SOME APPLICATIONS OF SIMPLE IMAGE ANALYSIS TECHNIQUES TO VERY HIGH RESOLUTION SATELLITE DATA

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ABSTRACT

Simple colour densitometry equipment is described, and is applied to NOAA 3 Very High Resolution Radiometer (VHRR) data to examine the resulting observational utility in meteorological operations and research. Examples are given of observations and measurement on thermal infrared imagery depicting cloud patterns associated with depression, evolution and frontal structure. Selected visible range imagery displays detail of a forest fire smoke plume and of sea ice characteristics.

INTRODUCTION

With the advent of the newer satellite observing systems meteorologists are now able to obtain imaged data of the earth's surface and cloud structure at greatly improved resolution (circa 1 km) and with a higher frequency of observation. The limitations on the numerical processing of the resulting enormous quantities of data dictate that they will be available to users primarily in photographic image format, although derived from scanning radiometers in both the visible and thermal infrared ranges.

It is well recognised that the derivation of quantitative information from such data as an input to fine mesh numerical models presents an even more difficult problem than the use of satellite imagery in broad scale numerical analysis - an undertaking to which considerable effort has been devoted (eg, Nagle and Hayden 1971, Troup and Streten 1972, Kelly 1975). Nevertheless, there is little doubt that such high resolution image data provide unique information despite the difficulties associated with their subjective interpretation. It seems probable, therefore, that these data will initially be of primary value in the area of manually prepared regional and mesoscale analysis and in forecast updating, and that hopefully they will later provide a source of input to fine mesh numerical models.

Such image data have always presented problems of interpretation, and despite the fact that the eye of an experienced synoptic meteorologist is probably the most effective analysis device, some types of equipment now available make possible finer distinctions and quantitative assessments of photographic grey scales than is possible by the unaided eye. The latter, however, remains responsible for the identification of meteorologically significant patterns and the selection of areas of interest on the images which may require enlargement, special processing, or densitometric examination.

In the present investigation one type of image analysis system was used to examine high resolution satellite data for selected situations in order to display its utility in meteorological operations and research.

VERY HIGH RESOLUTION RADIOMETER DATA

The data used in the analysis were derived from the Very High Resolution Radiometer (VHRR) carried in the polar orbiting NOAA 3 satellite and read out at the Command and Data Acquisition Facility at Gilmore Creek near Fairbanks, Alaska. These data have a resolution of approximately 1 km both in the visible (0.6 to 0.7 micron) and in the
thermal infrared (10.5 to 12.5 micron), and are typical of those now becoming available to a chain of receiving stations in North America and to a restricted extent elsewhere. Owing to the limited on-board storage of VHRR data the transmission from the satellite must be received by a ground station in the same general region for which the data are taken. Thus, the present examples refer to Alaska and northern Canada.

The data are in the form of photographic positive transparencies (approximately 25 cm × 25 cm) or prints derived directly from the master negative, which is itself produced via a Mairhead recorder from the ground processing unit at the readout station. It is possible with the processor currently employed in the United States to produce special negatives where the whole grey scale is used to show detail over a preselected range of reflectance in the case of the visible range, and temperature in the infrared range. These then exclude from the grey scale range any area which does not have a reflectance or temperature within the set limits. However, such techniques are at present largely research oriented (e.g., in the examination of small differences in sea surface temperature resulting from currents or upwelling) and are not yet readily able to be used on a day to day basis, i.e., special processing of the original data is required for each particular application to dictate the ranges to be selected.

A degree of flexibility is however possible using only the standard negative. This is produced for the broad range of temperature or reflectance observed in the earth-troposphere system, and is displayed in such a way that, for example, in the infrared the whitest part of the image represents the coldest cloud tops, and the darkest part the highest temperatures on the land or sea surface.

Such analysis methods employ colour coding of particular grey scales in the imagery to assist visual interpretation and will be described in the following section.

VHRR data and that now obtained from the first Synchronous Meteorological Satellite (SMS 1) launched in May 1974 provide resolution of the order of 1 km. These routinely produced data are capable of sectional enlargement and, particularly if enhanced by relatively simple techniques, provide much greater information on small scale meteorological systems than has previously been available. The utility of the VHRR data in a range of investigations and operational problems is emphasised in recent publications, e.g., Parmenter and Anderson (1974), Gurka (1974), and Streten (1974a).

**THE IMAGE ANALYSIS EQUIPMENT**

Several types of complex and costly equipment with the facility for grey scale enhancement, shape and pattern recognition, and inbuilt computer processing of data are now available. However, the primary meteorological requirement is to be able to distinguish objectively and readily map relative grey shades within selected significant regions of the satellite imagery. Such a function may, fortunately, to a large degree be achieved with relatively simple equipment, of which several combinations are available. Such types of equipment have principally been used for the display and analysis of biological and mineralogical specimens viewed by microscope, and in the study of data derived from aerial photographs. In particular, they have found much use in investigations using the 100 m resolution multi-spectral photography from the Earth Resources Technology Satellite (ERTS) in many fields including mineral exploration, geomorphology, forestry and oceanography.

A typical schematic equipment configuration is shown in Fig 1(a). A light source illuminates the image (preferably in the form of a positive transparency) onto which is focused a television camera which may be adjusted to view either the whole or part of the image. The output from the camera is fed through the analyser unit, which assigns a range of colours (usually eight) to the particular grey scale of the image. The analyser is adjustable so that if, for example, more detail is required in the brightest part of the image the region below a certain brightness may be made uniformly black and the variations in the bright area shown to best advantage over a full colour range. This operation is useful when cloud masses are being viewed
Fig 1(a) Schematic arrangement of typical image analysis equipment. Non-basic components are shown by broken lines.

Fig 1(b) Image analysis equipment layout at the CSIRO Division of Mineral Physics, Ryde, NSW.
Fig 2(a) VHRR infrared imagery over the North Pacific. 2043 GMT 18 March 1974.

Fig 2(b) Image analysis of the area within the frame of Fig 2(a).
Fig 4(a) Variation in the total (T), 'low' (L), 'middle' (M) and 'high' (H) satellite viewed cloud amounts (C) for the sequence of observations of Fig 3 expressed as a percentage of the standard area surrounding the depression centre. L', M' and H' show respectively the corresponding variation in relative percentage distribution for each observation.

Fig 4(b) Mean distribution of satellite viewed cloud amounts for a standard area surrounding the centre of depressions in B, C and D, development stages.
(a) at 2221 GMT on 8 July 1974 [B stage]

(b) at 2136 GMT on 9 July 1974 [C stage]

(c) at 2244 GMT on 10 July 1974 [D, stage]

Fig 3 Image analysed view of the central region of a depression near the north coast of Alaska.
Fig 5(a) VHRR infrared imagery over the North Pacific at 2008 GMT 3 June 1974.

Fig 5(b) Image analysis of the area within the frame of Fig 5(a).
Fig 6(a) VHRR visible range imagery of forest fire on 3 July 1974 located to the northwest of the Yukon River in northwest Alaska.

Fig 7(a) VHRR visible range imagery of indicated geographical features in the Canadian archipelago summer of 1974.
Fig 6(b) Image analysis of the framed area in Fig 6(a) showing the main smoke plume.

Fig 7(b) Image analysis of Nansen Sound region — framed area of Fig 7(a)
against a darker sea or terrain background which is not itself of particular interest. The image is displayed on a colour television monitor and this may be viewed by the operator as he varies the analyser controls, and changes exposure and focusing of the camera to examine the required part of the image. The analyser is provided with a digital meter which will automatically planimeter the percentage of area displayed in a particular colour, and may also be used to measure relative point intensities.

Variations on this basic configuration may provide, in addition, a black and white television monitor and/or a cathode ray oscilloscope. The latter enables a display to be made in terms of an intensity profile for a nominated line across the image or as a pseudo three dimensional isometric map with intensity displayed as the vertical co-ordinate. A further refinement is the use of a servo-mechanism to move the television camera relative to the images.

One such equipment layout is shown in Fig 1(b), that at the CSIRO Division of Mineral Physics at Ryde, New South Wales, which was used for the present observations. These examples are intended to show the advantages of the routine VHRR data, and the application to it of simple image analysis techniques for a range of meteorological situations that may be met under typical operational conditions.

ANALYSIS OF SOME VHRR INFRARED IMAGERY OF CLOUD PATTERNS ASSOCIATED WITH DEPRESSIONS AND FRONTAL BANDS

Fig 2(a) shows VHRR infrared imagery of the cloud vortex of a mature depression over the North Pacific on 18 March 1974. Fig 2(b) indicates the detail of cloud structure within the framed area of Fig 2(a) where an enlargement was made and analysed by the colour densitometer equipment. The cloud top temperature field surrounding several distinct mesoscale regions of major activity is qualitatively contoured with the coldest (highest) cloud tops being easily identified at high resolution. Unfortunately, at this stage, a temperature grey scale calibration is not available for these data. It is readily seen however, that observations of this type with the high frequency attainable from geostationary satellites, or from the proposed increased number of the polar-orbiting NOAA series carrying VHRR, should enable such mesoscale active regions to be examined in relation to time changes in intensity, dimensions, and movement. The value of extension of such observations to tropical systems of small dimensions and shorter life cycles is obvious.

Successive VHRR infrared observations viewed by the image analyser at approximately 24-hourly intervals showing the centre of a depression which moved slowly along the north coast of Alaska between 8 July and 10 July 1974 are displayed in Fig 3. In this case only a fixed central area (approximately 6 degrees of latitude in radius) is viewed by masking out the rest of the image. Further, by adjusting the analyser controls, the warmer earth surface features are excluded so that the background appears black on the screen and maximum enhancement is given to the cloud ranging from channel 1 (blue) representing the lowest cloud to channel 8 (magenta) for the highest tops. The colour densitometer view of the systems clearly differentiates between clouds at different levels and enables planimetric measurements to be made of different areal coverages. Although the colour levels are not strictly comparable from image to image the procedure adopted enables reasonable, though approximate, comparisons to be made of the extent of different cloud areas on successive days of uniform processing of the infrared data. In the present case the levels 1 and 2 are designated 'low', 3 and 4 'middle', 5 and 6 'high', and 7 and 8 'very high', the latter category however not being observed in this particular example.

Following the Troup and Streten (1972) classification, the cloud vortex progresses from the B (development) through C (mature) to D (decay) stage on successive days and has disintegrated entirely by the fourth day. The total cloud coverage (T = L+M+H of Fig 4(a)) within the central region approximately doubles from the B to the C stage and remains fairly constant into the D stage. However, the corresponding percentages of the total area covered by cloud (L', M', H' of Fig 4(a)) on each day which have cloud top temperatures falling within the particular levels vary throughout the life of the depression (Fig 4(a)). Thus, the relative percentage of
'low' cloud falls off at maturity and increases again with decay, while the relative percentages of 'middle' and 'high' cloud vary in opposite phase. A further five sequences totalling sixteen similar sets of observations to that shown in Fig 4(a) were available in the data sample. Unfortunately, however, probably because of the high latitude of the imagery, no early development (A) or wave (W) stages were observed in this limited sample. In total, these data may be described by the diagrams of Fig 4(b), showing the mean percentage distribution of cloud top height categories for each observed evolutionary stage. In general, these data are similar to those of the individual case shown in Fig 3 and 4(a). It is apparent, however, that many observations over a span of latitudes and longitudes would be necessary to obtain useful statistical information on cloud cover in depressions at different stages of development.

Because they refer to cloud tops the selected categories bear no relation to the classification of clouds observed from the ground and reported in standard meteorological observations. Further, a grey scale temperature calibration would be necessary to derive actual temperature categories, which could then be used with upper air analyses based on soundings to obtain actual heights of tops. The processing and display of calibrated infrared satellite data of similar resolution to VHRR from the United States Air Force DAPP system is described by Blankenship and Savage (1974). However, even in the absence of accurate calibration, the observations enable a rapid, qualitative assessment of the intensity of important mesoscale centres of meteorological activity and relative extent of cloud tops at particular levels. They thus provide a valuable complement to the broad scale analyses of cloud amount and height (Koffler et al, 1975).

A further example of this may be seen in the observation of frontal cloud. A VHRR infrared image of a depression over the North Pacific on 3 June 1974 is displayed in Fig 5(a), and in Fig 5(b) detail of the associated frontal band lying within the framed part of Fig 5(a) as viewed by the image analyser is shown. Here again, the background features have been blacked out and the cloud band image is displayed in a range of eight colours corresponding to density gradings. This enables an assessment of intensity and the mapping of active regions of high tops which would not otherwise be possible. Moreover, such observations, particularly in areas where simultaneous radar observations are available over a continental reporting network, present considerable scope for mesoscale investigations of frontal structure and the resulting rainfall patterns.

**ENHANCEMENT OF VHRR VISIBLE RANGE OBSERVATIONS OF SMOKE PLUMES AND SEA ICE FEATURES**

Although the VHRR thermal infrared data are most valuable for the observation of cloud masses with substantial variation in cloud top temperature, the use of the visible range imagery is necessary where only small variations in temperature but considerable changes of reflectance occur. Typical examples are the location of fog, channels in summer sea ice, and low level stratiform clouds in polar regions which, because of substantial low level inversions, may have cloud top temperature similar to or even higher than that at the earth's surface (Streten 1974b). Two examples of image analyses using visible range data are given here.

In Fig 6(a) a VHRR view is given of a forest fire in a wilderness region to the north of the Yukon River in western Alaska during the 1974 summer. Image enlargement and application of colour densitometry reveals details of the smoke plume (Fig 6(b)), which is of obvious operational value. The infrared image at this time does not clearly show the smoke trail because of the apparently small differences in temperature between the earth's surface and the smoke. A large area of fire, if viewed by the infrared radiometer, might, however, be expected to be detected dependent on the extent to which low level winds permitted a satellite view unobscured by the associated smoke plume. The use of combined VHRR visible and infrared imagery to operationally detect developing thunderstorm cells leading to forest fires is described by Jayaweera and Ahlinas (1975).
In an entirely different context Fig 7(a) shows VHRR visible range imagery of part of the Queen Elizabeth Islands in the Canadian Arctic in the 1974 summer. Enlargement and application of colour densitometry for the sea ice in Nansen Sound (Fig 7(b)) reveals more clearly variations in the surface reflectance. When used with point 'ground truth' observations, or with accumulated experience, such characteristic 'signatures' may enable detection of structural, age, and snow cover characteristics of the sea ice surface over an otherwise extensive inaccessible region.

CONCLUDING REMARKS

The examples given here indicate the value of VHRR visible and infrared data combined with simple techniques of image analysis. Studies of these data are finding increasing utilisation in many of the programs for which ERTS multispectral photography has previously been used. Availability of thermal infrared imagery and the higher frequency of observation (12-hourly as opposed to the 18 days between ERTS passages) are more important in many investigations than the relatively coarser resolution (1 km as opposed to the 100 m of ERTS). A notable case is in the field of hydrology where estimates of catchment snow cover and the extent of flood waters for particular drainage systems show promise of successful VHRR analysis.

In meteorology, image analysis of high resolution data should prove useful in many areas; in particular in studies of frontal cloud structure, thunderstorm development and movement, fog dissipation and tropical convective systems. Unfortunately no VHRR acquisition station now exists in Australia. However, a possible satisfactory alternative for many purposes may lie in the proposed geostationary satellite coverage of the southeast Asia and southwest Pacific area. This satellite, although of probably lower resolution than VHRR, has a potentially very high frequency of observation. Such an observational system may be expected to introduce a new era in meteorological operations and research over the tropics and lower mid latitudes in this region. At latitudes higher than about 45° in both hemispheres VHRR coverage from polar orbiting satellites will be necessary to achieve a high observational capability.

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