Forecasting Research

Forecasting Research Division
Technical Report No. 154

Thresholding Methods for the Identification of Cloud in Meteosat Imagery

by

P.M. Jackson

28 February 1995

Meteorological Office
London Road
Bracknell
Berkshire
RG12 2SZ
United Kingdom

Forecasting Research Division

Technical Report No. 154

Thresholding Methods For the Identification of Cloud in Meteosat Imagery

P M Jackson

28 February 1995

Forecasting Research Division
Meteorological Office
London Road
Bracknell
Berkshire RG12 2SZ
UNITED KINGDOM

Thresholding Methods for the Identification of Cloud in Meteosat Imagery

1 Introduction

This technical note explores the method by which we hope to improve the detection of cloud from the information available in geostationary satellite imagery. This is of particular importance for numerical forecast models, where automation of the task of cloud detection and classification from such imagery is becoming more important.

The discrimination of areas of cloud from cloud-free regions, and the distinguishing of one type of cloud from another, in particular the detection of areas of convective as opposed to frontal cloud, can be relatively straightforward for experienced meteorologists. However, it is important that reliable objective algorithms be developed for the automatic detection of cloud, so that appropriate use can be made in NWP models of the wealth of information contained in the available satellite imagery.

The frequent availability of Meteosat imagery has great potential benefit for the Mesoscale Model in particular. The work reported on here is primarily driven by the need to develop appropriate algorithms for processing Meteosat imagery for data assimilation into the Mesoscale Model.

For this report, we make use of data from the two Meteosat Channels, (Vis and IR), and the forecast surface temperature extracted from the Mesoscale Model. All the images included in this report are on the same space-view projection as currently sent to Frontiers, an area comprising 466 pixels by 256 lines. The current Mesoscale Model area lies in a subsection of this, covering an area of approximately 260 pixels by 160 lines.

A number of methods for classifying Meteosat Images have been considered. This note however, is concerned solely with cloud detection, and not classification, and deals with the use of threshold methods only.

2 Summary of Results

It was found that there is useful information within the Visible imagery which can be used in the detection of cloud. This is especially true for low cloud where the cloud-top temperature is close to the forecast surface temperature. The best results from use of the Meteosat imagery to detect cloud were obtained when the albedo information was used as a supplement to the current IR thresholding test, and not as a direct replacement.

The investigation into the use of visible imagery did reveal some anomalies in the normalisation. As the earth tips away from the sun during the winter, the calculated albedo expected at any particular pixel increases. Also, in the midday images there appears to be a peak in calculated albedo, even where there would appear to be no cloud in that region. Both these effects increase in intensity the further north the pixel lies. The method by which the visible imagery was normalised for this report follows the Autosat-2 method. This to be compared with the method used in Frontiers and Nimrod to identify differences, and possible errors.

3 Thresholding Options

3.1 Using the IR image and the forecast surface temperature

This is the method currently employed within the Mesoscale Model. Every half-hour, each pixel's brightness temperature in the reprojected infrared image is compared against the forecast surface temperature for that time in the corresponding MM grid square. A very simple algorithm is then applied. If the pixel temperature is more than 5^oK below the forecast surface temperature the pixel is regarded as fully cloudy, otherwise it is taken to be fully clear.

The contribution from each pixel is used to calculate a cloud-cover fraction for each of the model grid squares. Given that the areal coverage of a Meteosat pixel over this region is about 7.5 km by 5 km, several Meteosat space-view pixels will lie in the same model grid square. To ensure no loss of pixels from the original image, reprojection of the space-view area should be onto a grid finer than the current model area. (0.05^o squares ($\approx$ 5.5km) should prove sufficient). Calculation of MM grid square quantities should take account of each space-view pixel only once, so some of those nine 0.05^o squares which comprise each 0.15^o grid square will not contain a data value.

3.2 Using the Visible image alone

All visible images have been normalised using the secant of the solar zenith angle, so that pixel values in the range 1-254 correspond to albedos from 0-100%.

The simplest way to use the visible imagery would be to decide whether any pixel were cloudy or clear by means of a single albedo threshold value. This threshold should be set no lower than the value recorded at any pixel in the image under cloud-free conditions, otherwise pixels may be classified as cloudy even when clear.

The case of 04 October 1994 at 1000UTC (Figures 1a-1d) has been chosen to illustrate this result, as an example of an image containing clear and cloudy conditions over both land and sea. The method used to verify this method was subjective, and used the IR image for guidance in identifying cirrus not immediately apparent in the visible channel. When the single-value threshold was set at the observed value of what was judged to be cloud-free land, large areas of cloud over the sea were classed as clear because the albedo of the cloud was lower than that of cloud-free land.

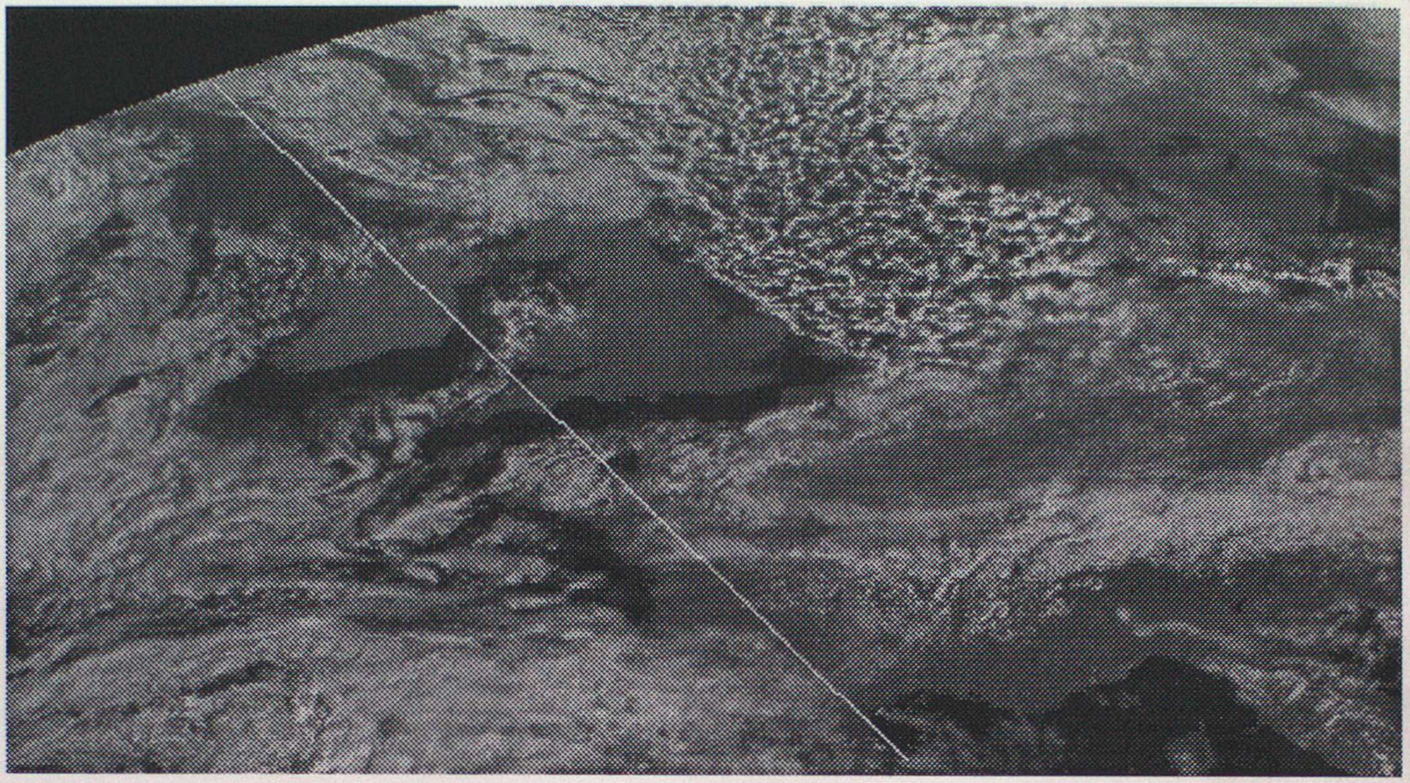


Figure 1a: Normalised Image 04 October 1994 1000

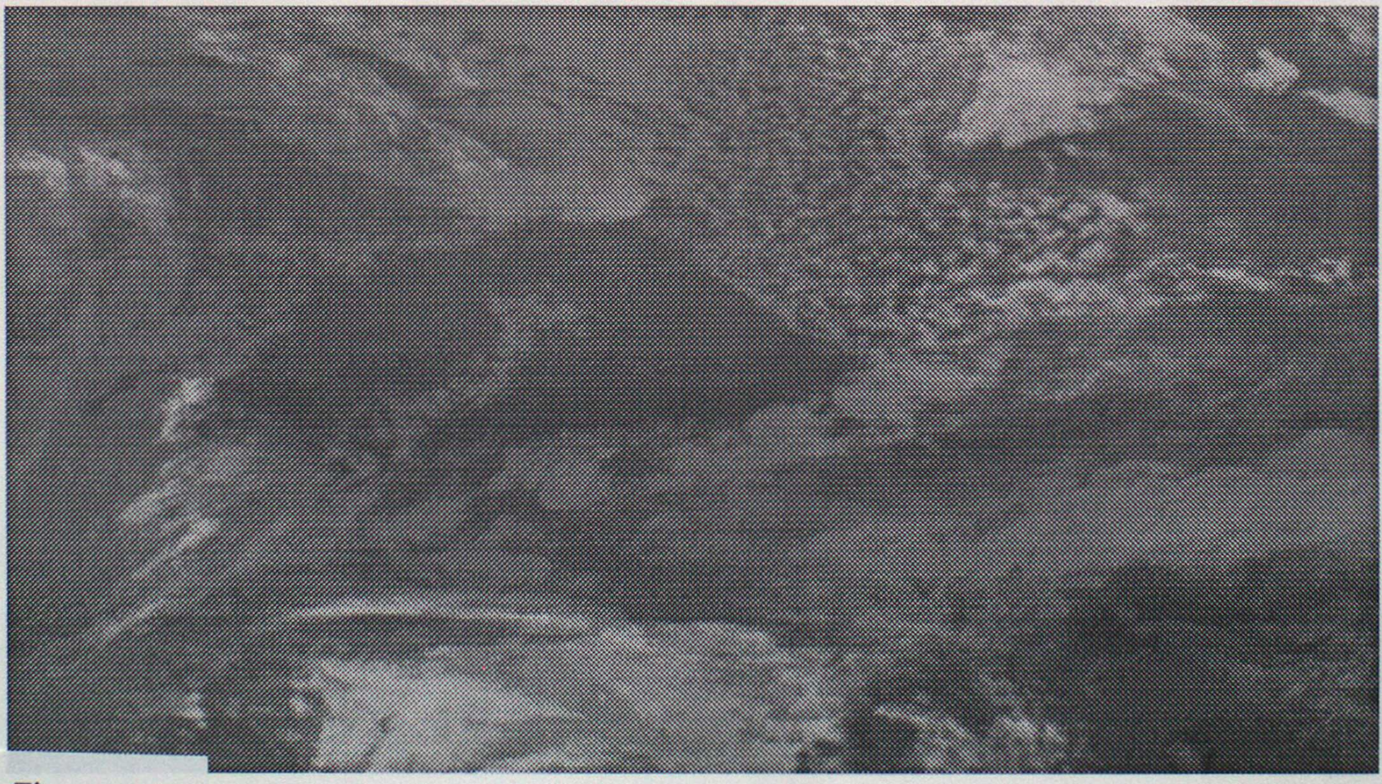


Figure 1b: Infrared Image 04OCT94_1000

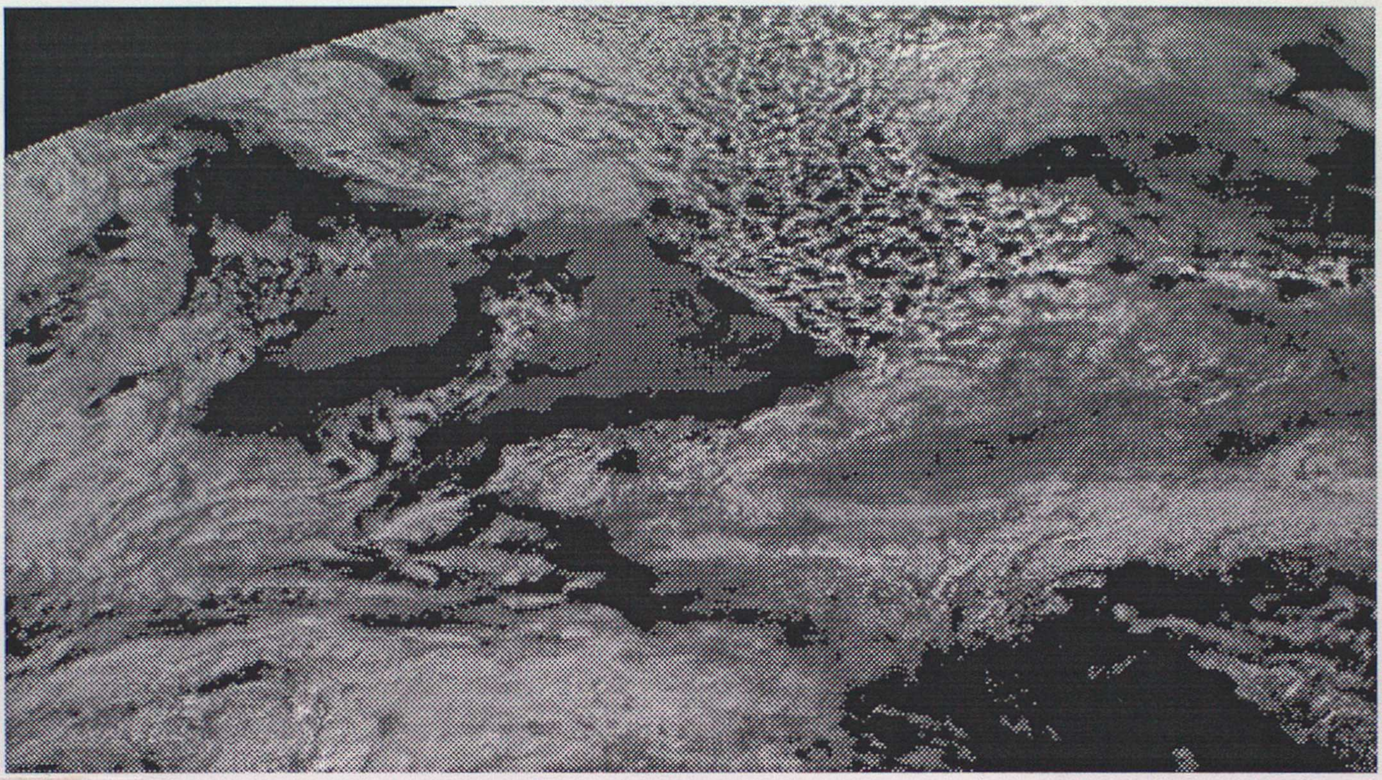


Figure 1c: 04OCT94_1000, Threshold applied 55

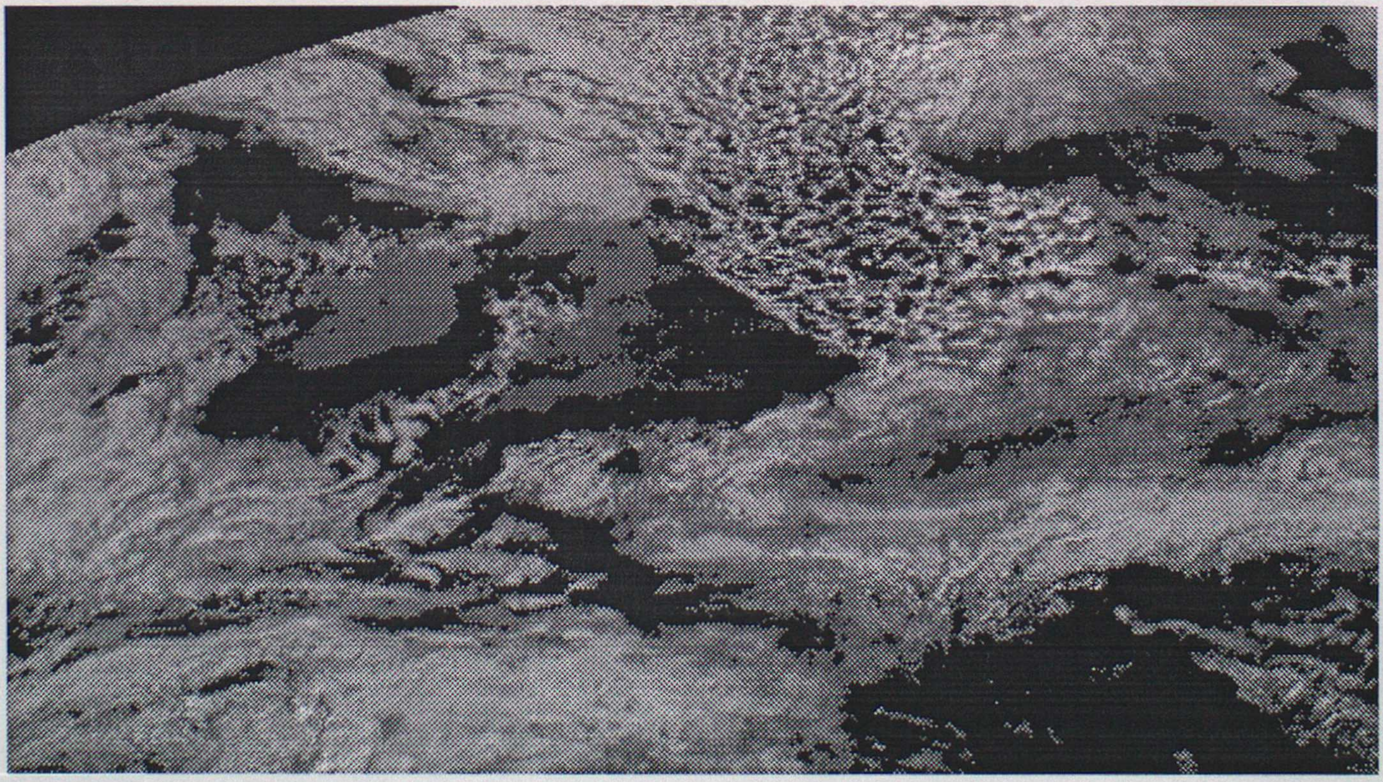


Figure 1d: 04OCT94_1000, Threshold applied 60

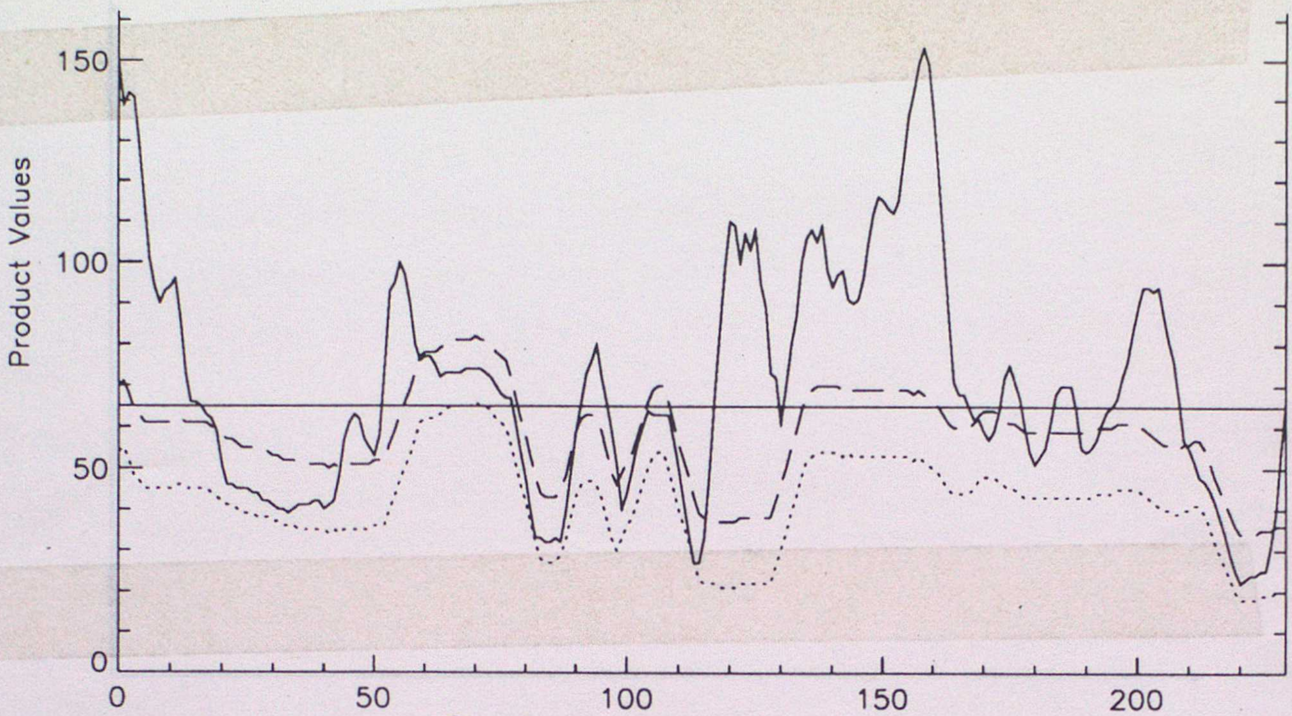


Figure 2: Slice of Product Values across Image 04 October 1994 1000 UTC

To illustrate this, figure 2 contains a profile of pixel values, taken along the line as shown in Figure 1a. The finely dotted line is the expected albedo across this profile, determined by the method as described below in 3.3.1. The lower values along this finely dotted line relate to areas of water, and the higher values occur where the profile crosses Eire, South Wales, South-West England and mainland Europe. The unbroken plot line shows the pixel values observed at that time, there being well-defined cloud near the edge of the image, low-albedo cloud north-west of Eire, a line of cloud in the Bristol Channel, and thicker bands of cloud over the English Channel and mainland Europe. In this particular example, the fixed threshold is drawn across at a pixel value of 65 (25.6% albedo), the maximum expected under cloud-free conditions, and a variable threshold is drawn at a level of 16 counts (6.3% albedo) above the finely dotted line (see 3.3.2 below).

Where the unbroken plotted line lies above whichever threshold is to be used, the pixel is taken to be to be 'cloudy', otherwise it is 'clear'. The results will differ only where the unbroken plot line lies between the fixed threshold and the variable threshold. This can be seen most clearly at the points along the x-axis 13-18, 43-51, and 225-230. Use of a fixed threshold would fail to identify these areas as cloud.

It is, however, recognised that even a variable threshold will not identify all cloud over land, as the threshold must still be sufficiently high to allow for the variation in albedo under cloud-free conditions.

The use of a variable threshold is discussed in the next section.

3.3 Combining the Visible with generated 'cloud-free' images

This option would infer the presence of cloud by comparing values in the current normalised visible image with the albedo expected under cloud-free, or clear-sky conditions for that month of the year. If a pixel in the visible image is brighter than in the reference image, that indicates an area of cloud (or possibly some other feature such as snow). Work has been carried out to assess the feasibility of this method, as described in the following section.

3.3.1 Generation of the clear-sky (reference) images

The period over which to generate these reference images had to be chosen so as to have a reasonable chance of a cloud-free event at each and every pixel in the image, but short enough to determine if there were a seasonal variation in albedo. The period of one calendar month was chosen in order to balance the two requirements. Towards this end, 'clear-sky' images have been produced for the months of July, August, September, and the first 19 days of October 1994 (Figures 3a-3d).

To generate these 'clear-sky' images, all available visible images within the period were collected, and normalised in turn, eliminating pixels which were within one hour of local dusk/local dawn, to be certain of good illumination, and so avoid over-brightening or over-darkening near the terminator. The albedo values occuring at each pixel were stored, and the lowest value occurring in that period was taken to be the expected albedo for that pixel under cloud-free conditions.

As can be seen in the generated images of 'clear-sky' conditions for each of the four months processed so far, there is a definite increase in albedo towards the pole. This effect becomes more pronounced in the later months of the year, and it may be either an atmospheric effect as the north pole tilts away from the sun in the northern winter, and the instrument looks through a greater depth of atmosphere, or some feature of the normalisation process. There is currently work going on to validate the normalisation, and depending on those findings, it may be necessary to change the current normalisation process.

It should be stated that while it is unrealistic for the 'clear-sky' image to show a latitudinal dependence in the reflectivity of the surface, any effect, be it atmospheric or in the normalisation, will be echoed in the image which is being compared with it. However, if the normalisation were to be changed at a later stage, the reference images would also have to be recalculated.

It was not clear at the outset whether the clear-sky image to be used should be that generated from the previous month's images (which would lag behind any seasonal change), or the images from the same month but previous year as the current image. However, inspection of the reference images showed a strong seasonal change in albedo, and it was felt that more realistic results would be obtained by using a reference image generated from the same month of the year as the current image. Using a reference image from the previous month would mean that the reference image would be too bright in comparison with the current image in the first half of the year, and too dark in the second half. Using a reference image generated from 1993 data for comparison

Figure 3a: Background Albedo for month of July 1994

Figure 3b: Background Albedo for month of August 1994

Figure 3c: Background Albedo for month of September 1994

Figure 3d: Background Albedo for month of October 1994

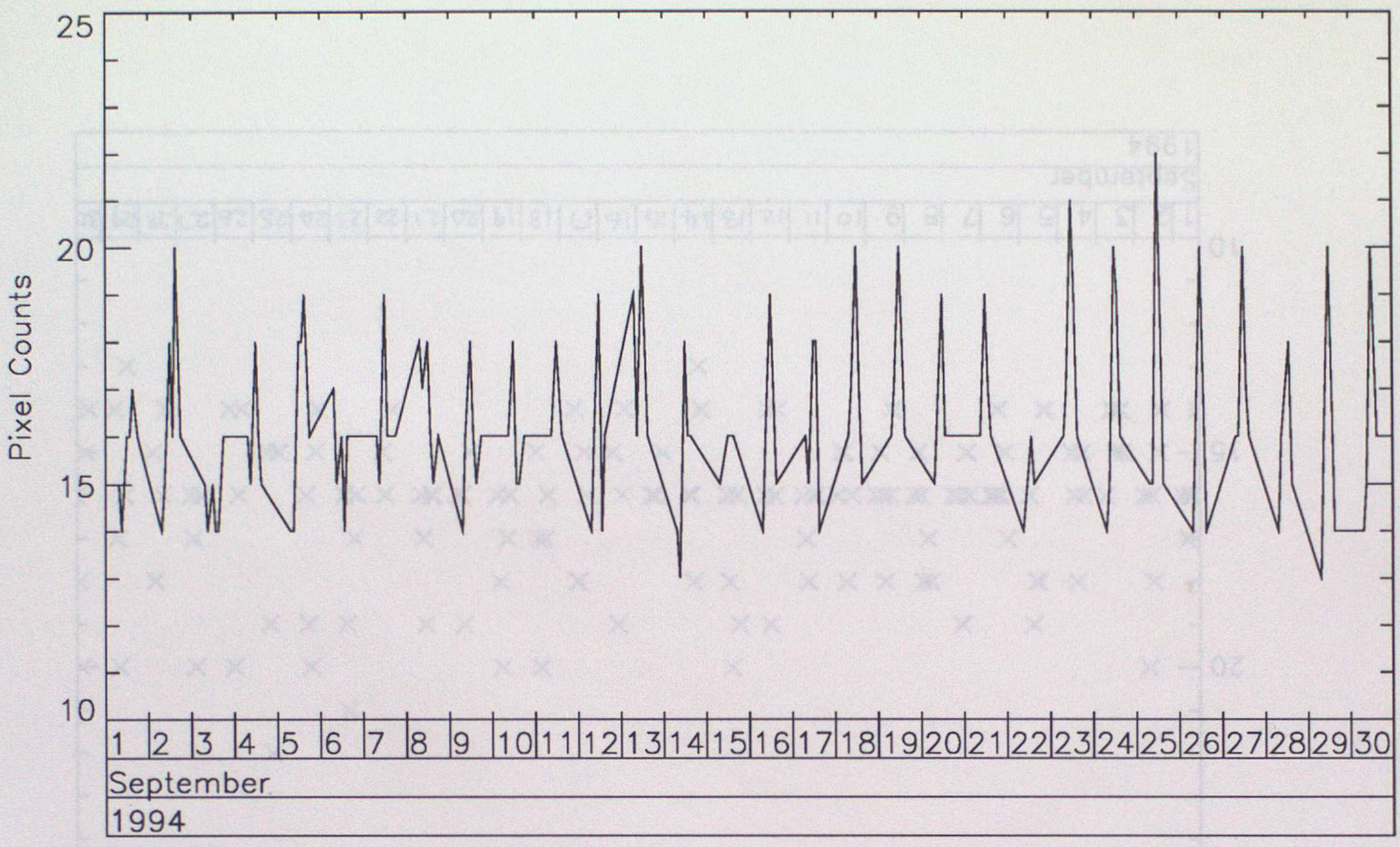


Figure 4:Thresholds Obtained for September 1994

with a 1994 image was considered. A strong reason for not using 1993 data was that in October of that year, Darmstadt made a change to the rectification of the images. The result of the new rectification was a far more consistently navigated product. Using data before this date could have introduced unwanted errors.

The reference image used was therefore generated from the current month's data, only possible because we were not working in real-time. This did mean that the image being compared had been one of 300 or more used to generate the reference image, but the effect of a single image in those 300 was felt to be minimal.

3.3.2 Determination of the Threshold Value using the Reference Albedo Image

This is a discussion concerning how the information in these reference images was used subjectively to determine the threshold to apply to a visible image, to 'best' separate cloud/no-cloud.

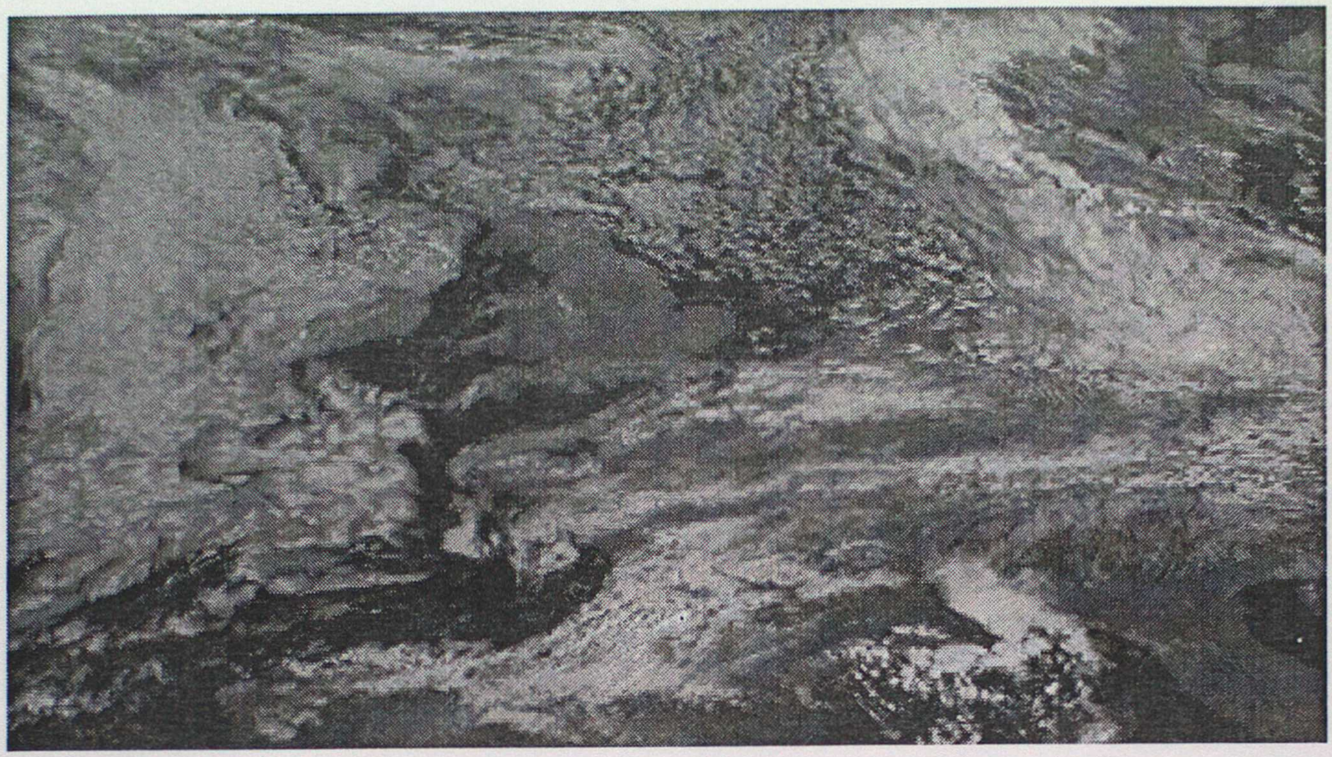
The threshold value was arrived at by displaying each of the 08, 10, 12, 14, 16 and 18UTC images from a chosen month in turn. Using the matching IR image for guidance in identifying cirrus, the difference threshold by which pixels were blacked out was adjusted until it was considered that all the cloud-free areas were defined. The threshold value thus determined for these two-hourly images was stored and is plotted on the graph in Figure 4. As can be seen, there is relatively little variation, either from hour to hour or from day to day. The average threshold value determined over the month was 16.32, with a maximum of 22 and a minimum of 13 (standard deviation was 1.79). We feel therefore that we can have some degree of confidence in justifying a threshold level of 16 for most images (but see notes regarding a feature of the midday images in Section 4).

To illustrate the result of using this variable threshold, a number of cases (those which have clear and cloudy areas over land and sea) are considered (Figures 5a - 6c). They are shown in matched pairs, the original visible image and an image in which pixels classed as clear are black. To facilitate comparisons between the two images, the 'cloudy' pixels retain the pixel values as they appear in the original image. In all of these cases, the same threshold has been applied, that of a difference in the pixel values of 16, equivalent to $(16*100./(254.-0.)) = 6.3\%$ albedo.

It should be noted that in most of the images processed with this variable threshold, a reasonable result is achieved. In most, if not all images, the land is classed as clear when appropriate, on occasions leaving residual 'cloudy' pixels in regions such as northern Spain, and less frequently Scandinavia. Inspection of the values found in the reference image over the area of Spain revealed a relatively large variation in pixel values, as compared to other areas of land in the clear-sky image, and it may be that a slight rectification difference plays a part when comparing the two images.

Since both these regions are outside the MM area, it is not seen as a serious failing at this time. When residual 'cloudy' pixels have been observed over the British Isles, the presence of thin cirrus has been inferred from the IR image.

Image To Classify 13AUG94 0900



Cloud Classified Image 13AUG94 0900

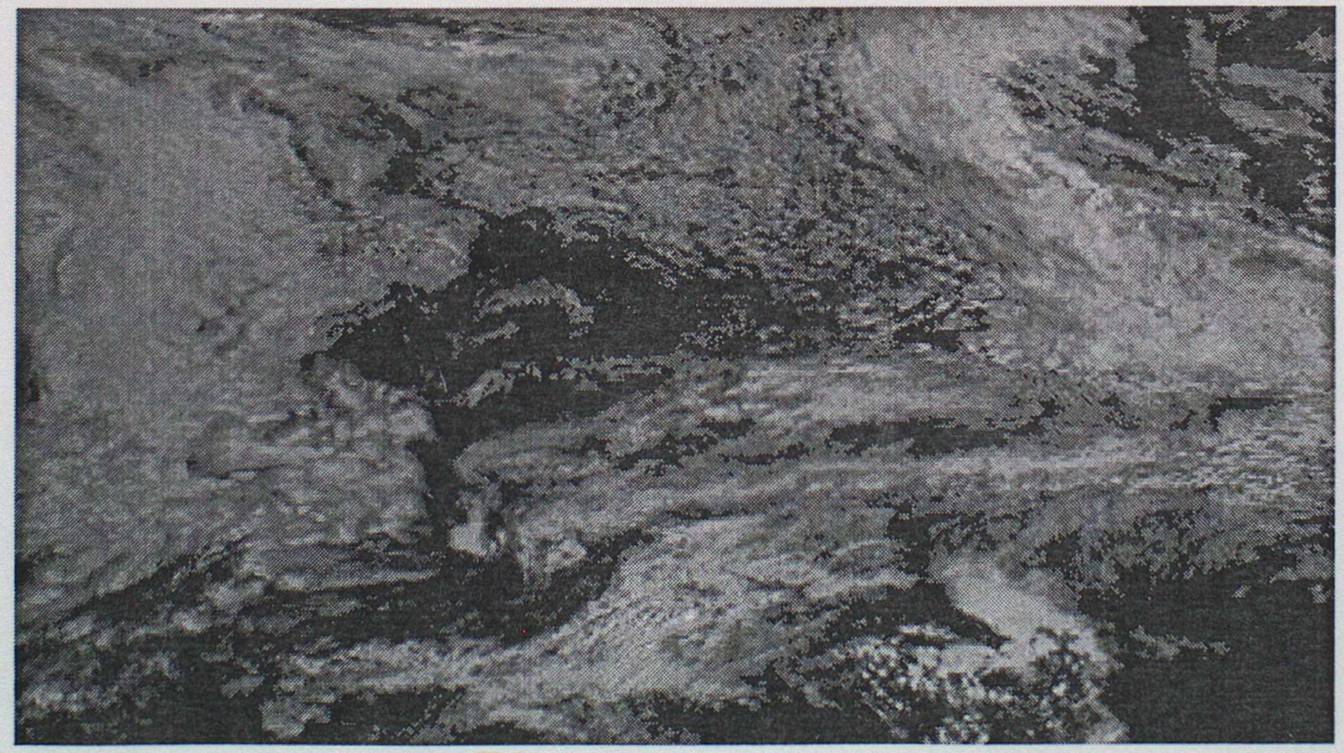
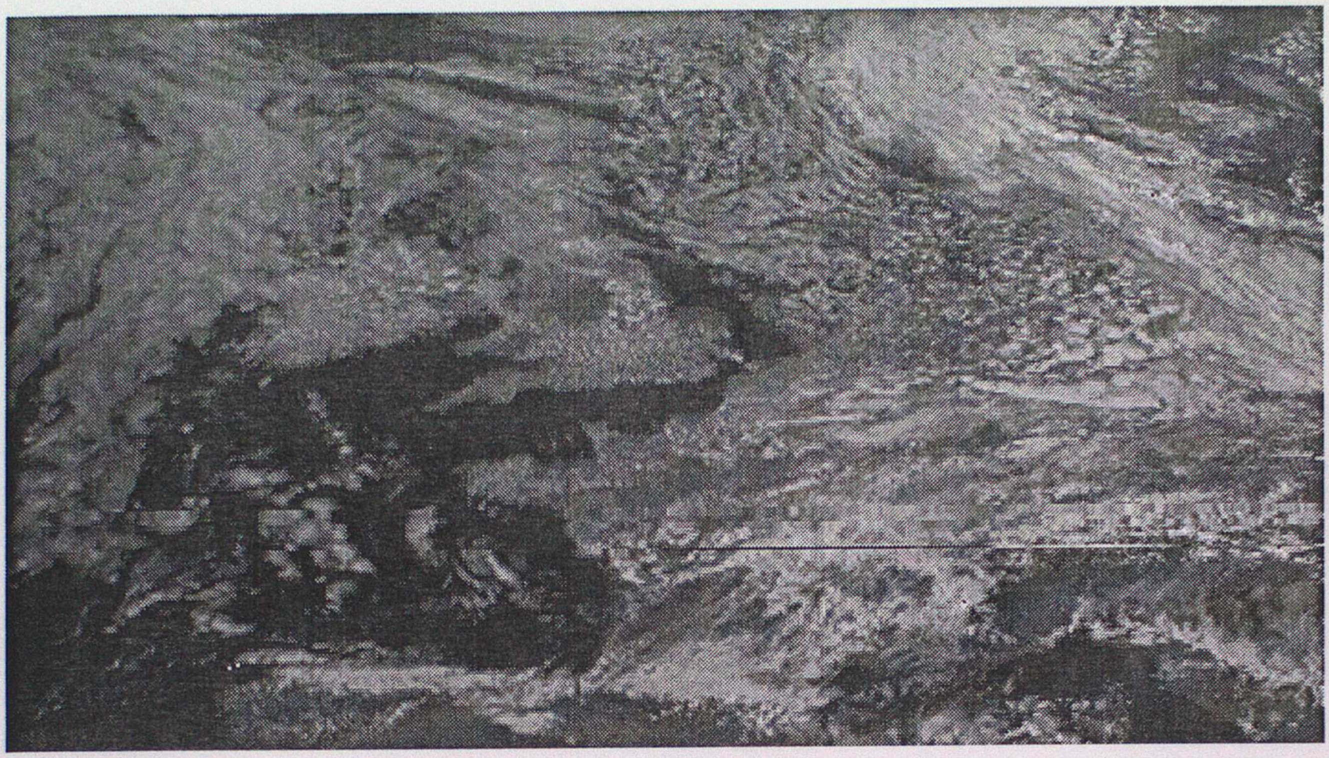


Figure 5a:

Image To Classify 13AUG94 1500



Cloud Classified Image 13AUG94 1500

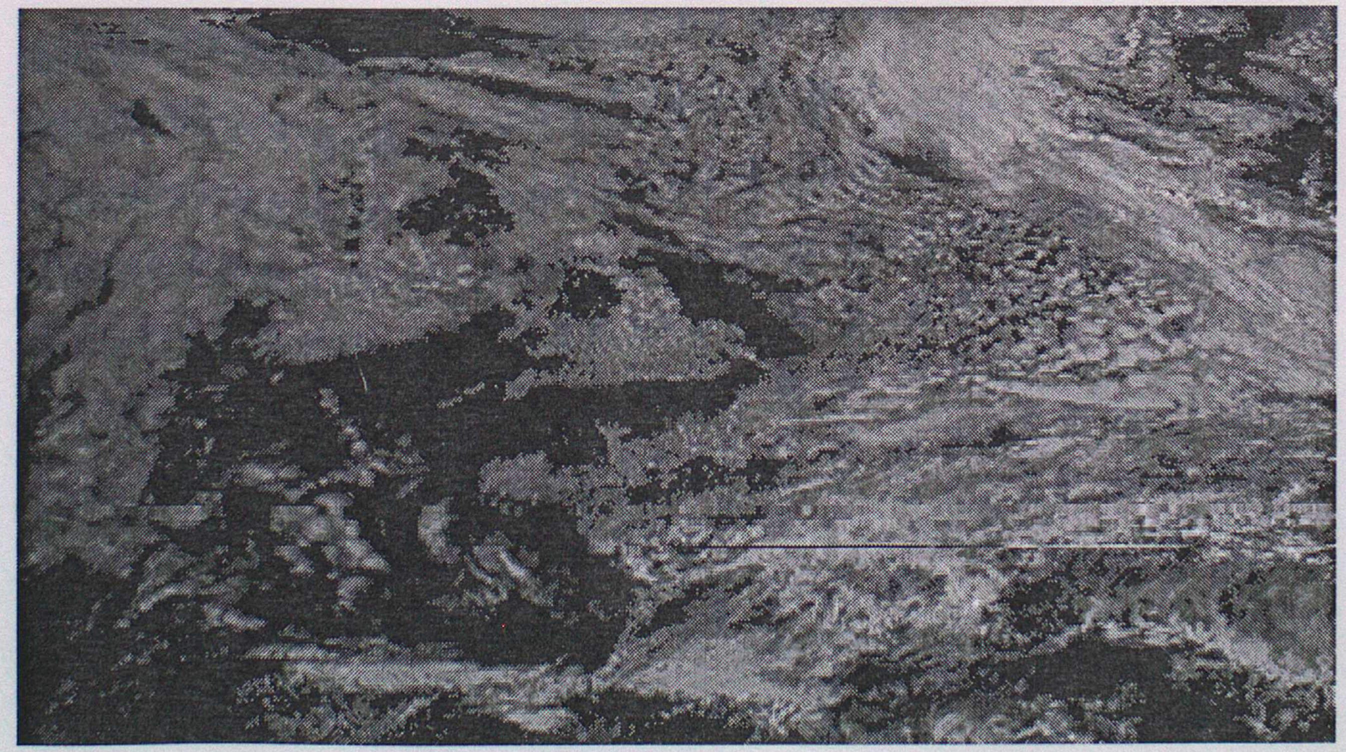


Figure 5b:

Image To Classify 13AUG94 1800

Cloud Classified Image 13AUG94 1800

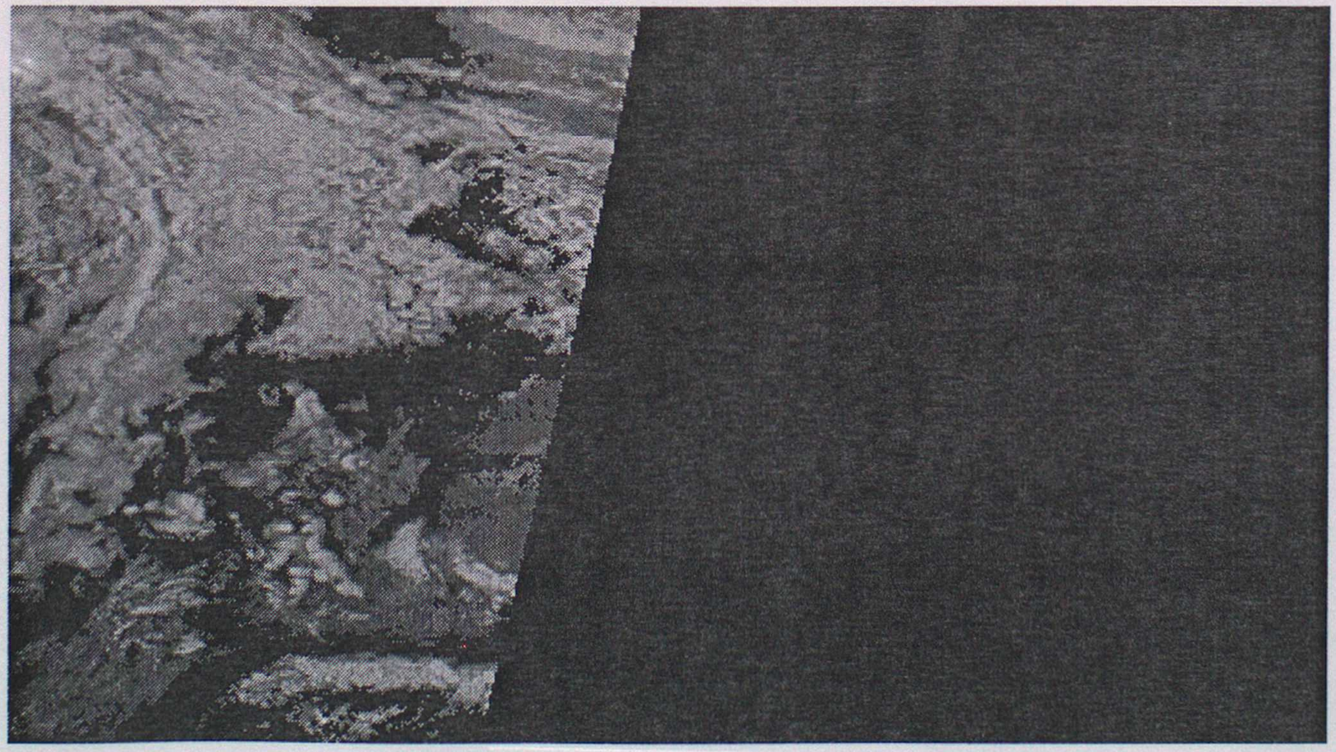


Figure 5c:

Image To Classify 01OCT94 1000

Cloud Classified Image 01OCT94 1000

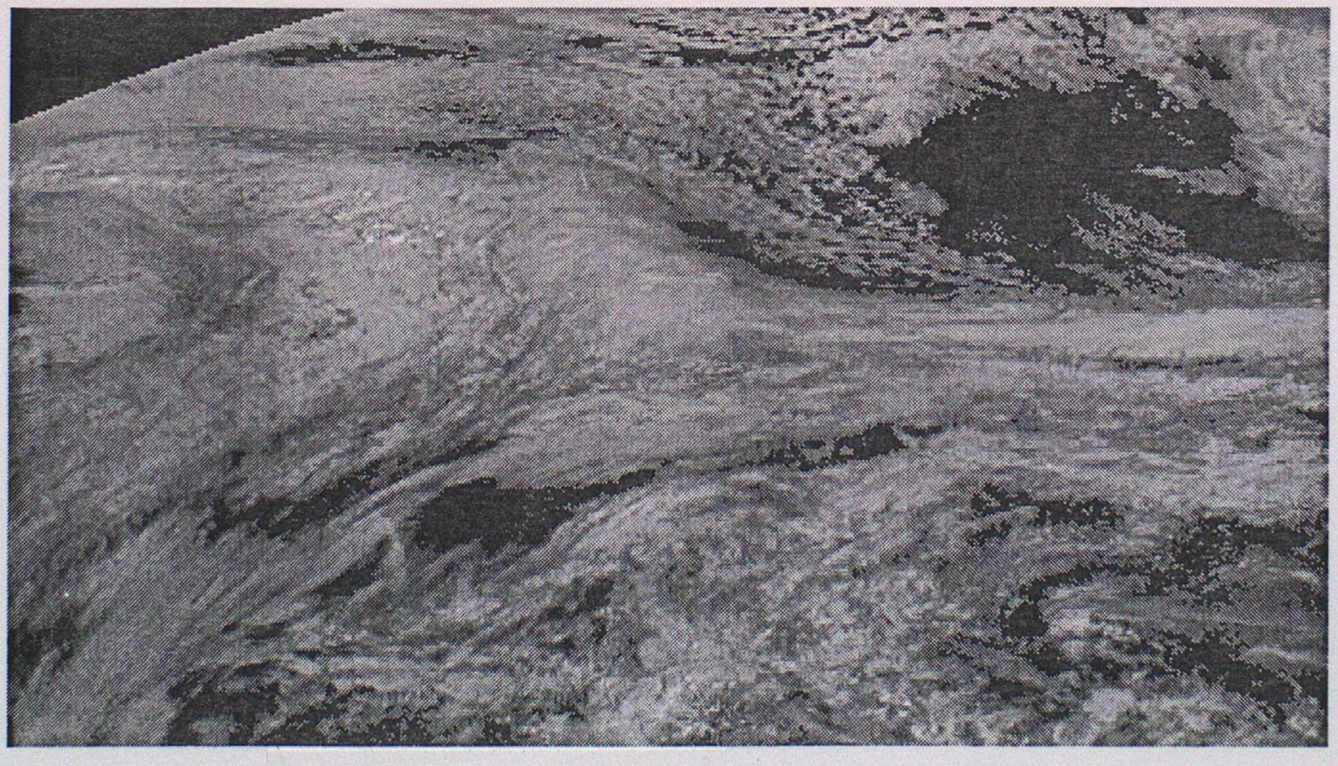
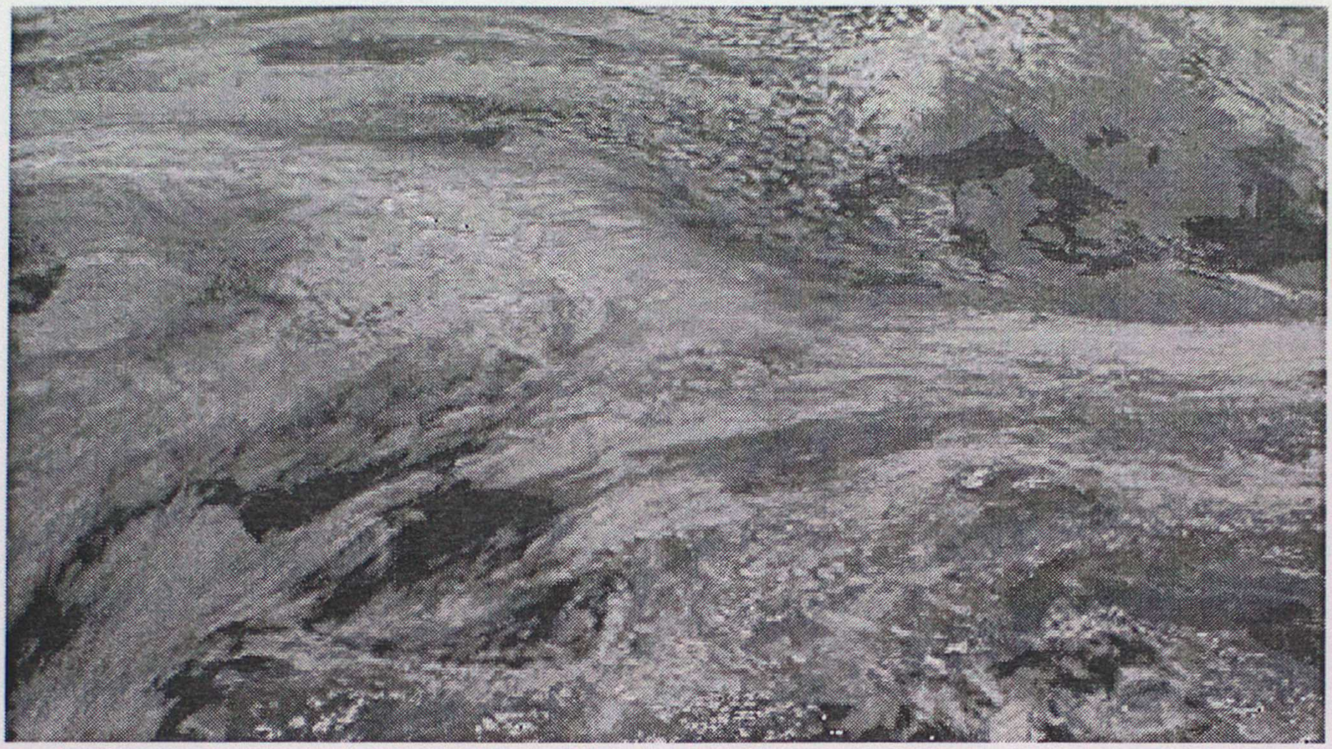


Figure 6a:

Image To Classify 01OCT94 1200



Cloud Classified Image 01OCT94 1200

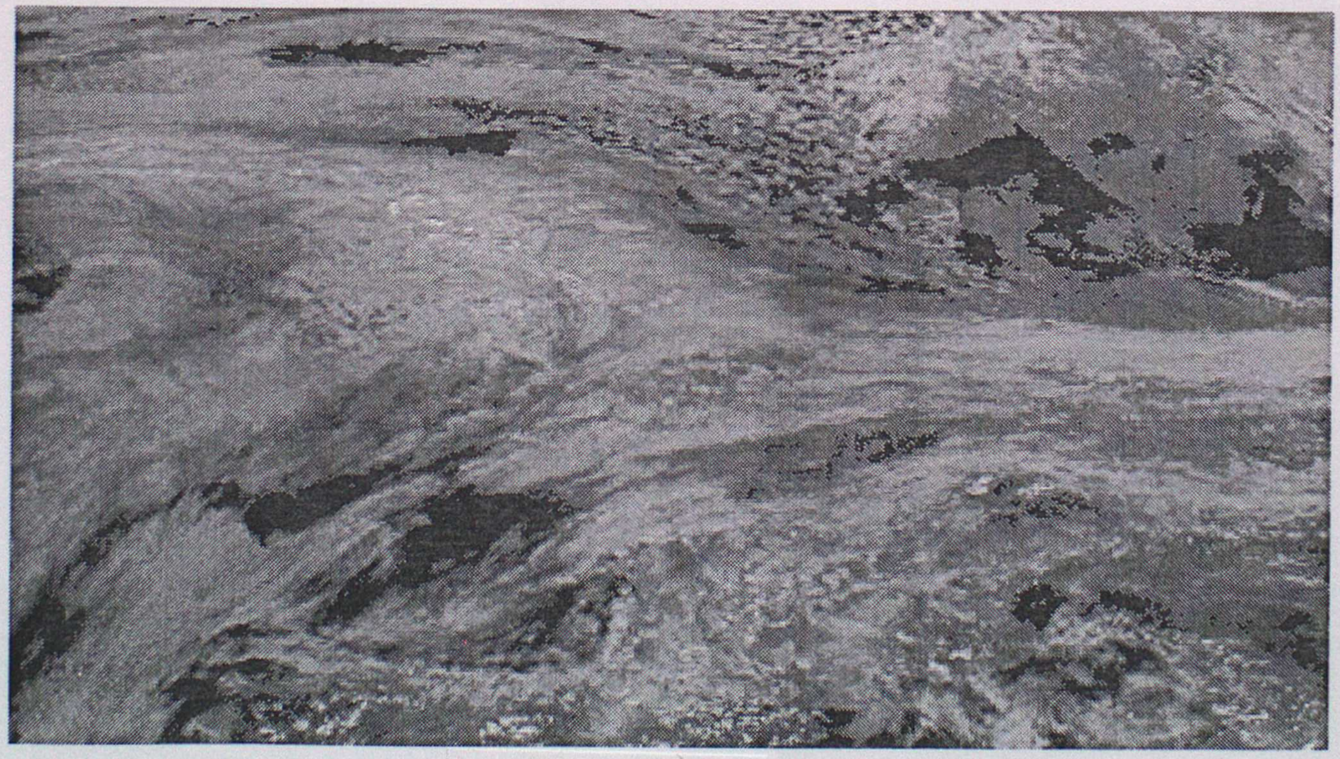
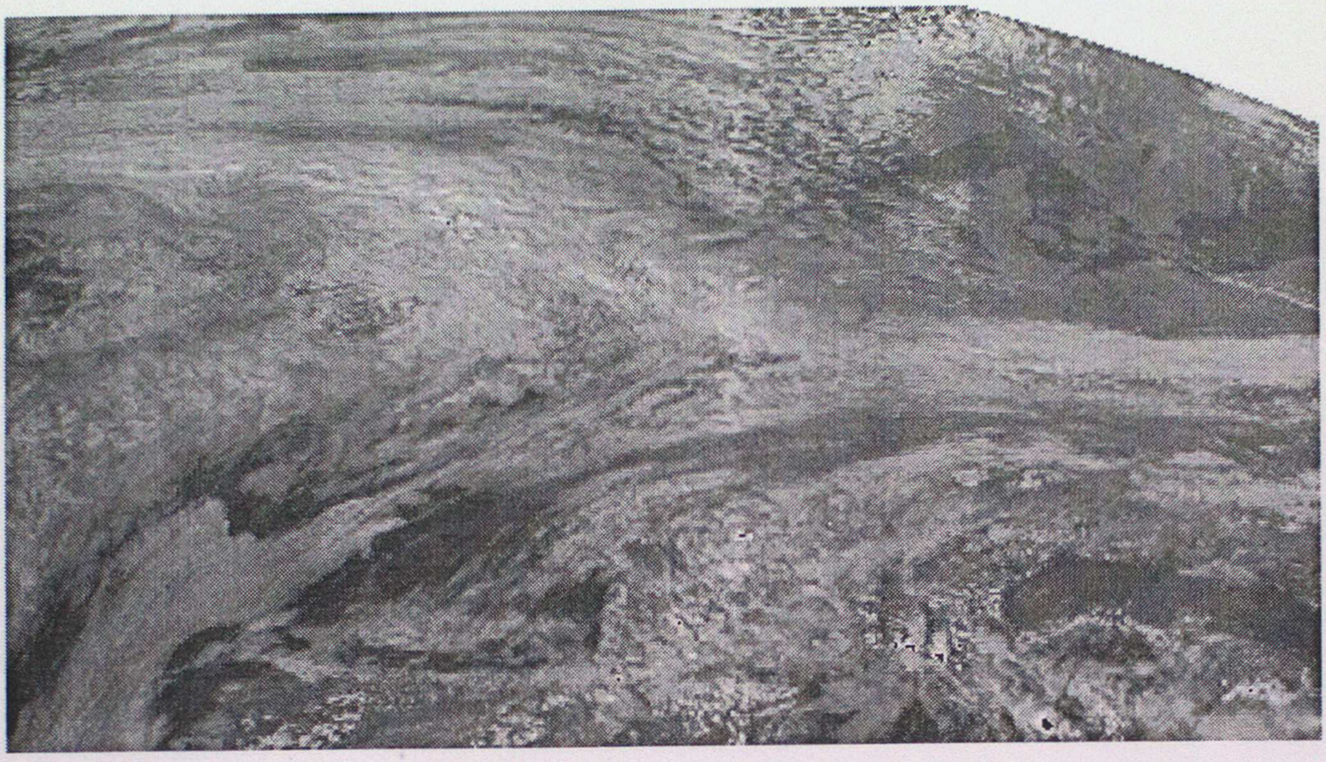


Figure 6b:

Image To Classify 01OCT94 1400



Cloud Classified Image 01OCT94 1400

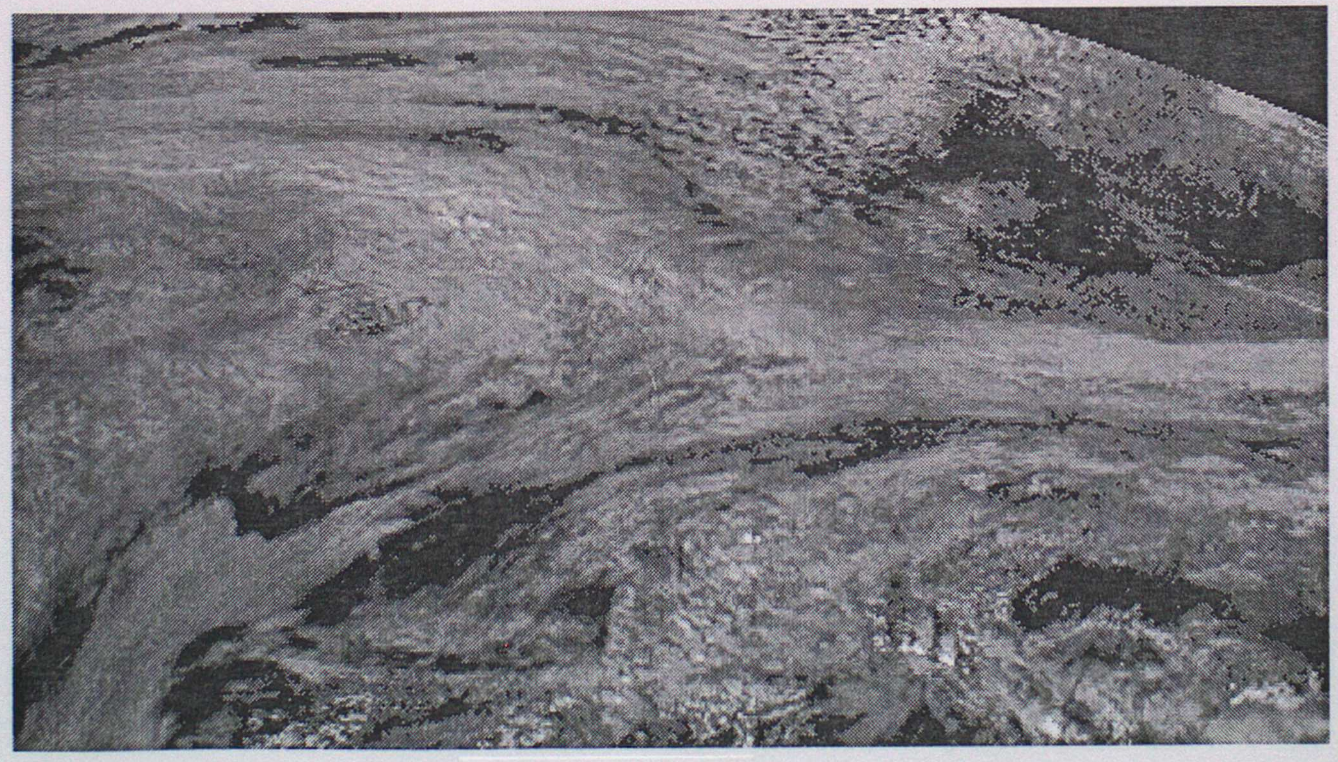
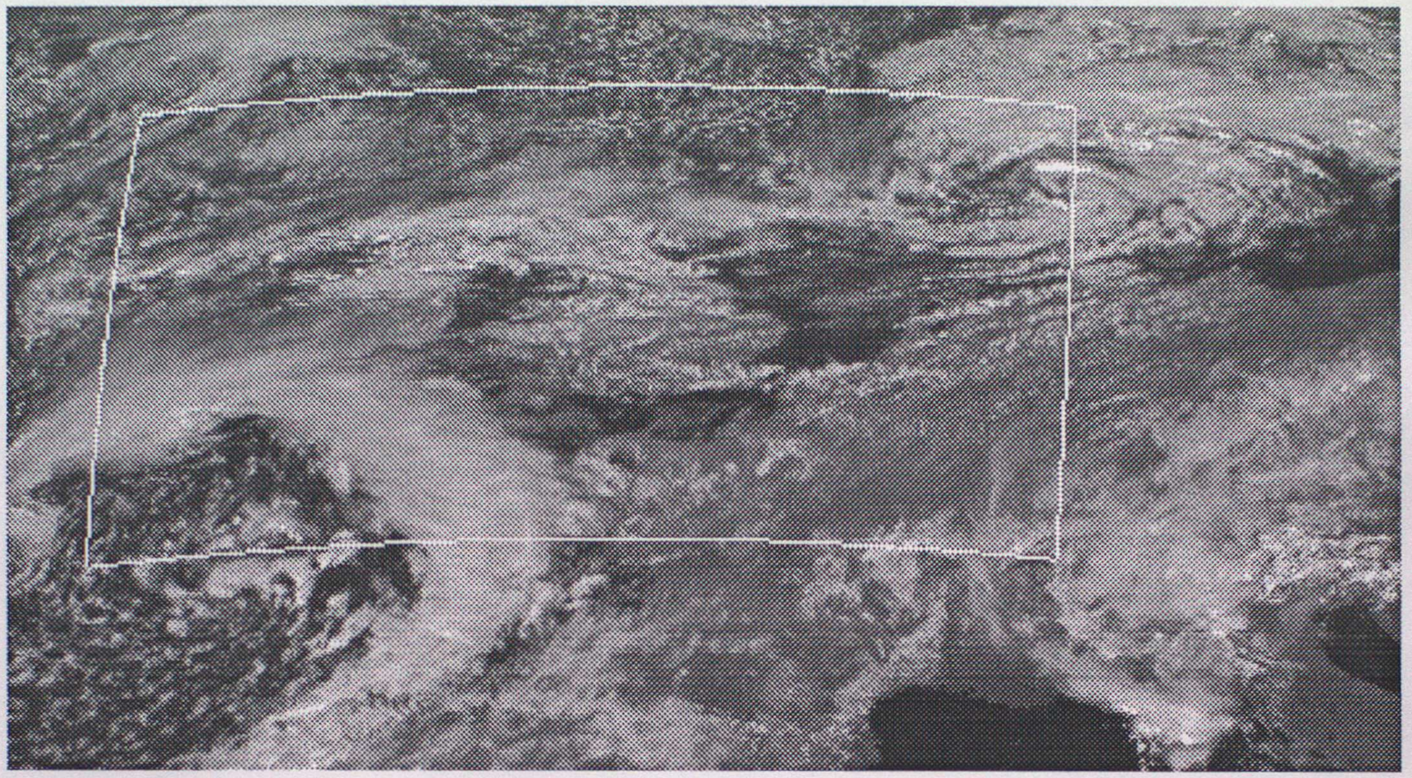
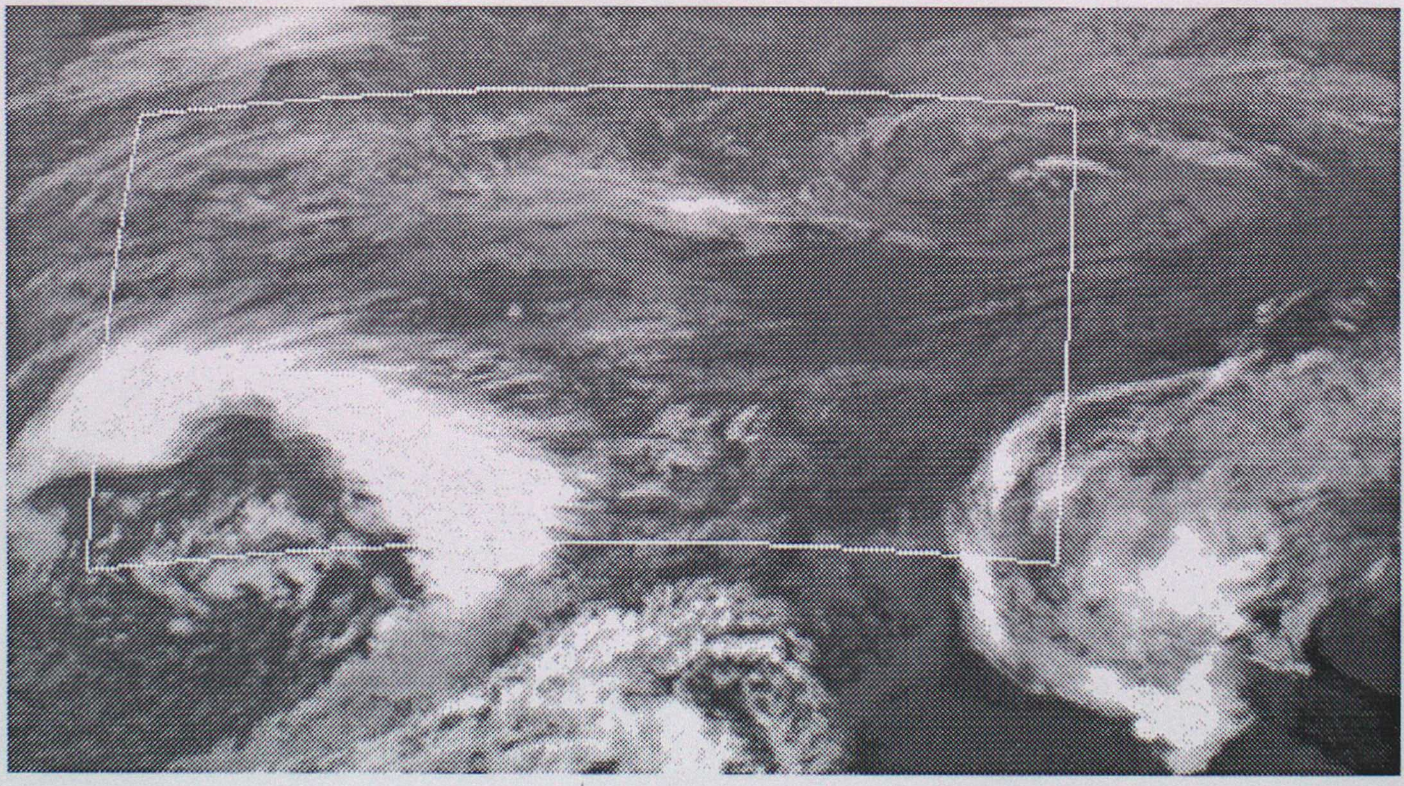


Figure 6c:

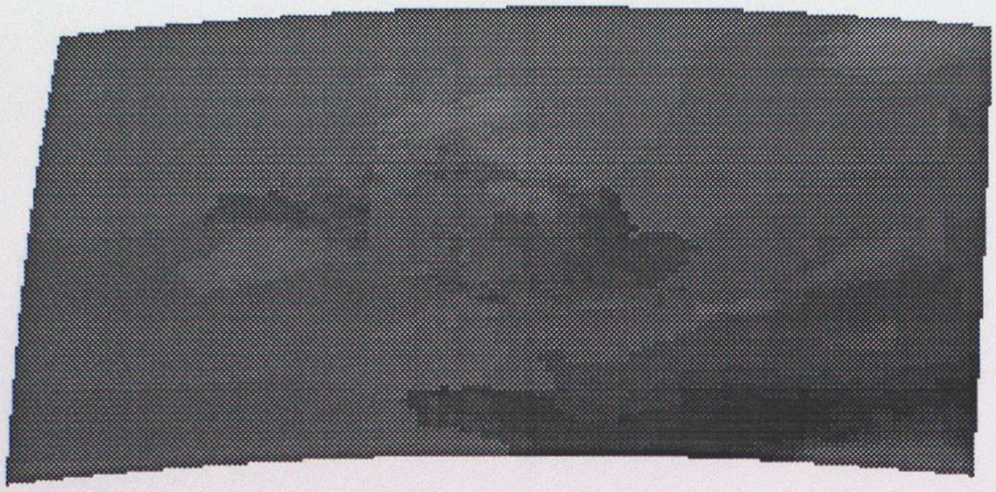


Normalised Visible Image 13SEP94 1200



Corresponding Infrared Image 13SEP94 1200

Figure 7a:



Surface Temperature Forecast 13SEP94 1200

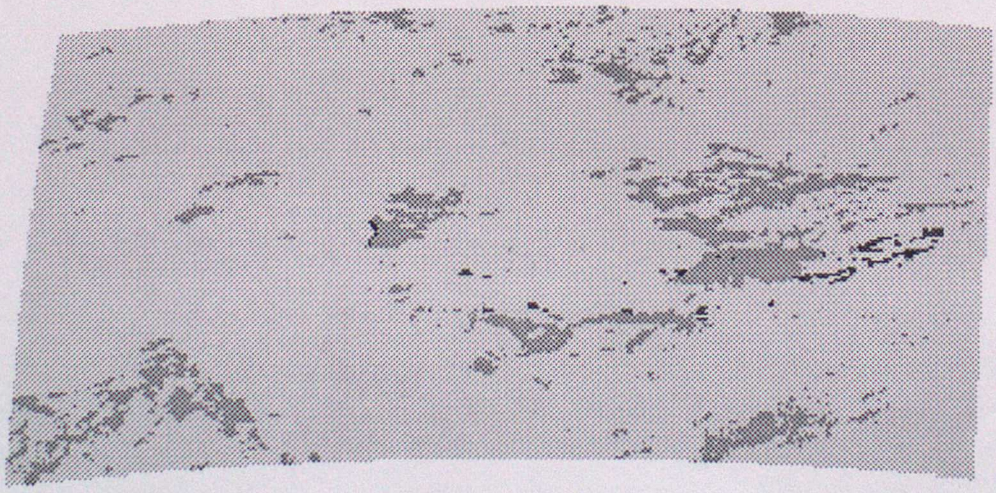


Image Classified as cloud by Vis only, Ir only, Vis/IR combined

Figure 7b:

3.4 Observed Anomalies in the Normalised Images

An anomaly in the normalised images, which was noticed when looking at a series of images from individual days, was an apparent 'brightening' over the entire image at midday. To properly investigate this feature, and estimate the numerical value of this increase, cases were sought where a series of images from a single day contained a region which remained free of cloud.

Few cases were identified, as it is fairly rare for any region to remain free of cloud for long over this portion of the earth, but of those found, the following features were noted. Throughout the day, albedo values over cloud-free land were reasonably constant for a given position, excepting the midday image. This showed a peak in albedo at midday, which became more pronounced with both increasing number of days away from the summer solstice and proximity to the pole. In the more extreme cases found, this could be nine or ten product values (3.5 to 4% albedo) greater than the 1100UTC and 1300UTC images. Over areas of cloud-free water, the albedo values showed a much smaller peak at noon (one or two product values or $<1\%$ albedo). Because of this low peak, no obvious correlation could be made with geographical position, or season.

Preliminary checking of the normalisation showed no obvious discontinuity in the calculation from hour to hour. Without further investigation and possible correction, it must be recommended that for the midday images, the variable threshold is increased to a level where cloud-free land is no longer classified as cloud, and that different thresholds are used over land and sea areas, because of the difference in size of the variation of albedo.

4 Discussion of results in particular cases

In the attached figures relevant to this section (figures 7-14), the area outlined on the space-view projection is the MM area. The forecast temperatures and output classification are shown only within this area. IR thresholding has been carried out using the current operational MM scheme, ie pixels with brightness temperatures more than 5K below the forecast surface temperature are classified as cloudy. For the Visible thresholding, the method of 3.3.2 has been used, with a difference threshold of 16 counts.

The key to the classification is:

White	Outside the MM area.
Pale grey	Cloudy in both Vis and IR
Mid grey	Cloudy in IR only
Dark grey	Cloudy in Vis only
Black	Clear

To show that there are indeed occasions when the Vis and IR thresholding agree fairly well, consider the two cases 13 September 1994 at 1200UTC and 24 September 1994 at 1200UTC. (Figures 7a,b and 8a,b). The former case shows a mixture of fronts, convection over the south-west corner of the image, and fairly thick cirrus.
In the classification, cloud is detected almost everywhere in the IR, with some gaps in the Visible where the cirrus is thinner.

The case of 24 September 1994 consists of a strong circulation in the south of the image with a clear gap within the 'comma'. The northern part of the image consists of close convective cells over the sea, with a broad sheet of medium-level cloud lying across the middle of the image. In the classification, there is good agreement between results from the IR and Vis, except that the IR threshold has picked up a little more cloud than is probably present near the centre of the circulation. The presence of thin gaps north of the cloud band is difficult to determine, even by eye. In this particular case, a higher IR threshold would have given less cloud and possibly a 'better' result in these portions of the image.

The two cases 10 October 1994 1200UTC and 13 October 1994 1200UTC (Figures 9a,b and 10a,b) show a greater difference in classification between the two thresholds. Both images contain areas of low cloud over the sea in the south-west portion of MM area. In the 10 October 1994 case, there are two main areas over the sea which have been classified incorrectly as cloudy in the IR, in the English Channel, and to the north-east of Scotland (shown as pale grey). In the case of 13 October 1994, the area incorrectly classed as cloudy in the IR is off the north-east coast of England, and E coast of Scotland. This latter case may be because the forecast temperature was too high in this region.

The area of low cloud in the south-west of both the images has been classified as clear by the IR threshold. Using the Vis threshold over the sea, a much greater area (shown as dark grey) has been correctly classified as cloudy. However, over the land surface, most probably because of the known problem with apparent increase in albedo at midday, large areas have been incorrectly classified as cloudy by the Vis thresholding.

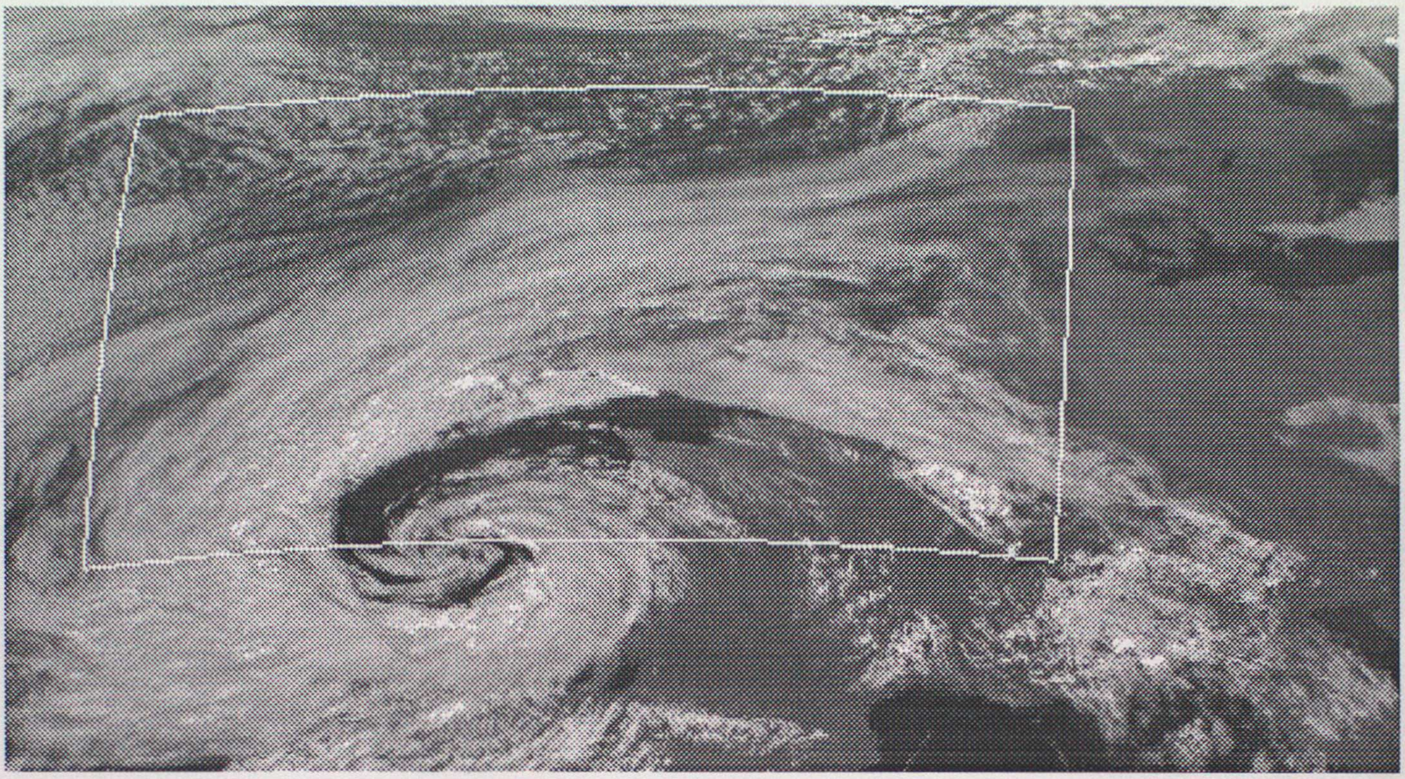
The cloud types which appear to be most troublesome to define automatically are low cloud, where the IR brightness temperature is close to the forecast surface temperature, and thin cirrus, where there is only a slight increase in albedo over that expected under clear-sky conditions, but with a stronger difference in the IR.

The cases of 02 September 1994 1500UTC and 21 September 1994 1500UTC (Figures 11a,b and 12a,b), contain cirrus classified as cloudy in the IR but not in the Vis. This can be seen around the Isle of Man on the 02 September, and west of the Brest peninsula on the 21 September. Also to be seen in the second case is a streak of low cloud in the north-west of the area classified as clear by the IR threshold, but cloudy in the Vis.

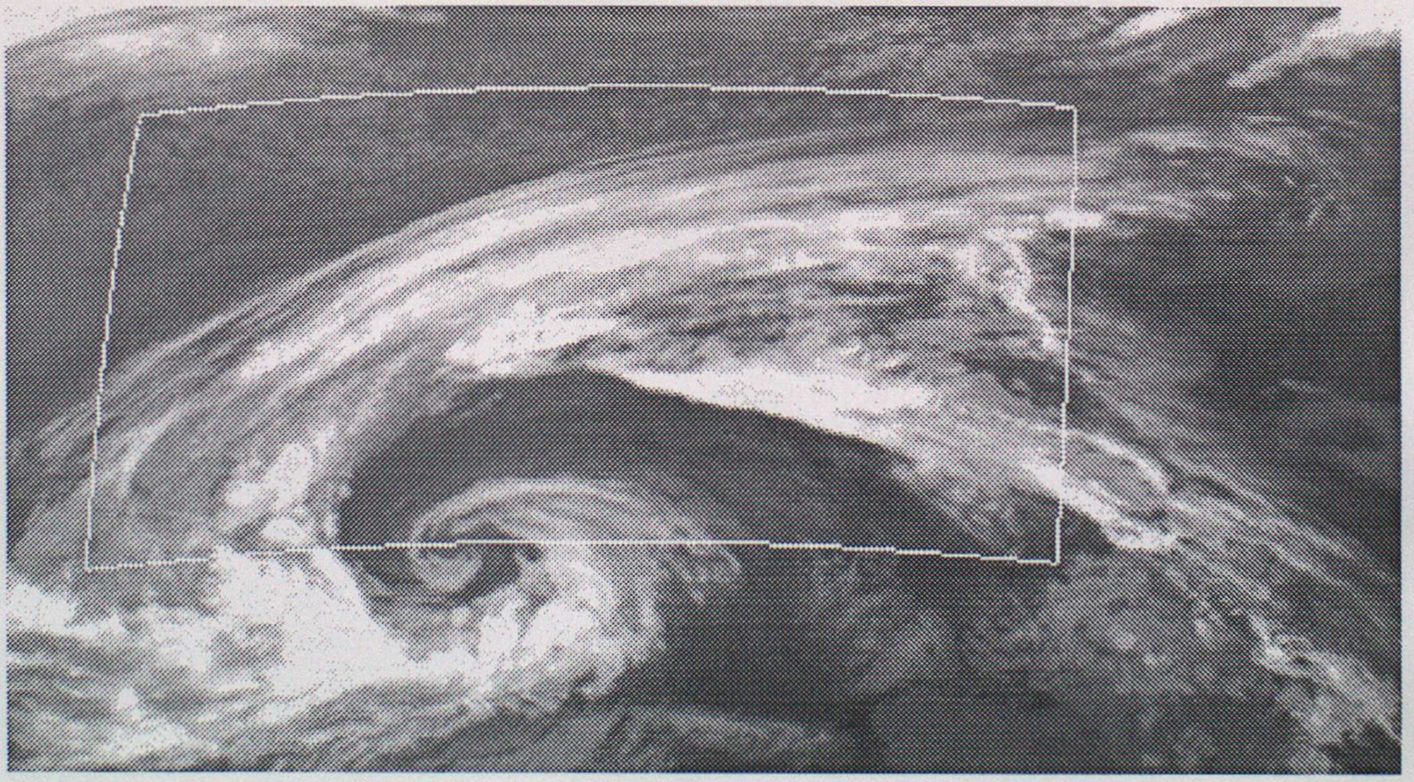
Two other cases where the IR threshold is too low or possibly where the forecast surface temperature is too warm are 18 September 1994 and 04 October 1994 at 1200UTC (Figures 13a,b and 14a,b). In the first case, an area of cloud-free sea south of Norway has been classified by the IR as cloudy, and clear in the Vis. In the second case, the sea areas south of England and Ireland are free of cloud, while again, being classed as cloudy in the IR and clear in the Vis. The case of 04 October 1994 also has some land being classified as cloudy in the Vis, because of this brightening at midday.

4.1 Summary of thresholding techniques

Use of an IR threshold to identify cloud has been in use within the MM for some time, and it is not proposed that this should be abandoned. Instead, combining this with

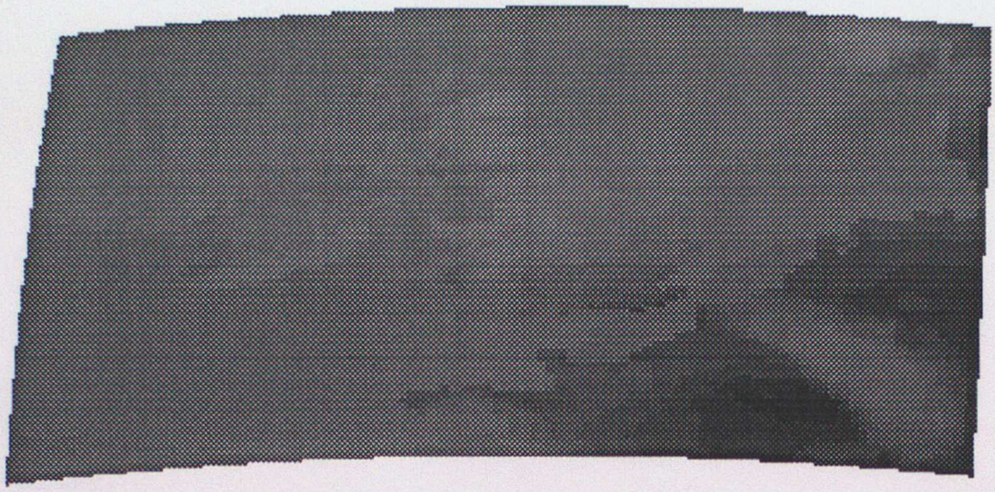


Normalised Visible Image 24SEP94 1200



Corresponding Infrared Image 24SEP94 1200

Figure 8a:



Surface Temperature Forecast 24SEP94 1200

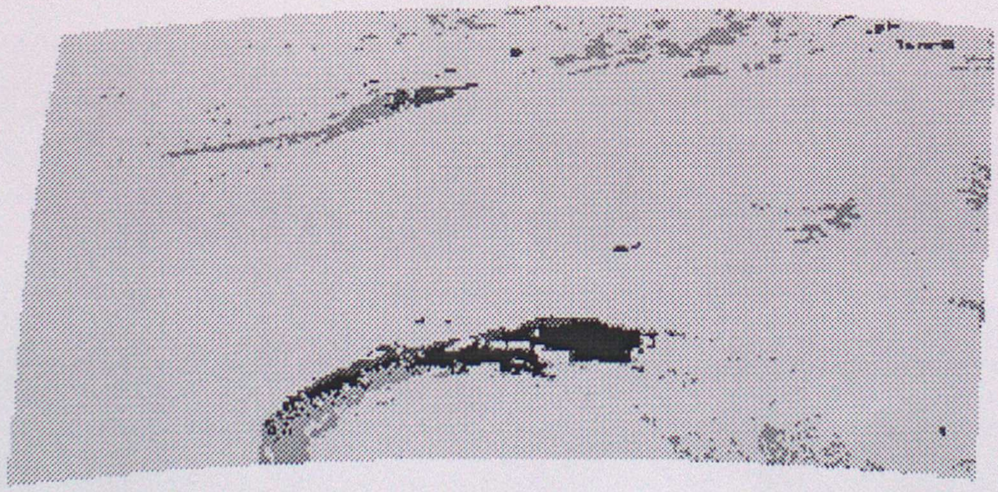
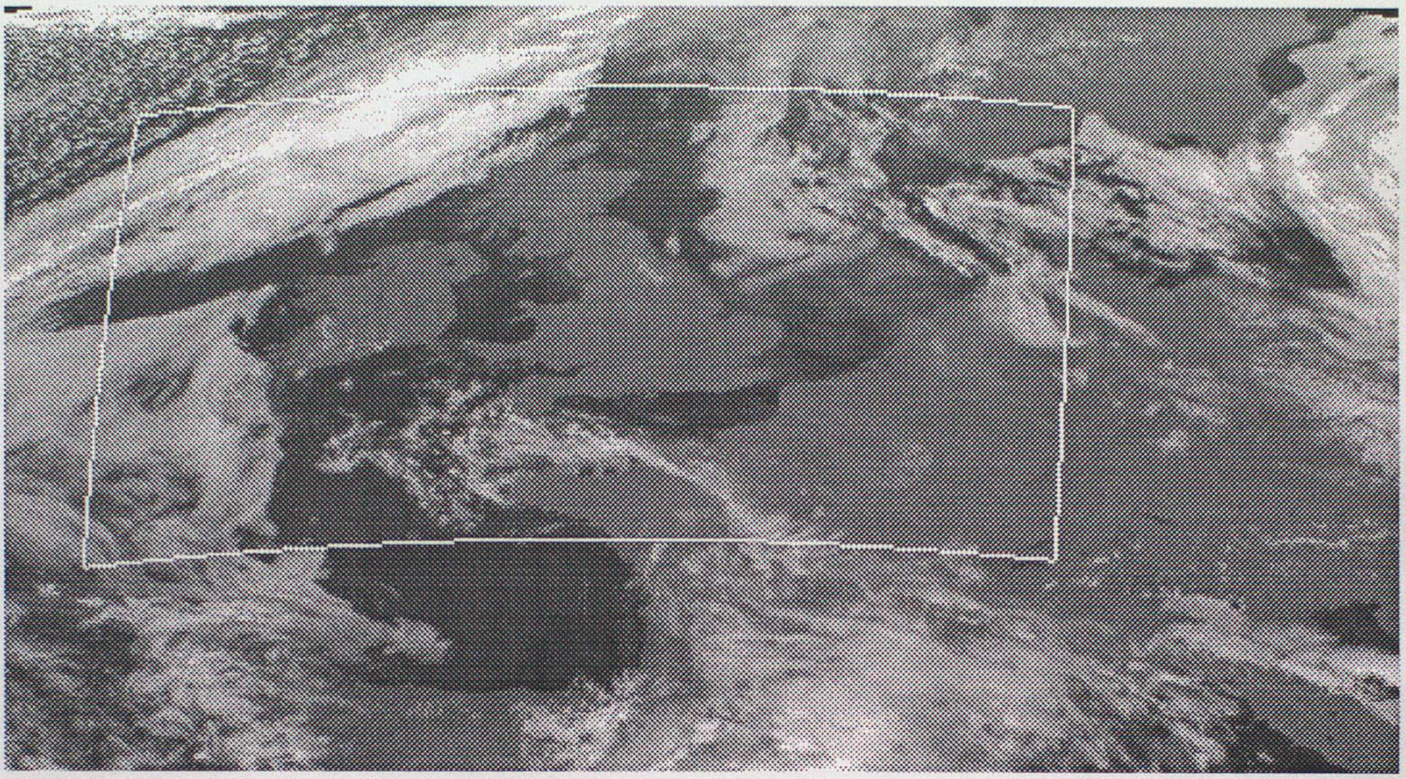
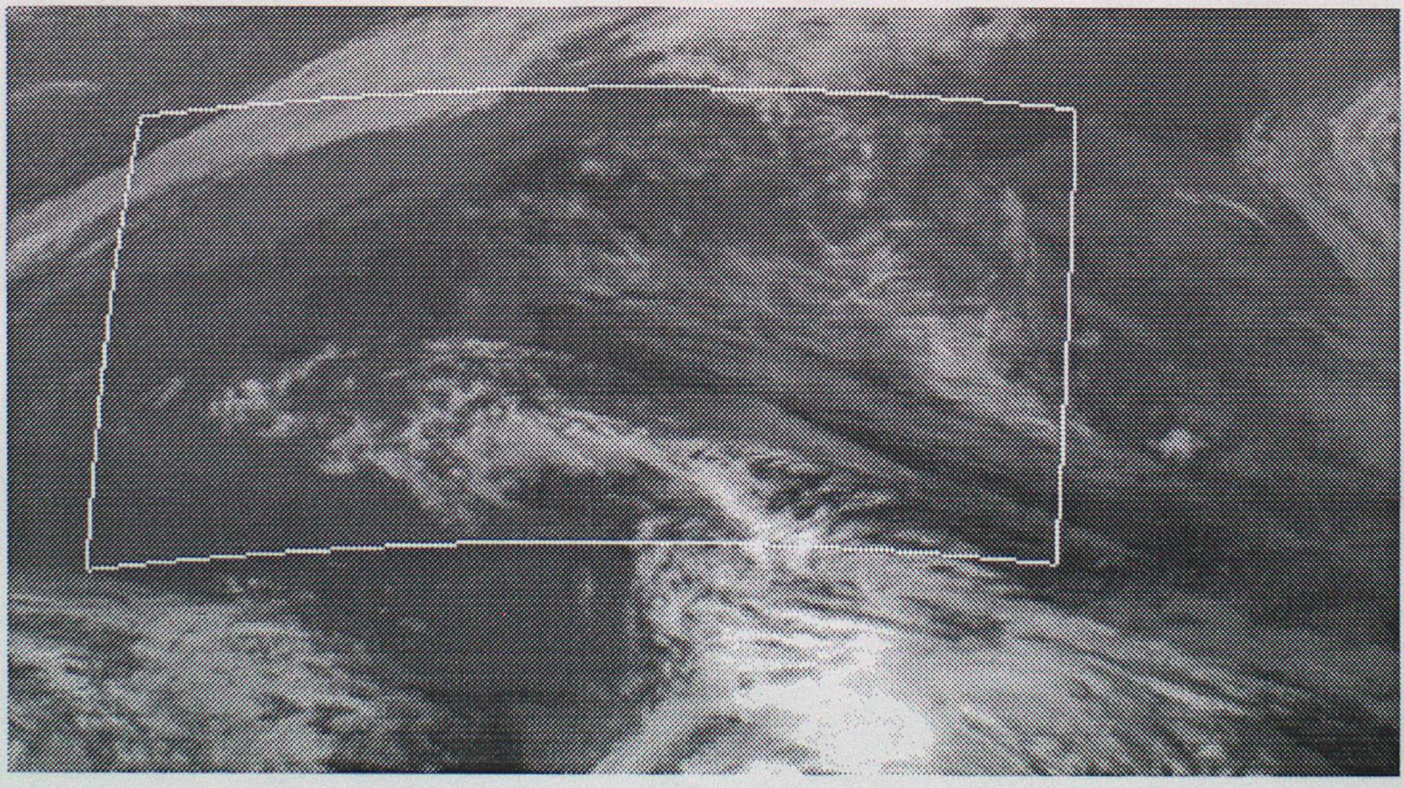


Image Classified as cloud by Vis only, Ir only, Vis/IR combined

Figure 8b:

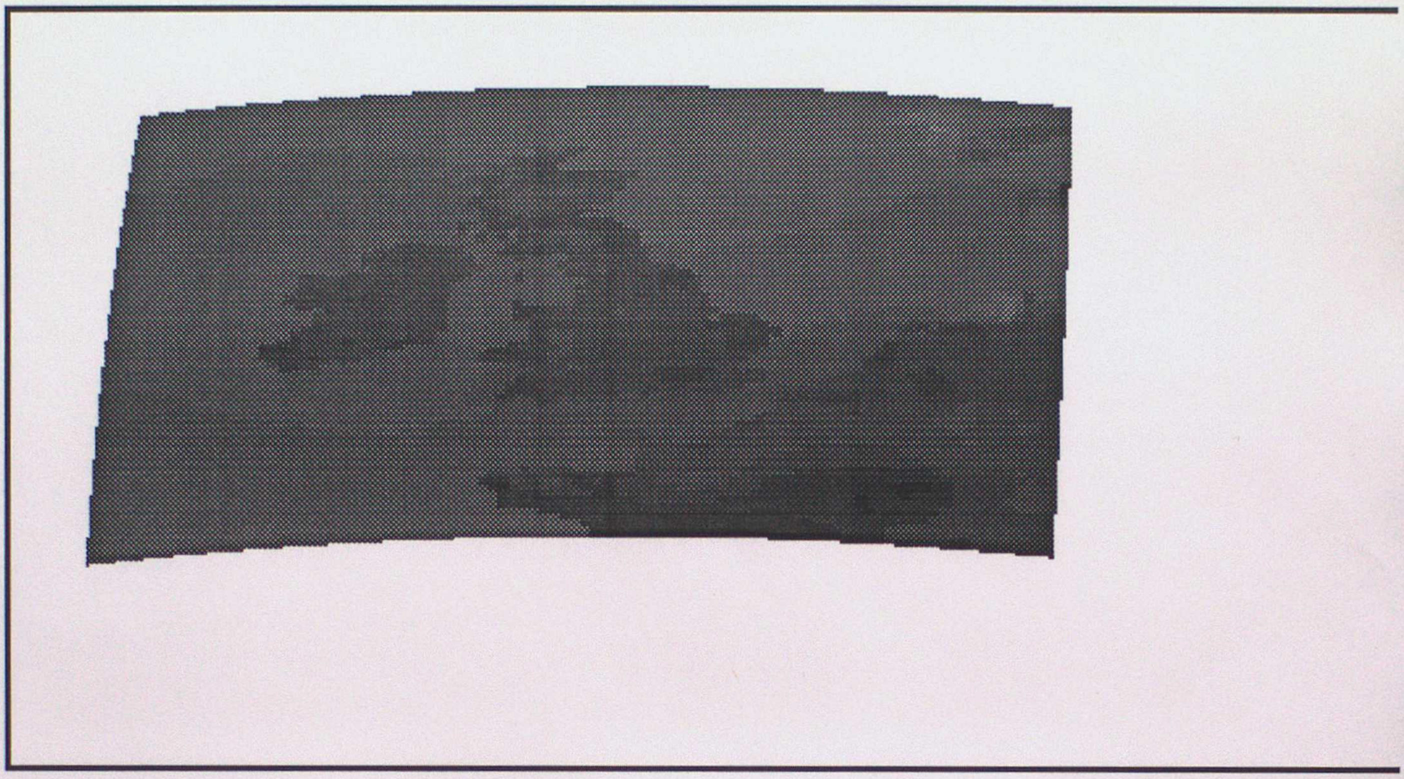


Normalised Visible Image 10OCT94 1200



Corresponding Infrared Image 10OCT94 1200

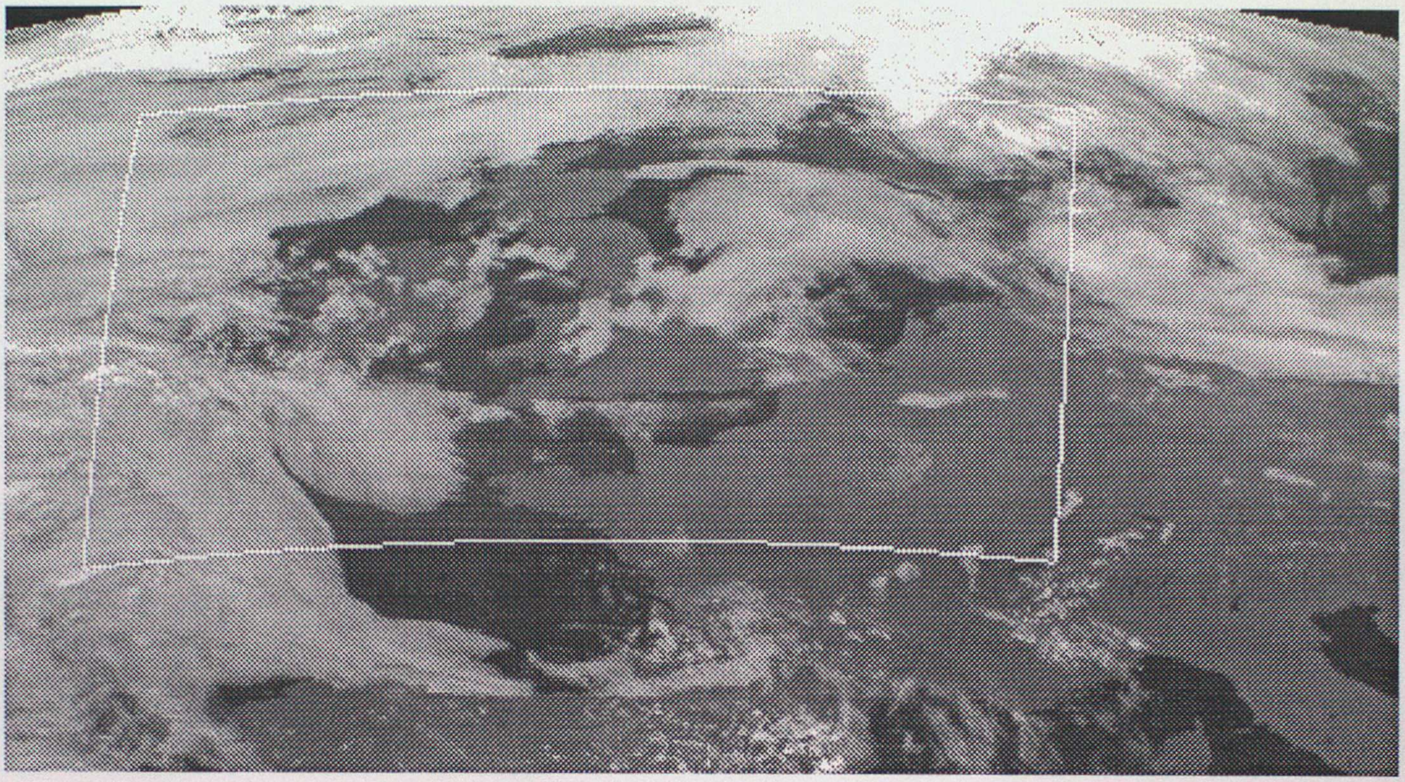
Figure 9a:



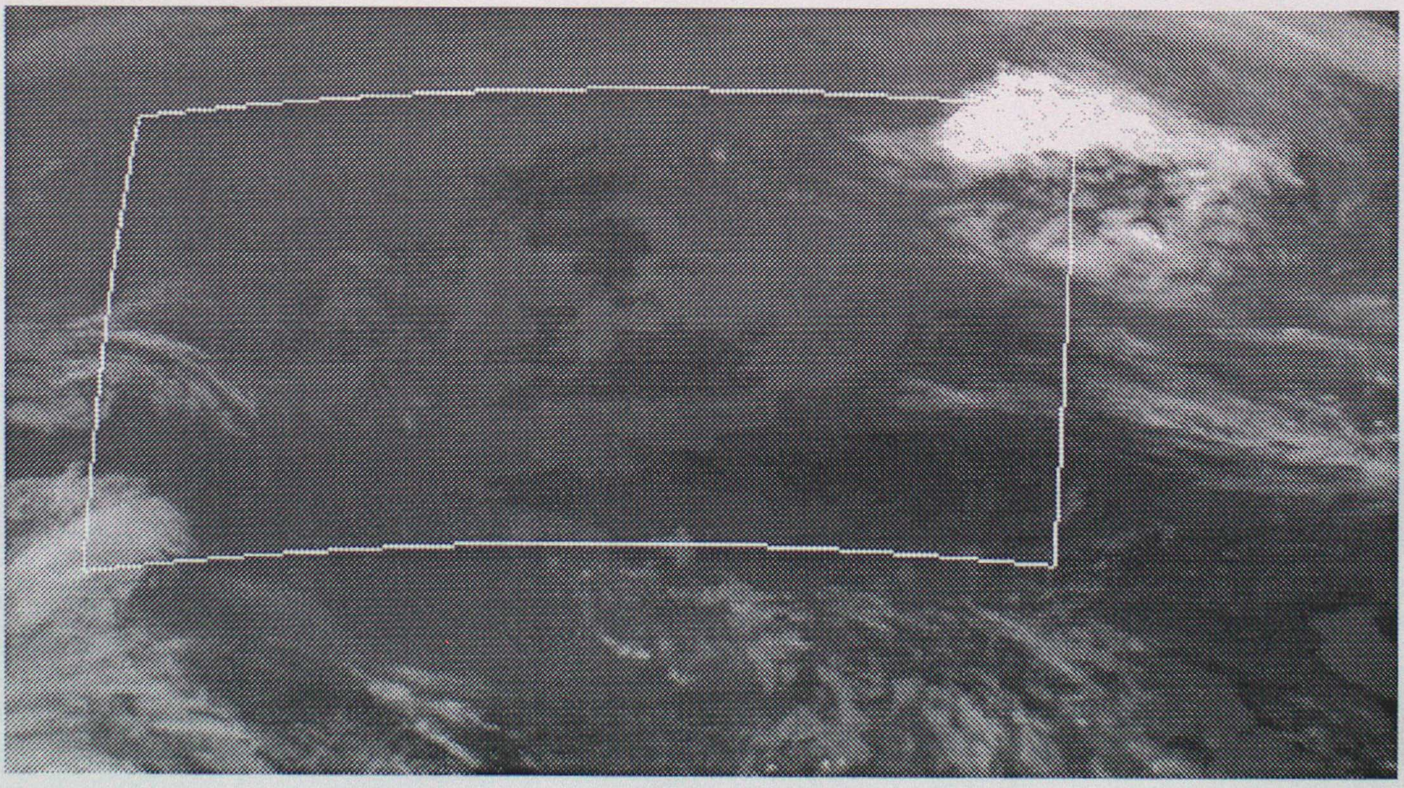
Surface Temperature Forecast 10OCT94 1200

Image Classified as cloud by Vis only, Ir only, Vis/IR combined

Figure 9b:



Normalised Visible Image 13OCT94 1200



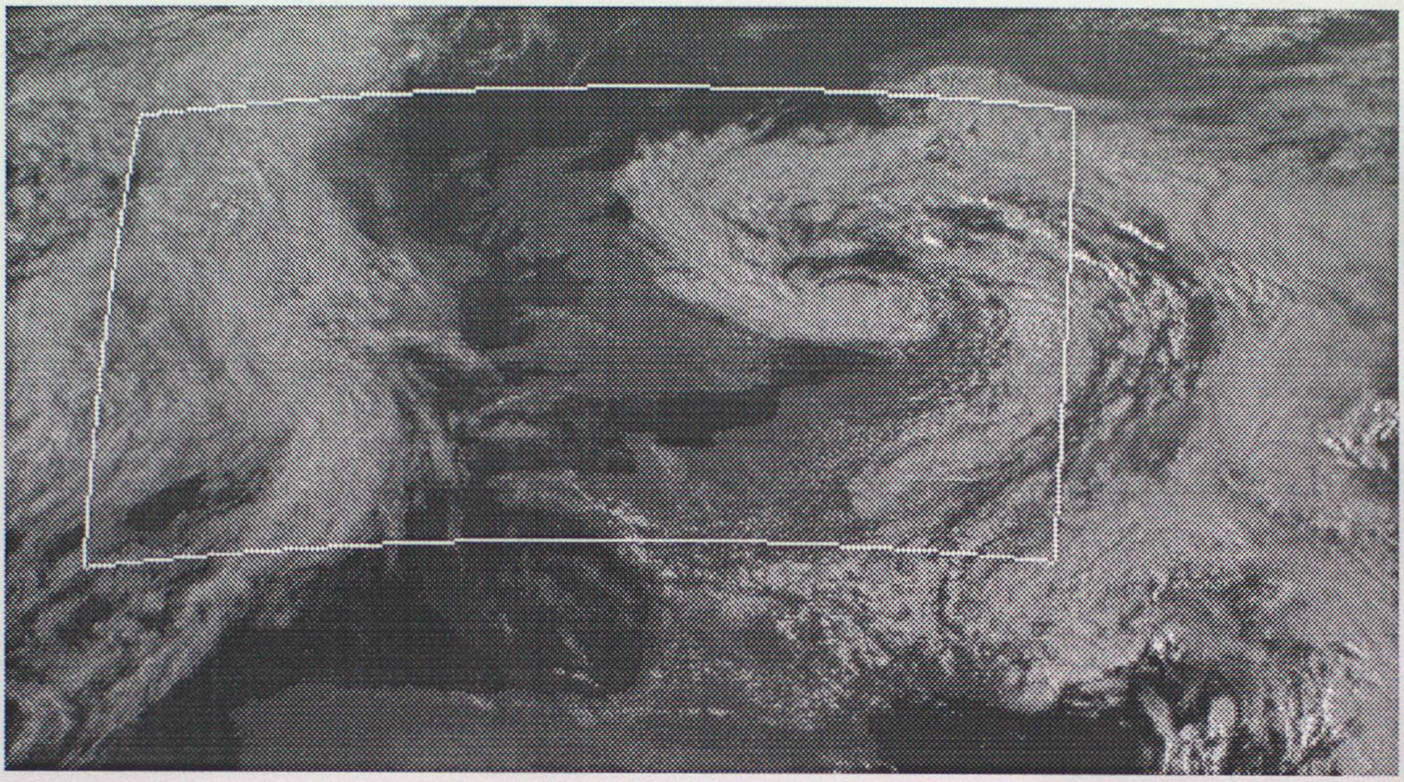
Corresponding Infrared Image 13OCT94 1200

Figure 10a:

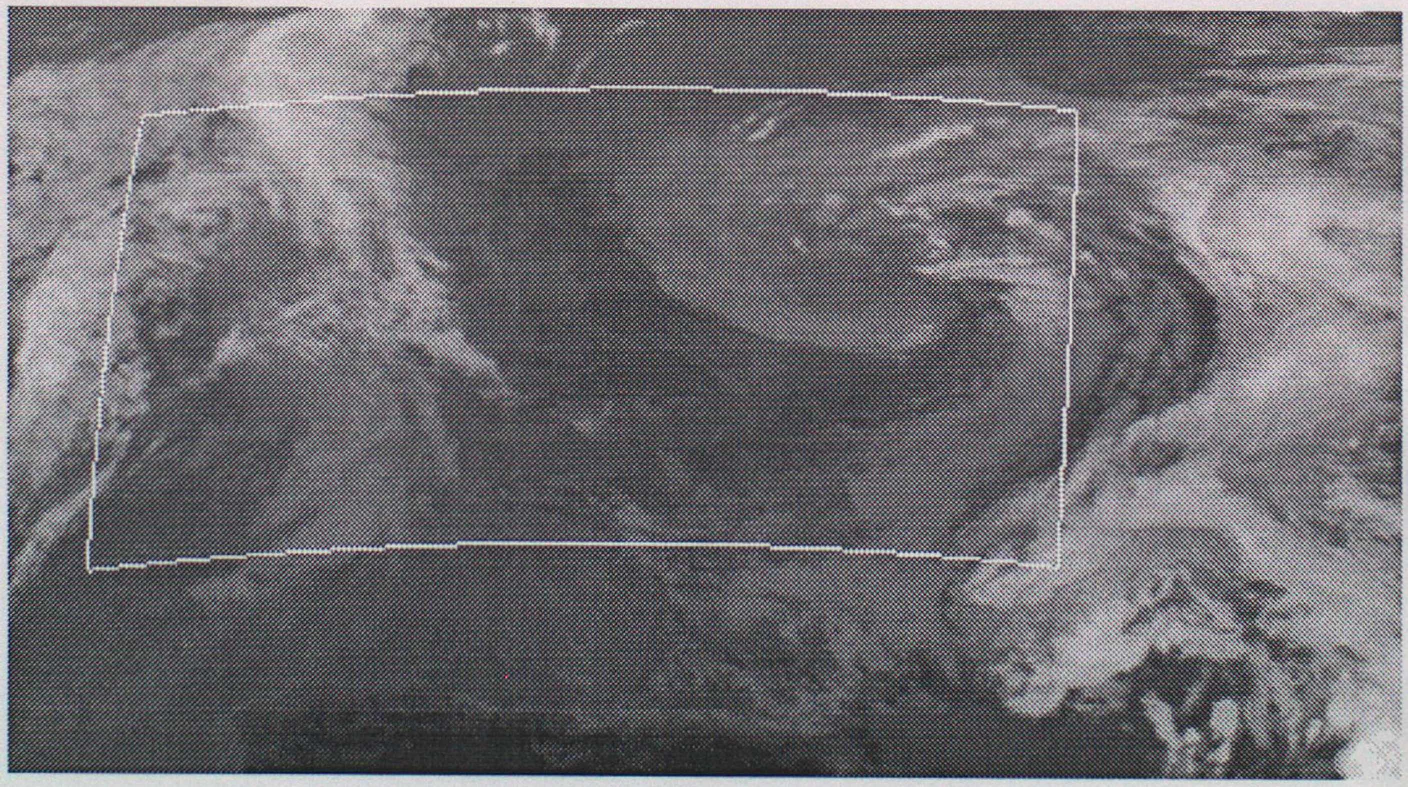
Surface Temperature Forecast 13OCT94 1200

Image Classified as cloud by Vis only, Ir only, Vis/IR combined

Figure 10b:

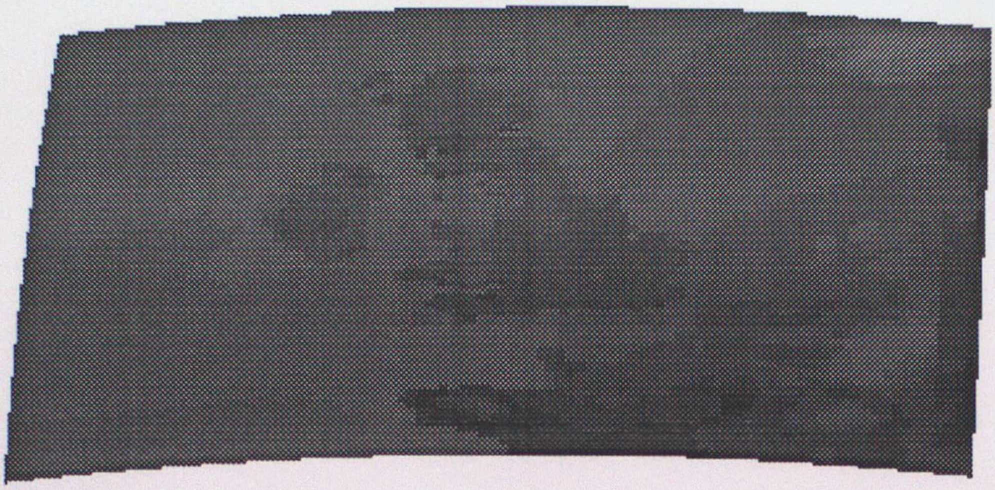


Normalised Visible Image 02SEP94 1500



Corresponding Infrared Image 02SEP94 1500

Figure 11a:



Surface Temperature Forecast 02SEP94 1500

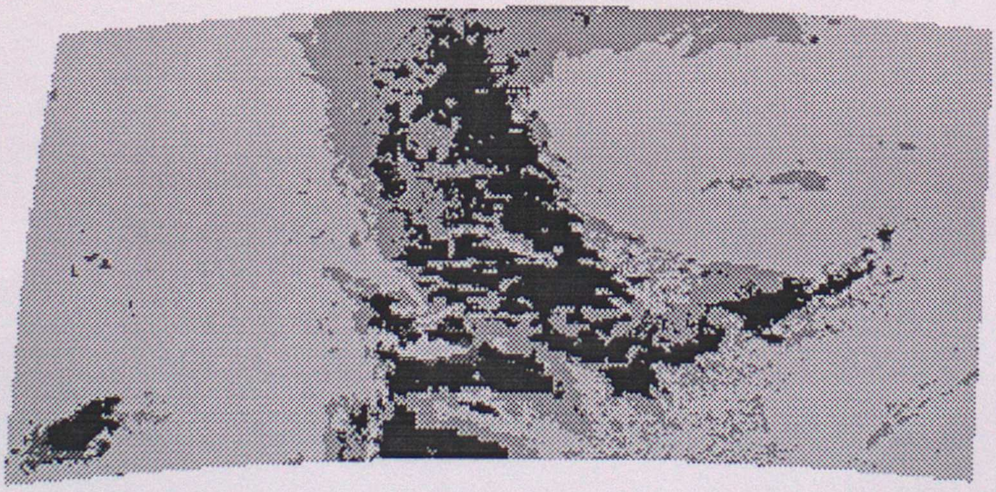
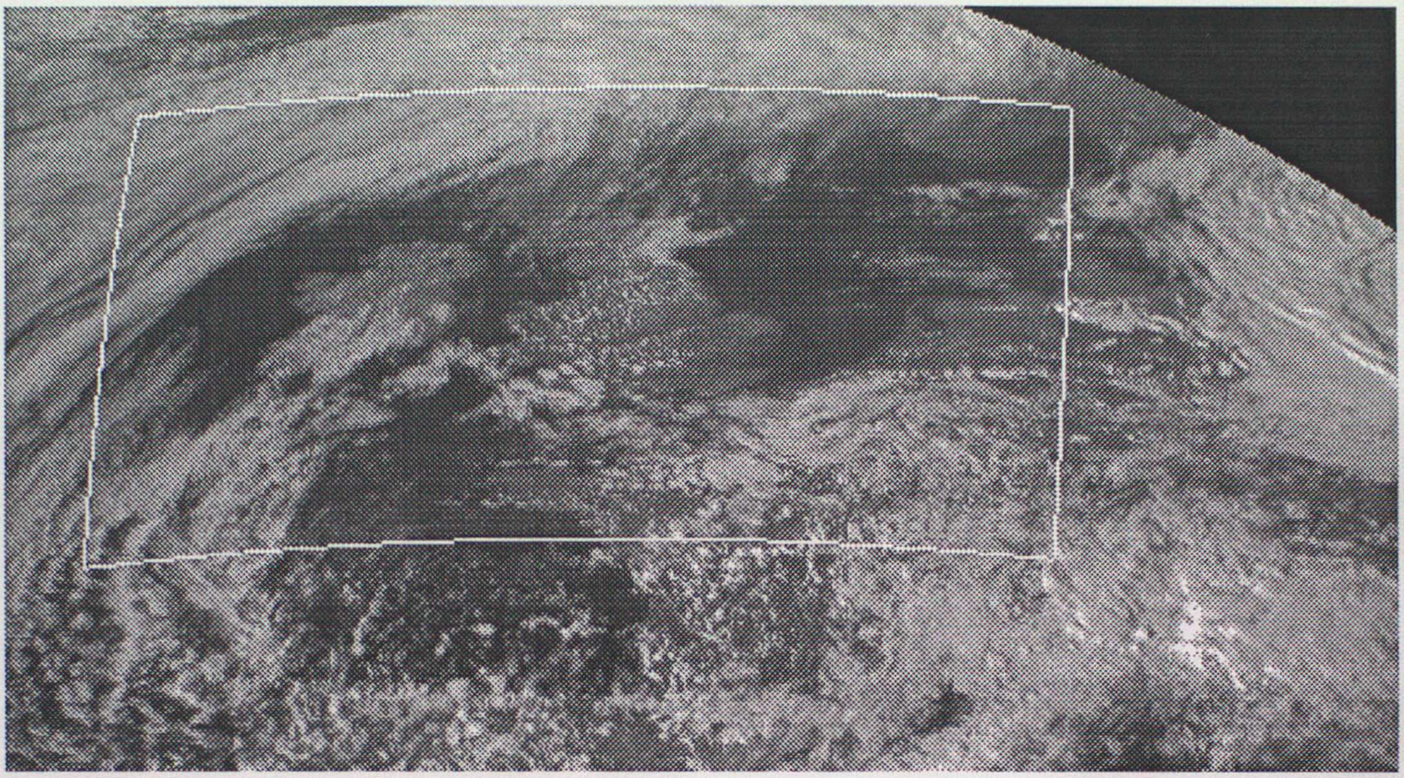
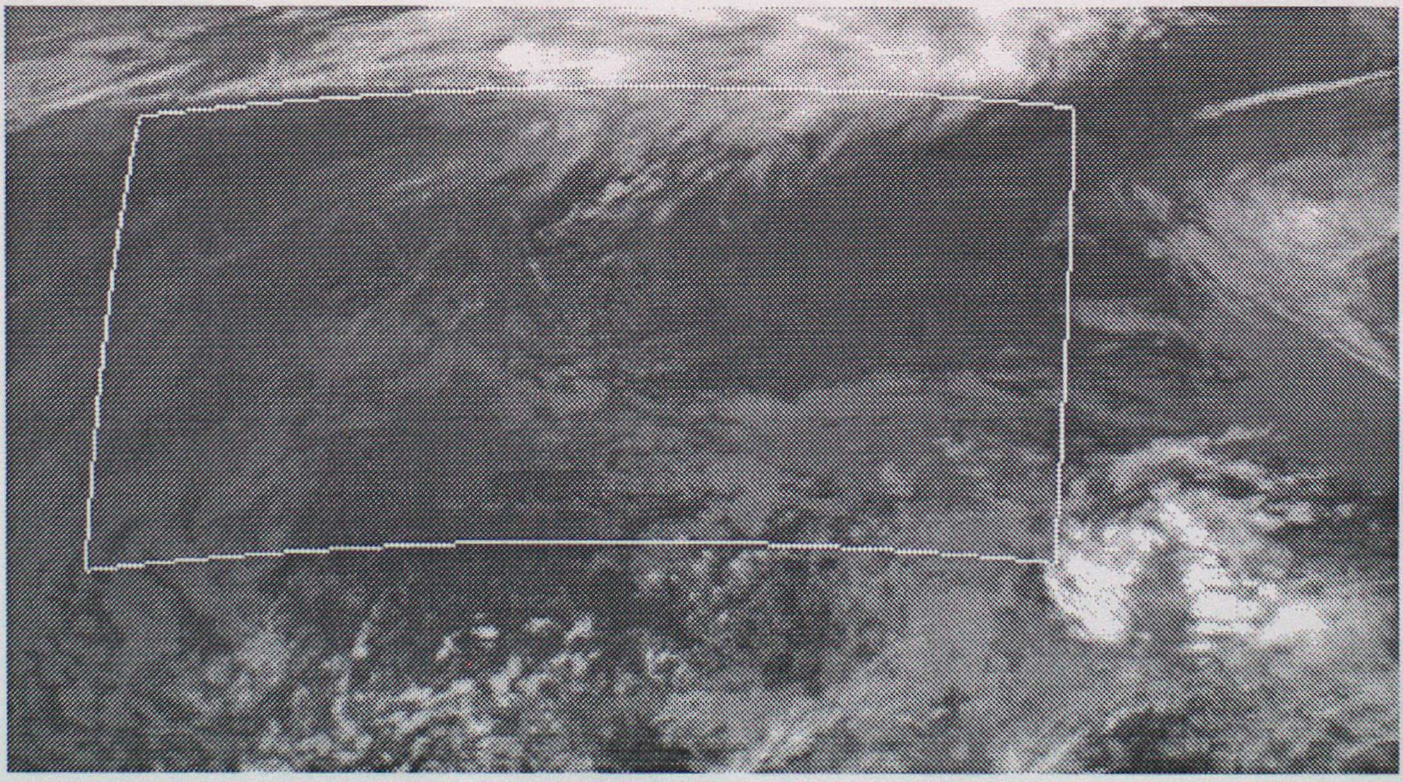


Image Classified as cloud by Vis only, Ir only, Vis/IR combined

Figure 11b:

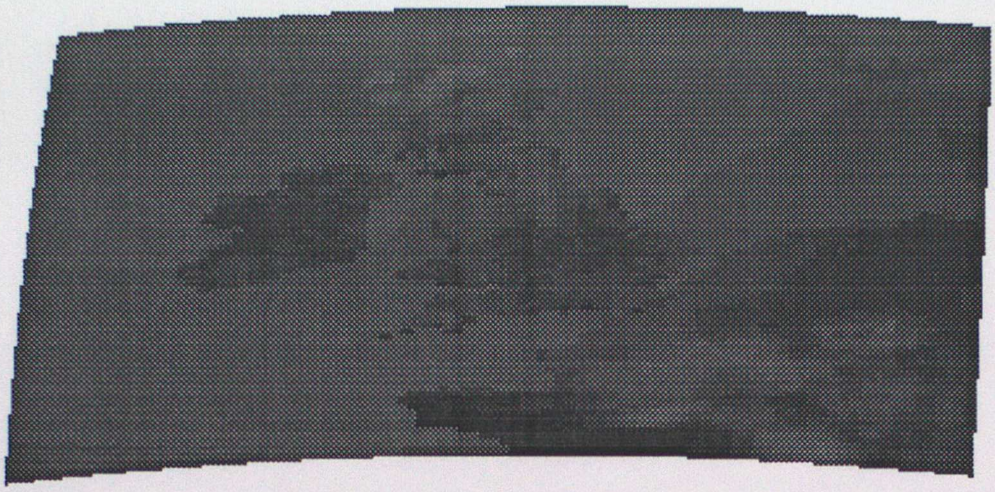


Normalised Visible Image 21SEP94 1500



Corresponding Infrared Image 21SEP94 1500

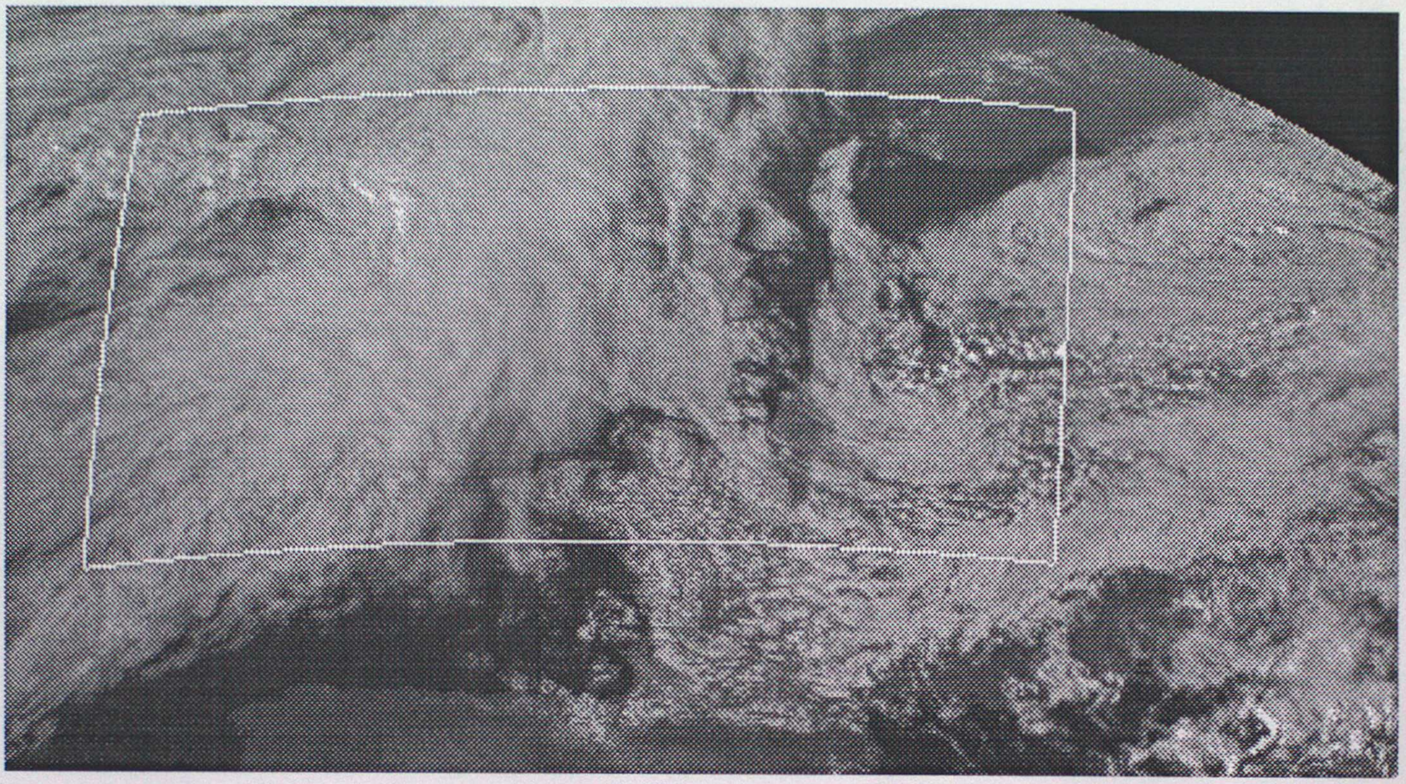
Figure 12a:



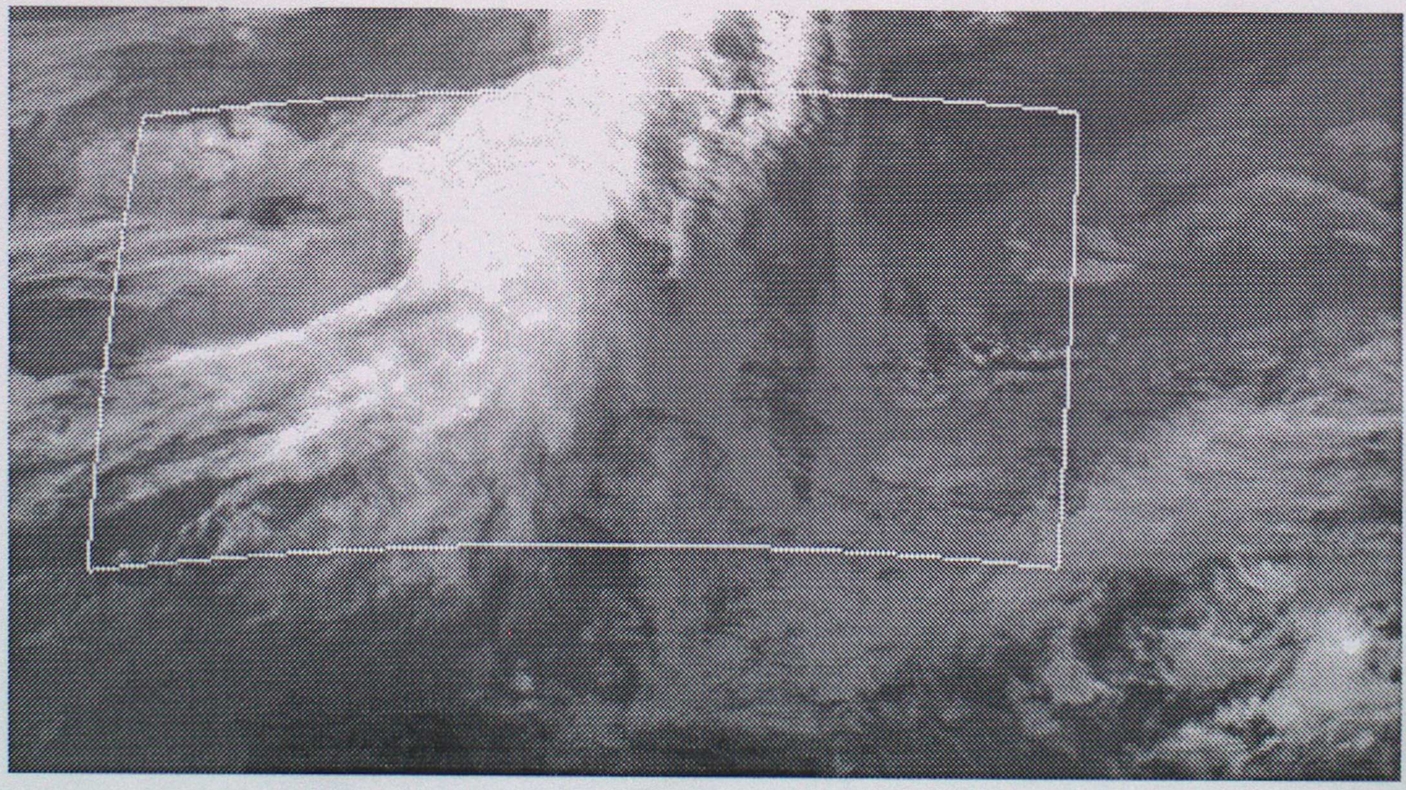
Surface Temperature Forecast 21SEP94 1500

Image Classified as cloud by Vis only, Ir only, Vis/IR combined

Figure 12b:

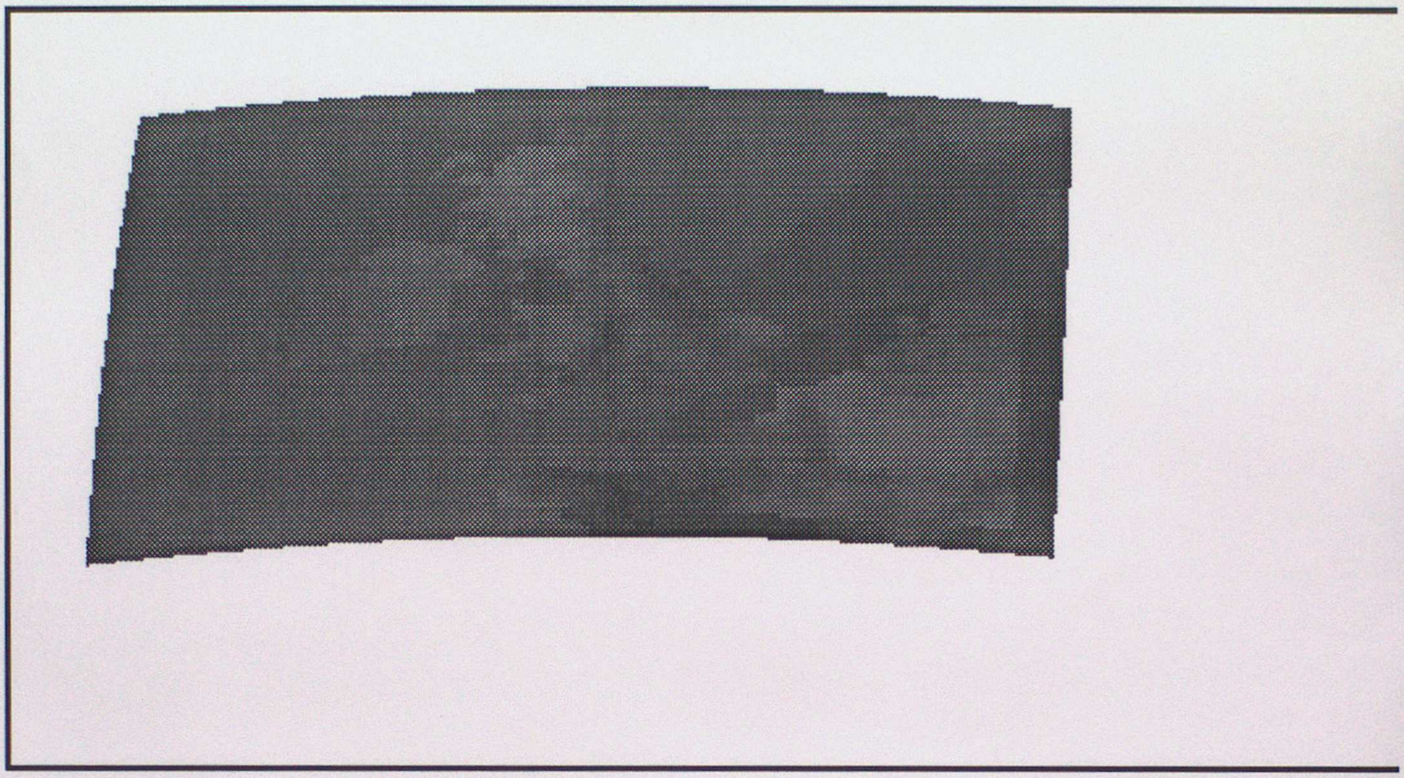


Normalised Visible Image 18SEP94 1500



Corresponding Infrared Image 18SEP94 1500

Figure 13a:



Surface Temperature Forecast 18SEP94 1500

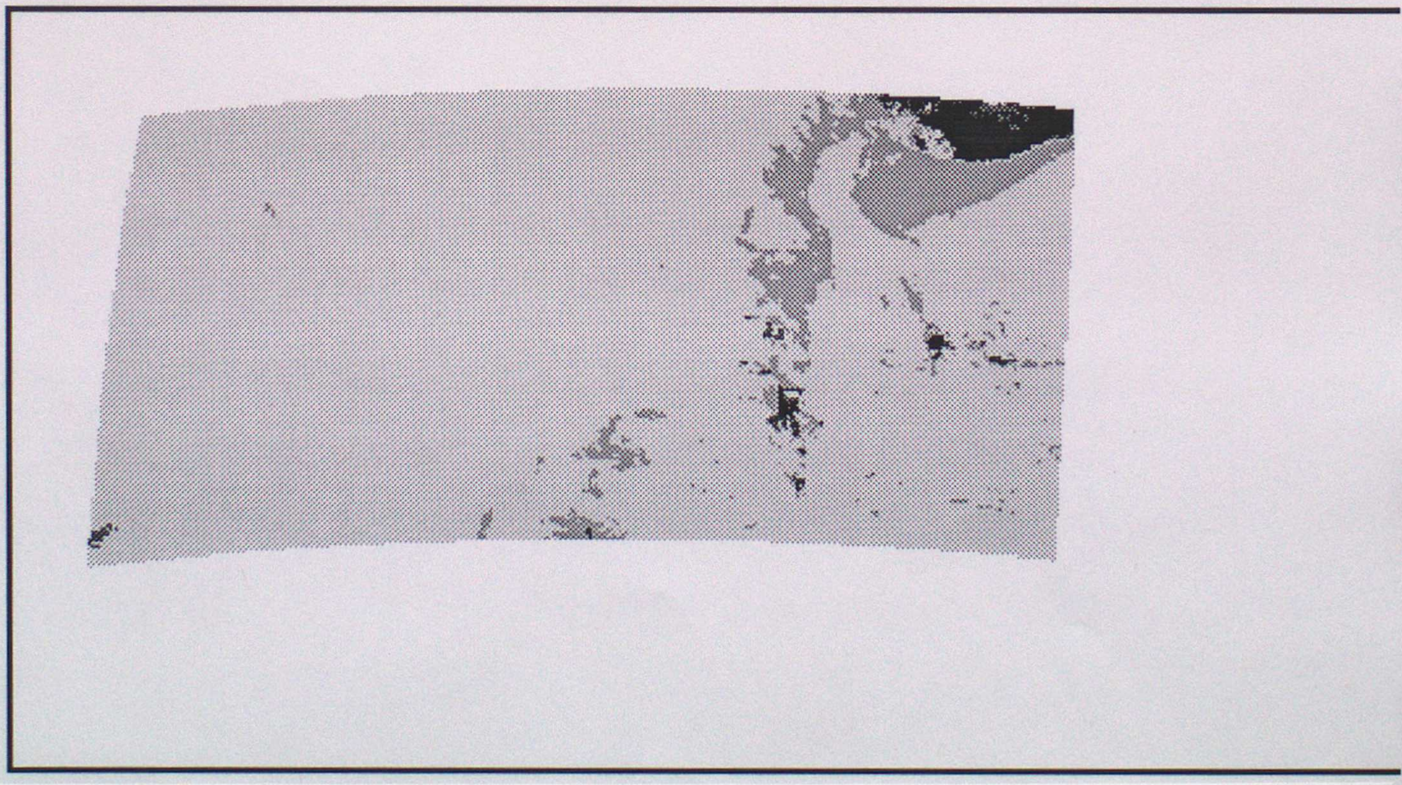
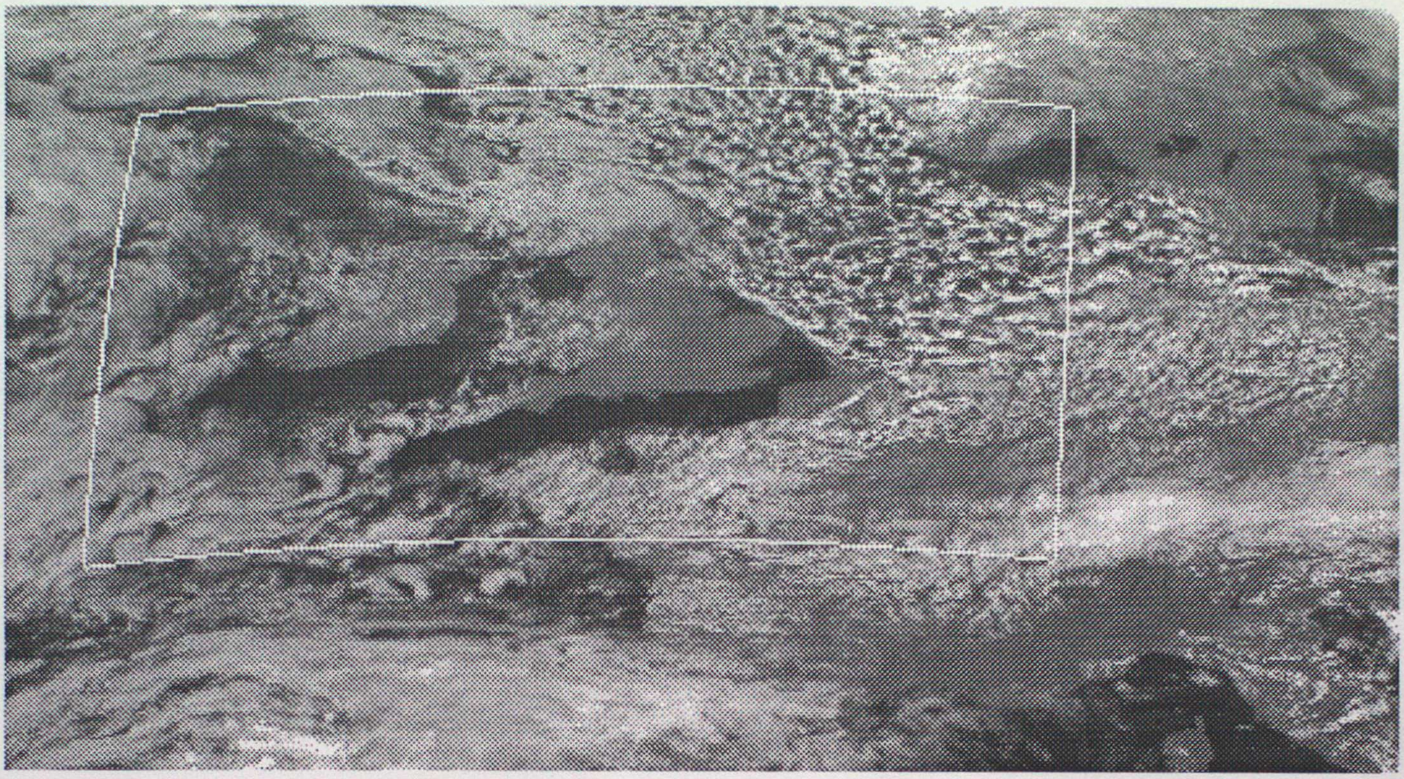
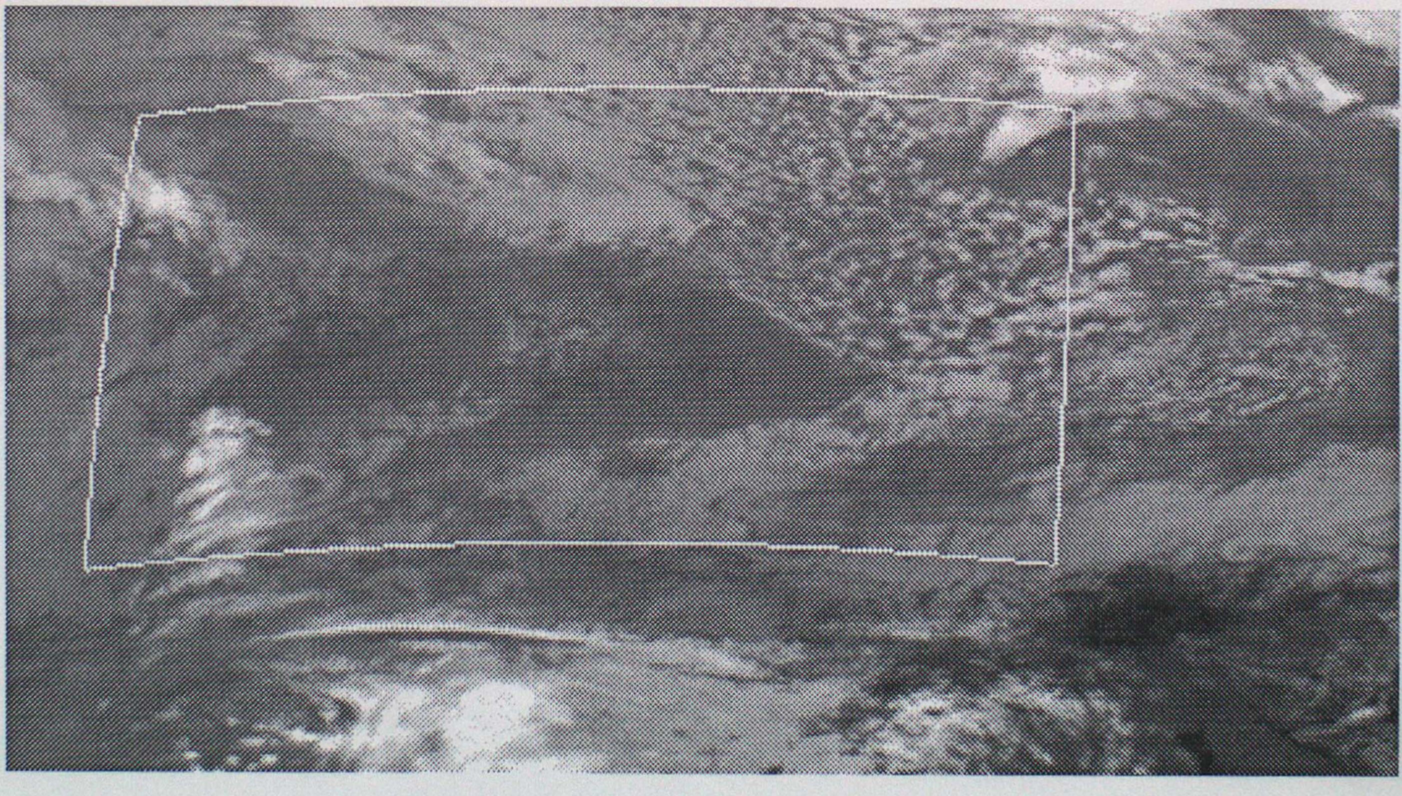


Image Classified as cloud by Vis only, Ir only, Vis/IR combined

Figure 13b:

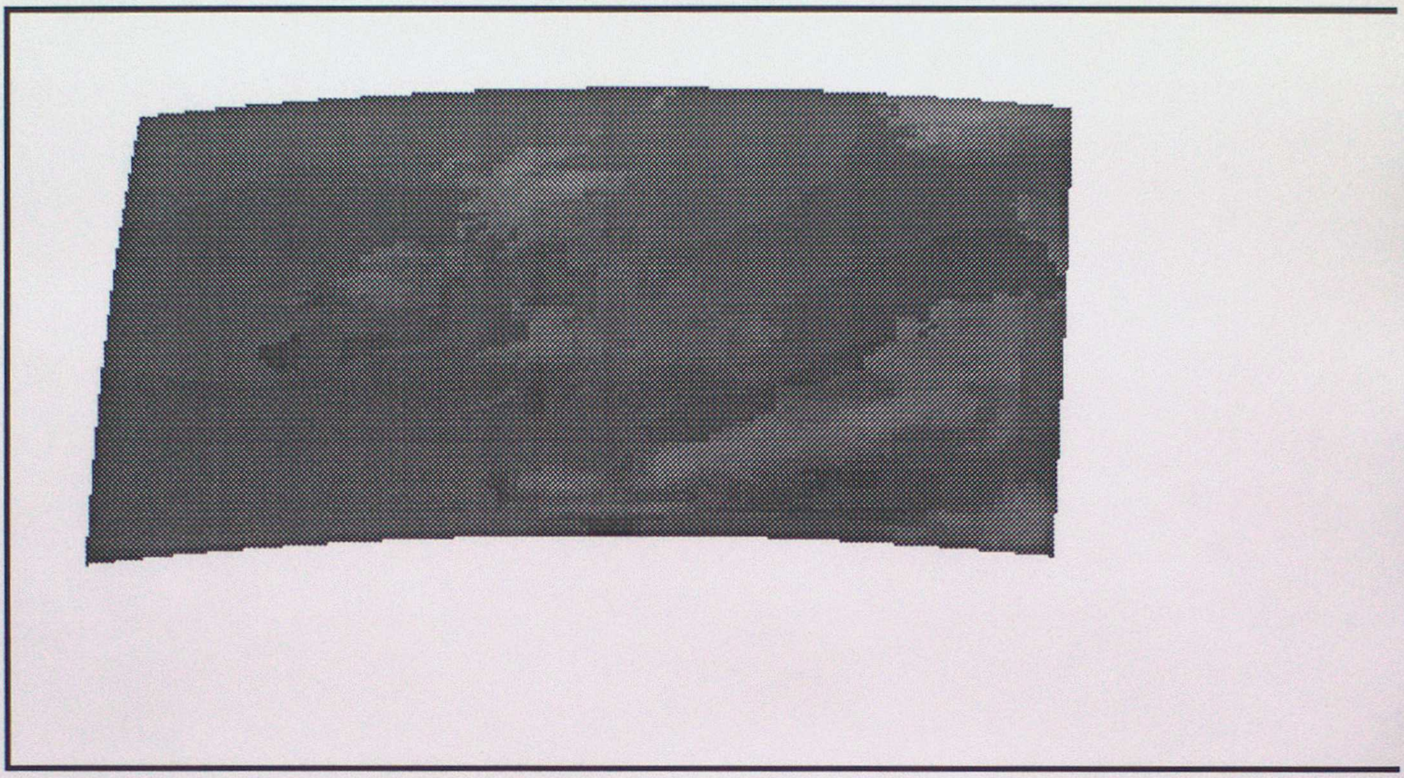


Normalised Visible Image 04OCT94 1200



Corresponding Infrared Image 04OCT94 1200

Figure 14a:



Surface Temperature Forecast 04OCT94 1200

Image Classified as cloud by Vis only, Ir only, Vis/IR combined

Figure 14b:

a visible threshold during the hours of daylight will allow the detection of bright, low cloud whose temperature is close to that of the forecast.

For Visible data, there is a good discussion of the thresholding technique and of the trade-off between sensitivity and mis-identification in Seze and Rossow (1991). For Visible data Rossow and Garder (1993) determine a land threshold of 6% albedo (consistent with the present analysis), but over the sea (where there is less variability in the clear-sky reflectance) use a threshold of only 3%. They make the point that the threshold should correspond to the uncertainty in the clear-sky values.

It is intended that during the day when both Vis and IR imagery are available, that both threshold techniques should be used. Where a pixel satisfies the IR criteria, or fails the IR and passes the Vis criteria, that pixel should be classified as cloudy. The remaining question as regards use of visible thresholding is, does using a variable rather than a fixed threshold result in a better overall classification?

If a pixel is classed as cloudy by the Visible threshold, but clear by the IR threshold, it may either be that the forecast surface temperature is too low, or that the pixel contains low cloud, with a cloud-top temperature similar to that of the surface. Conversely, if the IR classification is cloudy, but the Vis classification is clear, it may be that the forecast surface temperature is too high, or that thin cirrus is present which has reduced the IR brightness temperature at that point. There may be scope for developing a more subtle algorithm for marginal cases.

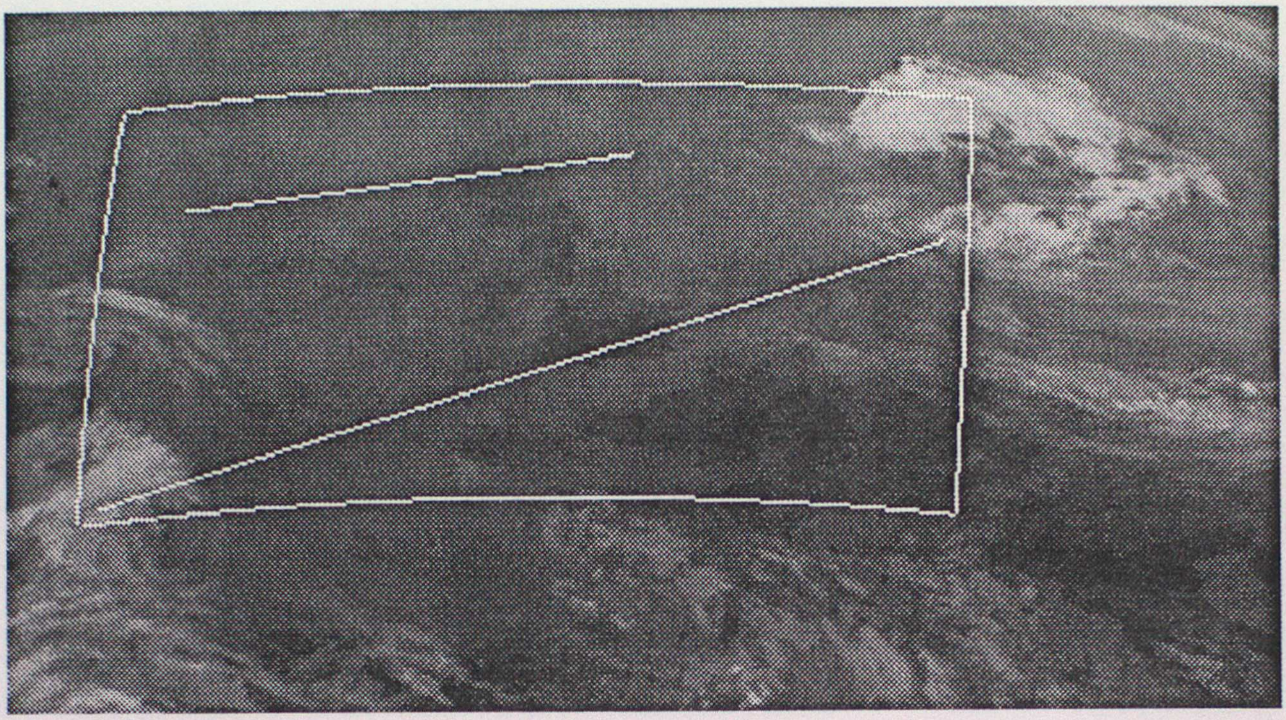
It is realised that there is more work to be done in both detecting and classifying cloud during the hours of darkness. It may be possible to use information gained from the visible classification during the day to determine a more accurate IR threshold value, which could be then be used at night. Investigation of a signifigent number of different situations, and at different times of the year would be required to see whether this method would give improved results.

4.2 Justification for using a variable visible threshold

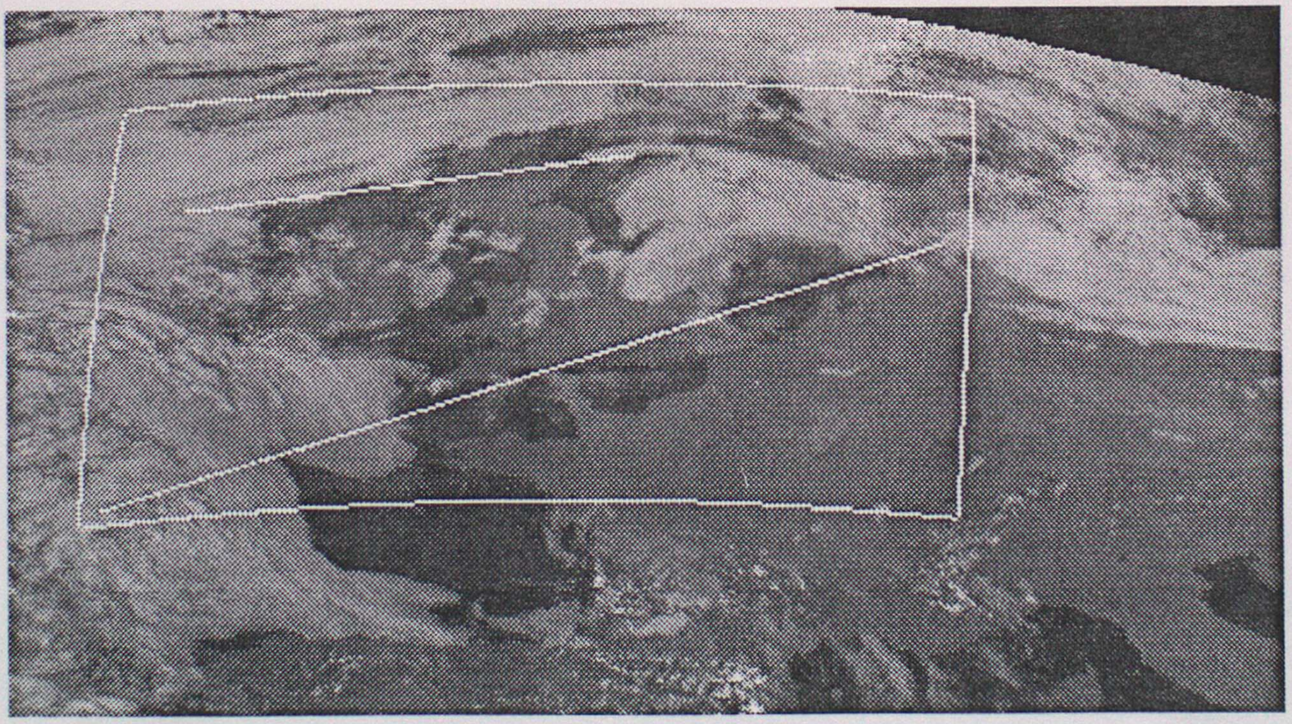
From the generation of the 'clear-sky' images, it can be seen that the minimum albedo value for land under cloud-free conditions can be as high as 24 or 25%. Allowing for uncertainties in these 'clear-sky' values, a fixed threshold in the visible imagery must be at least 30%, so that cloud-free land is not mis-classified as cloud.

The case of 13 October 1994 at 1300 UTC has been chosen to illustrate the results. To determine where the differences between IR and Vis thresholding lie, two profiles have been taken across the images, the paths of which can be seen on the two images (IR and Vis). (Figures 15a,b). The profile across the lower part of the image is through what appears to be low cloud or sea fog, while the profile in the upper part of the image skims the edge of an area of higher-level cloud.

In both plots (Figures 15c,d), the dashed line shows the variable visible threshold, and the dotted line the IR threshold (forecast surface temperature minus six degrees), along the path taken. On the left hand y-axis is shown albedo, and on the right is shown temperature. Both the albedo and temperature profiles are shown as solid plot lines, the lower plot line being the temperature profile. For both Ir and Vis, the pixel is

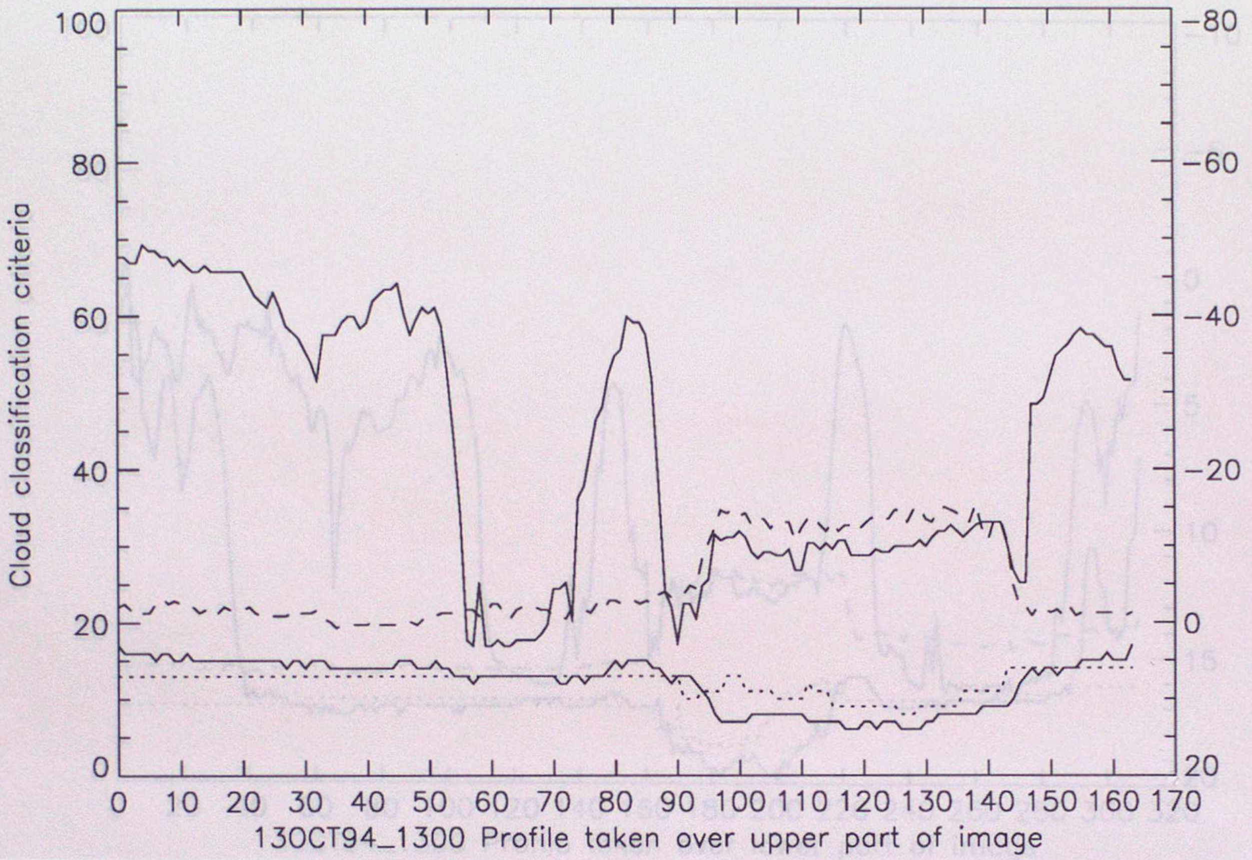


Infrared Image 13OCT94 1300 showing profiles



Visible Image 13OCT94 1300 showing profiles

Figure 15a, b


Cloud classification criteria
100
80
60
40
20
0
-80
-60
-40
-20
0
20
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170
13OCT94_1300 Profile taken over upper part of image

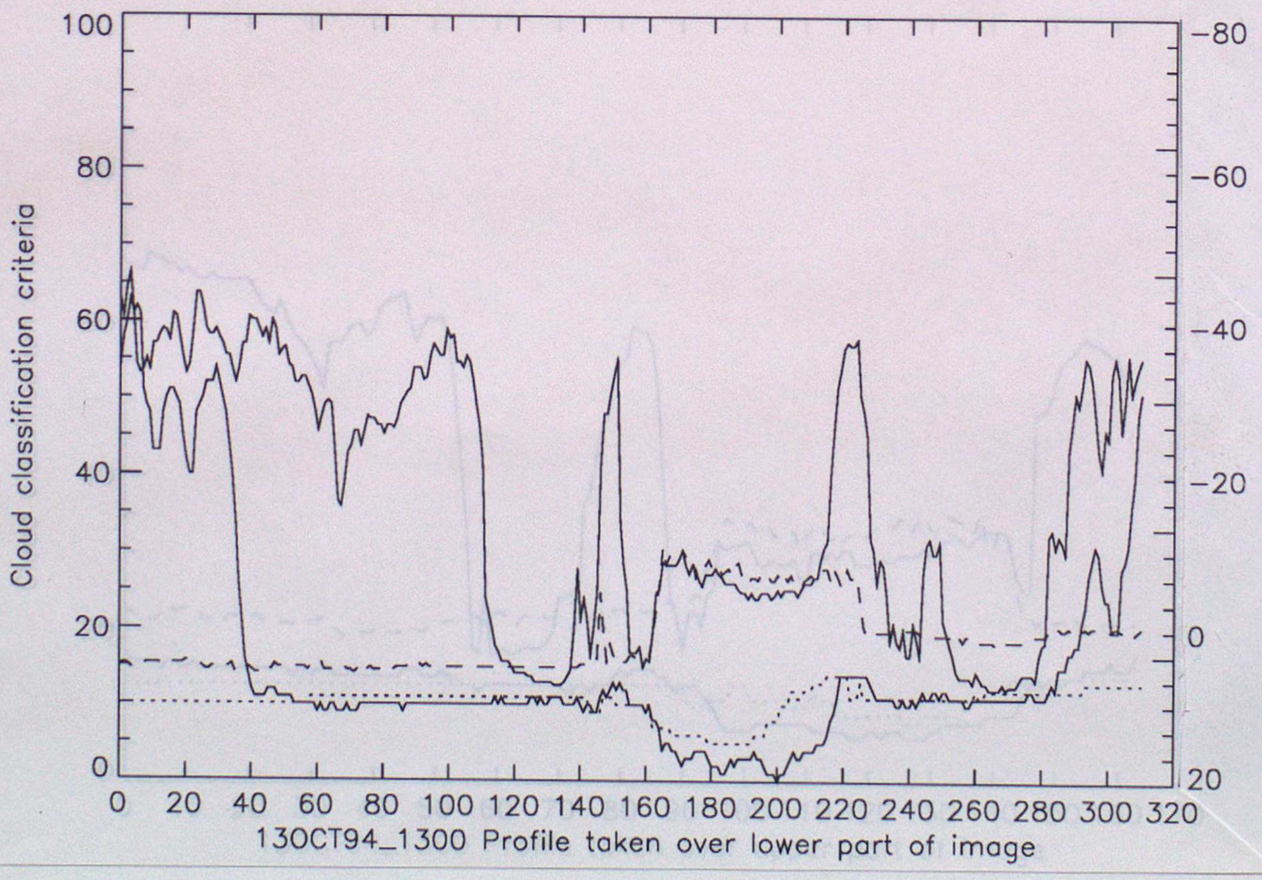
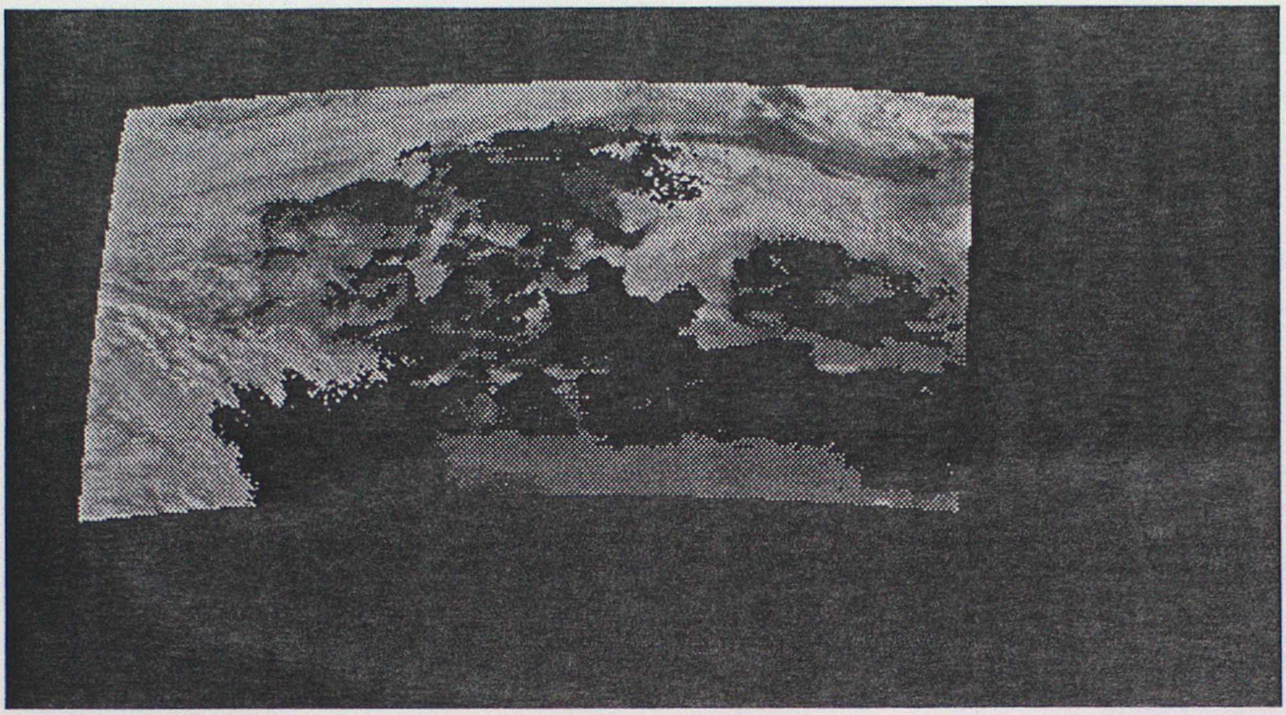
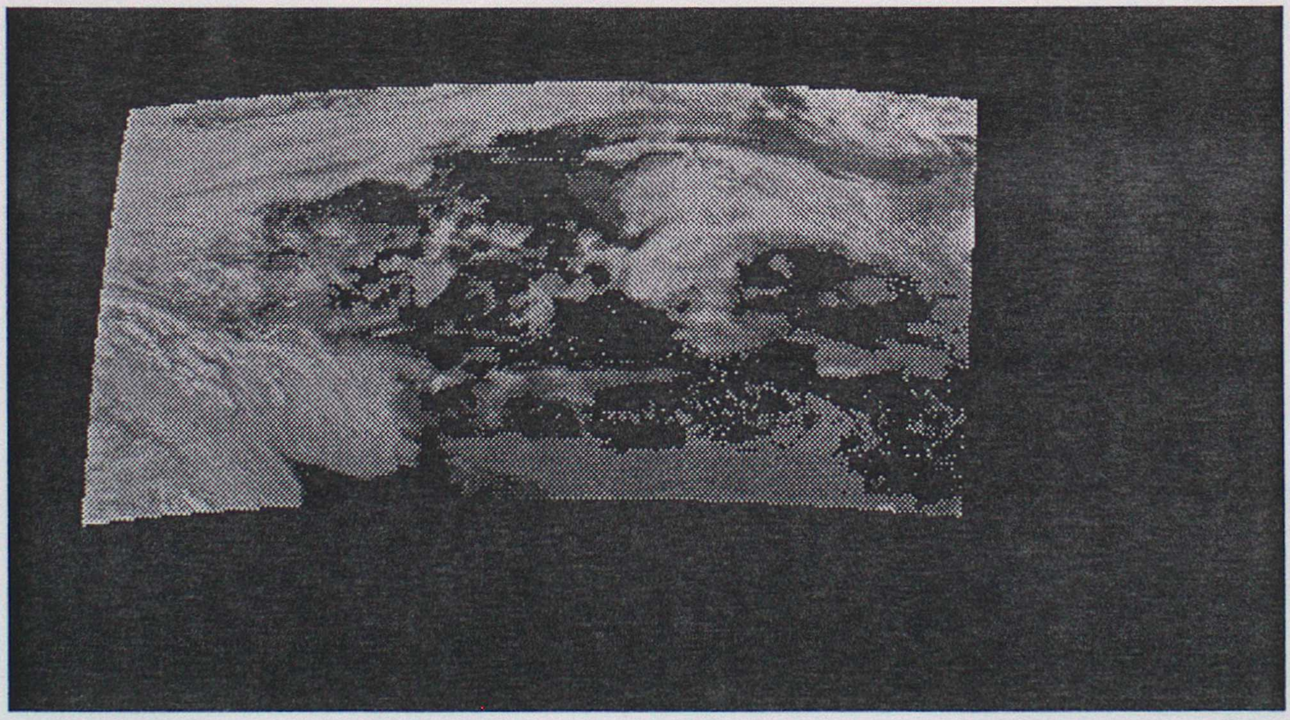

Cloud classification criteria
100
80
60
40
20
0
-80
-60
-40
-20
0
20
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320
13OCT94_1300 Profile taken over lower part of image

Figure 15c,d



(i) Cloud detected by IR threshold 13 October 1994 1300Z



(ii) Cloud detected by IR and variable visible thresholds

Figure 15 e,f

taken to be cloudy where the solid plot lines lies above the threshold, (dotted for Ir, dashed for albedo) The bigger difference between the two classifications occurs in the profile taken across the lower part of the image. Between pixels 60-120, the measured brightness temperature is above that of the threshold, so is taken to be clear. This coincides with a large area of low cloud, with an albedo of between 35-60%. At these values, above that expected for cloud-free land, there is no justification for using a variable threshold in favour of a fixed albedo threshold. It must also be shown that that there are areas of cloud not picked out by the IR threshold but with an albedo below 30% (the expected 'clear-sky' maximum). This condition is satisfied across the profile taken over the upper part of the image, parallel to the edge of a cloud mass, from pixels 70 to 75, and 144 to 148. While this gives us a smaller increase in the amount of cloud detected in the upper part of the image as opposed to the lower, it does demonstrate the detection of additional cloudy pixels by use of a variable visible threshold, as opposed to a fixed threshold.

The classified images (Figures 15e,f) show the result of applying (i) the current IR threshold, and (ii) combining the result from (i) with a variable visible threshold applied to those pixels where the IR threshold gave a 'no-cloud' result.

5 Conclusions

In the short-term, to produce a cloud-mask, we should be using a thresholding technique combining Vis and IR during the hours of daylight and IR at night. (Since we have been able to demonstrate that using the visible image enables us to detect the low, relatively warm cloud which is not apparent in the IR).

A visible threshold of 6% albedo works well, excepting the brightening feature associated with the midday Visible images. A possible refinement (Rossow & Garder (1993)) would be to have different thresholds for land and sea surfaces, since the sea surface reflectance is less variable than the land. However, given that the Visible thresholding is given a lower priority than the IR thresholding, further lowering of the Visible threshold by 2 or 3% albedo over areas of water should have little additional effect.

6 References

Rossow, W.B., and Garder, L.C., 1993, "Cloud detection using satellite measurements of infrared and visible radiances for ISCCP." J Clim, 6, 2341-2369

Sèze, G., and Desbois, M., 1987, "Cloud cover analysis from satellite imagery using spatial and temporal characteristics of the data." J Clim and App Met, 26, 287-303

Sèze, G., and Rossow, W.B., 1991, "Time-cumulated visible and infrared radiance histograms used as descriptors of surface and cloud variations." Int J Rem Sens, 12, 877-920