NOWCASTING FOG AND LOW CLOUDS WITH METEOSAT SECOND GENERATION

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Abstract

In this paper a method for automatic detection of low clouds and fog from Meteosat Second Generation (MSG) is presented. Nowcasting is performed by advecting the clouds or fog in a 3-D advection model, which includes condensation and evaporation. The fog nowcasting is illustrated in two case studies during the night.

1. Introduction

Until a few years ago fog detection with Meteosat was not possible at night, as the fog (or low stratus cloud) top often has nearly the same temperature as the earth or sea surface. See (1) for more information on automatic cloud detection with Meteosat-7. With Meteosat-8 detection possibilities have improved, because combination of different IR channels makes the fog visible even at night.

2. Fog and low cloud detection

The fog detection is performed by using the cloud mask product from the nowcasting ‘Satellite Application Facility’ (SAF). Fog top temperature is assessed by utilising the 10.8 μm channel from MSG. Equating this temperature to the temperature in a vertical profile from the Hirlam model (start searching from ground level is essential in case of fog) yields a fog top height. Hirlam is a high resolution limited area weather prediction model, operational at KNMI. Cloud base height, which is zero for fog, is computed by interpolation of synoptic observations of cloud base heights.

We have carried out preliminary verification of the quality of the cloud mask (all cloud types included) by comparing detection results with synoptic observations of cloud cover from about 60 synoptic stations in and around the Netherlands. As the cloud mask from the SAF only produces cloudy or clear pixels, comparison with synoptic cloud amount was performed by averaging the cloud mask in a rectangular area of 3 by 5 pixels in order to get a mean cloud amount. Verification results are shown in table 1, and they are based on comparisons on 5 nights (0 UTC) and 6 days (12 UTC) in February 2005.

<table>
<thead>
<tr>
<th>Time</th>
<th>Bias</th>
<th>RMS</th>
</tr>
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<tbody>
<tr>
<td>0 UTC</td>
<td>0.2 okta</td>
<td>2.0 okta (5 days)</td>
</tr>
<tr>
<td>12 UTC</td>
<td>0.6 okta</td>
<td>1.9 okta (6 days)</td>
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Table 1 Errors in cloud mask from SAF

3. Fog advection with MetCast

Once the fog, and possibly other cloud fields, is detected it is fed into the Metcast model by
modifying the 3-D water vapour and liquid water fields such that they match the cloud amount derived from the cloud mask, the cloud top temperatures and the synoptic observations of cloud base heights.

Metcast stands for the acronym Meteosat Cloud Advection System and it can compute 3-D advection, as well as condensation and evaporation. Advection is computed with numerical schemes described in (2). Cloud cover can change not only because of advection, but also due to vertical air motions. Turbulent diffusion can be simulated as well, but it was switched off in the experiments shown in this paper. Another important process affecting fog is radiation, but this process is not included in the Metcast model at all. Only indirectly, radiation computations in Hirlam can influence the clouds in Metcast, namely through the boundary conditions at ground level in Metcast, which are obtained directly from Hirlam.

Advection in Metcast is performed by using Hirlam wind fields that are computed beforehand. The horizontal resolution of Metcast was 11.1 km in the first case study and 5.5 km in the second case study.

The vertical resolution in Metcast was 40 m at sea level, slowly decreasing with altitude (proportional to the decrease in mean air density). The highest model layer was either 3.5 km or 11 km; these choices did not influence the fog forecasts.

We will now present 2 case studies of fog and low stratus detection and advection. The first is: 7 October 2005 (during the night). The cloud detection at 0 UTC had an error bias of 0.2 okta and a root mean square error of 2.9 okta. This latter case study was chosen because fog over Germany formed rather unexpectedly, and subsequently advected towards the north of the Netherlands.

The second case study was during 28 and 29 January 2006, also at night. This day was selected because fog and very low stratus advected to the Dutch north coast and the Wadden Sea from the east - northeast. At 18 UTC the cloud detection had an error bias of 0.5 okta and a root mean square error of 2.7 okta.

The Metcast model output is visualised by displaying the 'ceiling' of low clouds and fog. The ceiling is defined as the lowest altitude where the cloud cover is more than 4 okta; its value is an important parameter in e.g. aviation. The ceiling c has been correlated to the brightness of the image (0 is black, 255 is saturated white) according to expression (E.1). Thus only clouds and fog with a ceiling of a few hundred meters or less are clearly visible. The brighter the image, the lower the ceiling will be.

\[ b = \frac{255}{c/100+1} \]  

(E.1)

c: ceiling in m  
b: brightness of the image

In figures 1 through 6 results of the October case study are shown. Metcast was run with a 11.1 km horizontal resolution. The left pictures show forecast Metcast ceiling, whereas the right pictures show the difference of the 10.8 and 8.7 μm channels. These differences clearly show fog and very low stratus at night. In the figures on the right hand side the black areas refer to fog and low cloud, the white areas are high clouds, and the grey areas in between show clear sky regions.

At 0 UTC we see extensive low cloud and fog fields (black areas over western part of the North Sea and the south of the Netherlands), and a band of fog over Germany (orientated northwest - southeast).

We will focus on this latter fog band. During the night this fog band thickened (presumably due to radiative cooling) and simultaneously it moved with the wind to the west - northwest. See figures 2, 4 and 6 respectively.
The Metcast cloud ceiling is seen in figures 1, 3 and 5. It can be concluded that the fog advection is simulated well, but the fog remains too scattered compared to the satellite images. The fog
reaches the Dutch border between 2 UTC and 3 UTC, both in reality and in the Metcast simulation. The modeled fog band remains too thin however; this is probably due to the absence of radiative cooling in Metcast. At 3 UTC and 6 UTC we can discern the development of a second, much thinner fog band, north of the main band. This second smaller band is seen both in the simulations, see figures 3 and 5, and in reality, see figures 4 and 6. The extensive fog and low cloud fields over northern France move slowly to the west, see figures 2, 4 and 6. This slow motion of cloud and fog fields is also simulated in the model, see figures 1, 3, and 5. The eastern edge of the low clouds over the western part of the North Sea remains more or less stationary, both in the satellite images and in the model simulations.

Now we will discuss results of the second case study (28 January 2006). Compared to the previous case we ran the Metcast model with a doubled horizontal resolution: 5.5 km instead of 11.1 km. Again we show computed ceiling of the Metcast model (figures 7 and 9) and the satellite images are shown in figures 8 and 10. The interpretation of the satellite images is the same as in the October case.

In figure 8 we see extensive very low cloud fields over the north coast of Germany (North Sea and Baltic Sea). These clouds move to the west - southwest towards the Dutch north coast and the Wadden Sea. In addition we can also see several low cloud bands stretching from the Danish and German North Sea coast to the west – northwest, see figures 8 and 10, but these bands are hardly visible in the Metcast output, see figures 7 and 9.
Apparently, the ceiling of these latter cloud bands is a lot higher than that of the clouds present more to the east.

It should be noted that the computed ceiling from the Metcast model does not completely match the low cloud areas in the satellite images. Several reasons can be indicated for this:
1. The detection of low clouds is not possible when they are covered by higher clouds.
2. A ceiling of say 800 m is hardly visible due to the definition by equation (E.1), though such clouds will still be seen as low clouds in the satellite images.
Yet it is obvious that the low clouds over northern Germany and the eastern North Sea which are seen by MSG correspond well with those in the Metcast model.

4. Summary of findings

Fog and low stratus can be detected at night, though discrimination is only possible when synoptic observations of cloud base height are used in addition.

In the two case studies presented we have shown that advection fog and low stratus can be simulated in a 3-D advection model, once they have been detected by the cloud mask from the nowcasting SAF.
Though we did not show any Metcast simulations with turbulent diffusion switched on, the fog in the first case study appeared to be very sensitive to turbulence, e. g. it disappeared completely when vertical diffusion was computed, while applying a maximum diffusion coefficient of 0.8 m²s⁻¹.

We also found that the exact 3-D initialisation of fog fields has a significant impact on fog forecast quality. For example, cloud top height is computed by equating the measured cloud top temperature to the temperature in a vertical profile from the Hirlam model. If cloud top heights were computed by looking for temperature equality starting from above instead of from ground level, cloud top heights appeared to be unrealistically high in the first case study. As a consequence advection to the west was much too fast. This could be concluded by comparing fog model forecasts with a sequence of MSG fog detection images.
In general it is not always obvious how to construct a complete 3-D cloud field, as MSG only sees cloud tops and synoptic observations can only see cloud bases.

Furthermore, we found that boundary conditions of temperature and water vapour mixing ratio at ground level have a large impact on forecasts, especially when turbulence is switched on. These may not be very surprising results for clouds that are close to the earth’s surface and it indicates that an accurate surface scheme is of great relevance for fog forecasting. In the case studies presented in this paper boundary conditions of both moisture and temperature were taken from the Hirlam model.

5. Conclusions and outlook

We have shown that it is possible to detect fog with MSG at night, and subsequently compute the advection in a 3-D advection model. From the case studies we can conclude that, apart from advection, radiation probably also played an important role in the October case. This was at least strongly suggested because the simulated advection fog did not become thicker during the night, while the real fog did, probably due to cooling of the lower atmosphere.
Though we presented some verification results of the detected ‘nowcasting SAF’ clouds in general, it would be interesting to do so again for only fog detections. Also we would like to verify the forecast cloud cover by comparing it to synoptic observations and to cloud mask detections from the SAF. This will be performed in more case studies.
In addition we are planning to verify computed cloud base heights by comparison with synoptic observations.
Finally we plan to verify simulated cloud top (fog top) heights by comparison to radiosonde observations in particular case studies.

A useful nowcasting SAF product that we did not use so far is: cloud type. If this SAF product would detect e. g. a very low stratiform cloud, it would impose additional constraints on cloud top heights, possibly making the 3-D cloud initialisation more accurate.

Also, quite often synoptic information of cloud amount and cloud base heights is available for more than one layer. This information could further refine the 3-D cloud initialisation process.

We expect that a high resolution topography, as well as detailed soil moisture and temperature information is quite important for accurate fog forecasts.

6. References
