CGMS-34, EUM-WP-20

Prepared by EUMETSAT
Agenda Item: II/6.3
Discussed in Plenary or WG

ENHANCED CLOUD PRODUCTS INCLUDING CLOUD MICROPHYSICS
In response to CGMS action R33.03

This paper describes an optimum estimation method to derive a number of cloud and cloud microphysical products from the Meteosat Second Generation (MSG) multi-channel imagery. This method is currently developed and tested at EUMETSAT.
The paper is in response to Recommendation 33.03 which in turn responded to the GCOS requirement for improved cloud monitoring.

ENHANCED CLOUD PRODUCTS INCLUDING CLOUD MICROPHYSICS

1 INTRODUCTION

This paper describes an optimum estimation method to derive a number of cloud and cloud microphysical products from the Meteosat Second Generation (MSG) multi-channel imagery. This method is currently developed and tested at EUMETSAT. The paper is in response to Recommendation 33.03 which in turn responded to the GCOS requirement for improved cloud monitoring.

2 RETRIEVAL METHOD

2.1 General Concept

"Traditional" methods for cloud parameter retrieval most often based on a restricted set of spectral channels that are responsive to changes in the desired parameter. Since these relationships, even when they are physically sound and well established, are not completely clean of other effects, there is usually the need for the removal of these unwanted effects on the measurements. Typically corrections are then applied based on other channels as auxiliary data.

Such methods are usually computationally fast and efficient and are well suited for simple imagers like e.g. the first generation Meteosats (which has three channels in the VIS, WV 6.5µm and IR 11.0µm spectral range). With the increased complexity of more advanced imagers like the 12-channel SEVIRI instrument onboard MSG (for a detailed description see Schmetz, 2002), such methods could lead to numerous intricate logical loops in order to exploit the full potential of the multi-channel image data. In the end the dimensions of the problem will be too high to devise an optimised rigorous physical approach.

The community dealing with temperature and humidity profile retrievals from sounders like the HIRS or the AMSU instruments have developed more advanced retrieval methods to fully account for the obvious interdependency of the measurements. Rodgers (2000) gives a full description of such so-called inversion methods, which are commonly used in data assimilation for numerical weather prediction, where detailed error characteristics are needed which are well defined within the inversion methods.

EUMETSAT has taken the approach to also use such inversion or optimal estimation methods (OE) for the retrieval of cloud properties from the SEVIRI measurements. The following will very briefly describe the basic theory behind this method and its potential benefits. A full description of the method can be found in Watts et al., 1998. Section 3 of this paper will show some initial results for MSG.

2.2 Basic Theory

At the simplest level the OE methodology is very straightforward: it uses a radiative transfer model output y(x) to connect the cloud model x to the satellite measurements y_m, and then finds the best fit of y(x) to the measurements y_m by adjusting x. In a simple notation we are just looking at the minimum of the function

$$J = [\, y_m - y(x) \,]^2$$

Or in full notation

$$J = S_y^{-1}[y_m - y(x)]^2 + S_x^{-1}[x - x_b]^2$$

which accounts for the measurement (and radiation model) errors S_y. The new second term is used if we have any prior information on the cloud parameters, denoted by x_b, together with their error S_x. It should be noted that the notation is simplified for clarity and should be written in standard matrix notation.

The obvious gain from this method is its inherent simplicity: long and possibly complicated and interrelated logical loops are now avoided. Through the use of an appropriate radiation model it is assured that the information of all channels is incorporated in the solution. This implies that a further channel can be easily accommodated as long as it is included in the underlying radiation model. The theoretical framework also leads to a formal estimate of parameter error. In addition, through the residual retrieval "cost" J, we have a direct measure of the adequacy of the cloud model x used in the radiation model for the analysed satellite scene. This is rather important, as all cloud radiative transfer models have limitations. For instance, the commonly used one-dimensional radiative transfer models will not deal with the 3-d nature of clouds nor with cloud shadows on the ground. If the inspected scene contains such a shadow it is unlikely that the model parameters x can be adjusted to satisfy all the measurements (provided sufficient measurements are used compared to the dimension of x), as the cloud model does not account for this effect. The retrieval cost J is thus a useful form of scene quality control. Figure 1 shows an example.

A disadvantage of the optimum estimation approach is that it is computationally expensive as it necessitates realistic radiative transfer and iterative methods for the solution – however, fast approximations are available and computational power generally increases rapidly. The OE method also requires a correct definition of the error covariances, as otherwise all products would be compromised.

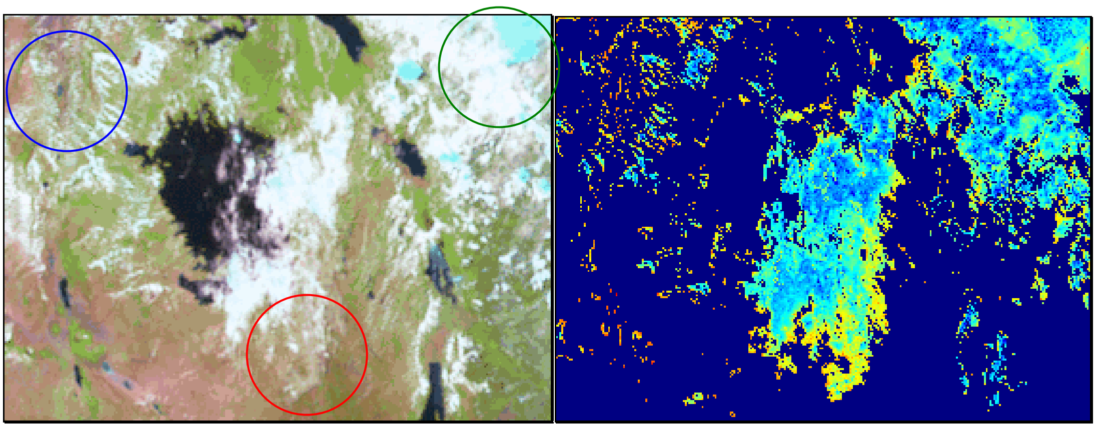

Figure 1: Demonstration of scene quality control through solution J values. The true-colour image left shows water and ice clouds over Africa, water clouds in white, ice clouds in cyan. The image right is the solution J, ranging from low (light blue) to high, red (dark blue indicates no cloud flagged). High values showing model problems appear for thin cloud over bright land surfaces (red circle), very small, possibly sub-pixel cloud (blue circle), and mixed phase cloud and shadow areas (green circle). Results are for Meteosat-8, 2004 June 05 1000Z, using the channels VIS0.6, VIS0.8, NIR1.6, IR10.8, and IR12.0.

3 APPLICATION TO MSG

The EUMETSAT realisation of the OE retrieval of cloud properties defines the cloud model vector x such that information on the cloud optical depth, the effective particle size, the cloud phase (water, ice or mixed) and the cloud top pressure are retrieved as enhanced cloud properties. The underlying radiation model is split into a "solar" and a "thermal" part so that all SEVIRI channels are considered in the retrieval. It should be noted, however, that daytime retrievals with the additional use of the SEVIRI VIS channels will always be of better quality than night time retrievals which necessarily rely solely on the thermal measurements with their rather weak response to some of the cloud properties x.
The following example of the OE results was obtained over two deep convective cloud systems in the tropics (05 June 2004, 0845 – 1400 UTC). Such systems grow rapidly, and the 15 min repeat cycle of the MSG satellites provide a unique opportunity to study the evolution process.

Figure 2 shows an artificial MSG true colour image of the considered systems (in the black and red box, resp.). A visual inspection of the time sequence showed that both systems were more or less isolated and not part of larger convective complexes.

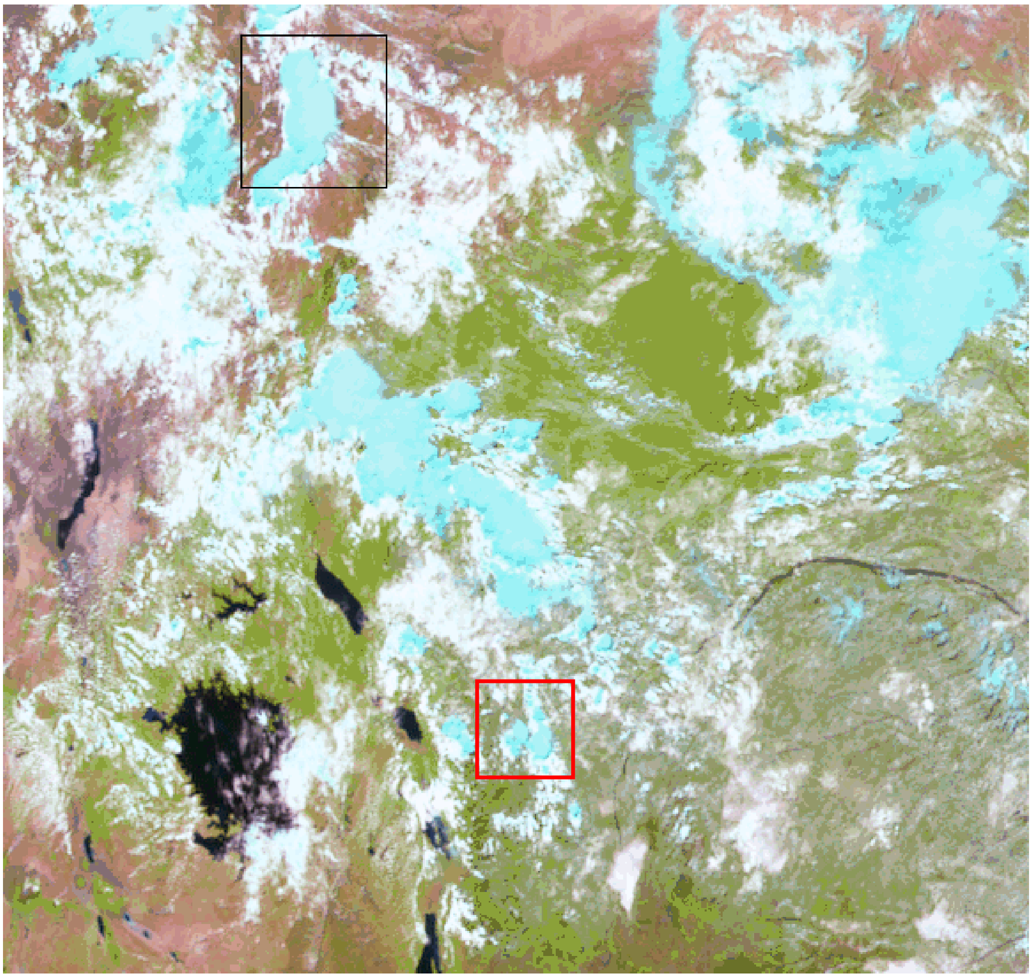

Figure 2: Cloud situation as observed by this true colour image on 05 June 2004, 1000 UTC. Results for the cloud systems in the two boxes are shown in the next Figures.

Figure 3 shows the time evolution of the cell in the black box, which was tracked by a simple moving rectangular area. The ordinate is cloud pressure from 600 hPa to 50 hPa, the abscissa is optical depth between 0 and 60. The colours of each point, i.e. each pixel result, represents particle size and phase – green to yellow are ice particles, 50 - 80μm, shades of blue are water droplets, 3-20 μm. The early hours, 0900 – 0945 UTC, are dominated by water and ice clouds which appear capped at just above 400 hPa. At 0945 UTC there is the first sign of the convective cell emerging through this layer and reaching 320 hPa. It is not particulary optically thick. It reaches 200 hPa in 15 min having roughly doubled in optical thickness. Again 15 min later, at 1015 UTC, deeper parts of the cloud have reached 100 hPa and higher. The remainder of the cloud continues to thicken and climb less quickly as the level of neutral buoyancy (here at 150 hPa) is passed. By 1100 UTC, two distinct populations are present, one around the level of neutral buoyancy and one more or less at the tropopause (100 hPa), and a few cloudy pixels appear above the tropopause. These two populations have distinctly different particle sizes. The behaviour of the anvil cloud from now on is slowly changing. Both populations persist with decreasing optical depth until the end of this sequence at 1245 UTC, when the upper group has fallen back into the lower.

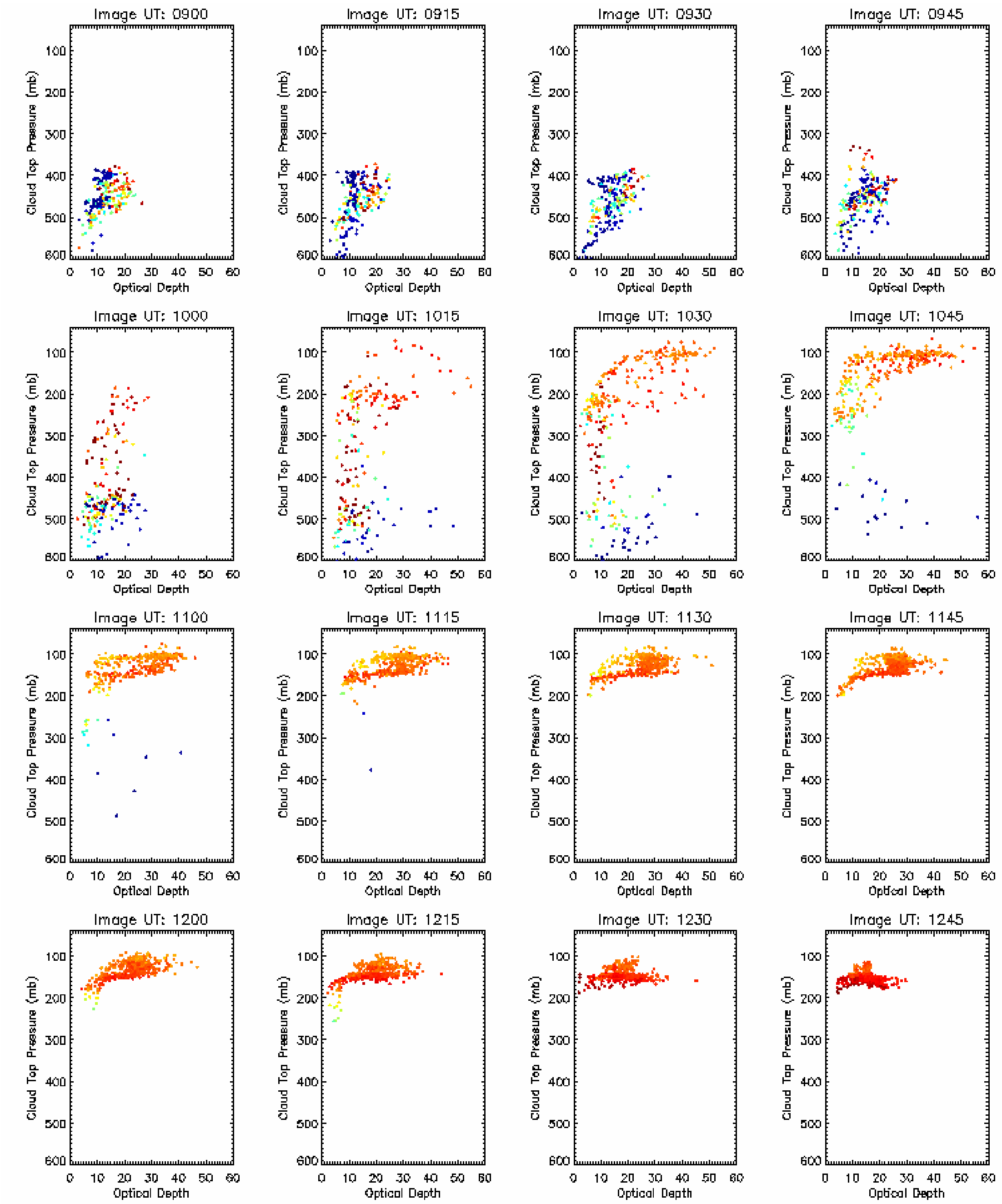

Figure 3: Time sequence of the OE results for the black box in Figure 2. For details and colour explanations see text.

Another interesting sequence is observed in the cell marked by the red box in Figure 2. In this case we clearly see the evolution of the convective cell starting with its appearance through the water cloud layer at 425 hPa at around 0945 UTC. It is not as energetic as the previous example – most of the cloud tops stop at the level of neutral buoyancy (again around 150 hPa). What may be interesting is the behaviour of the surrounding water cloud layer which appears to be lowered in response to the cell ascent. The change is from 450 hPa to around 550 hPa between 1000 UTC and 1100 UTC, and there seems to be a recovery later in the sequence as the convective ascent diminishes – possibly an observation of a gravity wave forced by the nearby ascent

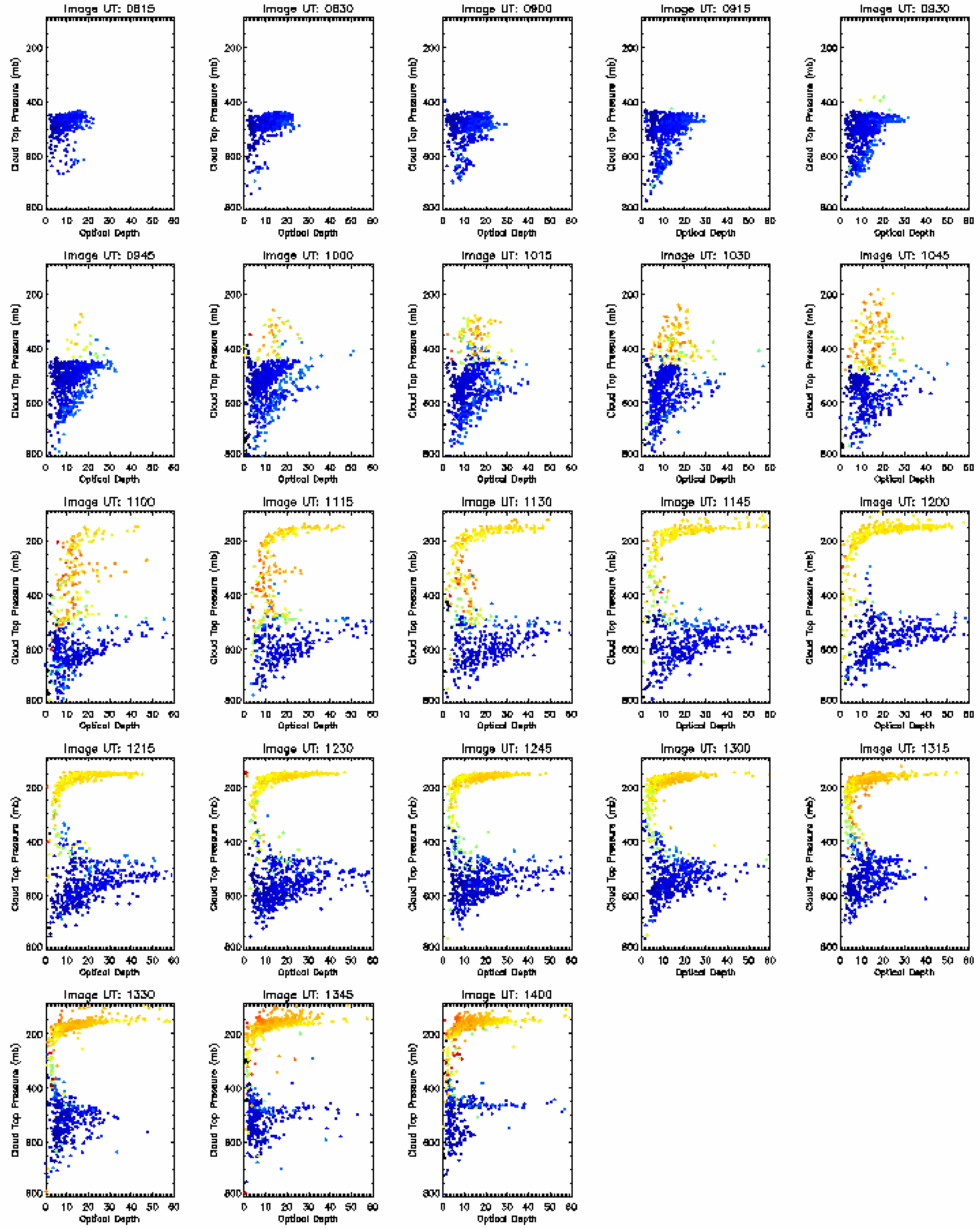

Figure 4: Time sequence of the OE results for the red box in Figure 2. For details and colour explanations see text.

4 CONCLUSIONS AND OUTLOOK

The first results from an optimum estimation method for deriving cloud parameters in a consistent manner from SEVIRI on MSG are very encouraging. The OE retrieval method seems to be both internally consistant where expected (low residuals in 'good' scenes), and to characterise typical cloud lifecycles well. Further development work is ongoing and involves the following issues:

- Inclusion of all SEVIRI channels in the retrieval. This is where the OE potential is greatest. The extra channels should allow for better quality control and lower errors in the final products. There might even be the potential to derive fractional cloud cover of sub-pixel clouds as an additional parameter within x.
- Explaining and accounting for large solution residuals J. Such residuals indicate that the new information is not well explained by the underlying cloud model and thus provide clues to enhancements of the model. Inclusion of more channels makes greater demands, and thus greater potential, for model improvements and understanding.
- Product validation: This is possible through comparisons to other cloud microphysical retrieval methods which are realised outside EUMETSAT. A Cloud Workshop held at SMHI in May 2006 initiated a comprehensive comparison of a number of MSG related cloud products.
- Potential to use the OE derived cloud heights in the MSG Atmospheric Motion Vectors, where more traditional height assignment techniques have limitations.

References

Rodgers, C.D., (2000): Inverse Methods for Atmospheric Sounding – Theory and Practice. World Scientific, Series on Atmospheric, Oceanic and Planetary Physics. 238 pp.

Schmetz, J., P. Pili, S.A. Tjemkes, D. Just, J. Kerkmann, S. Rota, A. Ratier (2002): An Introduction to Meteosat Second generation (MSG). Bull. Amer. Met. Soc., July 2002, 977 – 992.

Watts, P.D., C.D. Mutlow, A.J. Baran, A.M. Zavody (1998): Study on Cloud Properties Derived from Meteosat Second Generation Observations. Final Report. Available from EUMETSAT.