Hirlam pseudo satellite images

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1 Introduction

Determining the quality of a weather model analysis or short term forecast can be difficult and time consuming. Various model fields have to be compared to the observations (where present) while the judgement of the quality can only be made indirectly in data-sparse areas, on the basis of satellite images.

Clouds are the product of all processes in the atmosphere. Together with a thorough knowledge of conceptual models, satellite images can be translated to a 3-D state of the atmosphere. Also, with this knowledge, the evolution of the weather can be predicted a few hours in advance.

By calculating radiation temperatures and reflectivities from model parameters and presenting them as pseudo satellite images the comparison of the model state with observations can be made over the entire model domain, even in data-sparse areas. The evolution of model satellite images also can give the forecaster a feeling for the developments in the model while model developers may get a better idea of model deficiencies.

This contribution explains the simple and quick method that is used to produce pseudo satellite images. To enable hourly output without the necessity of storing the entire model state every hour, the pseudo satellite calculations have been incorporated in the Hirlam postprocessing so the output can be generated operationally and can be used for SatRep (satellite reports, see http://www.knmi.nl/satrep) and guidance purposes.

2 The method

The infrared satellite images as we see them are the intensity of the radiation from the surface and atmosphere at the top of the atmosphere, which is translated to the radiation temperature of a black body. This radiation comes from the surface when the sky is clear while the radiation comes from the clouds solely when they are optically thick enough. The translation of the infrared radiation to a temperature enables the meteorologists to determine the cloud top temperature from the infrared images. Together with temperature profiles from radiosondes or models this can be used to estimate the height of the cloud top of e.g. convective clouds. The principle of the cloud top temperature in infrared images now is used in the opposite way to make infrared images from model fields.

The Hirlam model includes cloud water as prognostic variable. With this parameter we can calculate the cloud top temperature as follows. The start temperature is the temperature at the lowest model level. Then we go trough all levels from bottom to top. If there is no cloud water at the current model level, then the cloud top temperature remains the same. If there is cloud water present, the cloud top temperature is adjusted to the temperature of that level. In equation form it looks like:

$$T_{cld} = T_{cld,prev}\left(1 - MIN\left\{1, \frac{Q_l \Delta P}{Q_{dp}}\right\}\right) + T_a\left(MIN\left\{1, \frac{Q_l \Delta P}{Q_{dp}}\right\}\right), \tag{1}$$

where T_{cld} is the cloud top temperature at the current model level, $T_{cld,prev}$ is the cloud top temperature at the previous model level, Q_l is the cloud water content of the current model level, ΔP is the thickness of the model level in Pascal, Q_{dp} is the threshold value of the cloud water above which the new cloud top temperature will attain the current air temperature and T_a is the air temperature at the current model level.

Figure 2 gives a schematic representation of the procedure that is applied. The cloud top temperature starts with the air temperature at the lowest model level. This temperature does not change until the first cloud layer is reached. These clouds are more dense than the threshold value, so the cloud top

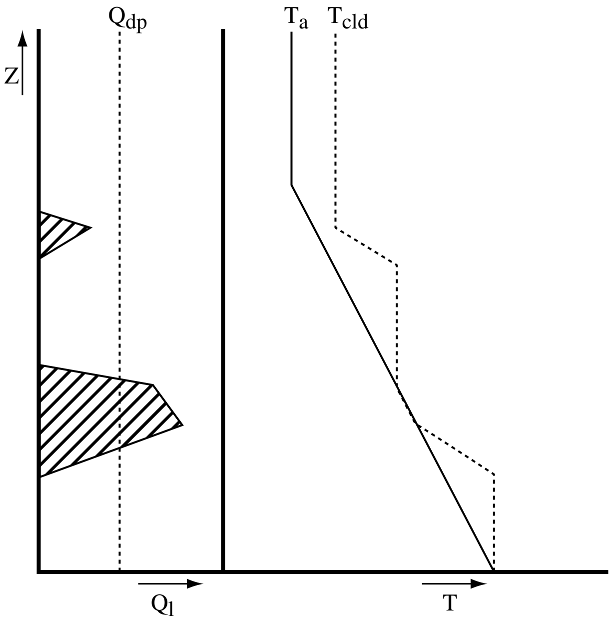

Figure 1: A schematic representation of the procedure that is applied to produce a cloud top temperature from model data.

temperature takes the value of air temperature at that level. Above the first cloud layer, there is a cloud free layer, causing the cloud top temperature to retain the old value. The clouds of the second layer are more transparent than the threshold value. Therefore the cloud top temperature is adjusted only to 75% of the difference between the current air temperature and the cloud top temperature. After this second cloud layer there is no more cloud water so the cloud top temperature does not change.

Applying the procedure and equation described above results in cloud top temperatures that resemble the cloud top temperatures in infrared images quite well. Shallow and optically thin clouds are only taken into account partly causing the end product to show gradation in the grey scales of the images. The same procedure can be applied to water vapour. You need another value of the threshold Q_{dp}. Voogt (2003) has shown that this method resembles a radiative transfer model quite closely when the correct (pressure and temperature dependent) threshold is taken. From comparisons with the radiative transfer model Voogt (2003) arrived at a threshold value of:

$$Q_{dp} = q_{wv} \left(\frac{p_0}{p}\right)^n \left(\frac{T}{T_0}\right)^m , \tag{2}$$

where p is the pressure, p_0 a reference pressure (1000 hPa), T the temperature, T_0 a reference temperature (300 K) and q_{wv} a scaling factor (0.70).

This procedure has also been applied to water vapour images with an additional impact of clouds (high clouds are visible in water vapour images) and (with some changes) to the reflectivity images (visible images). The calculation of the radiation temperatures and reflectivity is included in Hirlam in the postprocessing. The output can be called by using the parameters that are listed in table 1.

3 results

The results from these calculations are shown in figures 2 and 3. The first figure shows the comparison between the observed (bottom) and the calculated water vapour images. Comparing these two images

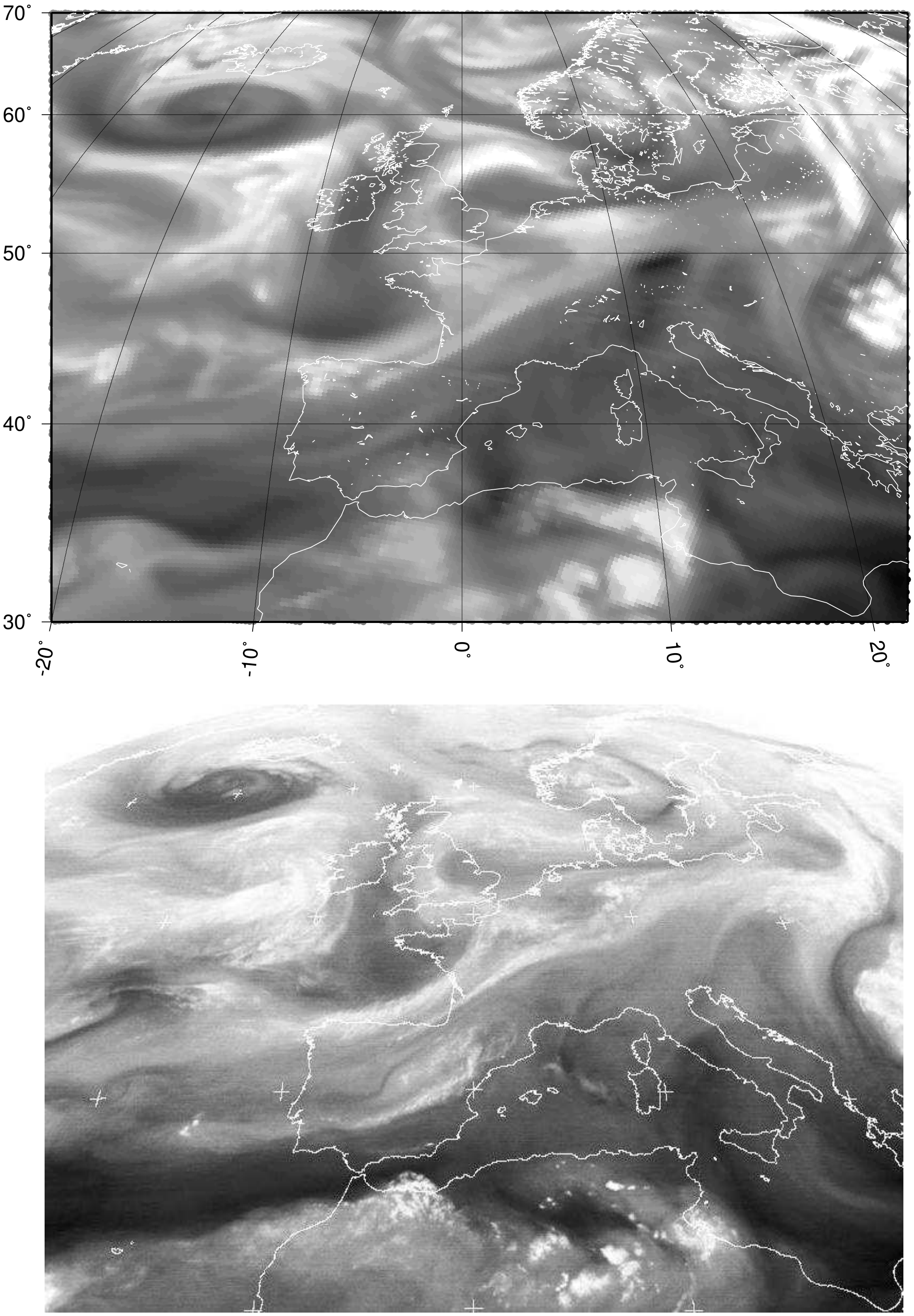

Figure 2: *The model water vapour plus cloud correction image (+6 forecast, analysis 2004082806) and the Meteosat water vapour image from the same time (courtesy Dundee University).*

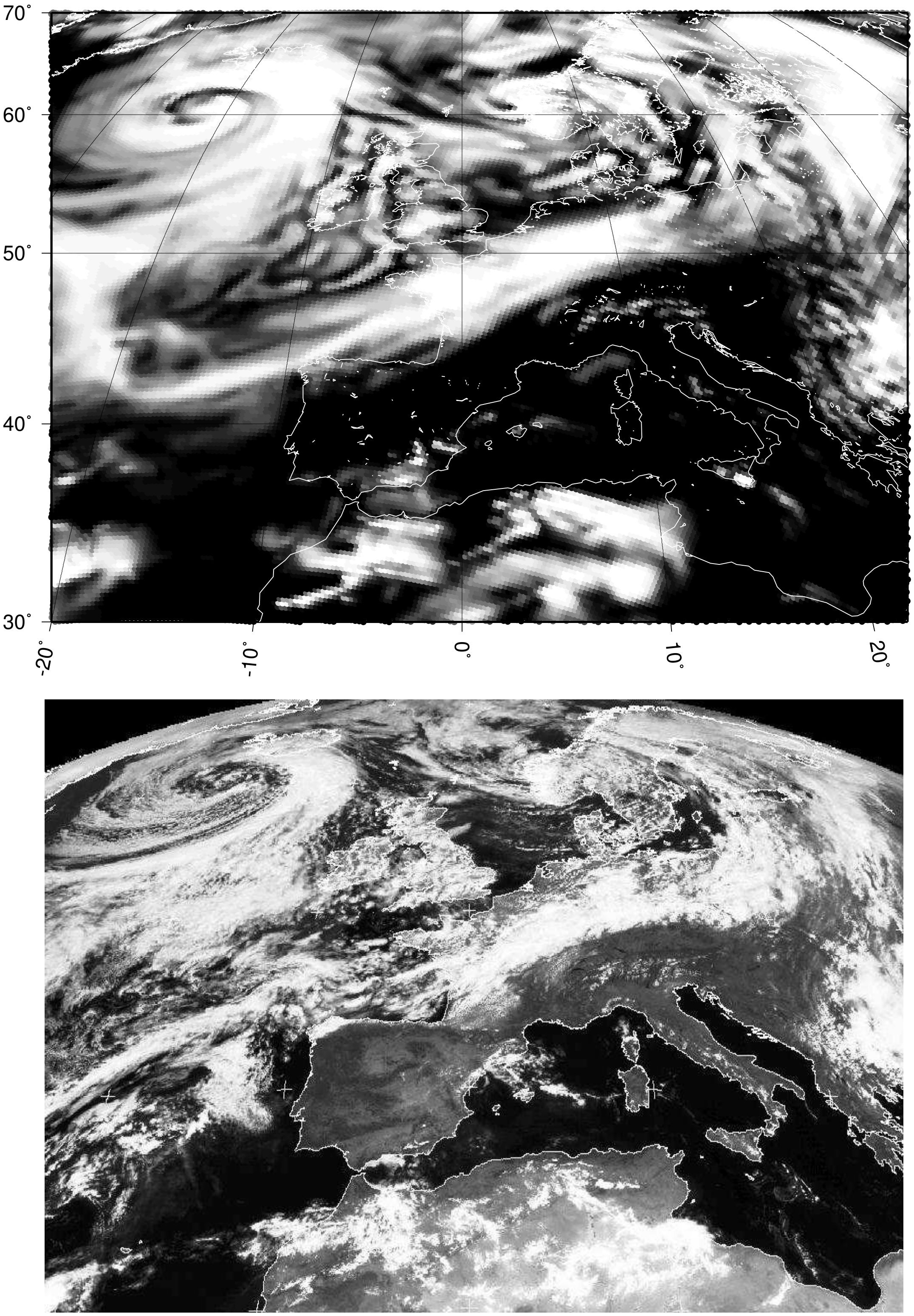

Figure 3: *The model reflectivity image (+6 forecast, analysis 2004082806) and the Meteosat visible image from the same time (courtesy Dundee University).*

Table 1: *The pseudo satellite output parameters in the Hirlam postprocessing. These values may change to better fit into the grib descriptions from WMO.*

parameter	number	leveltype	level
Infrared	131	105	0
Water vapour	132	105	0
Water vapour + clouds	133	105	0
Reflectivity (visible)	134	105	0

one can easily detect if the model has deficiencies in its fields, not only over land where the comparison with observations can be made also, but also over the sea. Also, meteorologists can see in one instant, with their knowledge of conceptual systems, if the model forecast is realistic or not and where interesting developments take place.

Comparing the observed image with the forecast, one can directly see the similarities and the differences. Striking similarities in figure 2 are the cyclone and its position southwest of Iceland, the relatively dry air over Scotland, Ireland to the Bay of Biscay, the structures over England, the North sea, France and Germany and the high water vapour levels over North Africa. Differences can also be found very easily. Over Central Europe a dark spot can be found in the model, where there is no evidence of such a system in the satellite image. Such a spot is usually associated with relatively high instability, so the model may generate erroneous deep convection in this area. Another difference is the position of the sharp water vapour gradient over Madeira. In the model it is positioned much more to the North.

Figure 3 shows the comparison between the reflectivity due to clouds in the model and the visible Meteosat image. Again, the comparison shows that the model has analysed and forecasted this situation quite well. The larger structures are in the correct place but as in figure 2 differences can be found. One of the differences is the position and structure of the front that stretches from Poland, Germany and France out to the Atlantic. Over Central Europe the front is shifted a little to the North of the observed position while over the Atlantic Ocean it is situated a little to the South and it seems dissolved west from 18° West. Another deficience is the underestimation of the convection over Northwest Germany and Northeast of the Netherlands. Looking at hourly pseudo satellite images one can easily detect the onset of moist convection and compare it to the observed convection. Note that the impact of cloud water from shallow convection on the reflectivity may be underestimated because cumulus clouds usually contain very little cloud water, especially when averaged on the grid scale.

Another deficiency of the model that can easily be spotted from these kind of images is the tendency of the model to forecast fog over the sea, especially the Mediterranean sea. In figure 3 this can be seen close to the French-Italian border. This model fog and low clouds are often accompanied by small precipitation amounts and relatively low temperatures over the Mediterranean Sea.

Results are also produced semi-operationally at KNMI and can be viewed on the internet through: http://www.knmi.nl/~tijm/H11IR.html.

4 Conclusions

Images that have the same appearance as satellite images can be made on the basis of high resolution model data. Incorporating these calculations in the model has the advantage that hourly output can be generated enabling a good comparison of a lot of aspects of the model with observations (real satellite images). These images can be a useful tool in the assessment of the quality of the model state, especially in data sparse areas. It also provides the forecasters with a product that is quite similar to something that they are very familiar with, making a quicker assessment of the quality of a model forecast. A loop of pseudo satellite images can help forecasters getting a feeling for the developments in the model by checking them against satellite loops. Also, the model images may aid model developers to find model deficiencies like too many clouds, a wrong distribution of clouds or problems in the convection (onset too early or too late). Finally, the pseudo satellite output may also be used in verification against satellite imagery.

The code that calculates the pseudo satellite output has been based on one of the most recent Hirlam beta releases (version 6.3.3) and can therefore be incorporated in the reference Hirlam quite easily. The grib numbers that are proposed in this contribution are not final and may therefore be subject to change.

Only the water vapour part of the code has been tuned against a radiative transfer model. The other settings that are used have been chosen based on visual comparison between the real satellite images and the pseudo images, so there is room for improvement. Especially for the reflectivity the impact of shallow cumulus clouds is too small causing cumulus, stratocumulus and fog being too grey in comparison with the real satellite images.

Reference

Voogt, M.H., 2003: Synthetic water vapour images from the Hirlam model using a radiative transfer model. *KNMI internal report* **IR 2003-07**, De Bilt, The Netherlands, 70 pp.