TRACKING CLOUD PATTERNS BY RAPID SCAN IMAGERY IN THE ALPINE REGION

Martin Bolliger[*], Peter Binder and Andrea Rossa
MeteoSwiss, Zurich

1 INTRODUCTION

Convective and stratiform cloud patterns are investigated by means of Meteosat-6 rapid scan imagery (Hanson, 1999) recorded over the Lago Maggiore target area during the MAP SOP. The data of the infrared channel are used to implement an automatic cloud tracking algorithm by a pattern-oriented technique. The increase of temporal resolution from the operational 30 minutes interval to the rapid scanning 5 minutes interval allows continuous cloud tracking and helps to isolate information on cloud development. In the present paper tracking is not used for the derivation of cloud motion winds, but rather to extract the cloud development within the tracked cloud fields. Tracking reduces unwanted effects caused by the earth-relative motion of the observed cloud fields and is regarded as a necessity for the determination of the magnitude of cloud development (Bolliger et al., 2001).

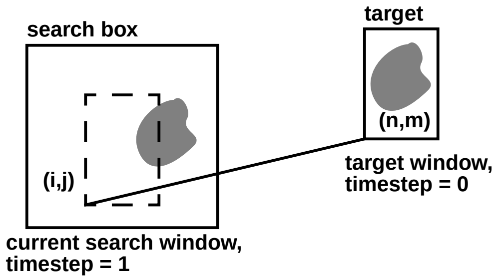
The paper focuses on the additional gain of meteorological information derived from rapid scanning data and on the use of the PCC (Pattern Correlation Coefficient) tracking algorithm in the Alpine region. In the following section, the pattern-oriented tracking technique will be presented. In section 3 results of sensitivity studies are discussed. A summary of the results and further remarks are given in section 4 to conclude the paper.

2 THE PCC TECHNIQUE

Cloud systems are tracked by the help of a standard pattern correlation coefficient (PCC) technique using data from the infrared channel (Leese and Novak 1971, Schmetz and Nuret 1987). The advantage of infrared imagery is the availability over 24 hours and the distinct cloud patterns they reveal compared to data from the water vapour channel.

The tracking principle is schematically depicted in Fig. 1. For the PCC tracking, a sequence of successive images is used. In the first image (timestep = 0) a cloud pattern is defined subjectively as a “target window”. As common target window size we use 15 x 15 pixels. This target window is sought for in the consecutive image (timestep = 1) within a search box by moving around until the best correlation match is found. The displacement between the location of the target area at timestep = 0 and the new location at timestep = 1 corresponds to the (cloud) pattern motion. The new location of the target at timestep = 1 defines the new target area, which is moved in the search box of the consecutive image (timestep 2) until the best correlation is found. Once the initial target is defined, the tracking algorithm runs automatically.

As input for the tracking algorithm, the pattern recognition technique uses the spatial variability of pixels of the target window. The Standard Pattern Correlation Coefficient is given by the covariance between the current search window and the target and the standard deviation in the search and target window, respectively (Fig. 1). For different locations *i* and *j* within a predefined search window the standard pattern correlation coefficient PCC(*i*, *j*) is computed according to Schmetz and Nuret (1987). Since the target window displacement between two consecutive images is limited, we assume a maximum target displacement of one pixel per minute[1] within a given



Standard Pattern Correlation Coefficient

$$PCC(i, j) = \frac{\sigma_{st}(i, j)}{\sigma_s(i, j) \cdot \sigma_t}$$

σ_{st} = covariance between current search window and target

σ_s = standard deviation in current search window

σ_t = standard deviation in target window

FIGURE 1: Concept of the pattern correlation coefficient technique (PCC). For details see text.

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[*] Corresponding author address: Martin Bolliger, MeteoSwiss, CH-8044 Zurich, Switzerland; email: martin.bolliger@meteoswiss.ch

[1] In midlatitudes, the size of a pixel of the infrared channel is ~ 5 km x 8 km resulting in a maximum cloud displacement of 480 km/h what is unlikely to occur.

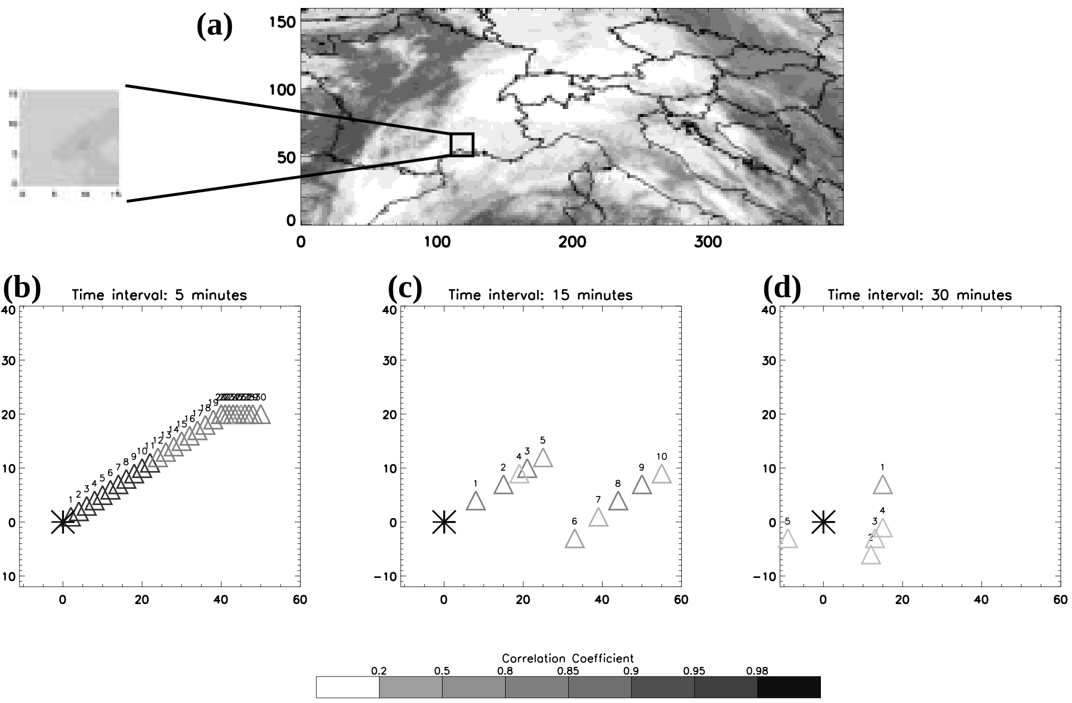

FIGURE 2: Results from PCC tracking on 24.10.99, from 12:00-14:30 UTC. In (a) the cloud cover as seen by the Meteosat-6 infrared channel at 14:00 UTC is depicted, the black box represents the location of the tracked target at 12:00 UTC, the weakly textured 15 x 15 pixel stratiform target is shown by the small panel to the left. (b) - (d) present the target displacements (triangles) with varying time intervals between two consecutive images: (b) 5 minutes, (c) 15 minutes, (d) 30 minutes. The star depicts the initial position of the target, the number within the triangles denotes the sequence of the displacement. High temporal resolution of images (i.e. 5 minutes interval) allows a continuous tracking even of a small and weakly-textured cloud pattern. This continuity degrades with the increase of time between two consecutive images: panels (b) and (c).

time interval. Therefore, for images with 5 minutes intervals the size of the search box is chosen to be the target window incremented by 5 pixels in each direction. The advantage of the PCC technique is that no object-specific definitions are required apart from the initial choice of the target window.

3 SENSITIVITY STUDIES

The sensitivity analyses were carried out by tracking targets using different time intervals between consecutive images. Further, the persistence of different target patterns has been examined.

3.1 Time interval

Investigations provide evidence, that the tracking accuracy depends crucially on the availability of imagery of high temporal resolution. Fig. 2 shows the target displacement of a weakly-textured target window (stratiform cloud pattern) using different time intervals between two consecutive images. A high temporal resolution of 5 minutes in Fig. 2 (b) allows a steady tracking of the target. When degrading the temporal resolution to 15 minutes as depicted in Fig. 2 (c), the target is tracked correctly up to the fifth position of displacement and from the sixth position (i.e. after 1 hour and 30 minutes), a new pattern is tracked. This new pattern was found within the search box and exhibits at this point in time the highest pattern correlation. From the sixth position the steady progression of the displacement positions is definitively interrupted. However note that the order of target displacement, illustrated with numbers within the triangles, is interrupted already at the third position (45 minutes). Comparing the third and the fourth position of the target displacement, the latter is closer to the initial position of the target (depicted by the star) despite the continuous target displacement away from the initial target position (cf. Fig. 2 (b)). This shows that already after 45 minutes the initially defined target is lost what is confirmed by the decrease of the correlation coefficient. A further degradation of the temporal resolution to 30 minutes, which is the operational mode of Meteosat-6, reveals that the interruption occurs earlier (Fig. 2 (d)) and when comparing to the results of the 5 minutes interval images, only the first position was tracked correctly. Note that a decrease in temporal resolution leads also to a decrease of the correlation coefficient values.

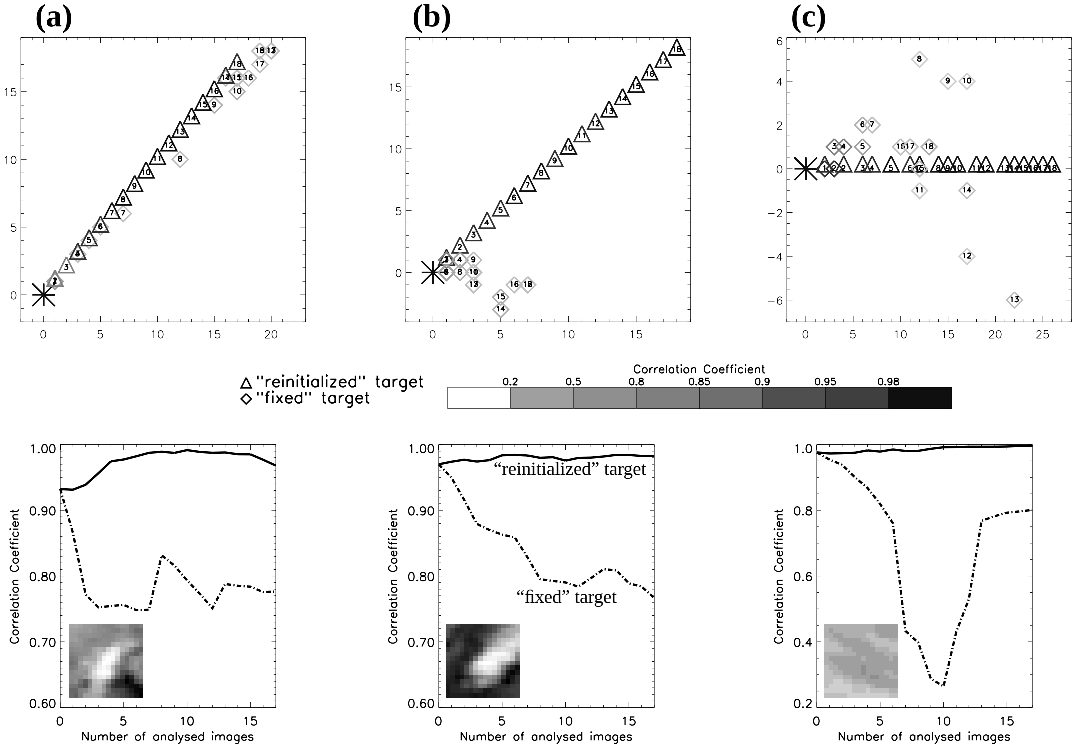

FIGURE 3: Ability to track differently textured cloud patterns of equal size (15 x 15 pixels) using "reinitialized" and "fixed" target strategy (see text for explanation) with 5 minutes interval imagery. The top row shows the location of target displacements, the bottom row the corresponding correlation coefficients and the tracked target patterns. (a) Cell-like pattern with moderate evolution, tracked from 10:30 - 12:00 UTC, 26. 09. 99. (b) cell-like pattern with rapid evolution, tracked from 19:30 - 21:00 UTC, 03. 10. 99., (c) weakly-textured straitiform pattern with weak evolution, tracked from 13:00 - 14:30 UTC, 20. 10. 99. The black star in the upper row depicts the initial position of the target, the number within the triangles denotes the sequence of the displacement.

3.2 *"Persistence" of a cloud pattern*

The persistence is dependent on the development rate of the observed cloud system. A cloud with none or weak evolution is persistent and permits an accurate tracking combined with high temporal satellite imagery. In the original tracking algorithm, the best matching pattern is used as new target for the subsequent timestep. Therefore, for each timestep the pattern of the target window is "reinitialized" over the investigated period allowing a tracking of cloud patterns which evolve. For investigations concerning the persistence of a cloud pattern, the redefinition of the target window for each timestep is limited to half hourly intervals (i.e. 0, 30, 60 90 minutes etc.) again corresponding to the Meteosat operational mode. This target pattern is referred to as "fixed" target. For each timestep, the pattern of the "fixed" target is compared to the patterns within the search box and the location of maximum correlation defines the target displacement between the two consecutive images. After each half hour, the "fixed" target pattern is redefined at the location of maximum correlation within the search box. There are two aspects for the interpretation of the results of investigations with "reinitialized" and "fixed" targets:

- The divergence of the "fixed" and "reinitialized" target positions: Coinciding positions of the "fixed" and the "reinitialized" target manifest a good tracking ability of the target patterns being redefined at 5 minutes or at 30 minutes intervals.
- The magnitude of the difference of the correlation coefficient between the "fixed" and the "reinitialized" target: Due to cloud development or ambiguity in matching, the correlation between the "fixed" and the "reinitialized" target degrades in time.

The difference between the correlation coefficients of the "reinitialized" and the "fixed" target is - apart from tracking errors (i.e. ambiguity in best match) - related to the magnitude of cloud development within the investigated period. Cloud development within short times leads consequently to a decrease of correlation between the "fixed" and the rapidly developing "reinitialized" target. In Fig. 3 three cloud patterns of equal size (15 x 15 pixels) with different development rates and textural characteristics were investigated with 5 minutes interval images over a period of 90 minutes. Fig. 3 (a) illustrates an isolated and slowly dissipating cloud over the Ligurian Sea, (b) a rapidly evolving cloud cell at the eastern border of the Swiss Alps and (c) a stratiform cloud pattern with weak evolution over the Po Valley with the corresponding correlation coefficients for each timestep. Comparisons of the figures reveal, that the displacement locations of the "fixed" targets coincide best in Fig. 3 (a) with the "reinitialized" target. In (a) the coincidence of target displacement is recognizable up to the seventh position, corresponding to a period of 35 minutes. From this point in time, the positions of both targets begin to diverge. Despite the locations divergence and the acceleration of target displacement compared to the "reinitialized" target, this is a good example of a continuous tracking of a target redefined in half hourly intervals.

In Fig. 3 (b) an area was investigated, where convection was constantly triggered at a given spot. The "fixed" target remains more or less stationary whereas the "reinitialized" target displaces with the predominant southwesterly flow. The stationary "fixed" target provides evidence, that the strong cloud development rate hinders a continuous tracking of the cloud pattern and its evolution. The stationary "fixed" target is a consequence of the quick and geographically fixed generation of the (convective) cloud patterns. This is an excellent example showing the capability of the PCC method to track *rapidly evolving convective cloud patterns* by adjusting the tracked target pattern for each timestep.

Cloud development is not the only parameter affecting the suitability of a target pattern for "persistence" studies. In Fig. 3 (c) investigations of "fixed" and "reinitialized" target patterns within not evolving stratiform cloud regions show, that a rapid decrease in correlation coefficients is observable, too. The stratiform region shows the limitation of a continuous tracking ability of weakly-textured "fixed" cloud patterns by the standard time interval (30 minutes) of Meteosat. The locations of target displacement diverge already from the third position. By searching for the best correlation match of a weakly-textured target within a search box characterized by a weakly-textured cloud structure an unambiguous association might not be possible. The results are chaotic target displacements of the "fixed" target. As a consequence, small and weakly-textured cloud patterns are not suited for pattern tracking over longer timesteps. This drawback of cloud regions with weak evolution can be minimized by defining larger target windows comprising more distinct texture information.

4 FURTHER REMARKS

In the present study the tracking is regarded as a complementary means to extract information on cloud development. The high temporal resolution of the Meteosat -6 rapid scans favours the tracking of cloud patterns, being rapidly developing convective systems or weakly textured stratiform clouds. The latter can hardly be followed on a contiguous path by 30 minutes timesteps.

The studies on "persistence" of cloud patterns provide evidence of the additional information gained by high temporal resolution of the satellite imagery. The gain in information is best observable by the analysis of the displacement locations and the correlation coefficients of the "fixed" and "reinitialized" targets. As shown, a slowly dissipating cloud (Fig. 3 (a)) is better suited for tracking using the "fixed" target criterion compared to rapid evolving or smooth cloud patterns (Figures 3 (b) and (c)). Machado et al. (1998) confirmed that the coincidence between two consecutive images works, as long as the time step between the satellite images is smaller than the time required for significant evolution of convective systems.

Despite the fact that some ambiguity in texture matching between two consecutive images is always possible, the PCC provides very satisfying results by the use of rapid scan data in the Alpine region.

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REFERENCES

Bolliger, M., P. Binder, and HP. Roesli, 2001. Heavy precipitation systems as observed by Meteosat rapid scans during MAP. MAP newsletter, 15, 102-105.

Hanson, C. G., 1999. High temporal resolution Meteosat imagery of the Alps in support of the Mesoscale Alpine Programme. Proceedings of the 1999 EUMETSAT Meteorological Satellite Data Users' Conference, Copenhagen. 495-499.

Leese, J., C. S. Novak and B. B. Clark, 1971. An automated technique for obtaining cloud motion from geosynchronous satellite data using cross correlation. J. Appl. Meteor., 10,118-132.

Machado, L. A. T., W. B. Rossow, R. L. Guedes and A. W. Walker, 1998. Life Cycle Variations of Mesoscale Convective Systems over the Americas. Mon. Wea. Rev., 126, 1630-1654.

Schmetz, J., and M. Nuret, 1987. Automatic tracking of high-level clouds in METEOSAT infrared images with a radiance windowing technique. ESA Journal, 11, 275-286.