LONDON, METEOROLOGICAL OFFICE.

Met.O.19 Branch Memorandum No.18.

Interim report on the processing of satellite imagery data in Met.O.19. By SALTER,P.R.S.

London,Met.Off.,Met.O.19.Branch Mem.No.18, 1975,31cm.Pp.8.2 Refs.

Diagrams held in Met.O.19 only.

MET O 19 BRANCH MEMORANDUM NUMBER 18

INTERIM REPORT ON THE PROCESSING OF SATELLITE IMAGERY DATA IN MET O 19

P.R.S. SALTER

(Due to the large number of photographic diagrams in this report, the reader must please consult a master copy containing these diagrams. This master copy is held in Met O 19).

Interim Report on the Processing of Satellite Imagery Data in Met O 19

by P Salter

1. Introduction

This report provides an account of work undertaken and continuing in Met O 19 on the processing of high resolution satellite data. Both quantitative and qualitative aspects have been considered. The quantitative approach leads to a numerical output concerning the distribution of sea surface temperatures (SST's) and cloud-top temperatures (CTT's), the latter perhaps leading in turn to cloud type distributions. Qualitative work has been concerned with pictorial displays of potential use in synoptic work.

At the outset it must be explained why Very High Resolution Radiometer (VHRR) data has been used in this work in preference to the alternatives of Scanning Radiometer (SR) data or Vertical Temperature Profile Radiometer (VTPR) data. In so far as quantitative work is concerned, ie the deduction of temperatures, there are difficulties in the interpretation of VTPR data due to the relative coarseness of their resolution. The VTPR instrument has a field of view at the earth surface of about 60 km square. The corresponding figures for the SR instrument are 8 km in the infra-red (IR) and 4 km in the visible (VIS) wavelength channels. On the other hand the VHRR instrument has fields of view at both 11.5 micron (IR) and 0.5 micron (VIS) of about 1 km square. This small field of view is more likely to be cloud free or to be wholly cloudy than the larger fields of view associated with the SR and VTPR instruments. There will, of course, be some VHRR observations in which the field of view will be partially occupied by cloud. Thus, for example, the VHRR instrument is more likely to "see" cloud free "holes" over the oceans from which SST's may be deduced. A further consideration arises with the SR data which is not related to the size of the field of view. The raw SR data is not received and archived either here or elsewhere and we have not been able to obtain this in digital form as has been so for samples of VHRR and VTPR data*, which have been acquired from Lannion

---

* It should be noted that VTPR data originates from the satellite in digital form while both SR and VHRR data are transmitted in analogue form, digitisation being undertaken on the ground as required.

and Lasham respectively. However, as will be explained later, it has been possible to degrade the VHRR data to correspond to the resolution appropriate to SR data or, in other words, to produce synthetic SR data.

The NOAA II, III and IV satellites have carried VHRR instruments and some data has been obtained from each. The radiometers scan from horizon to horizon at a constant angular rate. One scan line of both the IR and VIS channels consists of about 2000 contiguous observations and in a typical pass from North Cape to the Canaries which may be "seen" from Lannion there are about 7,500 lines. Thus there are over 15×10^6 pieces of data available from each channel originating from "a good overhead satellite pass". In computer terms, two standard magnetic tapes are required to store these data at normal density.

2. Quantitative Studies

As already noted a quantitative treatment of digital VHRR data allows the retrieval of SST's and CTT's. The details of the retrieval methods will not be given but a summary of the required treatment follows.

As a result of the ~~large~~ high resolution of the VHRR instrument, individual observations are likely to relate to wholly cloud free or cloudy areas with a few which contain partial cloudiness as explained above. The technique adopted to select observations for SST and CTT determination is to construct an histogram of a large number of observations originating from an area of about 32 x 32 or 64 x 64km ie 32 x 32 or 64 x 64 observations, thus leading to derived parameters which refer to a nominal grid spacing of around 32 or 64 km. Such an histogram will produce a sharp peak frequency of the radiances concerned which corresponds to a small range of temperatures or would if only the surface or a single cloud layer were contained within the frame of the observations. If broken cloud or multi-layered cloud were present then the histogram would show more than one peak. This is illustrated in Figure 1. Both IR and VIS observations may be handled in this way and the use of both channels helps to minimise the effects of noise. Land surface temperatures cannot be retrieved because of the influence of surface characteristics on emissivity.

Within Met O 19 most work has been carried out with IR observations and only a small effort has been made in using the two channels simultaneously. After selection as explained above the digitised IR signals were converted to radiances using calibration data derived from on board measurements which are in turn inverted to temperatures by Planck's equation. The ~~se temperatures~~ radiances are corrected for water-vapour content by means of transmission coefficients which are calculated from representative temperature and water-vapour profiles down the "pass". Once the corrected temperatures have been computed they are tested as to whether they correspond to sea or cloud by means of appropriate threshold values. In regions remote from the Arctic basin retrieved temperatures at or below 0°C during daytime passes will usually be associated with clouds. The difficulty with assigning realistic temperatures to cloud tops is that a knowledge of the cloud emissivity is required (and hence of the cloud constituents, water droplets, ice crystals or a mixture of both). In this respect a standard set of emissivities has been used in an empirical way from the work of Allen[1] and Platt[2].

Figure 2 shows the distribution of derived SST's for 29.9.73 together with cloud temperatures which have been symbolised. This diagram uses the IR only and transmission coefficients appropriate to the "straight down" view. Each value has been derived from an array of 32 x 32 raw data points which was used to produce an histogram. Figure 2 can be compared with Figure 3 which illustrates SST's derived from ships' observations. The two diagrams show that the derived SST's are, in general, 1-2°C higher than the "true" values and that there are some spurious values notably in the area WSW of Spain where there are two regions of low clouds. By incorporating the VIS data in conjunction with the IR it is hoped that it is possible to reduce the number of these contaminated values.

Figure 4 illustrates the effect of using "simulated" SR-IR data. The synthetic data are produced by averaging an 8 x 8 array of VHRR data which are then histogrammed from groups of 32 x 32 in the manner described earlier. Thus these derived values represent observations at a spacing of about 256 km, the spacing of a typical numerical weather model. However real SR data have a poorer resolution of brightness or temperature than VHRR data and this will degrade the numerically derived values.

3. Qualitative Study

3.1 General Comments on the Display of VHRR Data

VHRR data originates from the satellite in analogue form and, given a suitable (and expensive) recorder such as that available at Lannion, it can be displayed directly as a picture. The quality of the display is related to the ability of the particular recorder to represent the number of grey shades contained within the analogue signal. The only form of VHRR data available to us is contained on digitised tapes and it was thought worthwhile to attempt to display these data in pictorial form for comparison with SR displays.

There are two ways in which this can be attempted using facilities which currently exist within the Office. The first is to represent the data on a Visual Display Unit (VDU) associated with the computer. Since this display cannot easily be intensity modulated the only way in which the VDU can be used is to represent the various radiances (temperatures) by a series of alpha-numeric symbols. This is not attractive. The second and better method is to use the Calcomp facility which allows one to obtain photographic film which is either negative or positive depending on the computer software used. By producing a negative Calcomp film it is subsequently possible to obtain enlargements using normal photographic techniques. The scale of the final output may be adjusted to render it easy to use alongside synoptic charts.

3.2 Detailed Considerations and Use of Calcomp and Some Results

At Lannion the data are digitised to 256 levels before despatch to Bracknell. A computer programme is used to group the digital data into a convenient number of intervals to correspond to a range of grey shades for Calcomp plotting. Calcomp can produce 30 grey shades from white to black, which in practice gives too much detail for the normal use of cloud photographs. It appears sufficient to provide for only 10 shades. However reference to Figure 5 should be made. This diagram shows quite clearly the limitation of using Calcomp for displaying high resolution imagery. It is desirable to constrain the "pass" to a single Calcomp film frame which determines the line spacing (in practice about 75-100 lpi) to be used on the frame. Figure 5 illustrates that for a given line spacing the beam intensity of the Calcomp system has a limited range especially at the higher line densities. At a line spacing of 75-100 lines per inch there are about 9 grey shades available.

The computer time required to produce Calcomp frames has been found to be significantly less when the plotted line consists of a series of very short lines rather than dots. Thus all of the enclosed photographs have been produced by this faster method.

Enclosed with this report are VIS and IR images at various resolutions produced on the Calcomp system as explained above as well as some synthetic SR results for four different dates. The French (Lannion) photographs obtained by them from the analogue signals which have been applied to their expensive laser beam recorder have been added where these are available. The synthetic SR images are pictures of spatial resolution equal to that of the SR pictures at present used by CFO. These results cannot be directly compared with real SR pictures as the signal to noise ratios are different in the two system (VHRR and SR). However with the grey scale resolution used here the differences will not be significant. Probably the simulated SR results approximate to the product to be expected from the future TIROS-N SR system.

The attached photographs each show most of the available "pass". The black vertical lines sometimes present in the photographs near the edge are telemetry signals which can serve to indicate that data within these markers suffers 10% or less distortion. Although some of the results are at half and third resolution (ie 2 x 2 or 3 x 3 observations meaned to give a single value) the photographs show that even with this considerable degradation the significant cloud features are preserved. The VIS photographs are rather more contrasty than is desirable. This could be rectified by a small software adjustment. The results are all obtained from the standard Met O 12 Calcomp process. The enlargements were made by using the

Met O 21 dark room. It is expected that there will be an improved representation of grey tones if the film was processed outside the Calcomp system. Met O 12 have indicated informally that they could take part in an experiment using off-line film processing.

Despite the fact that the limitation of the grey scale imposed by Calcomp may be hiding some details of the poorer resolution pictures, it seems that for most operational purposes a spatial resolution of around 4 km is as good as a 1 km resolution. But for detailed analysis of ice-fields and small scale features the highest resolution is desirable. To achieve greater contrast between cloud and ice in the IR the grey scale should be reset and expanded. This will, even at poor ground resolution, lead to greater detail being obtained.

3.3 Computer Time

The computational times required to produce the Calcomp frames via the 195 are considerable. The CPU times for "on-line" production of the film for a pass of 4,500 lines of raw data are listed in Table 1.

Table 1

Resolution	CPU Time
2 x 2 IR or VIS	7.10 min
3 x 3 IR or VIS	3.75 min
Simulated SR-VIS (ie mean of 4 x 4)	2.75 min

Thus a full resolution picture in the IR or VIS channel for 4500 lines will consume nearly half an hour of 195 CPU time.

None of the photographs included in this report has a superimposed latitude-longitude grid. However the necessary software has been written to produce a 5-degree lat-long mesh over the same frame as the image so that no separate overlay is necessary for the geographical location of particular features. The computing time necessary to do this is an additional 10 seconds on the 195. Software also exists to "fit" the picture to a polar stereographic projection.

3.4 Analogue or Digital Data

The question arises as to whether to obtain and use analogue or digital data, leaving out the question of equipment cost and computer time. For the purpose of producing photographs only there is no particular advantage in using one data form or the other. However if the data is digitised then it can be used to produce numerical values of temperatures as explained above.

The digital data also allows the production of a geographical grid for locating the cloud positions since these data contain the information necessary to do this. Thus, in general, it is preferable to have access to the raw data in digital form.

4. Conclusions

This report is only an interim account on the "state of the art". It has been shown from one case study that it is possible to produce derived values of SST's and CTT's which are realistic when compared with conventional measurements. It is difficult to verify the cloud-top data in any practical way except possibly by chance aircraft reports, but perhaps the results are best left to be compared with photographs in the VIS channel. A rough check shows that the different cloud heights in Figure 2 more or less coincide with what is depicted in the corresponding photographic results. Using the VIS and IR channels together can be helpful in removing many erroreous values (such as shown in parts of Figure 2). Suitable threshold values may be set by the VIS data; alternatively a two-dimensional histogram may be constructed.

Testing the size of segment of raw data to process in a numerical scheme has shown that in the one case examined the coarsest resolution which can produce meaningful values is obtained from an array over an area not greater than 256 km square ie if one uses VHRR data one can block it into 256 x 256 arrays of raw data for processing, if SR is used one can block it in units of not more than 32 x 32 data points at a time.

The results from using Calcomp to produce a photographic representation of digitised VHRR data suggests that a resolution of about 4 km is sufficient to preserve the important cloud features. That is, that SR data is as good as VHRR data in this context. Improvements (if thought necessary) in the photographic results might be expected from using off-line processing of film from Calcomp.

The software for producing a geographical grid on the image data already exists but is undergoing some improvements. Software has also been written to "bend" the image to a polar stereographic projection but the computing time required is more than the time required to produce the image with a grid on it. Hence this has not been pursued.

With regard to future activity it could well prove worthwhile to compare VHRR and SR data with that obtained from the VTPR instruments. This could lead to an appreciation of the degree of success achieved in "declouding" VTPR window radiances. Further, more confidence could be gained in the interpretation of satellite data by comparing aircraft surface radiance measurements and sea surface temperatures as obtained conventionally. Such a comparison would help to evaluate objectively our calculations of transmission coefficients for "wet" profiles through the atmosphere. The initial approaches to MRF and the USA have been made to set up this exercise.

5. References

1. Allen, J R Measurements of cloud emissivity in the 8-13 μ waveband, J App. Mer., Vol. 10, no. 2, 1971, p 260.
2. Platt, C M R Emissivities of layer clouds in the atmospheric window (8-12 μ). Proceedings of International Conference on Weather Modification in Canberra, Sept. 1971.