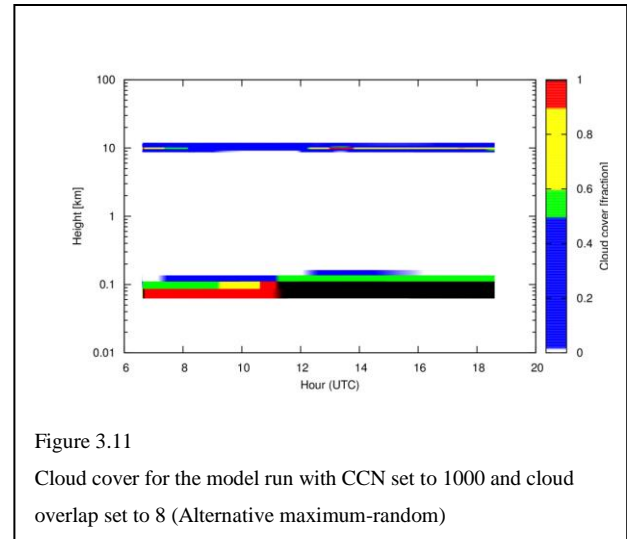
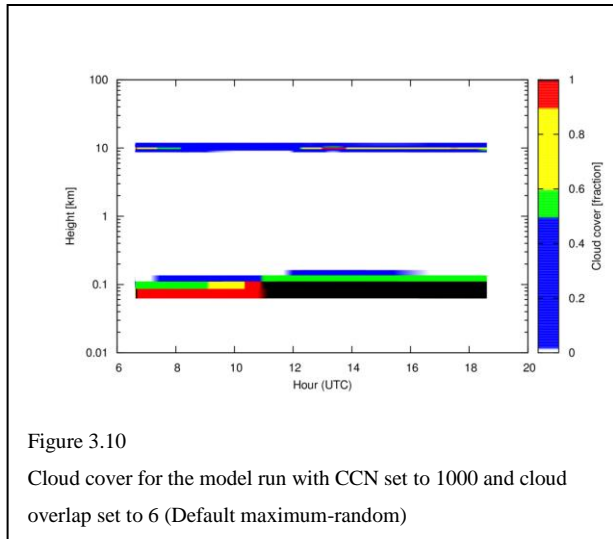


4.2.1 Land

Following the same procedure as for chapter 4.1.1 and 4.1.2, the following results are presented in Figures 3.3 – 3.13. These results were then compared to the satellite picture to investigate the optimal values of CCN and cloud overlap. Furthermore, Figure 3.3 is the result of the model run with CCN and cloud overlap set to default values.







Further investigation on the case of the 25th of November, the model predicted very low clouds, with cloud bases lower than approximately 61 meters, on the southern part of Jylland, as well as the Wadden Sea area. The MUSC model, however, seems to produce a cloud cover with a base on, or right above the limit of 61 meters for all results produced. However, comparing the resulting cloud cover shown in Figures 3.4 – 3.13, setting the cloud overlap to the default maximum-random, compared to the alternative maximum-random, seems to increase the cloud cover. Furthermore, Figures 3.4 – 3.13 seem to follow a kind of pattern. However, an exception is made when CCN is set to 100. During 12 – 14 UTC, the cloud cover at approximately 80 – 110 meters seems to decrease while the cloud cover from 110 – 160 meters instead seems to increase. Furthermore, since the MUSC model produced a cloud

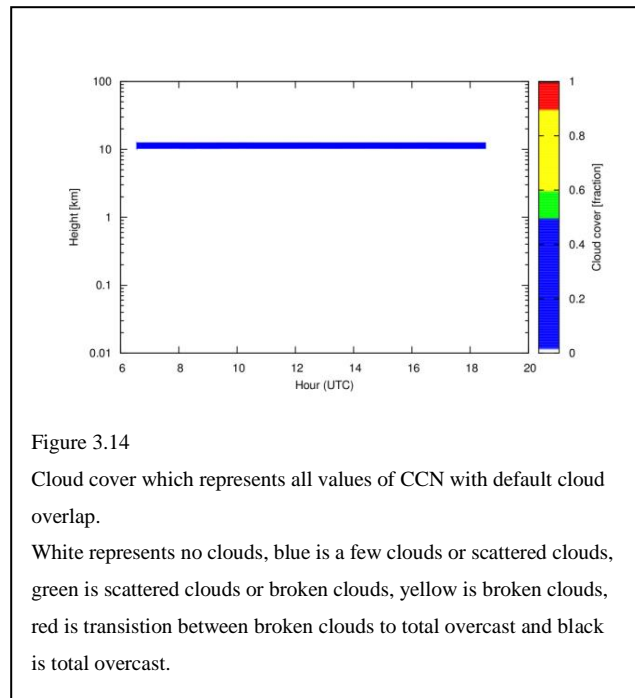
base of approximately 60 meters, this might cause the black area in Figure 3.1. However, since the MUSC model runs with the new turbulence scheme, the predicted cloud base might have been at a lower altitude for the HARMONIE-AROME model during this time. Nonetheless, comparing the results in Figure 3.4 – 3.13 with the satellite picture in Figure 3.2, high clouds as well as a thinner lower layer cloud might be expected. Assuming that the cloud cover might not change significantly for the nearest hours, the best values for the CCN seems to be 0, 10 or 100000 while the cloud overlap set to 8, gives the best result to the assumption made.

4.2.2 Sea

As previously, CCN values between 0 to 100000 as well as cloud overlap from 5 to 8 were inserted into the MUSC model where the results are presented in Figures 3.14 as well as in the appendix.

During the 25th of November 2016, while running the MUSC model over the sea, resulting Figures instead show no significant change when compared to each other or when compared to the default case. However, since the blue color scheme covers 0.01 – 0.49 cloud cover fraction, there might be a difference between the Figures

produced. Furthermore, compared to the model output from the HARMONIE-AROME run in Figure 3.1 as well as the satellite picture in Figure 3.2, the MUSC model output seems to be a better result than the HARMONIE-AROME model output, compared to the satellite picture. As for the land case in chapter 4.1.2, this might be since the MUSC model runs with an improved turbulence scheme which mixes the air better than the older turbulence scheme.



5 Conclusions

Two different parameters were evaluated during this study to see if it was possible to improve the output of the HARMONIE-AROME model, which, during two chosen dates, produced error in cloud forecast. Furthermore, if it was possible to improve the model outcome, which would be the best values for the parameters evaluated. However, the version of the MUSC model used in this study was not identical to the HARMONIE-AROME model. The MUSC model in this study used a new turbulence scheme, which improved the mixing of air in the model. Therefore, a recreation of the HARMONIE-AROME model output was difficult to produce. For instance, the case of 17th of March over land, the HARMONIE-AROME model output produced an overcast of clouds, while the recreation in the MUSC model with default values produced no cloud cover at all. Furthermore, even when evaluating extreme values for the parameters, no change was found for this case. This could imply that the turbulence scheme might have a greater effect on the cloud cover than the CCN. Moreover, no significant change in cloud cover was found when evaluating the parameters in general for both the cases. However, during both the sea case on the 17th of March and the land case on the 25th of November, small differences were seen between the Figures from the MUSC model. Comparing these with each other, the best value for CCN seems to be 10, if evaluating for both cases. Furthermore, the alternative maximum-random cloud overlap seems to give the best results over land the 25th of November, while random, the default maximum-random or maximum seems to be the best value for cloud overlap during the sea case 17th of March. However, due to the alternative maximum-random being a test and the options random, maximum-random and maximum being the only assumptions in use, the best cloud overlap assumption would be the default maximum-random (6), which is already set as a standard. Furthermore, due to the small changes in the model output, speculations are made if the focus should be on improving other schemes in the model than CCN and cloud overlap. Nonetheless, since only one satellite picture for one hour is available as a reference, problem arises when evaluating the total model output. Therefore, further investigation might be needed. However, the investigation might not improve the HARMONIE-AROME model significant.

References

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6 Appendix A, Scripts

```
#!/bin/bash

SCRIPT_DIR=$HOME/scripts
TEMPPROFILE=$SCRIPT_DIR/Stuvademakeroner.plt
CLOUD=$SCRIPT_DIR/PNEB.plt
TESTDIR=$HOME/MUSC/harmonie_MUSC_cy40h1/test
C_SWITCHES="-background white -alpha remove -density 400 -quality 100 -
scale 50%"

function escape_slashes {
    sed 's/\\/\\/\\//g'
}

a="TRUE"
b="FALSE"

#Loop over MUSC experiments:
#for exp in land_2017020603 sea_2017020603 land_2017021418

for exp in land_2016112500 sea_2016112500
do
    namelist=$TESTDIR/$exp/namelist_arome_musc
    runfile=$TESTDIR/$exp/Runmusc_arome_fa

#   for LOGIC in $b $a
#   do
#       sed -i "s/LOCND2=.* /LOCND2=.{LOGIC}.,/g" $namelist
#
#       for RANGE in 0 4 7 9
#       do
#           sed -i "s/RADGR=.* /RADGR=0.{RANGE},/g" $namelist

#           for ranger in 0 2 5 7 9
#           do
#               sed -i "s/RADSN=.* /RADSN=0.{ranger},/g" $namelist

#               for logger in $b $a
#               do
#                   sed -i "s/LHARATU=.* /LHARATU=.{logger}.,/g" $namelist

FIGURES=$TESTDIR/Figures/${exp} #_Har_${logger}_ICE3_${LOGIC}
[ -d $FIGURES ] || mkdir $FIGURES
```

```

#CCN experiment loop:
for CCN in 0 1 10 100 1000 100000
do
    sed -i "s/CCNLND=.* /CCNLND=${CCN}.0/g" $namelist
    sed -i "s/CCNSEA=.* /CCNSEA=${CCN}.0/g" $namelist

#Cloud overlap experiment loop:
for overlap in 5 6 7 8
do
    sed -i "s/NOVLP=.* /NOVLP=$overlap/g" $namelist
    OUTDIR="$TESTDIR/$exp/wrk_CCN_${CCN}_overlap_$overlap"
    TMPDIR=$(echo "${OUTDIR}" | escape_slashes)
    sed -i "s\/\home.*wrk_.*\/${TMPDIR}\/g" $runfile

    $runfile
    cd $OUTDIR
    for y in '01.0000.lfa' '02.0000.lfa' '03.0000.lfa'
'04.0000.lfa' '05.0000.lfa' '06.0000.lfa' '07.0000.lfa' '08.0000.lfa'
'09.0000.lfa' '10.0000.lfa' '11.0000.lfa'
    do
        mevol ZRH Out.0$y
        evol_line_add.sh ZRH.tmp.evol
        mevol PT Out.0$y
        evol_line_add.sh PT.tmp.evol
        mevol PQ Out.0$y
        evol_line_add.sh PQ.tmp.evol
        paste PT.tmp.evol.gp PQ.tmp.evol.gp ZRH.tmp.evol.gp
> TD.tmp.evol.gp

        cp TD.tmp.evol.gp $OUTDIR
    done
    mevol PNEB Out.*
    evol_line_add.sh PNEB.tmp.evol
    mevol PU Out.*
    evol_line_add.sh PU.tmp.evol
    mevol PV Out.*
    evol_line_add.sh PV.tmp.evol
    mevol PVERVEL Out.*
    evol_line_add.sh PVERVEL.tmp.evol

#Copying plotting to workdir
for x in PNEB VERTICALVELOCITY Vwind Uwind
do
    cd $OUTDIR
    cp $SCRIPT_DIR/${x}.plt $OUTDIR

    #sed -i "s@set output .*@set out
'${FIGURES}/${x}_${CCN}_${overlap}.eps'@" ${x}.plt

    gnuplot $OUTDIR/${x}.plt
done

#gnuplot $SCRIPT_DIR/PNEB.plt
#gnuplot $SCRIPT_DIR/Stuvademakeroner.plt

```

```

#gnuplot $SCRIPT_DIR/VERTICALVELOCITY.plt
#gnuplot $SCRIPT_DIR/Vwind.plt
#gnuplot $SCRIPT_DIR/Uwind.plt

rename 's/Uwind/PU/' $SCRIPT_DIR/tmp/*.eps
rename 's/Vwind/PV/' $SCRIPT_DIR/tmp/*.eps
rename 's/PNEB/PNEB/' $SCRIPT_DIR/tmp/*.eps
rename 's/Stuvademakeroner/TEMP/'
$SCRIPT_DIR/tmp/*.eps
rename 's/VERTICALVELOCITY/PVERVEL/'
$SCRIPT_DIR/tmp/*.eps

for VARIABLE in TEMP PNEB PU PV PVERVEL
do
    convert $C_SWITCHES $SCRIPT_DIR/tmp/${VARIABLE}.eps
$FIGURES/${VARIABLE}_${CCN}_${overlap}.jpg #_g_${RANGE}_s${ranger}.jpg
    #convert $C_SWITCHES
$FIGURES/${VARIABLE}_${CCN}_${overlap}.eps
$FIGURES/${VARIABLE}_${CCN}_${overlap}.jpg
    rm $SCRIPT_DIR/tmp/${VARIABLE}.eps
    #ls $FIGURES
done

done
cd $SCRIPT_DIR
done
done
# done
# done
# done
#Reverting the namelist default settings:
sed -i "s/CCNLND=.* /CCNLND=400.0/g" $namelist
sed -i "s/CCNSEA=.* /CCNSEA=50.0/g" $namelist
sed -i "s/NOVLP=.* /NOVLP=6/g" $namelist
# sed -i "s/LHARATU=.* /LHARATU=.TRUE./g" $namelist
# sed -i "s/RADSN=.* /RADSN=1.0,/g" $namelist
# sed -i "s/RADGR=.* /RADGR=0.5,/g" $namelist
# sed -i "s/LOCND2=.* /LOCND2=.TRUE./g" $namelist
#done
# sed -n '441,453p' $namelist

```

```
set term postscript enhanced eps colour

set output '/home/forsker9/scripts/tmp/PNEB.eps'
set view 0,0
set pm3d map
set palette define ( 0 "white", 0.01 "white", 0.02 "blue", 0.49 "blue", 0.5
"green", 0.59 "green", 0.6 "yellow", 0.89 "yellow", 0.9 "red", 0.99 "red",
1 "black" )
set log y
set xlabel "Hour (UTC)"
set ylabel "Height [km]"
set zrange [0:1]
set cbrange [0:1]
set cblabel "Cloud cover [fraction]"
splot "PNEB.tmp.evol.gp" u 1:2:3 t ''
```

7 Appendix B, Figures Land 17th of March 2016

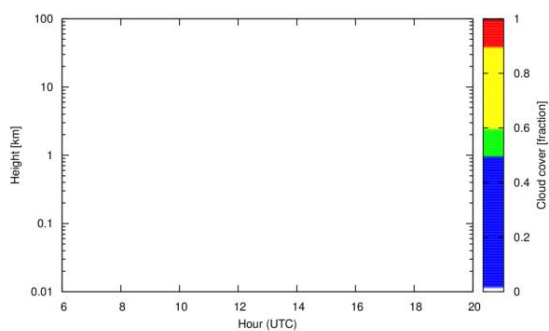


Figure B1

CCN set to 0 and overlap set to 5 (random) for land 17th of March 2016. White represents no clouds, blue is a few clouds or scattered clouds, green is scattered clouds or broken clouds, yellow is broken clouds, red is transition between broken clouds to total overcast and black is total overcast.

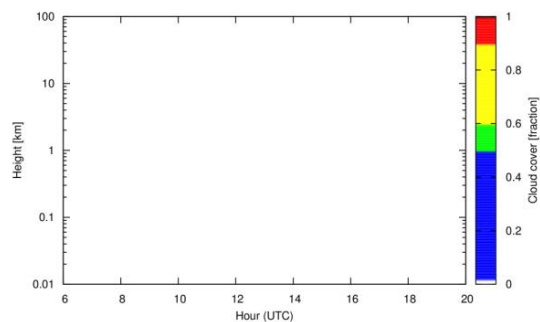


Figure B2

CCN set to 0 and overlap set to 6 (default maximum-random) for land 17th of March 2016

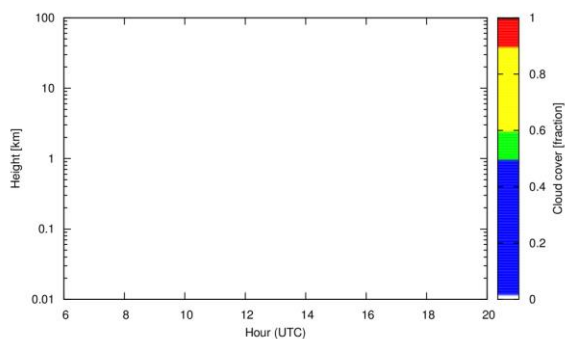


Figure B3

CCN set to 0 and overlap set to 7 (maximum) for land 17th of March 2016

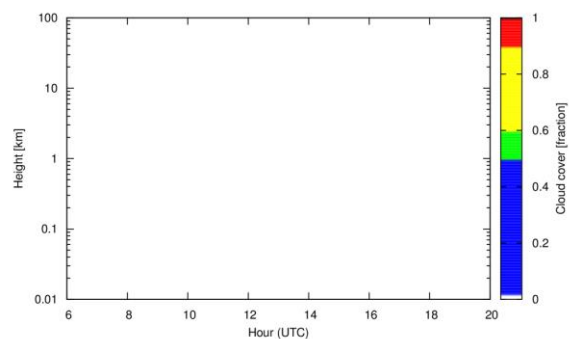


Figure B4

CCN set to 0 and overlap set to 8 (alternative maximum-random) for land 17th of March 2016

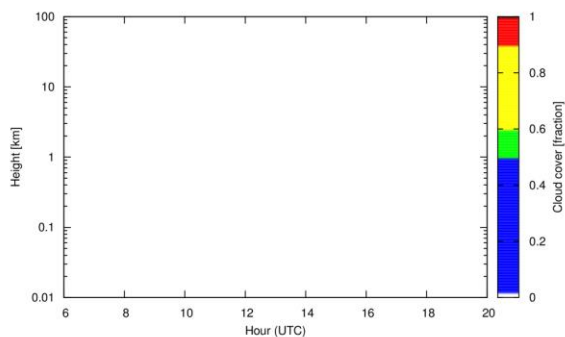


Figure B5

CCN set to 1 and overlap set to 5 (random) for land 17th of March 2016

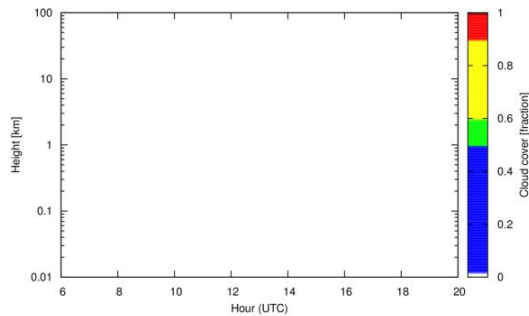


Figure B6

CCN set to 1 and overlap set to 6 (default maximum-random) for land 17th of March 2016

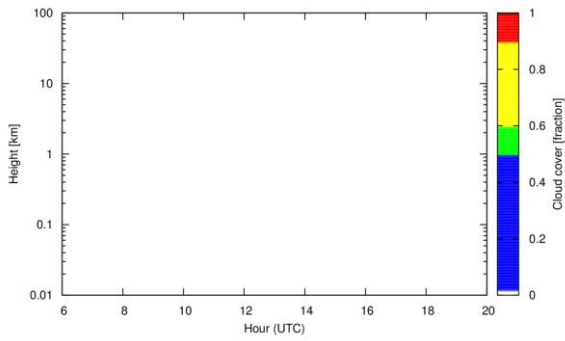


Figure B7
CCN set to 1 and overlap set to 7 (maximum) for land 17th of March 2016

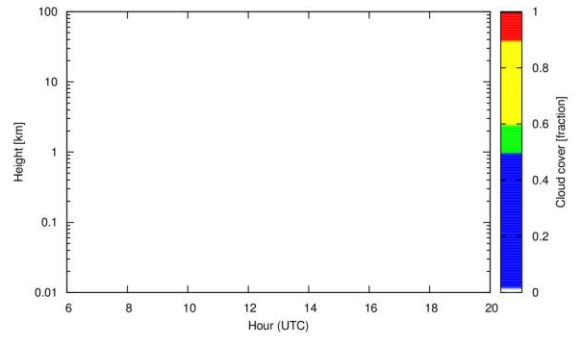


Figure B8
CCN set to 1 and overlap set to 8 (alternative maximum-random) for land 17th of March 2016

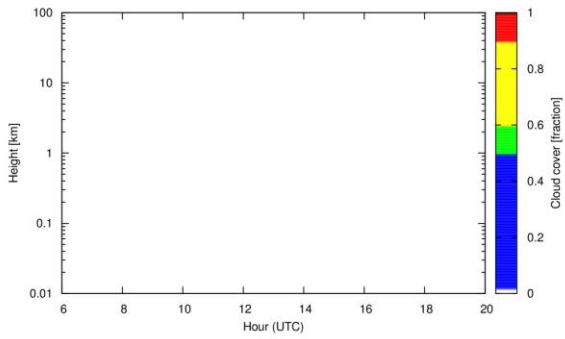


Figure B9
CCN set to 10 and overlap set to 5 (random) for land 17th of March 2016

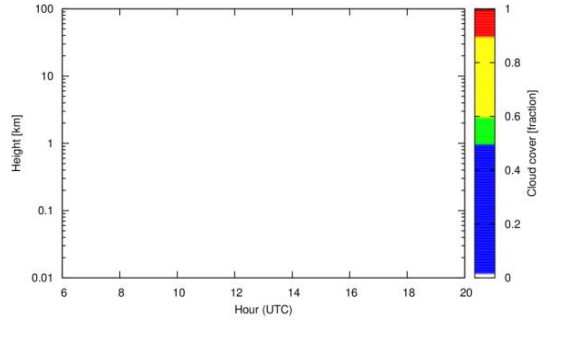


Figure B10
CCN set to 10 and overlap set to 6 (default maximum-random) for land 17th of March 2016

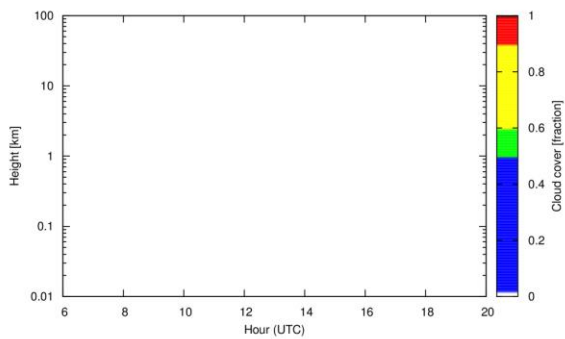


Figure B11
CCN set to 10 and overlap set to 7 (maximum) for land 17th of March 2016

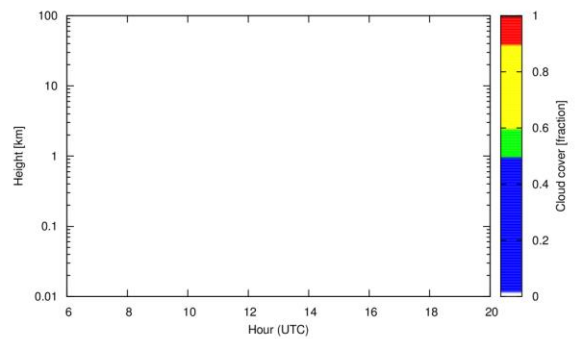
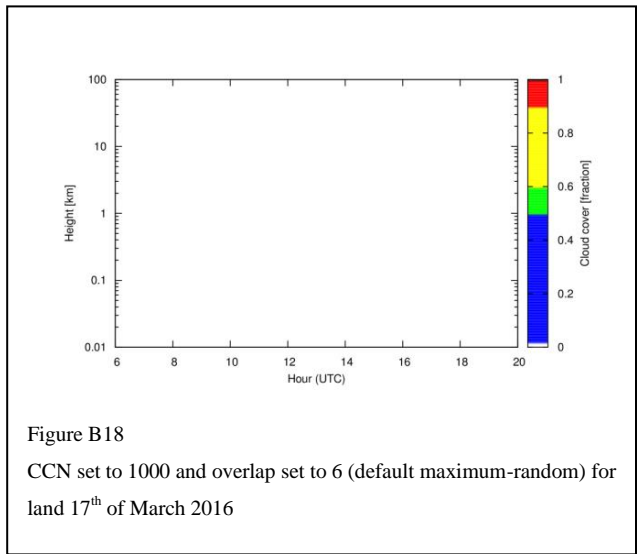
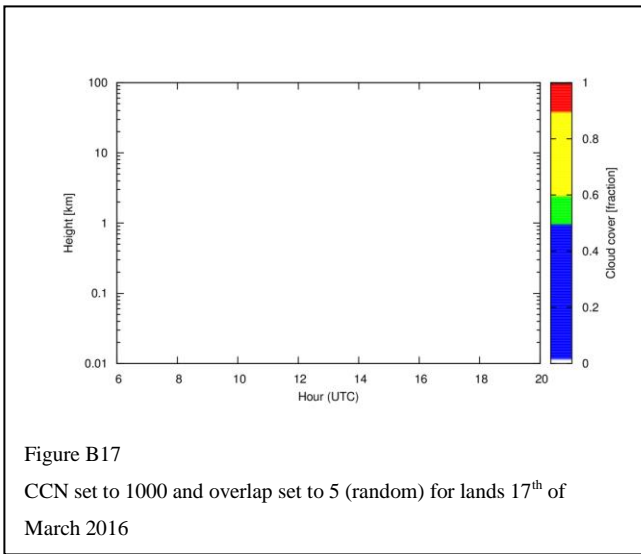
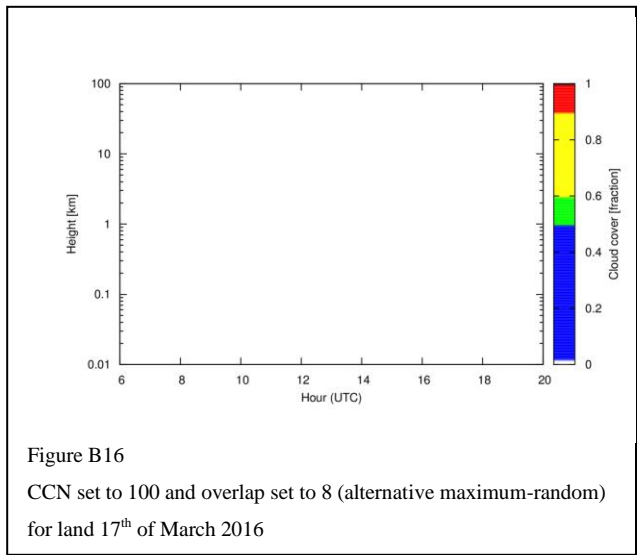
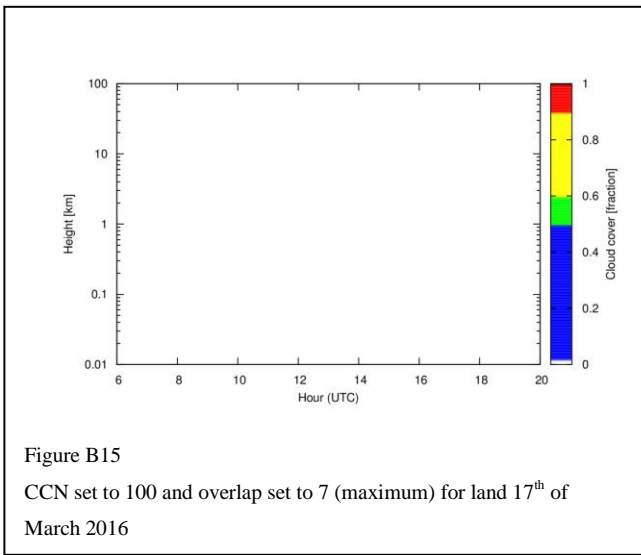
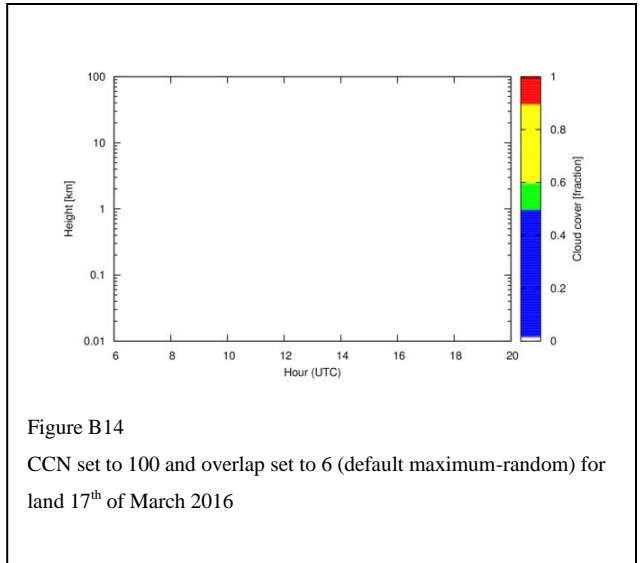
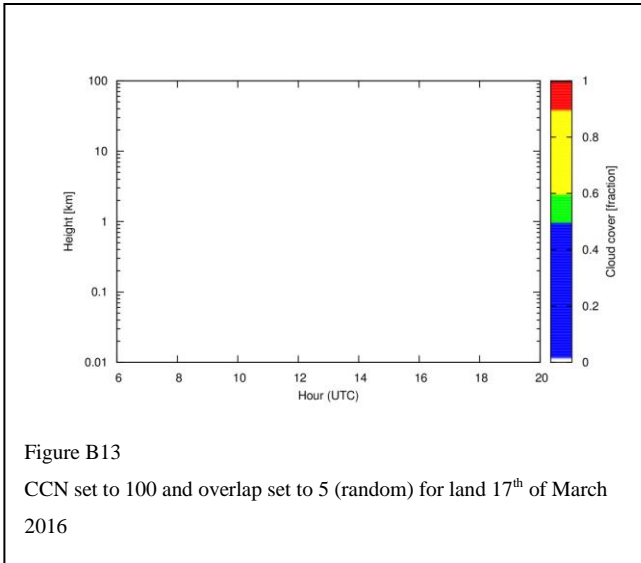


Figure B12
CCN set to 10 and overlap set to 8 (alternative maximum-random) for land 17th of March 2016



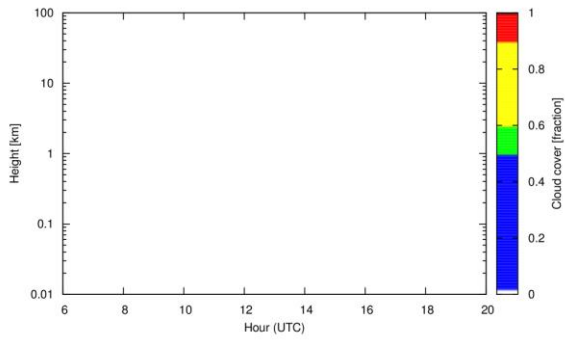


Figure B19
CCN set to 1000 and overlap set to 7 (maximum) for land 17th of March 2016

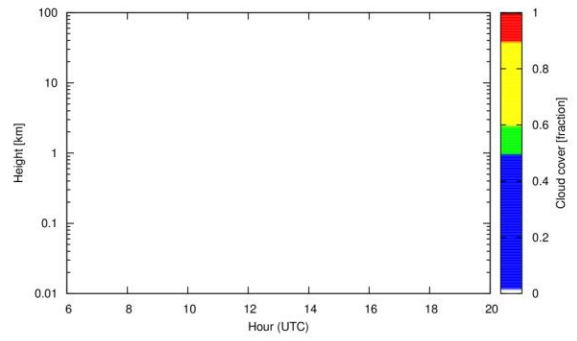


Figure B20
CCN set to 1000 and overlap set to 8 (alternative maximum-random) for land 17th of March 2016

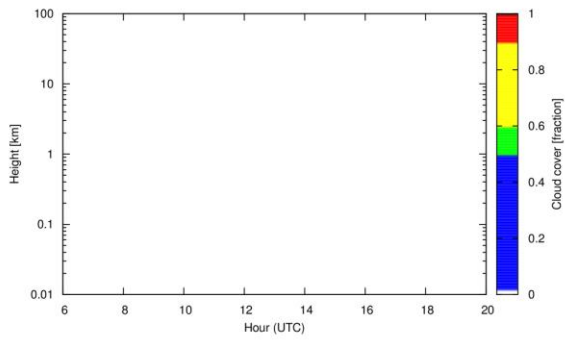


Figure B21
CCN set to 100000 and overlap set to 5 (random) for land 17th of March 2016

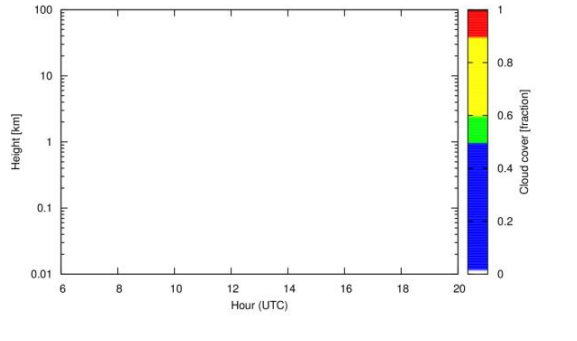


Figure B22
CCN set to 100000 and overlap set to 6 (default maximum-random) for land 17th of March 2016

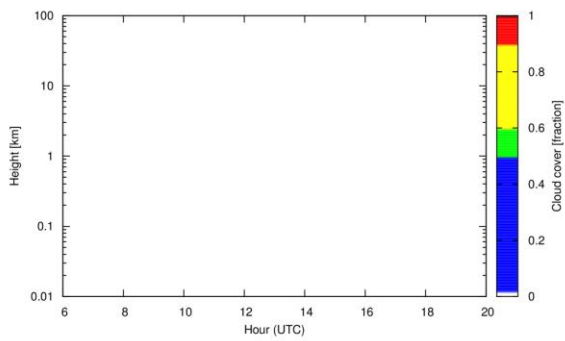


Figure B23
CCN set to 100000 and overlap set to 7 (maximum) for land 17th of March 2016

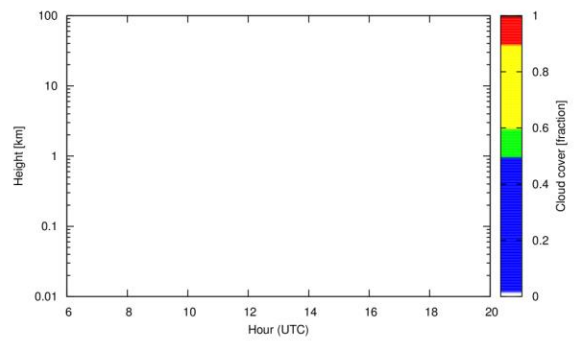


Figure B24
CCN set to 100000 and overlap set to 8 (alternative maximum-random) for land 17th of March 2016

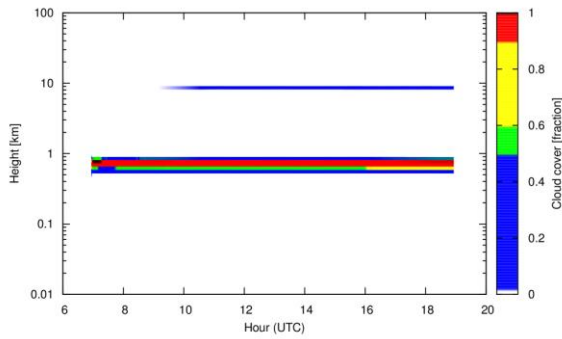


Figure B25
 CCN set to 0 and overlap set to 5 (random) for sea 17th of March 2016. White represents no clouds, blue is a few clouds or scattered clouds, green is scattered clouds or broken clouds, yellow is broken clouds, red is transition between broken clouds to total overcast and black is total overcast.

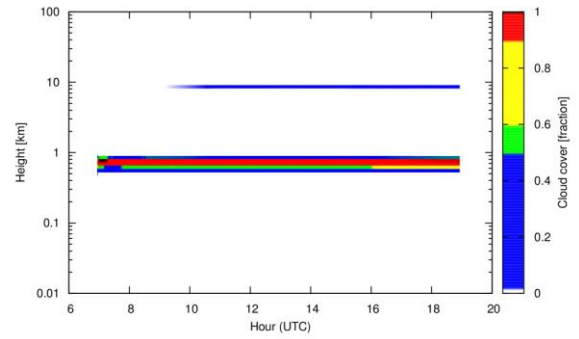


Figure B26
 CCN set to 0 and overlap set to 6 (default maximum-random) for sea 17th of March 2016

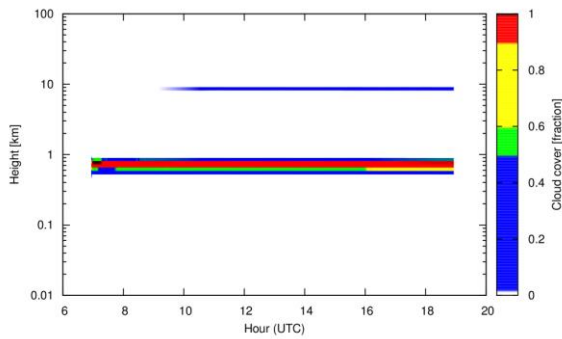


Figure B27
 CCN set to 0 and overlap set to 7 (maximum) for sea 17th of March 2016

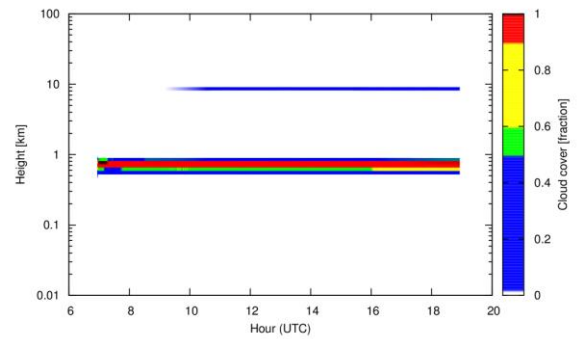


Figure B28
 CCN set to 0 and overlap set to 8 (alternative maximum-random) for sea 17th of March 2016

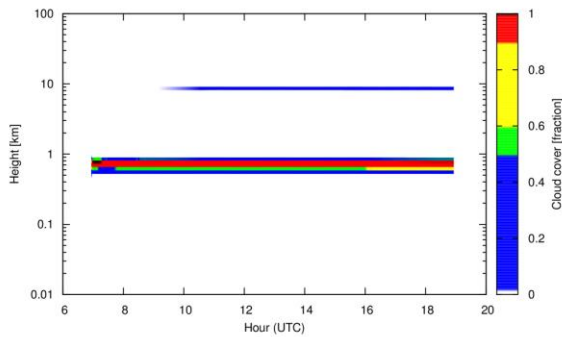


Figure B29
 CCN set to 1 and overlap set to 5 (random) for sea 17th of March 2016

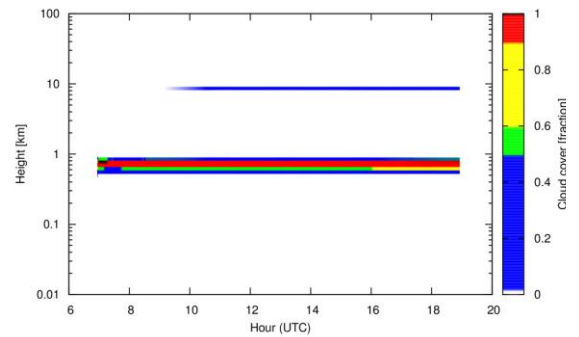


Figure B30
 CCN set to 1 and overlap set to 6 (default maximum-random) for sea 17th of March 2016

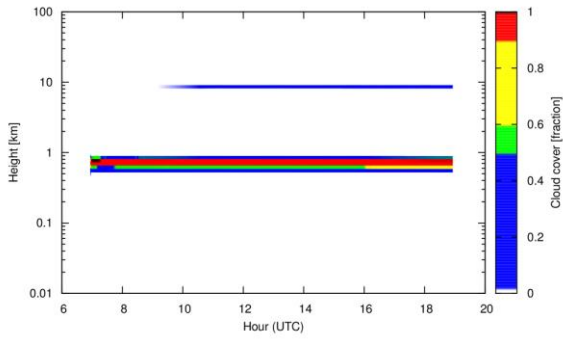


Figure B31
CCN set to 1 and overlap set to 7 (maximum) for sea 17th of March 2016

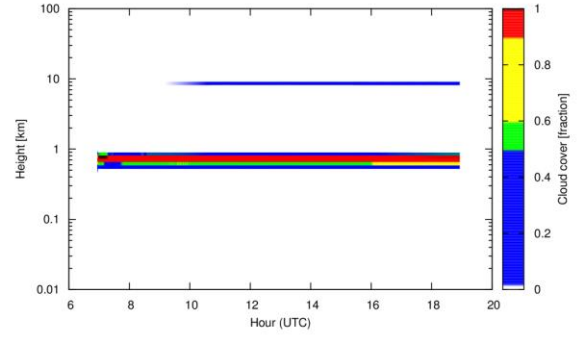


Figure B32
CCN set to 1 and overlap set to 8 (alternative maximum-random) for sea 17th of March 2016

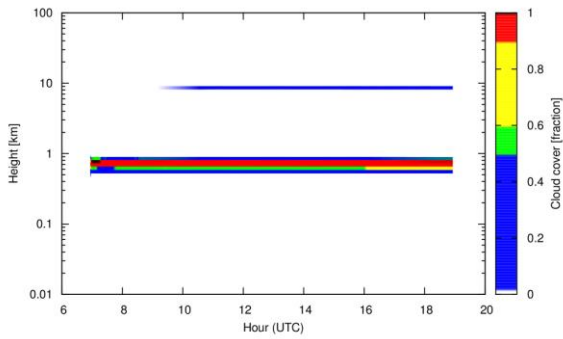


Figure B33
CCN set to 10 and overlap set to 5 (random) for sea 17th of March 2016

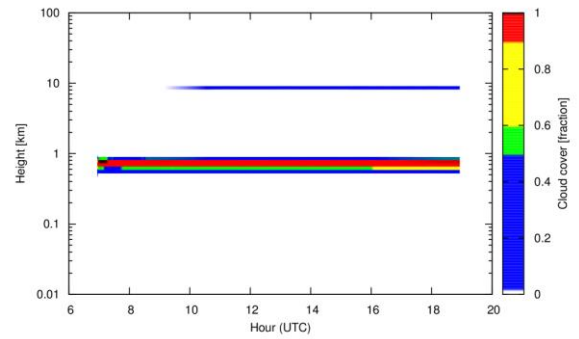


Figure B34
CCN set to 10 and overlap set to 7 (maximum) for sea 17th of March 2016

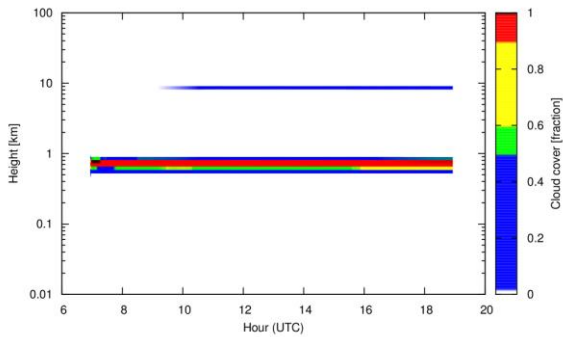


Figure B35
CCN set to 100 and overlap set to 5 (random) for sea 17th of March 2016

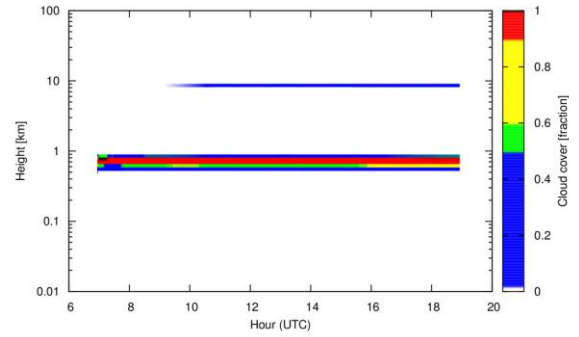


Figure B36
CCN set to 100 and overlap set to 7 (maximum) for sea 17th of March 2016

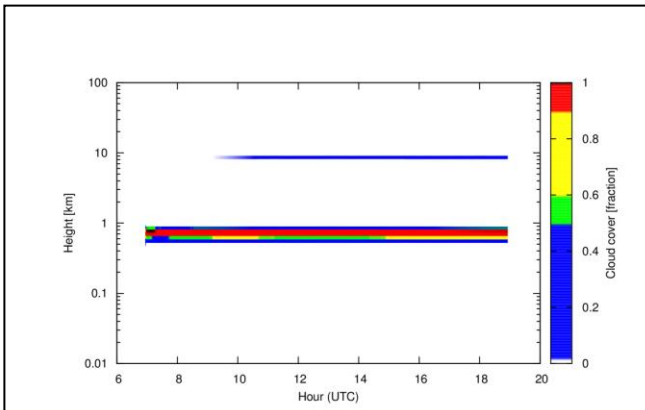


Figure B37
 CCN set to 1000 and overlap set to 5 (random) for sea 17th of March 2016

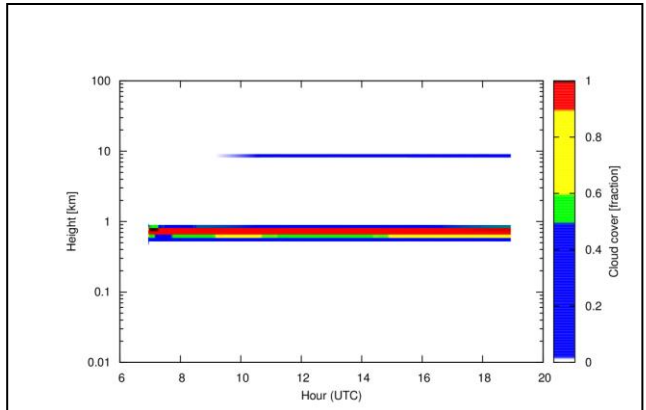


Figure B38
 CCN set to 1000 and overlap set to 7 (maximum) for sea 17th of March 2016

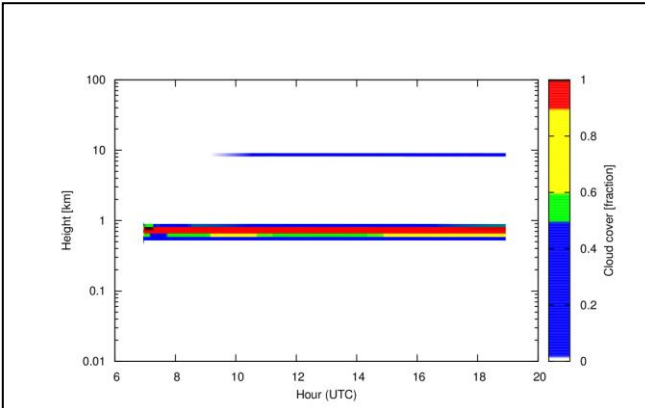


Figure B39
 CCN set to 100000 and overlap set to 5 (random) for sea 17th of March 2016

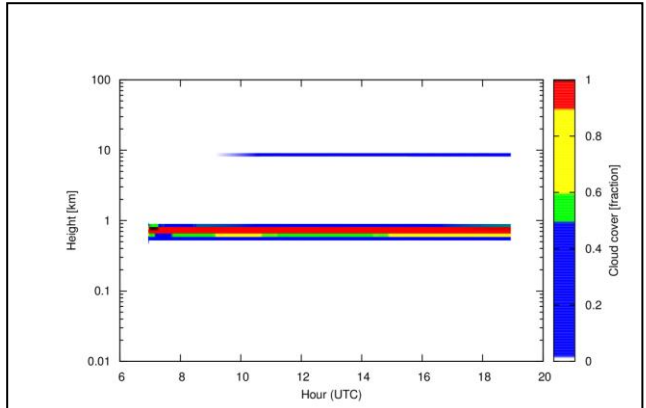


Figure B40
 CCN set to 100000 and overlap set to 7 (maximum) for sea 17th of March 2016

Land 25th of November 2016

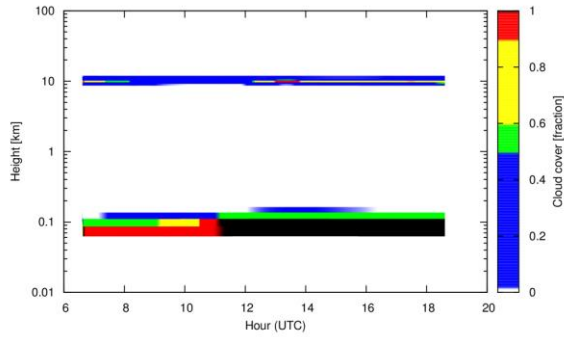


Figure B41
 CCN set to 0 and overlap set to 5 (random) for land 25th of November 2016.
 White represents no clouds, blue is a few clouds or scattered clouds, green is scattered clouds or broken clouds, yellow is broken clouds, red is transition between broken clouds to total overcast and black is total overcast.

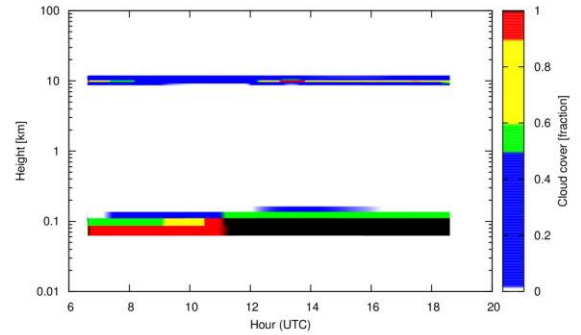


Figure B42
 CCN set to 0 and overlap set to 7 (maximum) for land 25th of November 2016

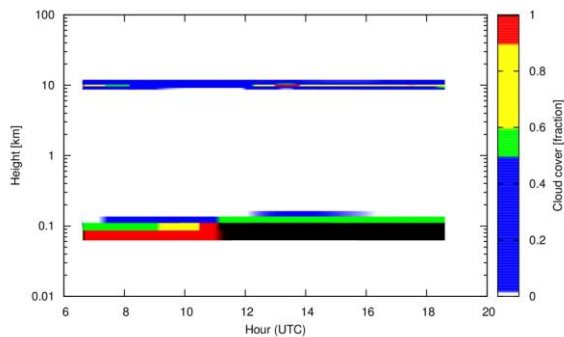


Figure B43
 CCN set to 1 and overlap set to 5 (random) for land 25th of November 2016

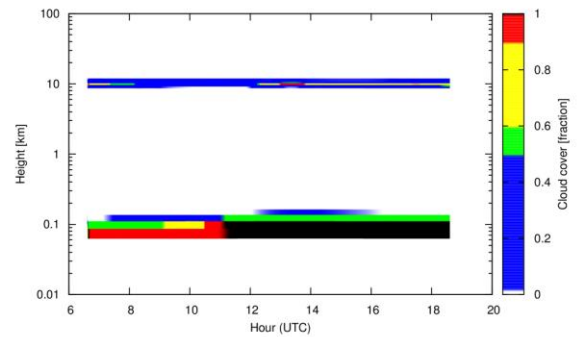


Figure B44
 CCN set to 1 and overlap set to 6 (default maximum-random) for land 25th of November 2016

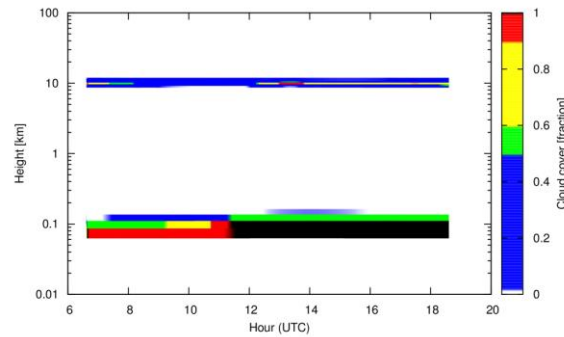


Figure B45
 CCN set to 1 and overlap set to 7 (maximum) for land 25th of November 2016

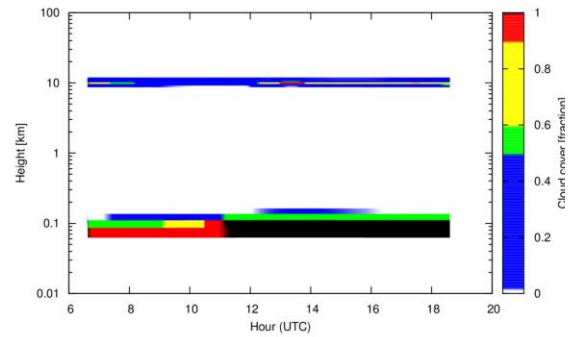


Figure B46
 CCN set to 1 and overlap set to 8 (alternative maximum-random) for land 25th of November 2016

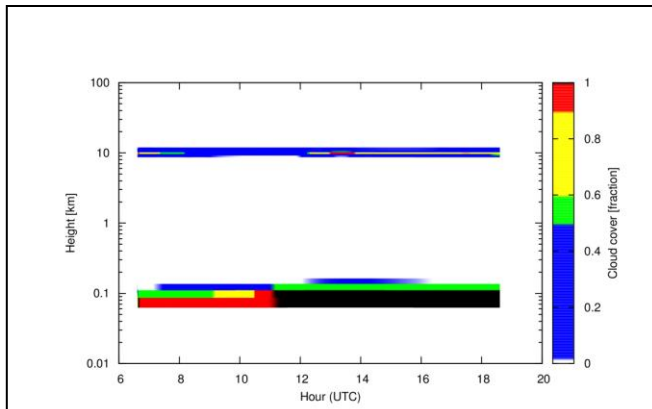


Figure B47
CCN set to 10 and overlap set to 5 (random) for land 25th of November 2016

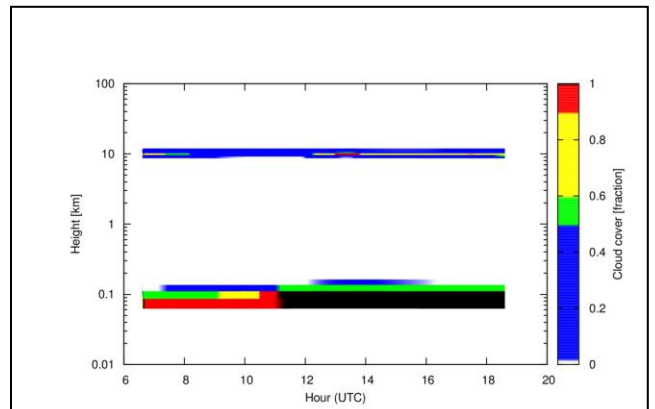


Figure B48
CCN set to 10 and overlap set to 7 (maximum) for land 25th of November 2016

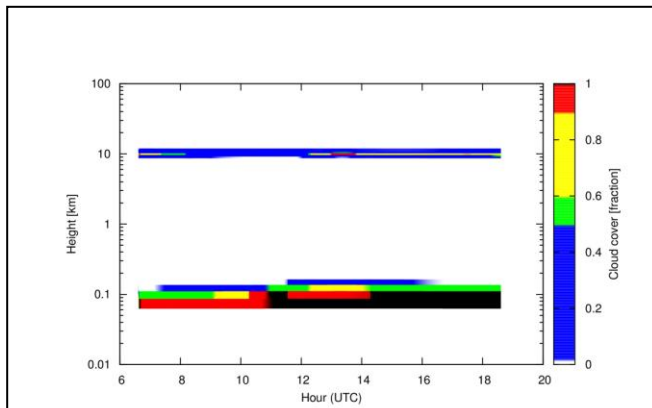


Figure B49
CCN set to 100 and overlap set to 5 (random) for land 25th of November 2016

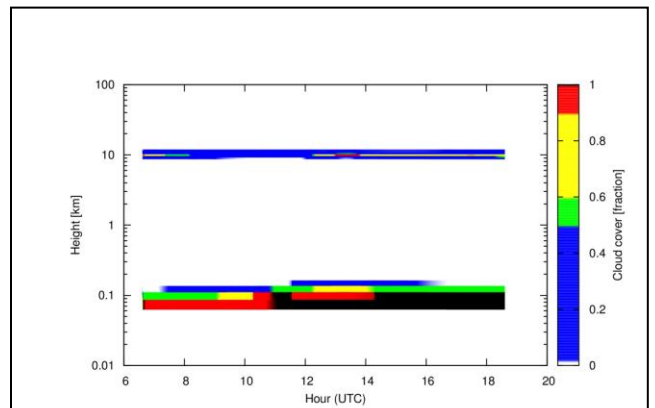


Figure B50
CCN set to 100 and overlap set to 7 (maximum) for land 25th of November 2016

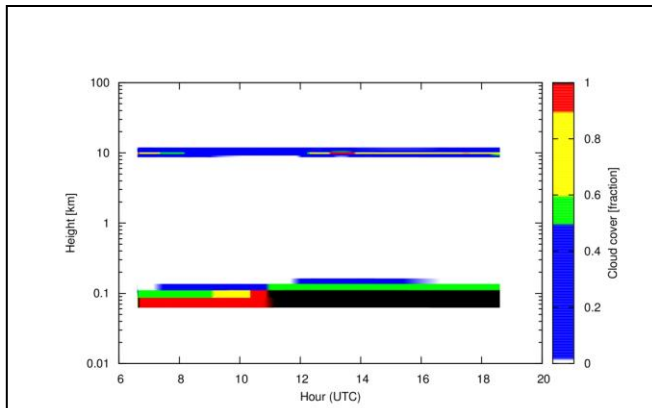


Figure B51
CCN set to 1000 and overlap set to 5 (random) for land 25th of November 2016

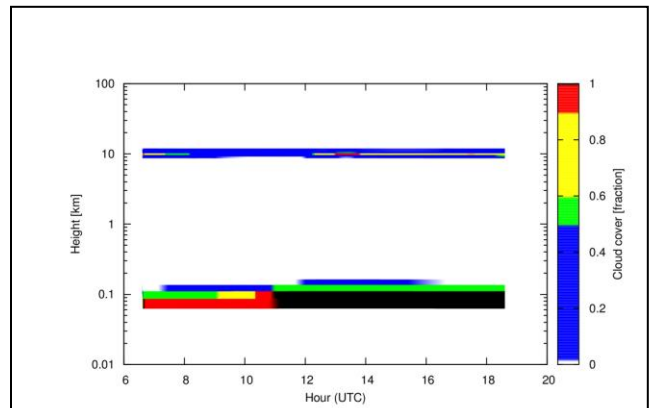
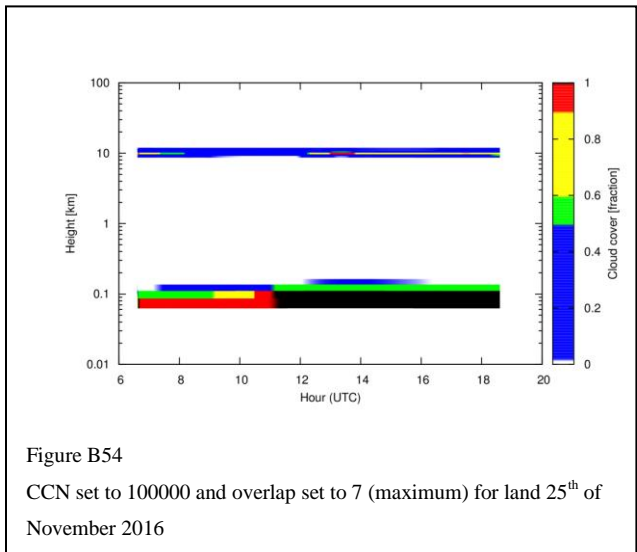
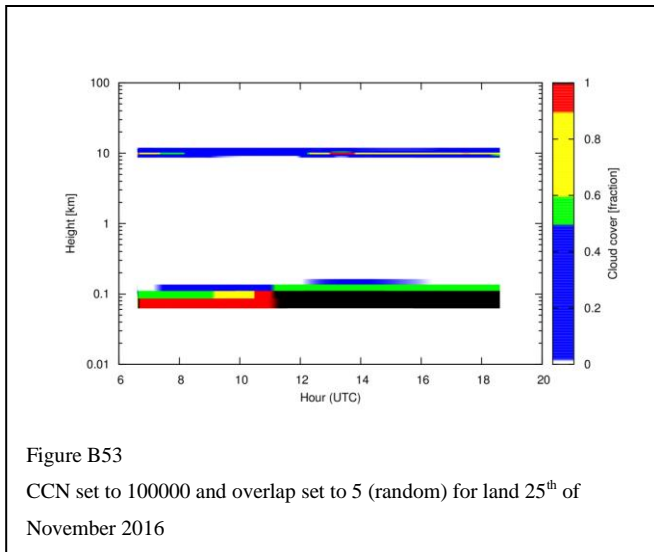


Figure B52
CCN set to 1000 and overlap set to 7 (maximum) for land 25th of November 2016



Sea 25th of November 2016

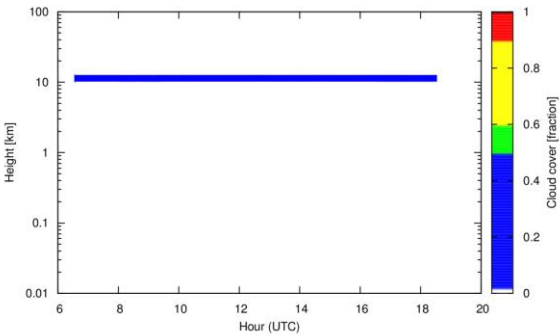


Figure B55
 CCN set to 0 and overlap set to 5 (random) for sea 25th of November 2016. White represents no clouds, blue is a few clouds or scattered clouds, green is scattered clouds or broken clouds, yellow is broken clouds, red is transition between broken clouds to total overcast and black is total overcast.

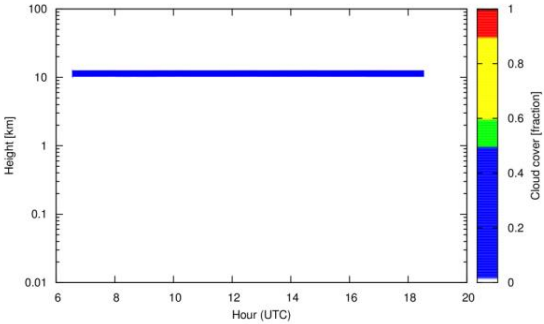


Figure B56
 CCN set to 0 and overlap set to 6 (default maximum-random) for sea 25th of November 2016

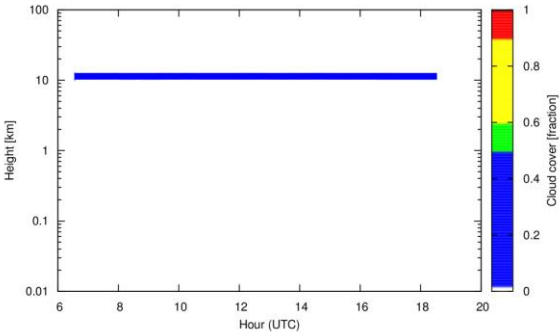


Figure B57
 CCN set to 0 and overlap set to 7 (maximum) for sea 25th of November 2016

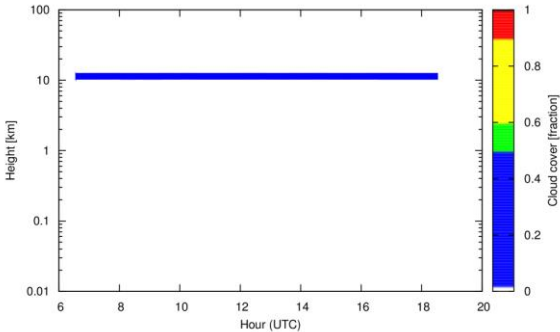


Figure B58
 CCN set to 0 and overlap set to 8 (alternative maximum-random) for sea 25th of November 2016

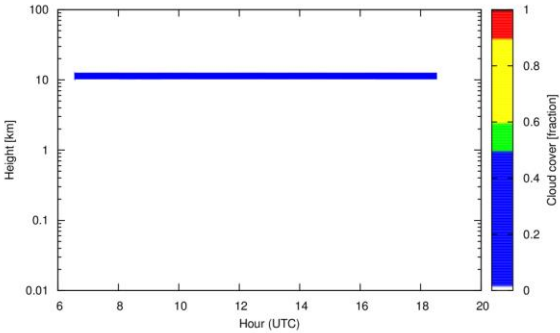


Figure B59
 CCN set to 1 and overlap set to 5 (random) for sea 25th of November 2016

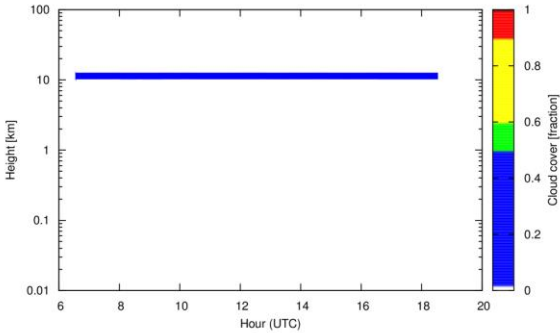


Figure B60
 CCN set to 1 and overlap set to 6 (default maximum-random) for sea 25th of November 2016

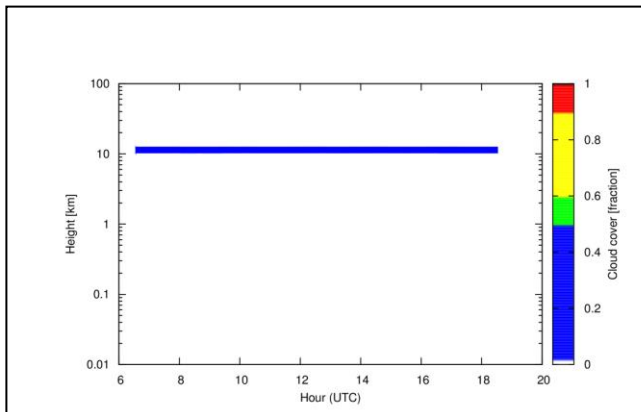


Figure B61
CCN set to 1 and overlap set to 7 (maximum) for sea 25th of November 2016

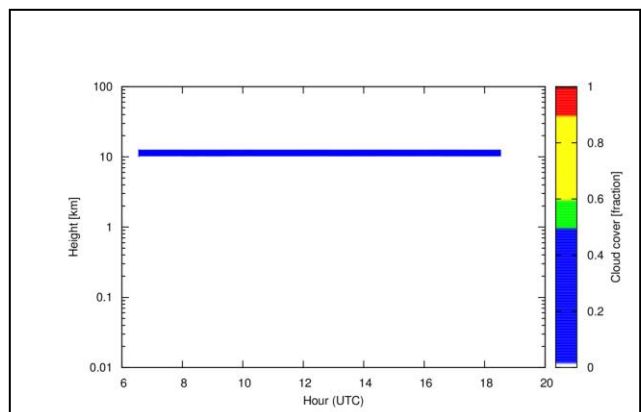


Figure B62
CCN set to 1 and overlap set to 8 (alternative maximum-random) for sea 25th of November 2016

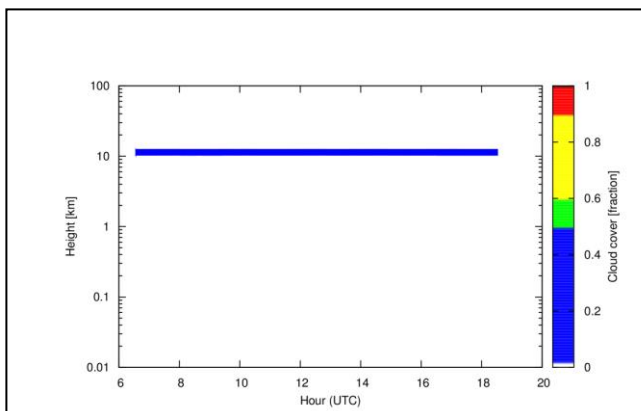


Figure B63
CCN set to 10 and overlap set to 5 (random) for sea 25th of November 2016

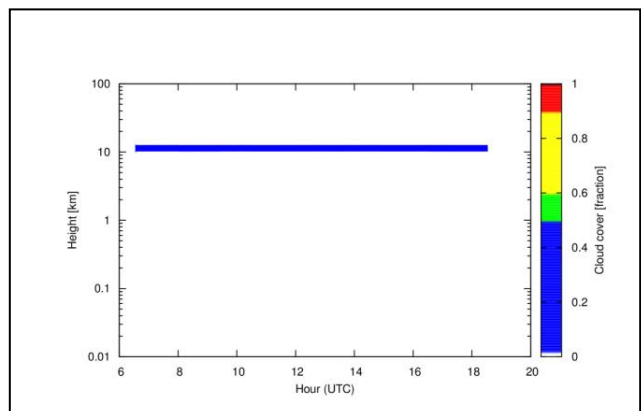


Figure B64
CCN set to 10 and overlap set to 6 (default maximum-random) for sea 25th of November 2016

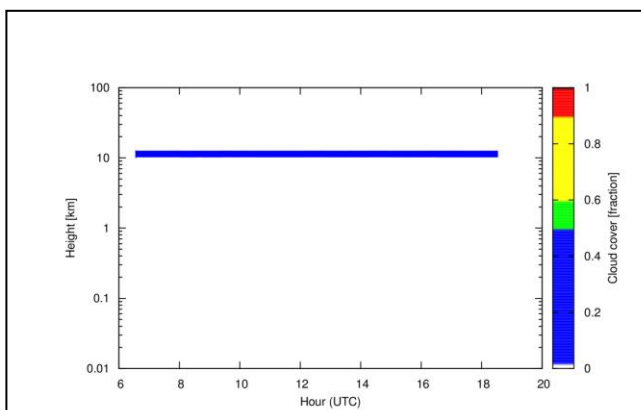


Figure B65
CCN set to 10 and overlap set to 7 (maximum) for sea 25th of November 2016

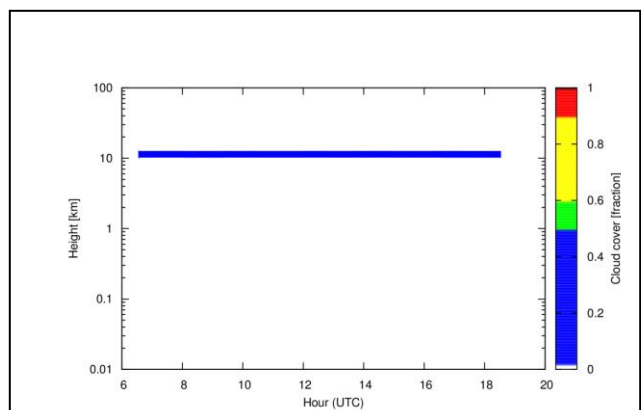


Figure B66
CCN set to 10 and overlap set to 8 (alternative maximum-random) for sea 25th of November 2016

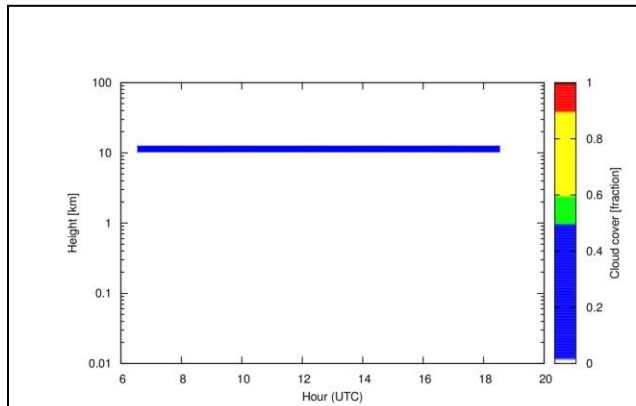


Figure B67
CCN set to 100 and overlap set to 5 (random) sea 25th of November 2016

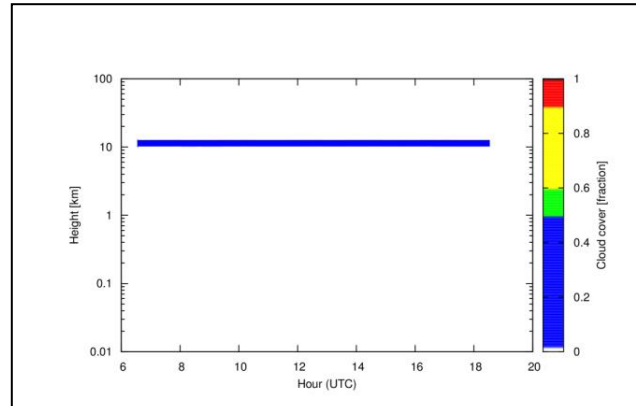


Figure B68
CCN set to 100 and overlap set to 6 (default maximum-random) for sea 25th of November 2016

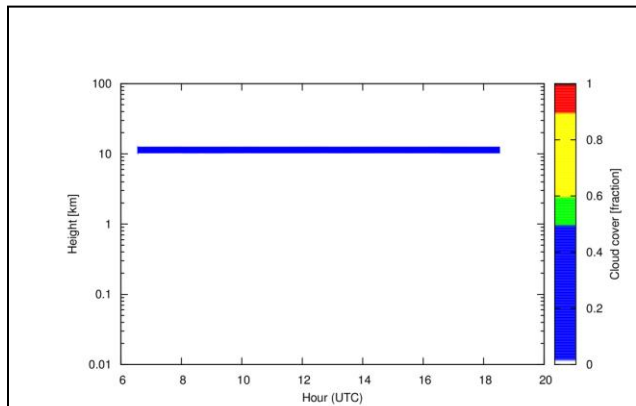


Figure B69
CCN set to 100 and overlap set to 7 (maximum) for sea 25th of November 2016

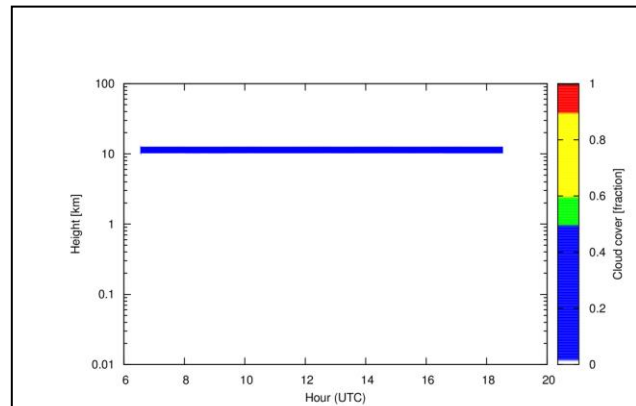


Figure B70
CCN set to 100 and overlap set to 8 (alternative maximum-random) for sea 25th of November 2016

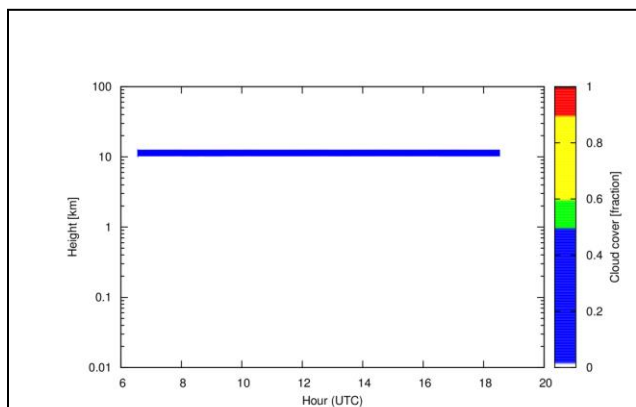


Figure B71
CCN set to 1000 and overlap set to 5 (random) for sea 25th of November 2016

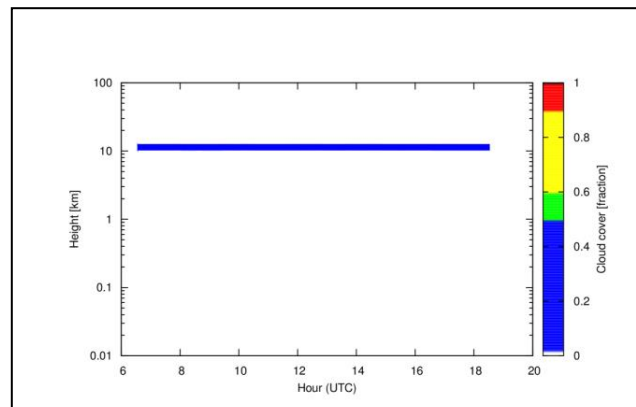


Figure B72
CCN set to 1000 and overlap set to 6 (default maximum-random) for sea 25th of November 2016

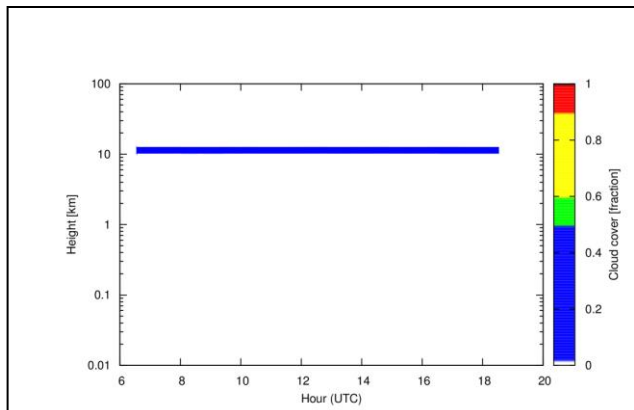


Figure B73
CCN set to 1000 and overlap set to 7 (maximum) for sea 25th of November 2016

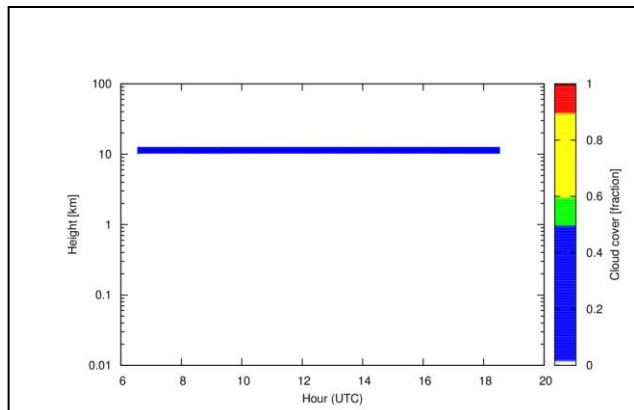


Figure B74
CCN set to 1000 and overlap set to 8 (alternative maximum-random) for sea 25th of November 2016

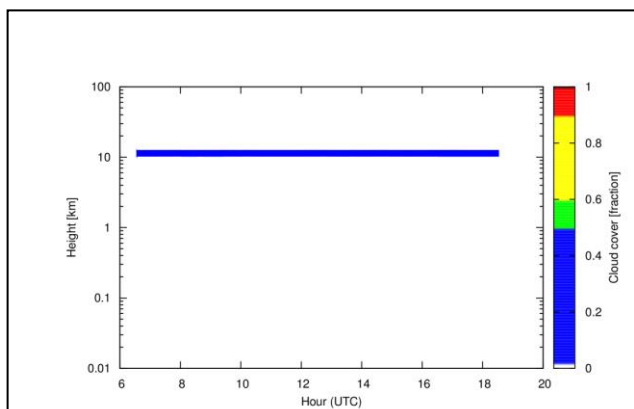


Figure B75
CCN set to 100000 and overlap set to 5 (random) for sea 25th of November 2016

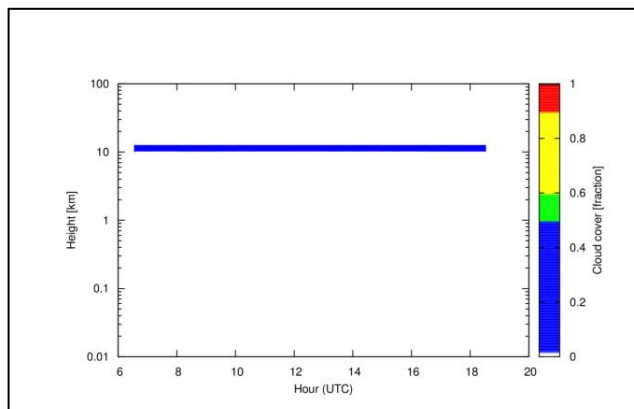


Figure B76
CCN set to 100000 and overlap set to 6 (default maximum-random) for sea 25th of November 2016

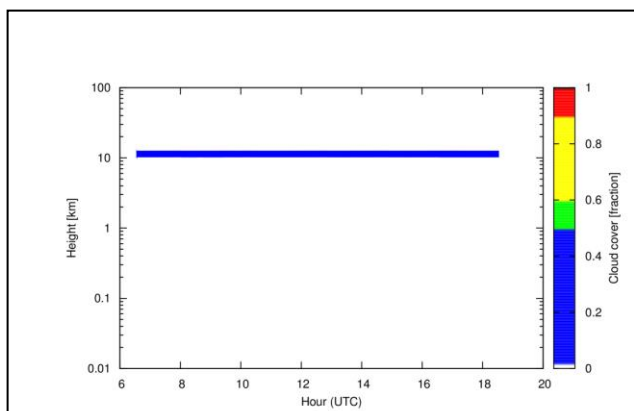


Figure B77
CCN set to 100000 and overlap set to 7 (maximum) for sea 25th of November 2016

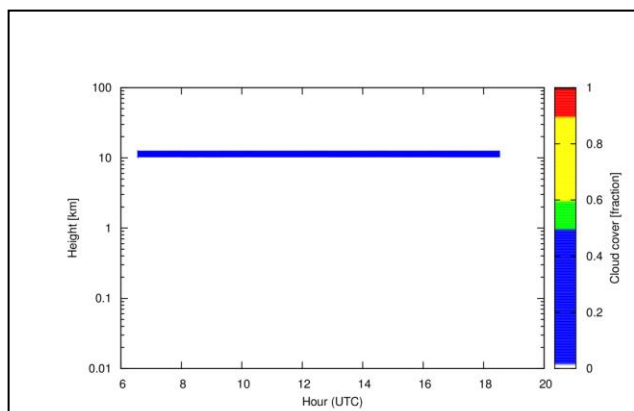


Figure B78
CCN set to 100000 and overlap set to 8 (alternative maximum-random) for sea 25th of November 2016