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Determination and correction of the relative shift between the visible and thermal infrared GOES sensor images

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Abstract. A simple method for the correction of the relative shift between the visible and thermal infrared GOES sensor images is introduced. It makes use of the variance operator and the cross-correlation between two patterns. Results indicate that the proposed method is very promising.

1. Introduction

There have been many indications that, in general, a *relative* displacement between the visible and thermal infrared GOES sensor images exists in some data sets prior to August 1981. This problem is probably caused by misalignments of the visible and thermal infrared sensors of the satellite. These shifts have been reduced or eliminated with the launch of GOES–5 in August 1981. Up to now this problem is usually corrected by trying to identify, by eye, some strong gradient caused by coastline features or small cumulus clouds (Bellon *et al.* 1982). In this paper a method which corrects automatically this relative shift is proposed. Most important, as will become apparent, the proposed method could be used to test for future shifts in the satellite sensor data.

2. Data

The data used in this work consist of GOES visible (0·54–0·70 μm wavelength) and thermal infrared (10·5–12·6 μm wavelength) sensor images. After processing, these data are presented in cartesian coordinates and in digital form with a spatial resolution of 4×4 km. The true spatial resolution of the sensed infrared images is 8×8 km. From these images, using a simple linear interpolation scheme, 4×4 km resolution images have been constructed to obtain resolution equivalence between the visible and thermal infrared data. More details on the data processing can be found in Bellon (1979). The temporal resolution of the GOES sensor data is 30 min. The intensity range of the visible image is 0–63 and that of the thermal infrared is 0–255.

3. Method

The method used in this paper can be presented in two steps. In the first step the variance operator is used and in the second step the cross-correlation between two patterns is used.

Over the neighbourhood of each point (i,j) of the image, the variance operator, $\sigma^2(i,j)$, is defined as (Reeves 1975):

$$\sigma^2(i,j)=\frac{1}{9}\sum_{k=i-1}^{i+1}\sum_{l=j-1}^{j+1}[f(k,l)-\bar{f}(i,j)]^2$$

where

$$\bar{f}(i,j)=\frac{1}{9}\sum_{k=i-1}^{i+1}\sum_{l=j-1}^{j+1}f(k,l)$$

For any point (k,l), $f(k,l)$ is the thermal infrared DN, when the thermal infrared image is considered, or the visible DN when the visible image is considered. In other words the variance operator at each point will involve the eight immediate neighbours.

The variance operator works on the principle that at the boundary of two different classes there is a large mix of pixel DN, and so the variance is high. After the investigation of the first results from the use of the variance operator, it became apparent that the main features of the image in both the visible and thermal infrared channels give rise to high variance operator values in their boundaries. It was also observed that the positions of these boundaries did not coincide in the visible and thermal infrared images. Therefore when a shift between the two variance operator fields is predicted so that the best match is achieved, the actual shift between the visible and thermal infrared images will be indicated. Figures 1 and 2 are examples of variance operator fields for the visible and thermal infrared image respectively, over the Toronto, Ortario area on 4 December 1980 at 16.00 G.M.T. On this date and

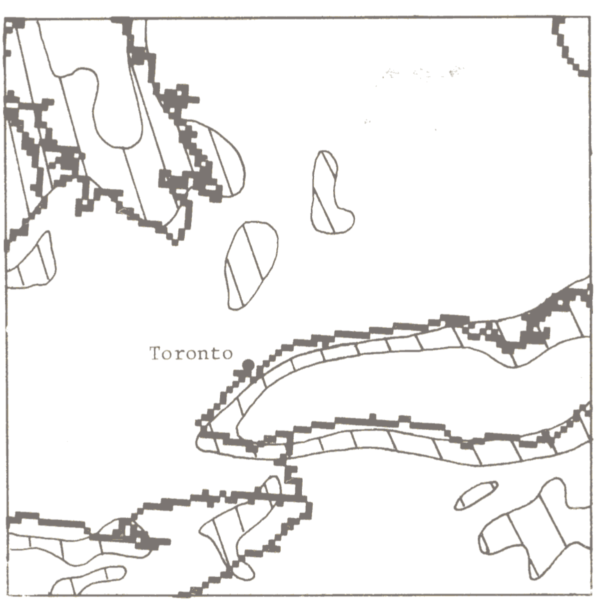

Figure 1. Variance operator field of the visible image over the Toronto area, at 16.00 G.M.T., 4 December 1980. Hatched areas represent regions with variance operator values greater than eight. The actual geographical boundaries are also indicated.

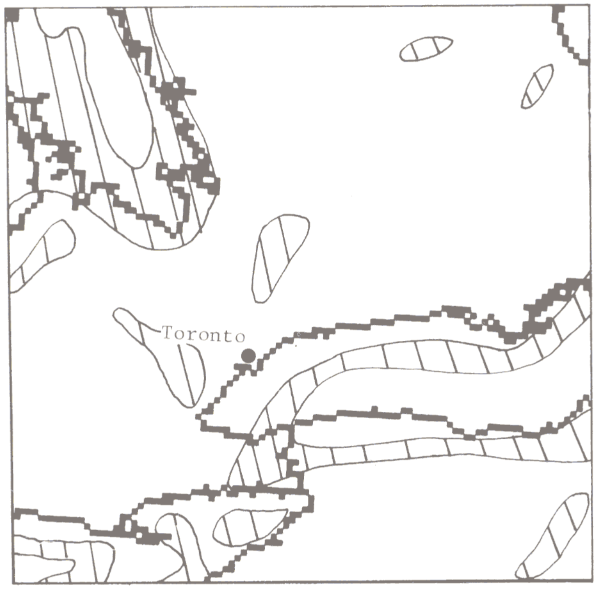

Figure 2. Variance operator field of the infrared image over the Toronto area, at 16.00 G.M.T., 4 December 1980. Hatched areas represent regions with variance operator values greater than eight. The actual geographical boundaries are also indicated.

over this area the skies are mainly clear but some clouds are present. The geographical boundaries around the Toronto area are also indicated. The hatched areas indicate values of the variance operator greater than eight. This is an arbitrary consideration based on the visual inspection of the images and their variance operator fields. It was observed that within regions that represent smooth fields (for example, lakes, overcast, smooth land, etc.) the variance operator hardly exceeds the value of eight. On the other hand, in the boundary of two different classes, this value is usually higher than eight. In any case, this value should be regarded as a limit which will separate higher from lower values and it is used for illustrative purposes only.

After the variance operator has been applied to both images a cross-correlation between the two variance operator fields was performed. The cross-correlation can be expressed mathematically as below and indicates the degree of matching which exists between two patterns as their relative position in space is varied

$$\gamma(x_0, y_0) = \frac{1}{NS_V S_I} \iint (V(x,y) - \bar{V}) * (I(x+x_0, y+y_0) - \bar{I})\, dx\, dy$$

where

(*a*) $\gamma(x_0, y_0)$ is the cross-correlation coefficient between the two patterns at a spatial lag (x_0, y_0).
(*b*) $V(x, y)$ and $I(x, y)$ are the spatial distributions of the variance operator values for the visible and infrared image respectively.
(*c*) $N = \iint dx\, dy$ is the area of integration.
(*d*) $\bar{V}$, $\bar{I}$ are the average values of the fields $V(x, y)$ and $I(x, y)$ over the area N.

(*e*) S_V, S_I are the standard deviations of $V(x, y)$ and $I(x, y)$ over N, i.e.

$$S_V = (\iint (V(x, y) - \bar{V})^2 \, dx \, dy / N)^{1/2}$$

The spatial lag at which the cross-correlation coefficient is maximized will indicate the displacement in the west–east (x) and north–south (y) direction. For more information on the computation of $\gamma(x_0, y_0)$ see Tsonis and Austin (1981).

4. Results

The table gives some preliminary results obtained according to the above procedure, over the area of figure 1. The sky condition is also given for each day. The north–south and west–east displacement is given in kilometres. Positive displacements mean that the thermal infrared image is displaced south–eastwards with respect to the visible image. The number in parentheses is a comparison with results obtained by Bellon *et al.* (1982), who tried to navigate the visible and thermal infrared images by examining visually sharp coastline features. An apparent agreement between the two methods is clear. The method seems to work satisfactorily for different weather situations such as partly cloudy, cloudy or mainly clear skies. This is not surprising since different 'classes' whose spectral responses differ will, most likely, be present irrespectively of the weather situation. Therefore, boundaries between those 'classes' will be defined by the variance operator. It can also be observed that on 13 October 1981, the shift is much reduced as compared to those previous to August 1981. The advantage of a method like the above is that visual inspection could be avoided and that the navigation between visible and thermal infrared image can be undertaken quickly and before any analysis of the data which will involve both images.

5. Discussion and conclusions

A simple method has been presented for the correction of the relative shift between the visible and thermal infrared GOES sensor images. The method employs the variance operator and the cross-correlation between two patterns. The use of the variance operator results in a variance operator field with higher values in the boundaries of the various classes that exist in a satellite sensor image. After that, the cross-correlation between the variance operator fields of the visible and thermal infrared images can be used effectively to determine the spatial lag at which the best matching between the two fields is achieved. This spatial lag indicates the relative shift between the two variance operator fields and consequently between the visible and thermal infrared images. Comparison of the results with those taken by visual

Relative shift between the visible and infrared images.

Date	Time	Sky conditions	North–south displacement (km)	East–west displacement (km)
4 December 1980	16.00 G.M.T.	Mainly clear	16 (12)	8 (10)
1 April 1981	18.00 G.M.T.	Cloudy	12 (12)	12 (10)
6 June 1980	17.30 G.M.T.	Partly cloudy	8 (9)	12 (10)
23 July 1980	18.00 G.M.T.	Cloudy	6 (6)	8 (10)
13 October 1981	19.00 G.M.T.	Mainly clear	6 (6)	4 (3)

inspection of the images indicates that the method appears to be very promising. It should be mentioned that the use of the variance operator is necessary because a direct cross-correlation between the visible and thermal infrared images is not very effective. The cross-correlation is very effective when a strong gradient is present and this is better achieved by using the variance operator. Even though a correction of the relative shift between the two images is very important for point to point comparisons, for example in classification, a correction of the shift between the images and the actual geography is sometimes needed. These so-called *absolute* navigational errors are also present and are usually caused by satellite manoeuvres. These manoeuvres are necessary to maintain the satellite's position and orientation within certain bounds. Accurate orbit and altitude parameters are determined within a few hours of the manoeuvre but for the first few images this is not possible. These shifts are, usually, corrected by visual inspection. An alternative which is under study is the following: geographical boundaries could be superimposed in the satellite sensor images. If the weather situation is mainly clear skies then most of the high values in the variance operator fields of the visible and thermal infrared images are due to the terrain. For example, in figure 1 and 2 around the boundaries of Lake Ontario there are high variance operator values resulting from the different visible and thermal infrared values for water and land. If there is a shift between the images and the actual geography then the geographical boundaries generated in the variance operator fields will not coincide with the actual superimposed geographical boundaries. In such cases the superimposed geography can 'act' as a third variance operator field where high values have been assigned to the geographical boundaries, and a similar procedure to the one described above could be employed. However, such a method could only be applied when it is mainly clear skies and most of the 'noise' in the variance operator fields is generated by the geography. The presence of clouds will undoubtedly create problems and if the amount of cloud is high such a method cannot be applied. It is believed that one method applicable *to all weather situations* is not feasible at this time. However, the proposed method can effectively be used in different weather situations to correct the *relative* shift between the two images and it can also be used to test for possible shifts in the future data.

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