Cloud Type Separation by Spectral Differencing of Image Pairs

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ABSTRACT

A technique is presented for discriminating different cloud types through an image subtraction of visible and infrared SMS/GOES picture pairs. The technique emphasizes how one could separate snow from clouds and identify cirrus by the subtraction method. Quantitative threshold values are shown which can be used in an objective manner to make this separation.

Use is made of an all-digital image display device allowing such mathematical operations to be performed on satellite data. Techniques such as this can be made operational through the interfacing of the image analysis system with a direct-readout SMS/GOES ground station and distribution network.

A number of papers have appeared in the literature discussing the increased cloud information content available through the use of multiple spectral channels from in-flight satellite detectors. These are summarized in a recent article by Reynolds and Vonder Haar (1977). Two major interpretation problems have always plagued satellite image analysts. The first involved discriminating between cloud cover and snow cover; the second involved the identification and location of cirrus clouds. Although these are by no means the only problems in interpretation, they represent difficulties often encountered during operational analysis and research studies.

The approach used in the present investigation utilized GOES satellite picture pairs, where a spectral difference is taken. The technique has been implemented on a recently developed video-computer system designed by a team of atmospheric scientists and engineers at Colorado State University. The system has been named ADVISAR (All Digital Video Imaging System for Atmospheric Research) reflecting the solid state makeup of the video refresh section and the interactive design of the user-computer interface. Because of the very high stability and precision of the video image (512×512 8-bit semi-conductor memory matrices are used to display image data), cloud signatures are very easy to recognize by simple numerical or visual analysis.

Various approaches have been tried with satellite picture pair differential imaging in the past. Pichel *et al.* (1973) have used artificial stereo techniques in conjunction with NOAA Satellite Scanning Radiometer (SR) infrared and visible picture pairs to attempt cloud-height extraction. Another result came from time-differencing sequential visible (Serebreny *et al.*, 1970) or sequential infrared digital images such that the scale and position of the picture pairs are equalized. Such a transformation results in an image signature providing separate information on cloud stability, growth, dissipation and advection. A separate approach discussed here is to *spectrally* difference a visible (VIS) image with a colocated (space and time)

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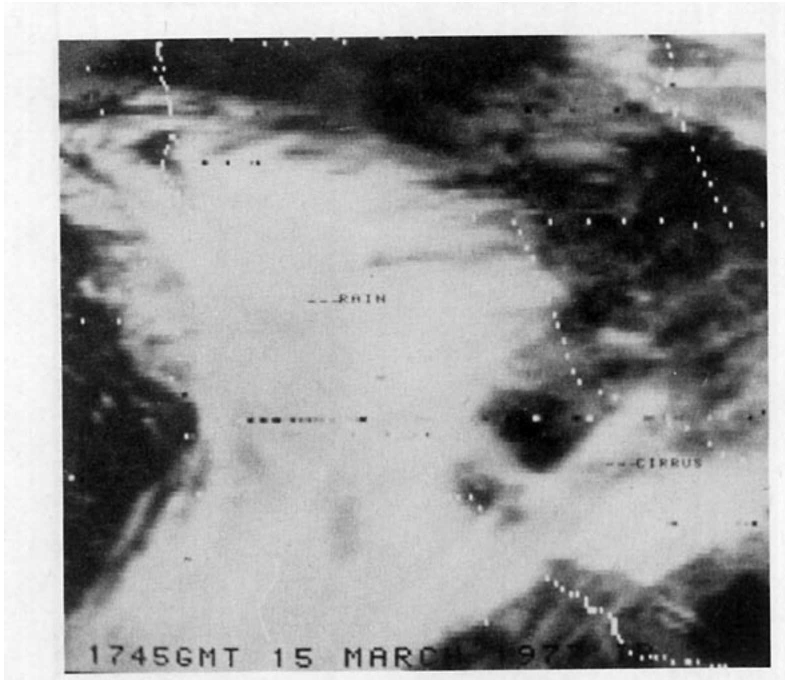

Fig. 1a. 1745 GMT 15 March 1977 SMS-2 infrared image displayed at an equivalent 2 km resolution.

infrared (IR) image. In this instance, obvious cloud type signatures appear in the transformation. The technique was applied to an SMS-2 IR-VIS image pair obtained in March 1977 during the Bureau of Reclamation's Sierra Cooperative Pilot Project.

A moderately complex storm system had moved into the California coastal area on 15 March 1977. The satellite data over the storm were kindly provided by the Atmospheric Science Laboratory, White Sands Missile Range. Figs. 1a and 1b illustrate the infrared and visible imagery used in the analysis; the two data sets have been equivalently scaled and colocated in time and space. This can be achieved because of the simultaneous dual channel imaging characteristics of the Visible Infrared Spin Scan Radiometer (VISSR) on board SMS/GOES-type sat-

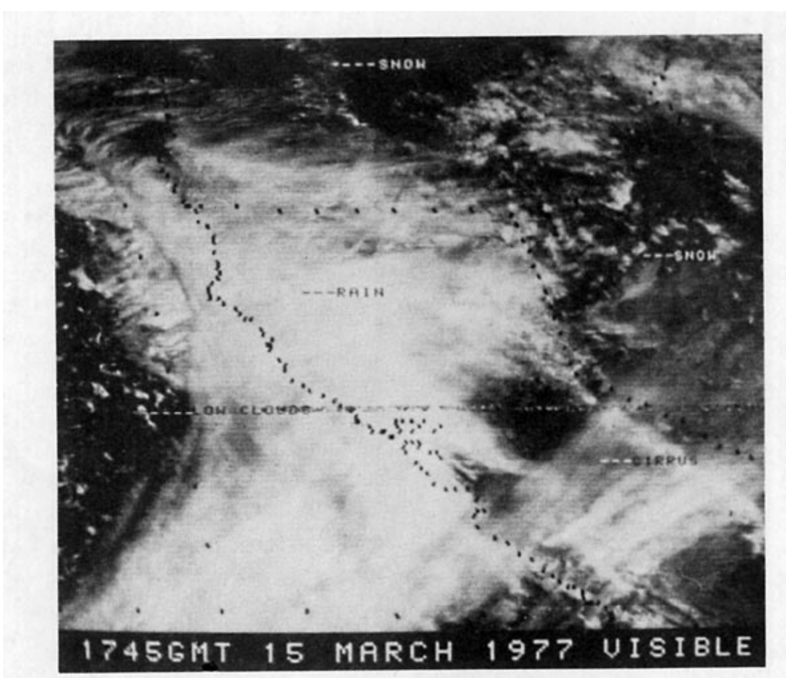

Fig. 1b. Visible portion of Fig. 1a at 2 km resolution.

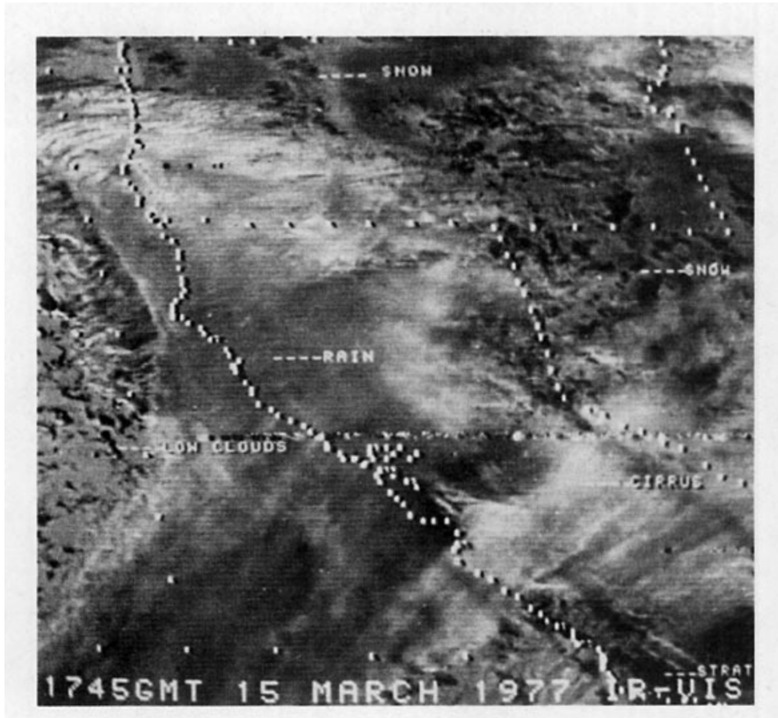

FIG. 1c. Difference image made by subtracting Fig. 1b from Fig. 1a. See text for explanation.

ellites. The raw IR and VIS counts have both been normalized to an 8-bit scale (0–255), but have not been converted to radiometrically linear units. The difference matrix shown in Fig. 1c has also been rescaled to the 0–255 range, thus all three images of Fig. 1 utilize the complete dynamic range of the ADVISAR video refresh memories.

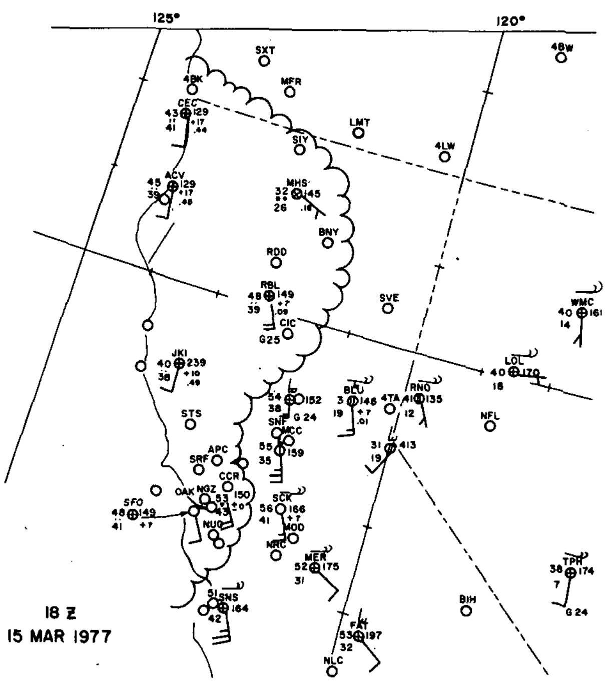

FIG. 2. 1800 GMT 15 March 1977 surface chart for the region shown in Fig. 1. Note the location of precipitation and cirrus with respect to Fig. 1c.

For clouds that are cold and bright (high IR count, high VIS count), the difference signature is seen as a medium value or gray. These areas correspond to the deeper clouds associated with the precipitation region of the storm as shown by the 1800 GMT surface observations given in Fig. 2. This is also verified by the radar summary chart shown in Fig. 3. The regions that are cold and dim (high IR count, low VIS count) show up as high values in the difference image. These areas are most likely interpreted as cirrus clouds. Areas that are warm and bright (low IR count, high VIS count) appear as the very lowest values in the difference images or black. These areas are interpreted as low clouds or snow cover depending on the actual differential threshold magnitude. Fig. 4 graphically shows the actual threshold values that discriminate the different surface and cloud features. It should be understood that the magnitudes of the counts as in Fig. 4 are certainly time-dependent due to sun angle changes. They are also dependent on the relative sun-cloud-satellite geometry (McKee and Cox, 1976; Reynolds *et al.*, 1978). Presently work is in progress (Smith and Loranger, 1977) to calibrate SMS/GOES visible sensors in order to obtain albedo measurements from the raw digital counts. This will allow consistent quantitative threshold values to be obtained. It should be noted that the infrared data are not without time-dependent variation. Change in surface heating will change the threshold counts seen in Fig. 4.

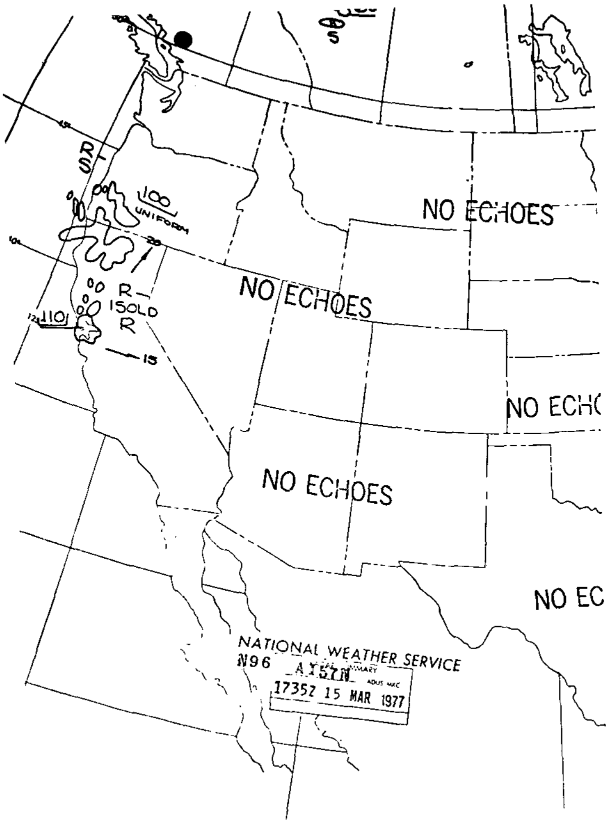

Fig. 3. 1735 GMT radar summary chart for 15 March showing the areas of precipitation in northern California.

The thresholds shown in Fig. 4 are not perfectly distinct, but a simple visual analysis clearly shows areas of confusion and through techniques such as image sequencing would remove some of the ambiguous areas. To better differentiate snow versus low clouds the use of time sequencing would show some motion in the clouds whereas the snow cover would remain stationary. The video refresh memory in the ADVISAR consists of eight individual 512×512 8-bit display matrices which provide the necessary time domain control to discriminate stationary versus transient features. Fig. 5 is again a difference image obtained by subtracting the 1745 GMT visible image from the 1815 GMT visible image. This was done to show in one image the cloud motion while also showing the stationary features of snow. Fig. 5 immediately shows the low cloud movement (black to white areas) and the stationarity of the snow signature (gray). Granted, these low clouds are over the ocean in this

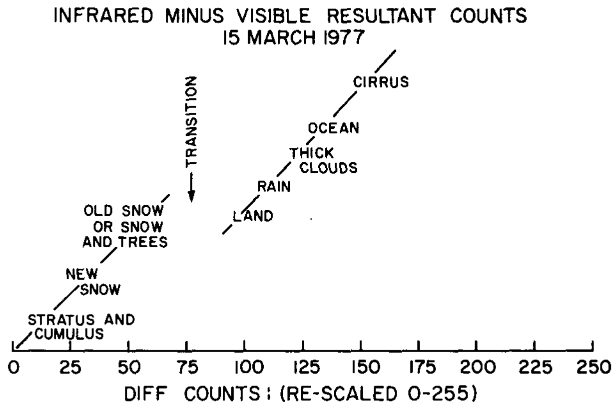

Fig. 4. Schematic diagram showing the magnitude of the difference counts between different surface and cloud features.

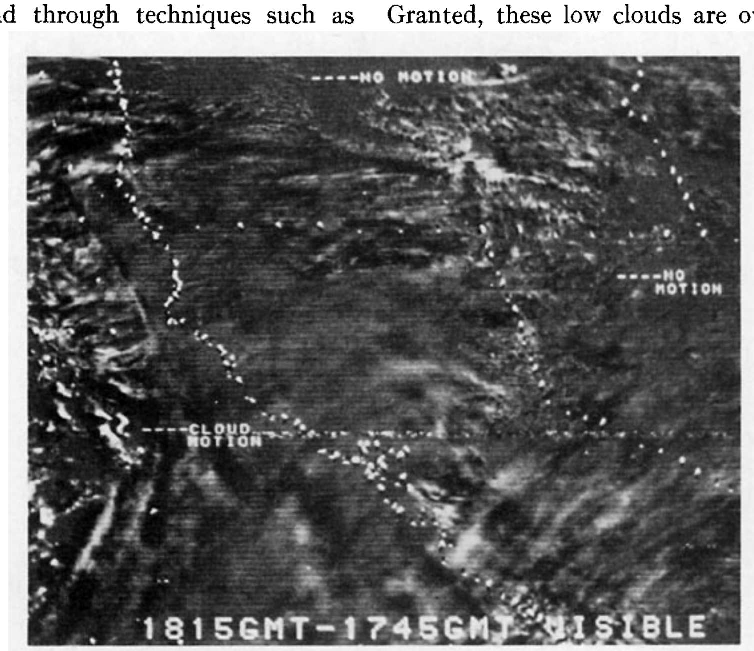

Fig. 5. Difference image made by subtracting the 1745 GMT visible image from the 1315 GMT visible image for 15 March. Areas of black-white transition denote cloud motion.

case so interpretation would not be a problem but the method is viable over land surfaces as well.

There are immediate benefits from a quick and quantitative satellite image analysis technique. First of all it could be utilized in real time by converting the results to facsimile signals and distributing them from the GOES-TAP network (see Corbell *et al.*, 1976). Furthermore, since the differential image is created in a *digital* format, it retains *quantitative* information on cloud and surface features. Such data might provide a better means to estimate rainfall, cloud height, cloud emissivity, snowfall monitoring, cloud climatologies, etc. It should be pointed out that techniques such as described in this investigation are a result of the solutions to research problems involving satellite image navigation, calibration, and precision digital image processing systems. There will be an increasing emphasis on the development of more complex mathematical operators which can be adapted to real time satellite data processing and distribution. There will also be increased performance of satellite detectors coupled with rapidly decreasing costs in solid state components for satellite image processing systems. However, the determination of practical, operational, "man-in-the-loop" application is an ultimate goal of all these technologies. The technique shown here is intended to encourage meteorologists to think about the increased information for the future improvement of real time weather forecasting and analysis from spatial, temporal and spectral transformations of satellite imagery.

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