GEOMETRIC CLOUD HEIGHTS FROM METEOSAT AND AVHRR

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ABSTRACT

Geometric cloud height estimation provides an alternative to cloud top temperature methods if two satellites view the same cloud. First we demonstrate the stereo cloud height derivation with a combination of Meteosat 7 and Meteosat 5 5 km resolution Infrared data. Comparison with the temperature technique shows consistency in the majority of the clouds, but some differences. This demonstrates the stereo method as a verification tool for satellite cloud top temperature height retrievals. A case study of Meteosat plus AVHRR shows that the geometric technique can be extended beyond the range of overlapping geosynchronous observations. This uses an asynchronous stereo technique because the observations are not simultaneous.

1. Introduction

Estimating winds from cloud motion measured by satellite imagery has been studied for more than twenty years (Menzel, 2000). It is now being performed operationally for weather forecast model initialization. One source of uncertainty in the resulting wind fields is the height of the wind vector (). Combining the cloud top temperature, cloud emissivity and a temperature profile is the standard method for estimating cloud heights. Observations from different view points of the same cloud provides a method to measure cloud heights just from the geometry of the observations. This can be done with simultaneous stereo or asynchronous stereo where the cloud motion is derived at the same time as the geometric height().

2. Simultaneous Stereo: Meteosat 7 plus Meteosat 5

At EUMETSAT an automatic procedure has been developed to track clouds across sequences of images to estimate cloud motion (Schmetz et al. 1993). This has been adapted to the stereo problem. First a Meteosat 5 image from the INDOEX project (63^{o}E subpoint) was remapped to the Meteosat 7 projection (0^{o}E subpoint). This remapping assumes the input and output grids are on the geoid. Then the images were feed into the automatic tracking program to select and match cloud locations. The pair of latitude, longitudes were then analyzed for geometric height. These locations differ because of different parallaxes from the different view points. In essence the stereo software draws a line from the observation point and the apparent location of the cloud. A least squares fit is used to find the closest approach of the two lines from the different view points. With perfect measurements, the lines would intersect, but the fit is required because small measurement errors and navigation errors preclude the intersection of the two lines.

Figure 1 shows a Meteosat picture with superimposed cloud heights represented as colored spots. The first test of the algorithm is spatial consistency: are the heights random or organized like the underlying clouds. Qualitatively, the heights seem reasonable.

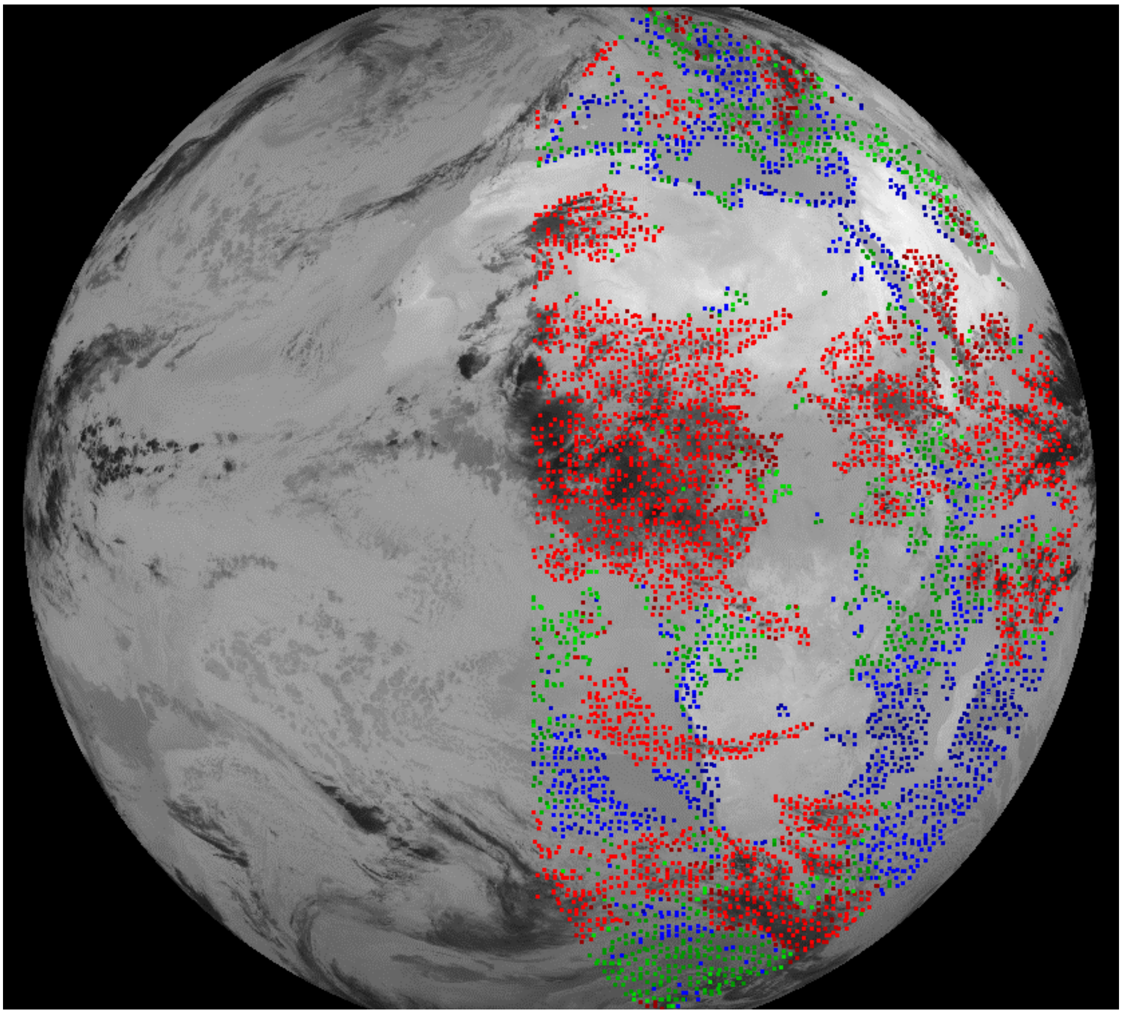

Figure 1. IR stereo cloud height analysis June 21, 1998: Consistency shows that the technique produces reasonable results. Red >7 km; Green 4 km < Z < 7 km; Blue < 4 km

This was applied to 5 km resolution infrared data. At first sight, this would seem too coarse a resolution to detect the subtle parallax shifts of cloud at different levels. But in fact the location of groups of pixels can be located to better than $\pm$ one pixel. This is incorporated in the standard EUMETSAT tracking software.

In the EUMETSAT cloud track procedure, the cloud top temperature is converted to cloud top pressure using the ECMWF temperature profile prediction for the time of the image (Schmetz et al 1993). Using the same profile, the geometric cloud heights were converted to pressure for comparison. Figure 2 shows a scatter plot of the two cloud top pressure estimates. In the majority of the cases, there is a match in heights within 107mb. This consistency is similar to other cloud top height comparisons (Nieman et. al., 1993).

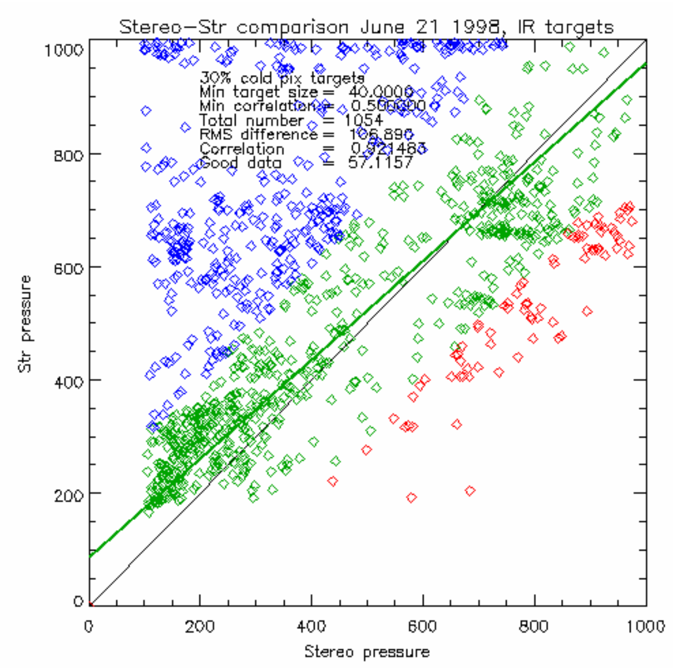

Figure 2. Cloud pressure derived from a simple cloud top temperature scheme (30% coldest pixels of a target) compared to the stereo pressures. The clusters in green show good correspondence. The red and blue clouds show areas of disagreement and potential algorithm improvement.

A further segregation of the cloud types is preformed in the automatic analysis. From the radiance in the window channel and the water vapor channel it is possible to distinguish semitransparent clouds. Figure 3 and 4 shows a comparison of the semitransparent clouds with stereo results. The cloud from the blue locations are clearly areas where the semi-transparent analysis should have been applied. The has been verified by a thorough image analysis showing that all these points originate from one extremely thin cloud for which the semi-transparency correction scheme did not sufficiently correct the pressure. The red areas indicate areas where the semi-transparent analysis was applied and in some cases over corrected the heights. The geometric scheme measures the height of the cloud edge but the temperature scheme searches of the coldest cloud top. Further study on the mismatched locations is warranted.

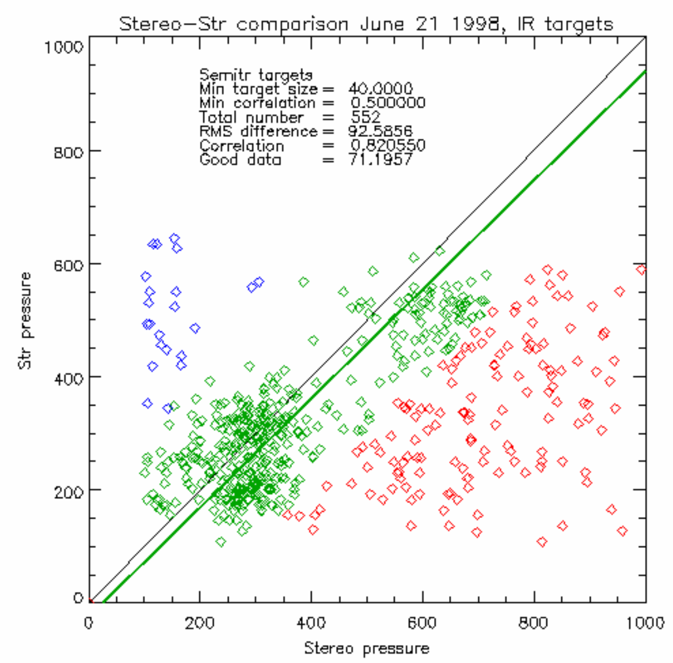

Figure 3. Cloud pressure from the semi-transparent cloud height analysis and stereo pressure.

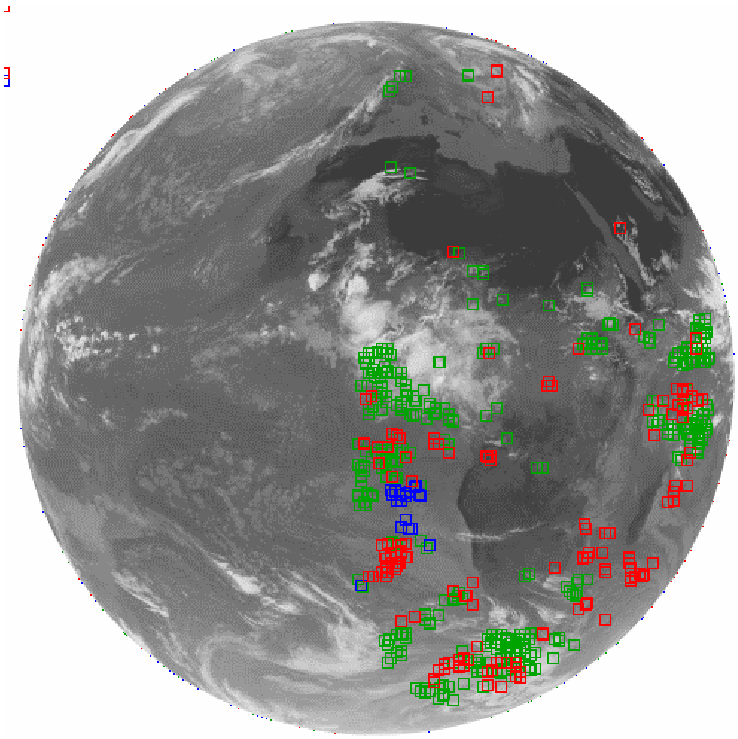

Figure 4. Cloud height matching between stereo heights and height derived with the semi-transparency scheme. The red targets clustered over the South Atlantic are related to very thin cirrus that were not detected by the temperature scheme. The blue targets east of Africa were falsely interpreted by the temperature scheme as transparent clouds.

3. Asynchronous Stereo: AVHRR + Meteosat 7 or Meteosat 5

To further test the geometric technique, a merger of AVHRR and Meteosat was performed. Here an asynchronous stereo analysis is required, because the observations are not simultaneous and the clouds often move between observations. The idea of fitting is performed here as well but allowing the cloud to move between observations. (Campbell 1998)

Figure 5 shows an image of AVHRR remapped to the Meteosat 7 projection, 1999 day 150 near 17:00. A movie loop of the M7 image at 17:00, AVHRR and M7 at 17:30 shows displacements of the clouds due to motion in time and parallax from the different view points. Again the automatic cloud selection and tracking software was run on these images to find successive cloud locations from the three images. The asynchronous technique uses the times, view points and locations of each cloud track to derive both motion and geometric height. Superimposed on the figure 7 are the cloud height estimates. As in the simultaneous stereo case, regional consistency shows the technique is working qualitatively.

As a reference, stereo heights were derived from the pair of Meteosat 5 and 7 images at 17:00. Figure 6 shows a scatter plot of heights of matching clouds. Very similar heights were obtained from the two. A hand adjustment was needed to the remapped AVHRR image, because the operational navigation of AVHRR is often not accurate to $\pm$ 10 km. This is not an inherent problem of the satellite, but a choice of NOAA operational procedures.

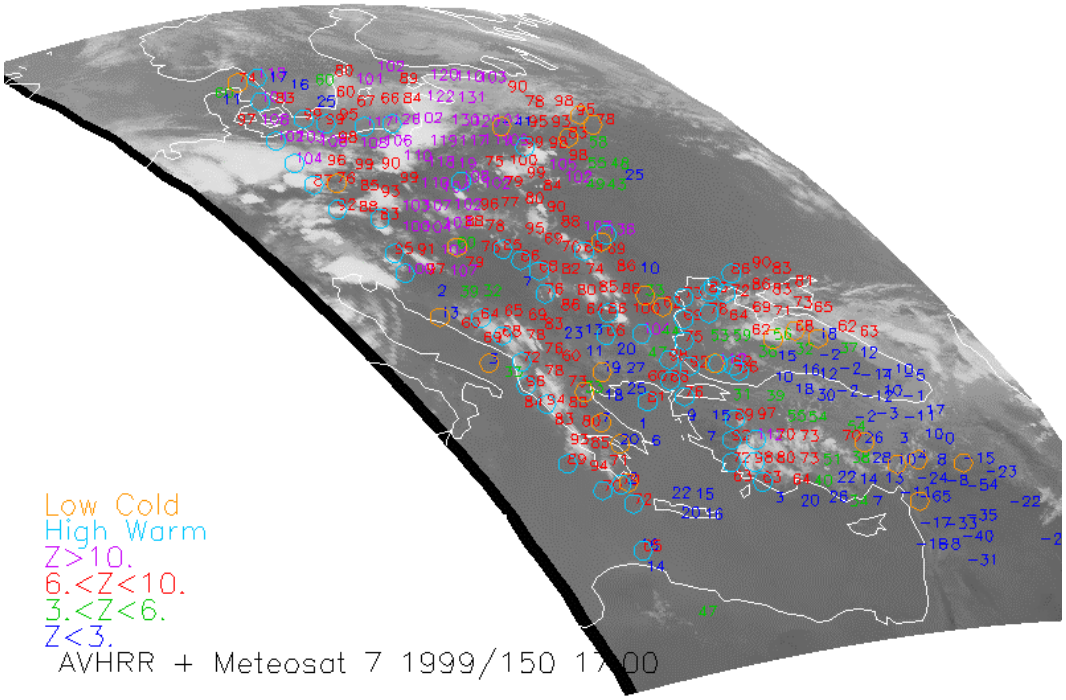

Figure 5. Asynchronous Stereo heights in hectometers (10=1km) from Meteosat 7 at 17:00 and 17:30 and AVHRR between those times for day 150 of 1999. As discussed below, geometric heights with large disagreements between temperature and heights are noted as colored circles: warm high objects (blue) and cold low objects (orange).

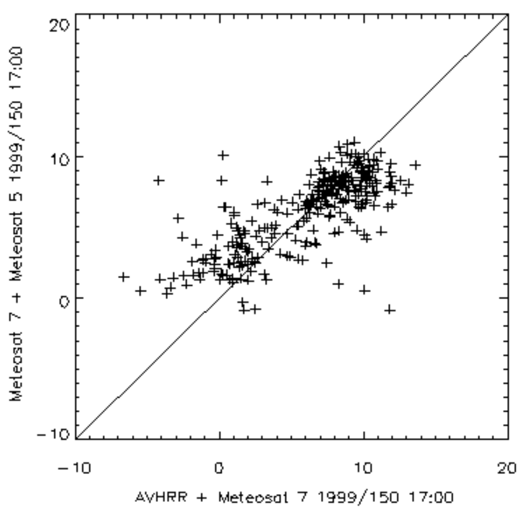

Figure 6. Asynchronous stereo AVHRR + M7 vs Stereo M7 + M5.

Similarly a comparison is possible between the geometric cloud height and the cloud top temperature. Figure 7 shows qualitative consistency: high clouds are colder that low clouds. Cloud which are warm and high (geometric) and cold and low (geometric) are noted in figure 5 with colored circles. As in the first case discussed above, there is some organization to the anomalous clouds, they appear at the edges of the cloud systems and thus have less well defined temperatures.

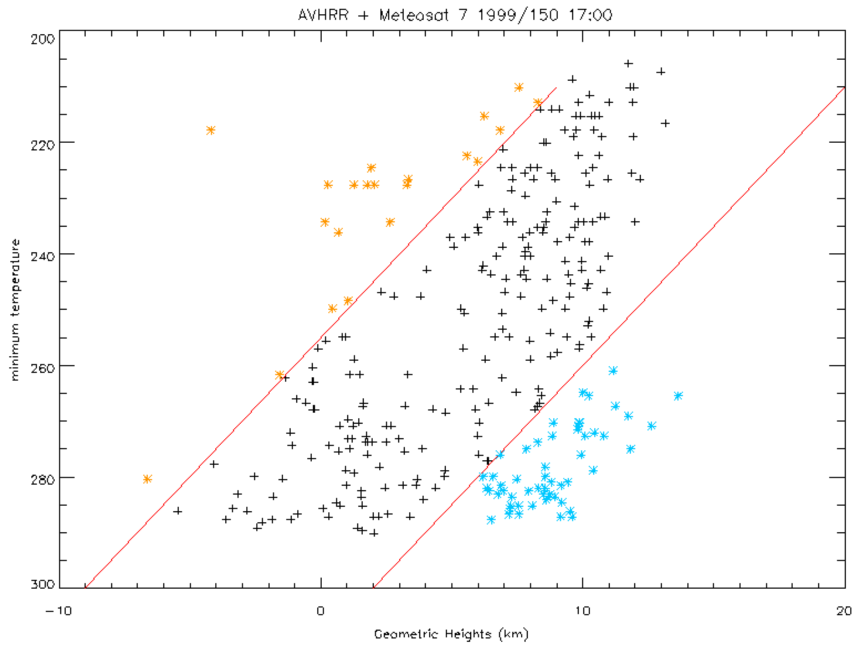

Figure 7. Scatter diagram of geometric heights vs cloud top temperature (the coldest pixel in the 50 km region of the cloud.

4. Discussion

The stereo cloud height estimates from Meteosat 5 km resolution data are not more accurate that the temperature methods, basically because 5 km pixels do not provide accurate enough cloud locations for stereo heights better than $\pm$ 2 km. But we did demonstrate that geometric methods can locate problem clouds for testing temperature methods. This will lead to improved temperature methods with algorithm refinements.

On the other hand, the comparison shows that stereo cloud height estimates of cloud with variable cloud top temperatures do not measure the cloud top height. The stereo method is actually measuring the height of the cloud edge. If one wants just cloud top heights, the inhomogeneous clouds should be dropped from the stereo reports because there are clouds with complicated cloud top shapes and in fact do not have a single cloud top heights. Less successful tests were also performed with Meteosat visible channel observations. There was more scatter in cloud heights in regions across the overlap area between the two satellites.

With higher resolution MSG observations, the stereo method will improve. Combination with GOES IR observations or the older Meteosat will require the asynchronous method because simultaneity will not occur very often with different scanning schedules.

The stereo analysis will be used in the verification of the cloud tracking software once MSG is launched later this year. Modest improvements will be made in the temperature height retrieval with more accurate temperature measurements, but that technique is limited by knowledge of the temperature profile. The geometric techniques are not limited by the fact that the atmosphere is isothermal near the tropopause so more precise results are possible with improving resolution and better cloud matching.

5. Conclusion

We have demonstrated geometric cloud height estimation using a simultaneous stereo to analyze automatically selected clouds and cloud locations. In comparison to the standard cloud top height estimate from temperature, the stereo method is able to identify problem areas in the temperature results leading to algorithm improvements. Similarly, rejecting the clouds with variable cloud top temperature will improve the stereo results.

The merger of polar orbiter and Meteosat observations shows that the geometric cloud height analysis can be extended beyond the regions of overlap between geosynchronous satellites.

Some of the images in the report can be viewed in animation at: http:///acamar.cira.colostate.edu.

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REFERENCES

Campbell, G.G., 1998, Asynchronous Stereo Height and Motion Analysis: Applications, *Proc. Fourth International Winds Workshop*, EUMETSAT, EUM P24.

Menzel, P., 2000, Cloud tracking with satellite imagery: From the pioneering work of Ted Fujita to the present, *Bull. Amer. Meteor. Soc.,* accepted for publication.

Nieman, S. J., J. Schmetz and W. P. Menzel, 1993: A comparison of several techniques to assign heights to cloud tracers. *J. Appl. Meteor*., **32**, 1559-1568.

Schmetz, J., K. Holmlund, J. Hoffman, B. Strauss, B. Mason, V. Gartner, A. Koch and L. van de Berg, 1993, Operational Cloud-Motion winds from Meteosat Infrared Images. *J. Appl. Meteor*., **32**, 1206-1225.