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REAL-TIME DIRECT READ-OUT SATELLITE SUPPORT TO METEOROLOGICAL RESEARCH PROGRAMS AND FORECASTING UNITS

by

HARVEY J. MILLER

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Atmospheric Science

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**DEPARTMENT OF ATMOSPHERIC SCIENCE
COLORADO STATE UNIVERSITY
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METEOROLOGICAL RESEARCH PROGRAMS AND
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ABSTRACT

REAL-TIME DIRECT READ-OUT SATELLITE SUPPORT TO
METEOROLOGICAL RESEARCH PROGRAMS AND
FORECASTING UNITS

An existing Automatic Picture Transmission ground station system is modified and expanded to provide experimental and operational meteorologists the means with which to collect, analyze, and display direct read-out satellite data on a real-time basis. The necessary equipment for construction and the programs needed to operate a multiple input and display system for direct read-out satellite data are described in detail. Such a system not only allows fast and accurate earth location of the data, but also presents the data in a quantitative manner, as opposed to the qualitative photographic type displays of standard APT stations.

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1.0 INTRODUCTION

The purpose of this paper is to describe a method for the application of direct read-out satellite data to real-time meteorological projects.

Ever since the launch of TIROS I in April of 1960 much has been written on the acquisition and use of satellite data. Most of this literature, however, concerns the description of data centrally collected and processed and analyzed at some later time. In December 1963, with the launch of TIROS VIII, the first direct read-out Automatic Picture Transmission (APT) camera was put into orbit. Since then many such systems have been orbited in the ESSA series, and recently in the ITOS, NIMBUS, and NOAA series'. The latter series' also included direct read-out infrared instruments. The direct read-out data from these satellites is received world-wide by stations equipped with APT sites. Unfortunately this data is very rarely used to its full potential. The methods for earth locating and processing this data are too time consuming and inaccurate to make it profitable, thus it is ignored.

The design of a multiple input and display system for this data, which would provide the operational or scientific meteorologist with the means to quickly and accurately process and display this direct read-out data, is a valid goal. This is particularly true for comparatively small operations or short duration operations that might require highly tailored or special purpose data. This type of data is usually hard to obtain from the central data collection agencies without special data transmission by land line, and can very rarely be obtained on any real-time basis.

The increasing availability of computers makes possible the design and use of such a data handling system. The fantastic capacity of computers to process and display data both quickly and accurately can be used to provide the operational or experimental meteorologist with a tool with which he can obtain and tailor satellite data to his specific needs.

This paper is a description of a real-time, direct-readout, satellite data processing and display system, designed and tested by the author, here at Colorado State University. Several examples of the use and application of this system are also presented.

2.0 DIRECT READ-OUT SATELLITE DATA

2.1 The Basic Measurement

All meteorological satellites share a common purpose, the remote radiometric sensing of clouds and the Earth's surface. The evolution of the instrumentation to make these measurements has been rapid and fruitful. In less than a decade we have gone from the relatively crude television pictures of the early Tiros satellites to the soon-to-be launched GOES geostationary satellites and ITOS D polar orbiting satellites, both of which will carry instrumentation capable of taking many different measurements over various wavelength bands. The informational content of satellite data has thus seen tremendous growth over the past few years.

Direct read-out satellite data has shared in this growth; unfortunately, the processing and display of this data has not.

APT satellite data as received and displayed on standard APT receivers is generally of a qualitative nature. The data is generally recorded on tape and then played back through either an oscilloscope and photographed or played back through a photofacsimile device for display.

The image data thus displayed has a dynamic range limited to 4 to 8 shades of grey, depending upon the quality and sensitivity of the display device and photographic material upon which the product is printed. Thus, the resulting "pictures" are useful only in observing relatively large brightness differences in the case of APT video data, or large temperature differences in the case of APT IR data. This limits the use of APT "pictures" to locating large, bright cloudy areas from less cloudy and bright or clear areas. Very little information can be gained

on brightness differences between clouds of different type, although large and frequently very bright cumulo nimbus clouds can usually be distinguished from less active stratus type clouds. Cirrus and low, thin stratus clouds are frequently below the brightness threshold and are not visible on the picture. On the IR data, cirrus and cumulo nimbus clouds usually show up well due to their large temperature contrast with the warmer clouds or ground below, but warm clouds such as fog or low stratus usually disappear into the background. Little or no significance can be attached to the cloud top temperatures due to the wide range of temperatures included into each shade of grey on the picture.

Fortunately, the full potential of the data is limited by the display system, and not the instruments themselves. To realize this potential, we need to devise a better display system. The computer is the obvious answer. If the analog signal is converted to numbers, then the fantastic capacity of the computer to handle numbers can be used to bring out the entire dynamic range present in the data from the satellite instruments.

2.2 Analysis and Display

The brightness of a cloud, as viewed from above, depends on many factors such as cloud form, depth, type, concentration, and illumination condition. Fritz (1954) gives some values of average reflectance over a vast range of cloud types and has developed a relation for calculating cloud reflectance which agrees well with observation. In general, Fritz's values do not show a marked influence on reflectance by solar zenith angle, internal condition of the clouds, or condition of the

underlying surface. The most important factor is the parameter h/L ; where h is the cloud thickness and L is the mean free path of the light ray. Figure 1 shows the variation in reflectance as a function of the parameter h/L for different solar zenith angles. Note that for the thicker clouds ($h/L \geq 25$), the change in reflectance with solar zenith angle is slight. Another consideration in cloud brightness is the viewing angle with respect to the sun. Figure 2A is a depiction of the reflectance pattern of a cloud model derived from Nimbus III data. Figure 2B shows the pertinent geometry of reflectance. In general, these figures show that for a given solar zenith angle between 35 and 60 degrees, there is a slight tendency towards forward scattering along the sub-satellite path ($\psi=0^\circ$ and 180°) for all viewing angles θ . In other words, the same cloud would appear brighter if it were directly south of the satellite than directly north of the satellite in the northern hemisphere. Also, at any viewing angle θ , as you move away from the sub-satellite path, the reflectance, and thus cloud brightness, increases. Since we are concerned with pictures from the APT camera, and these pictures are comprised of individual scan lines of data, then the θ of each line is different, and the ψ of each point along the line is different. Thus, the absolute value of a cloud's brightness is a function of its position in the picture. However, if it is noted that the vidicon camera has an angular field of view of 90° and that the rate of change of reflectance is not very great between these limits, then we can say that relative to its background, the thicker cloud will be the brightest and that the brightness of the same type of cloud will vary only slightly over the extent of the picture. Thus, in general, the large thick clouds of active synoptic situations such as thunderstorms and tropical storms

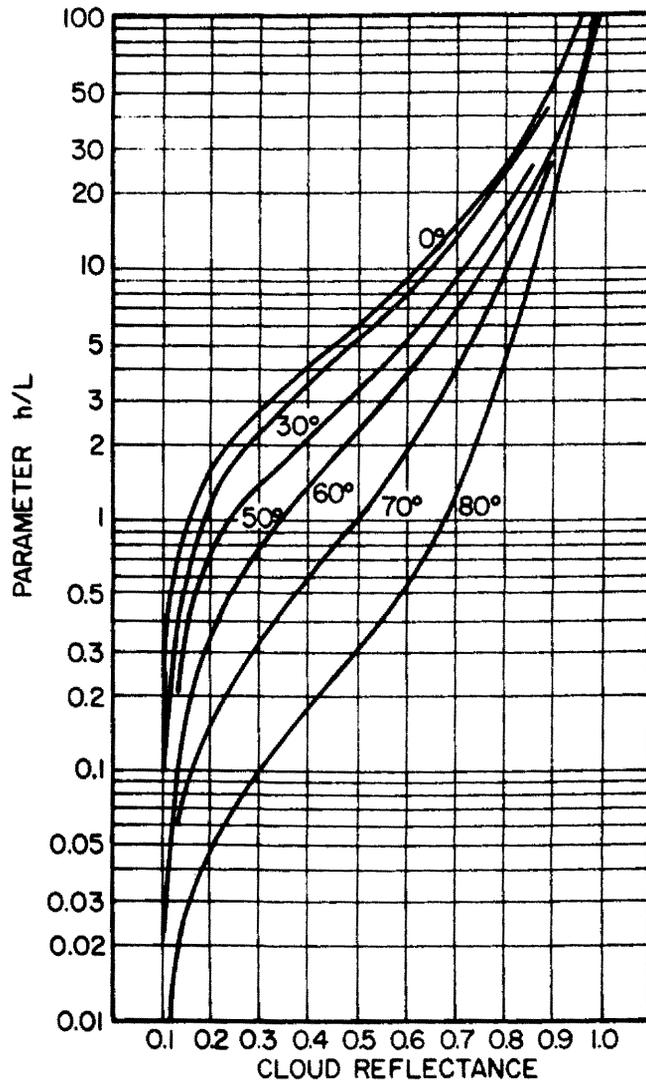


Figure 1. Variation in reflectance as a function of cloud thickness parameter h/L for different solar zenith angles. (from Handbook of Geophysics and Space Environments.)

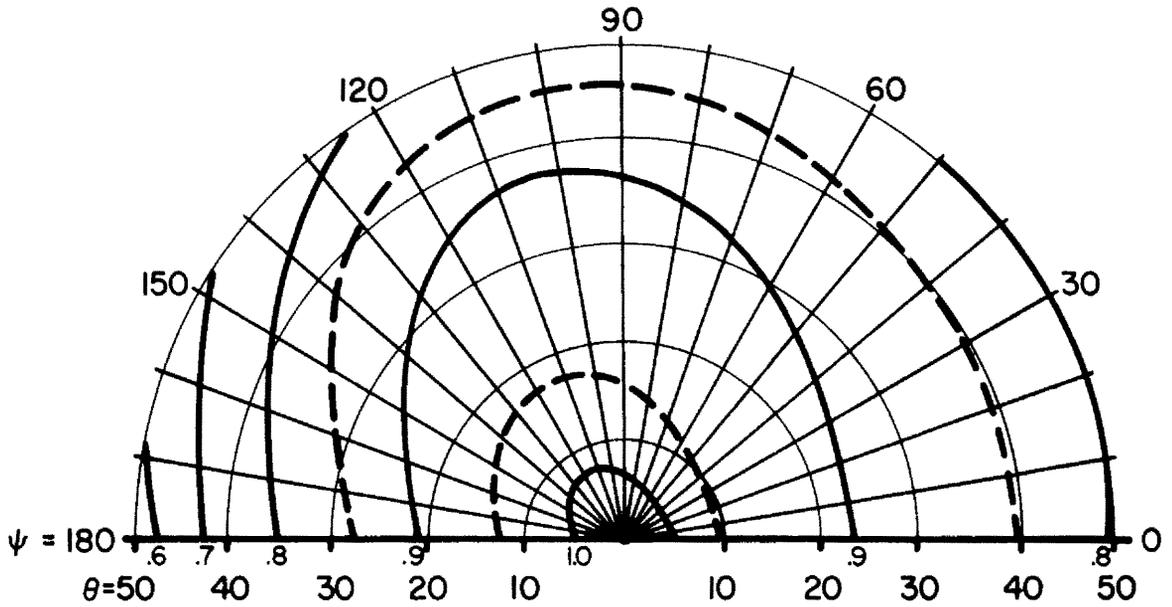


Figure 2a. Reflectance pattern of the Nimbus III cloud model as a function of azimuth angle ψ and viewing angle θ . Reflectance values are with respect to a Lambert surface.

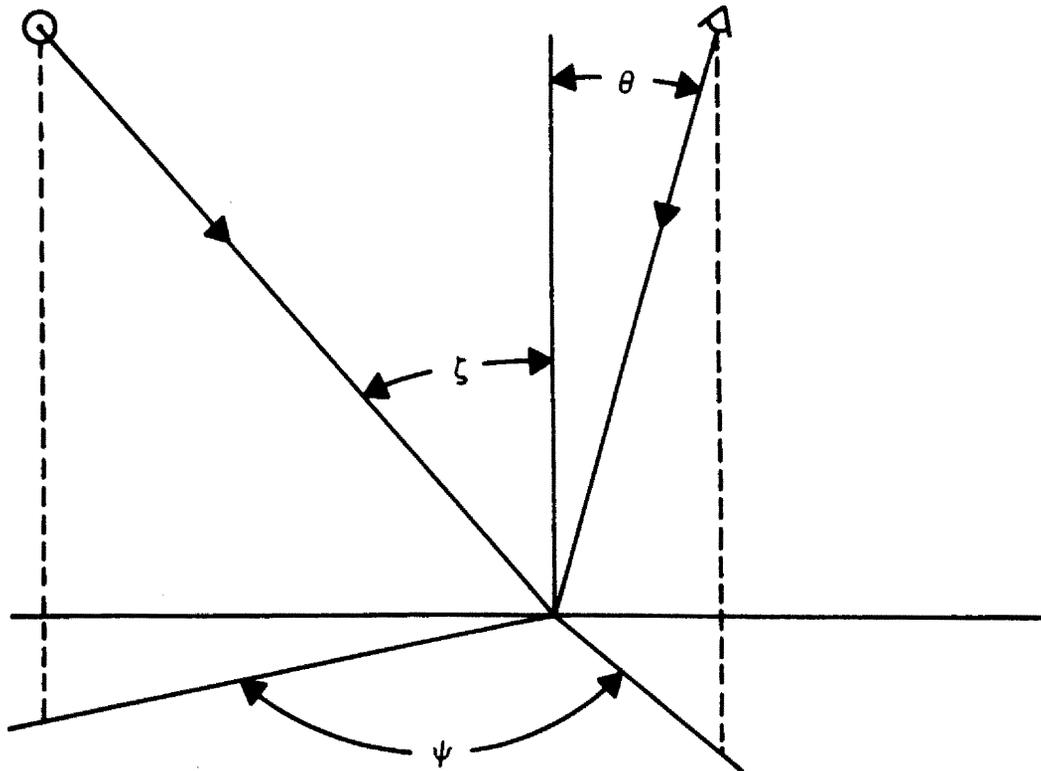


Figure 2b. Geometry of reflectance

will appear brightest on satellite pictures. If a severe weather watch is being conducted, then only the brighter areas need be displayed. The IR data could be used in the same way, by only displaying the coldest temperatures. The large, thick cumulo nimbus clouds would have cold tops due to their extreme height and would thus stand out against the background as cold areas. Cold cirrus type clouds associated with jet streams could be isolated also by displaying only the coldest IR data. Specific values of brightness or temperature could be displayed. For example, Grant, et. al. (1971) have shown that over the Colorado River basin snowfall can be increased the greatest amount if cloud seeding is done in clouds with top temperatures between -15° centigrade and -20° centigrade. Thus, for an operational seeding program over this area, the decision to seed would depend upon clouds in this category being present. The only thing that need be displayed for this application would be the IR data over the Colorado River basin, with cloud temperatures in the desired range.

Contouring programs for the display of the data could also be written. This would provide a somewhat more abstract "picture" of the data, but one which could be more easily analyzed for such features as areas or lines of equal brightness or temperature. Gradients of the data field could more easily be discerned using a contoured field. Using a contoured data field the possible variations in display increase considerably. More than one data field can be displayed on one chart. Contours of IR data could be superimposed upon the APT brightness field. Several examples of this type of analysis and its aid to mutual interpretation are given by Vonder Haar (1969) and Dittburner (1969). Figure 3 is a depiction of the relation between infrared radiation and albedo.

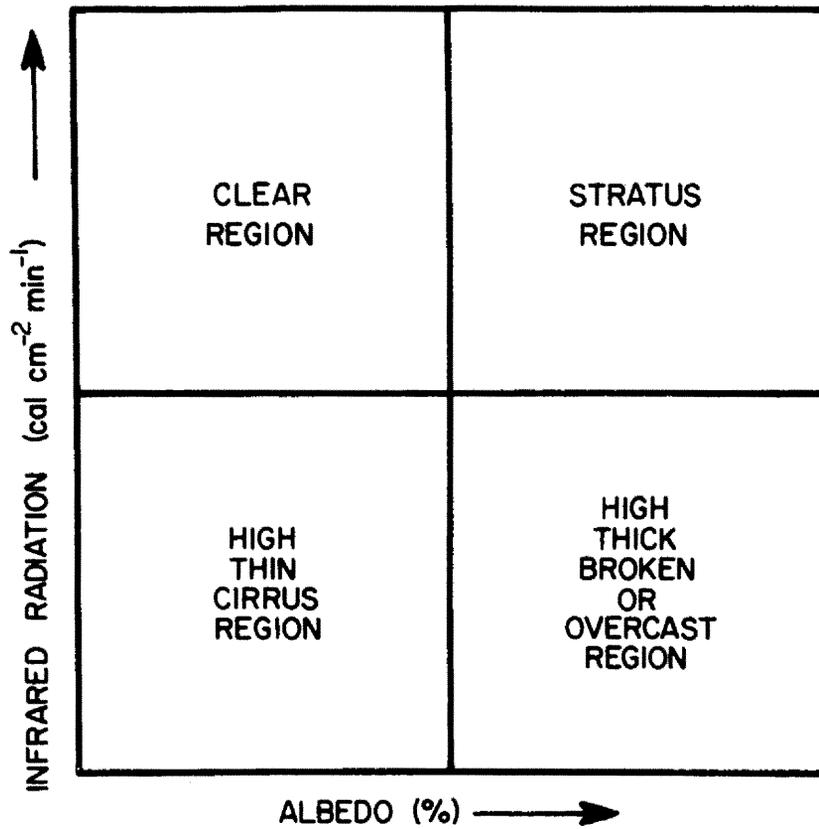


Figure 3. Simple depiction of relation between infrared radiation, albedo (normalized reflected solar radiation), and condition of earth-atmosphere scene viewed from a satellite (after Dittberner, 1969).

This simple figure illustrates how the combination of longwave and short-wave data could aid in the mutual interpretation of four major physical situations encountered in satellite data analysis.

Combinations of data from different sources could also be displayed together. For example, satellite data could be combined with radar, or conventional data, or both. If, for instance, a severe weather watch was being conducted the brightest and coldest satellite data could be displayed indicating active weather regions. With this, intense radar echoes could be plotted on the same map indicating precipitating clouds, and conventional weather observations of high winds and precipitation could be plotted. The result would be a chart of potential severe weather derived from three independent data sources, making it possible to precisely locate and track areas of danger to aircraft, etc.

With the aid of some sort of storage method; either tape, disc-pack or drum, the change with time of the data could be analyzed. This could be done every 12 hours for the satellite data, or in the high latitudes where the data from consecutive passes overlaps significantly, every 100 minutes or so, corresponding to the orbital period of the satellite. Data from the geosynchronous Applications Technology Satellites could be incorporated also. Since this satellite is capable of producing a picture every 30 minutes or so, the change with time of the data could be analyzed much more accurately and over much shorter time periods.

Of course, to be useable these analyses must be displayed in some manner. First, and most obvious, the data can simply be printed out directly as digitized, with no computer analysis at all other than the conversion of the voltage values of the original satellite signal to brightness values in the case of APT data or temperature values in the

case of IR data. This would produce a "picture", in number form, that is equivalent to what could have been produced originally from the analog signal. However, the resolution has been increased, since we no longer are dependent upon the sensitivity of photographic paper.

A significant improvement over the above procedure would be to print the data as above, with a superimposed latitude-longitude grid over the data. This improvement is mandatory for proper location of the data, and can easily be programmed into the display. This would allow pinpointing the location of significant synoptic features with respect to the area of interest.

Once the data is earth located, specific areas could be isolated for study. Perhaps only a limited area is to be observed for a specific project, then this area could be displayed and the remainder of the data discarded. Also, different map scales could be produced, areas could be enlarged to suit the needs of the user at will.

By now, the potential usefulness and value of a multiple input and display system for meteorological data is obvious. Its speed, adaptability, concise presentation of data, and capacity to be tailored to specific needs or desires of the user, makes it an invaluable tool to real-time meteorological operations. A system such as this can contribute immeasurably to savings in time spent by the meteorologist in assimilating weather data, as well as contributing to the mutual interpretation of the individual data, thus contributing significantly to any operational or scientific project being conducted.

3.0 THE REQUIRED COMPONENTS OF A REAL-TIME SATELLITE DATA SYSTEM

The construction of a real-time system for the multiple input and display of direct read-out satellite data requires the assembly of rather specialized components. These components can be grouped into the two broad categories of hardware and software.

3.1 HARDWARE

3.1a Satellite Receiver

The first piece of equipment is, of course, the satellite signal receiver (APT system). This system should be of good quality and be capable of creating sufficient gain to reduce undesirable noise to a tolerable level. The components of this system are:

1. Directional antenna.
2. FM receiver - capable of being tuned to the various transmission frequencies of the different satellites.
3. Tape recorder.
4. Display device - oscilloscope or photofacsimile.

The display of the original signal is not mandatory to the success of this computer analysis and display system, but does serve as a quality control device on the original data before computer processing.

3.1b Digitizer

To convert the satellite signal to a form amenable to computer processing, an analog to digital converter must be employed. This system

should, as a minimum, be capable of digitizing two input channels, and have an adjustable sampling frequency. The adjustable sampling rate is necessary since the APT data and the IR data have different scan rates, and thus different sampling frequencies. The digitizer should be adjustable at least to a maximum frequency of 3500 samples per second to produce sufficient resolution in the APT data. Details of the sampling rate will be given in the following section of this paper.

The digitization process should produce at least an 8 bit representation of the original signal levels. This produces a 256 digit scale, which is adequate to include the entire dynamic range of both the IR and APT data. It should also produce output that will be in a form compatible with the computer that will be used. The output can be on computer magnetic tape, drum or disc storage, or even directly into the computer.

An important point to consider in the digitizer is whether or not the conversion of the data from analog to digital is linear. If not linear, then the transfer curve must be known, since it will have an important effect on the interpretation and calibration of the data as will be seen later.

3.1c Computer

Of course, for the analysis of the digitized satellite data, access to at least a small computer is necessary. The computer should be of sufficient size to allow a good degree of sophistication in programming and should have sufficient storage devices for processing more than one APT picture or IR pass or both. For the programs written in this paper, a computer with a 25K (decimal) word core would have been sufficient, although a much larger one was used.

The standard output device for most computers is the line printer, and this is an adequate device for the display of satellite data. A useful, and somewhat more versatile display system is a microfilm recorder. This type device usually is not so limited in the number of points displayed on one frame as the printer and also allows one to create a display that is more pleasing to the eye than the printed paper. However, a microfilm recorder is not always available and it requires an additional microfilm reader for reading of the computer output. Another method for display would be to re-convert the digital computer output to analog signals and display on a photofacsimile recorder.

3.2 SOFTWARE

The software programs necessary to operate a system such as this can be as extensive as one wishes, depending upon the complexity of the analysis and display being produced. The fundamental programs that are required, as well as some that make this system unique will be mentioned in this section. Complete descriptions of most of these programs are given in the Appendix to this paper; other programs will be referenced and their details may be found in the original author's work.

3.2a Satellite Tracking

Accurate knowledge of the satellite's location as a function of time is necessary for the successful acquisition of APT pictures. The satellite's location is essential to earth locating the pictures and is also necessary to track the satellite with the directional antenna. It

is thus necessary to have a clock that can be easily and quickly read to +1 second, since the satellite's ground speed is about seven kilometers per second.

Graphical satellite location can be determined using data obtained from the Daily APT Alert and Ephemeris Predict Message and applying the procedures as given in the APT Users Guide prepared by the APT Coordinator, United States Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite Center, Washington, D. C., 20283.

The same information about satellite location can be obtained more accurately and economically by using a computer program.

Wooldrige and Cotton (1970) developed a program that provides "look angles" for the receiver antenna and subsatellite points for use in earth locating APT photographs. The program uses the TBUS Bulletin as input and calculates the information needed in tracking the satellite, picture gridding, and acquisition planning. The calculation follows the procedures given in the APT Users Guide to provide the orbital information required for APT station operation. A complete program listing, sample output, and detailed explanation of the data cards and formats is provided in Wooldrige and Cotton's unpublished report.

3.2b Grey-Scales

The data as it is output from the digitizer appears as an 8-bit or 12-bit, or whatever the case may be depending on the digitizing hardware, representation of the original analog signal. Table 1 shows the approximate values for the dynamic ranges of earth scenes for both video imagery and IR imagery. Also given is the instrument precision and the

	NATURAL VARIATION OF SCENE	SIGNAL PRECISION (NOISE EQUIVALENT)	DIGITAL STEPS NEEDED	DIGITAL STEPS USED	
				8-bit	12-bit
VIDEO IMAGE	500 TO 10,000 FOOT-LAMBERTS	± 1 dbm ON OUTPUT SIGNAL AMPLITUDE	32	256	4096
INFRARED IMAGE	200° K TO 320° K	$\pm 1^\circ$ K	120	256	4096

Table 1. Dynamic ranges of direct read-out instruments and their digital representations.

number of digital steps needed to represent the total dynamic ranges at this precision for each type of image data. The fourth column shows the number of digital steps produced by an 8-bit and 12-bit digitization. This is clearly beyond the limits of sensitivity of the instruments; thus we can group these values into effective shades of grey and bring them more into line with what we know to be the resolution of the sensors on board the satellite.

For the video image data, 32 shades of grey are all that is necessary to represent the data. In practice this is usually reduced to 16 grey-shades, since for luminance values above about 5,000 foot-lamberts the response of the vidicon tube becomes non-linear and thus the effective resolution deteriorates appreciably. Thus, if we program the computer to group the brightness data into 16 shades of grey, we will simplify the analysis of the data considerably while retaining any operationally significant brightness differences present in the original data.

For the IR data, 120 shades of grey are sufficient to represent the data with a 1°K resolution. Probably a more realistic resolution would be 2 to 3°K due to uncertainties in the calibration temperature of the radiometer, non-linearities in the system transfer functions and atmospheric attenuation of the radiation.

Much of the uniqueness and versatility of this system arises from the programming of these so-called grey-scales. The exact methods used in grey-scaling will bear directly on the final interpretation of the data, and it is advantageous to write these programs in such a manner so as to be easily variable depending upon the intended use of the data. For example, selective grouping of temperatures or brightness values into grey-scales that are non-linear can be used to enhance the brightest

areas, etc. Resolution on the high-end or low-end of the data could selectively be enhanced, while effectively reducing or eliminating any resolution over values of little interest to the user.

3.2c Earth Location

For meteorological observations to be meaningful, they must be earth located.

A program for earth locating the IR data has been written (Madden, 1971) and can be used in our system. The program calculates latitude-longitude information based on orbital parameters input via the APT TBUS Bulletin. Since this information is already available to the computer from the Satellite Tracking program, no new information need be supplied to the computer.

A basic program has been written for the production of APT grids for use in earth locating video data also (Bonner, 1969). This program uses the satellite sub-point and a manual measurement of fiducial mark locations on the APT pictures to produce latitude-longitude grid overlays for the pictures. This program, with some modification, can be adapted to produce latitude-longitude grids directly on the APT data in the computer, without the intervening step of measuring the APT picture.

3.2d Analysis and Display

Of course, all of the foregoing programs are of no use unless data is displayed in a useful manner. The display programs are, like the grey-scale programs, a large contributor to the versatility of this system. Programs for contouring, overlaying or combining data, etc., are essential to the tailoring of the final product.

4.0 THE CSU SYSTEM

4.1 APT RECEIVER

All tests and results of the present study were derived from an APT system at the Department of Atmospheric Science, Colorado State University, Fort Collins. This system was originally designed and constructed to make satellite cloud photographs available for routine forecasting in connection with lee wave field programs and for investigations of meso- and macro-scale orogenic weather phenomena. The only product the system was designed to produce was Polaroid pictures of direct read-out video data. This system has been modified and expanded for our work to increase the utility and versatility of the products by use of computer analysis and display of the satellite data. The following is a description of the components of this expanded system and the method used to record and convert the satellite data for computer analysis.

4.1a Antenna System

The antenna is a Technical Appliance Corporation Model 9982 cross-polarized model modified for circular polarization. The specified frequency is 136.5 MHz with a minimum rejection of 80 db at 123 MHz and at 148 MHz. The antenna gain is approximately 15 db.

The antenna mount located on the roof of the Atmospheric Science Building at Colorado State University is an AS-833/GRS-1 surplus missile tracking base which is heavy enough to keep the antenna in position during occasionally high chinook winds encountered locally. The antenna can be operated remotely from a console located near the receiver inside the building.

The signal from the antenna is boosted by an FET pre-amplifier circuit located on the antenna itself. The amplified signal is then fed through coaxial cable to the FM receiver located in the building.

4.1b FM Receiver

The receiver is an integrated circuit solid-state type with a sensitivity of 0.4 microvolts and a bandwidth of 120 MHz; it can be voltage-tuned by means of a ten-turn potentiometer to receive the 135.6 MHz WEFAX (ATS), the 136.95 MHz NIMBUS, and the 137.50 MHz ITOS and 137.62 MHz ESSA satellites.

The signal from the pre-amplifier leads to a single stage field-effect transistorized RF amplifier. It is then converted to 29.18 MHz using a Fairchild uA703 integrated operational amplifier that has a gain of about 30 db. The signal is then converted to a frequency of 10.7 MHz and fed into a four-stage integrated circuit amplifier which has a sensitivity of approximately 2 microvolts. The 2.4 KHz sub-carrier is detected and then fed into a full-wave rectified, unfiltered, AM detector; after amplification by a Fairchild uA709 operational amplifier, the signal is fed through a solid-state band pass filter with a bandwidth of ± 900 Hz.

4.1c Recorder

The signal is now recorded on a Wollansak 3M stereo magnetic tape recorder. When producing a picture, the tape is played back into a synchronization circuit which feeds the 2.4 KHz signal into a phase-locking oscillator to produce the pulse frequency of 4 per second of the satellite picture.

4.1d Oscilloscope

The signal is then put into the oscilloscope time base unit which is externally synchronized. A Miller integrator receives the pulse which is led to the vertical amplifier to sweep the oscilloscope face.

The oscilloscope is a 561 Tektronix with a P-11 phosphor. A Fairchild 450A mounting secures a 3¼" x 4¼" back-pack polaroid camera to the oscilloscope to record a time exposure of the televised picture on the oscilloscope face. Polaroid type 107 film is used in the camera.

4.1e Data Collection

Due to the untimely demise in June of 1971, of both the NOAA I and ITOS I satellites, no DRIR data is presently available. However, for purposes of this study, several DRIR tapes were obtained from the National Environmental Satellite Service in Washington, D. C. These tapes were made just prior to the NOAA I failure, and were night-time NOAA I DRIR passes recorded in much the same manner as would have been done here at CSU, had our equipment and programs been operational in time.

The video data used in this study was APT data recorded from the ESSA VIII satellite during late June of 1971. The procedure used to record this data was to first run the Wooldridge-Cotton WXSAT program based on the 19 June 1971 TBUS bulletin input. The output of this program gave the ascending node times, acquisition times, and sub-satellite latitude-longitude points for every 10 seconds of the time the satellite is above the local horizon, as well as the azimuth and elevation angles, needed for aiming of the antenna, at one minute intervals. Using this tracking information the satellite transmission was then recorded,

noting to the nearest second the starting time of each picture, at 3 3/4 inches-per-second on one channel of the stereo tape recorder. After a complete pass of the satellite was recorded, the tape was played back through the oscilloscope and Polaroid pictures produced. Usually, three pictures per pass could be received and three passes per day could be read out.

No Polaroid pictures were made of the DRIR data. This would require a modification to the equipment, and although not difficult to do, was never done for this study.

4.2 ANALOG-TO-DIGITAL CONVERTER

The data collected as described in the preceding section is analog data. In order to make this data amenable to automated processing, it is necessary to convert it to digital data. This section is a short description of the data conversion system, locally called the REDCOR.

The Colorado State University data conversion system is a sophisticated system, capable of handling many types of analog signal inputs. It is capable of handling up to 16 channels of input and has a maximum sampling frequency of 25,000 samples per second. It produces a 12 bit digital representation over a maximum input voltage range of -1.414 to +1.414 volts.

The basic components of the system are:

1. Redcor Model 70-11 computer (4K core, 840 μ sec. cycle time, priority interrupts, direct memory access I/O)
2. ASR-35 Teletype (10 characters/sec., ASCII code)

3. Ampex TM-11 digital magnetic tape drive (800 or 556 bpi, CDC 6400 compatible)
4. Redcor Model 667-031 analog-to-digital converter:
 - a. 16 multiplexed input channels, one sample-and-hold;
 - b. 12 bit digital representation;
 - c. maximum rate of 25 KHz;
 - d. input range from -1.414 to +1.414 volts.

A more complete description of the hardware and capabilities of the REDCOR can be found in the User's Manual, Data Conversion Service, University Computer Center, Colorado State University.

Although the REDCOR has its own input tape drive we used our own stereo tape recorder as playback device for input directly into the converter.

Prior to digitization the APT data was re-recorded on new tapes with the horizontal phase bar (line sync) on one channel of the new tape and the complete data signal on the other channel. This was done by using a second tape recorder and connecting one channel to the data channel of the original tape recorder, and the other channel to the line sync signal separator circuit of the APT receiver. Thus, a new satellite analog data tape was generated with the complete data signal on one channel, and the line sync on the other channel.

The reason for the separate sync channel was to aid the computer in locating the sync. This was necessary because on many pictures, very bright data occurred near the sync signal and thus it was not easily distinguishable from the data. Also, due to tape stretching and slight variations in tape speed, every line of digitized data does not necessarily contain the exact same number of sampling points. Thus, the

separate sync channel allows one to keep track of the start of each line of data, without relying on the number of points per line.

This re-recording can be avoided in the future by simply recording the sync signal on the second channel of the original recorder.

These new two-channel tapes were then taken to the CSU Computer Center for digitization on the REDCOR System.

Mention should be made at this point on sampling frequency for the analog-to-digital conversion.

For the APT pictures, if we choose to produce 800 digital samples per line of the picture, and we know that the line scanning rate of the pictures is 0.25 seconds per line; then the sampling frequency required is:

$$\frac{\text{samples/line}}{\text{scan rate}} = \frac{800}{0.25} = 3200 \text{ samples/sec} \quad (4.1)$$

The equivalent ground resolution per data sample produced by this sampling frequency can be calculated. If we assume the equation,

$$\Delta x = h \Delta \alpha \quad (4.2)$$

is true for small angles $\Delta \alpha$, where Δx = diameter of the spot on the ground, h = height of the satellite, and $\Delta \alpha$ = the instantaneous field of view of the experiment; then the equivalent ground resolution is equal to Δx . The APT camera has a field of view of 108° , thus:

$$\Delta \alpha = \frac{108^\circ/\text{line}}{800 \text{ samples/line}} \times \frac{2\pi \text{ radians}}{360^\circ} = 2.36 \frac{\text{milliradians}}{\text{sample}} \quad (4.3)$$

and

$$\Delta x = h\Delta\alpha = 1460\text{Km} \times 2.36 \frac{\text{milliradians}}{\text{sample}} = 3.45 \frac{\text{Km}}{\text{sample}} \quad (4.4)$$

This may be compared to the ground resolution for the APT sensor system on ESSA VIII of 2.71 km. (APT USERS GUIDE, 1969) and shows that the equivalent ground resolution determined by our chosen sampling rate is well matched with actual sensor parameters.

Using the same procedure for the IR sensor and choosing 600 samples/line, knowing that the earth view portion of the scan line is 109° and the scan rate is 1.25 seconds/line, the sampling frequency is 1585 samples/second producing an instantaneous field of view of 3.22 milliradians and an equivalent ground resolution of 4.7 km/sample.

Since we are interested only in the amplitude of the signal, the signal from the tape recorder was fed into a Fairchild uA702A absolute value amplifier prior to being fed to the A-to-D converter. The output from this amplifier circuit is equal to the positive absolute value of the input signal with a gain of 10. Thus, we now have a signal which reflects only the amplitude of the original signal and we can sample at any frequency without regard for the frequency of the original analog signal.

This circuit also contains an adjustable potentiometer so that the voltage output of the tape recorder could be adjusted to match the required +1.4 to -1.4 volts input range of the REDCOR.

4.3 COMPUTER AND DISPLAY DEVICES

The computer is a Contral Data Corporation Model 6400. This is a 60 bit-per-word machine with a total storage capacity of 65K (decimal)

words. Access to the CDC 6400 was via a CDC User 200 Remote Terminal. This limited input to the computer to cards, and output to printed display, from the remote terminal. Other inputs, such as digitized tapes had to be hand carried to the main computer location for processing.

The primary mode of display in this study was the line printer, although the microfilm printer was also used.

4.3a Preliminary Data Processing

The first step in the processing of the digitized data is to build an array in the computer that is a duplicate of the original "picture". To do this, the earth scan portion of each line of data must be separated from the phasing signals, line syncs, and various other signals present.

For the vidicon camera data (APT), the tape is searched for the sudden change from the high amplitude phasing and start tones to the lower amplitude data values. This locates the first line of data. A check is then made to insure that the first line has been reached by counting 800 lines and searching for the end of the last data line as represented by the change in signal level from relatively low values to the high, steady values of the carrier signal. Once the 800 data lines have been found, the line sync channel of the digitized tape is checked for each line of data. This allows the location of the line syncs to be found, and all data between these sync signals is earth-scan data. This earth-scan data is then fed into an 800 x 800 array, which when filled is the digitized picture.

For the scanning radiometer data, the problem of locating the earth-scan portion of each line is somewhat more complex. Since the

scanning radiometer views the earth by means of a mirror rotating through 360 degrees, each line of data contains views of the spacecraft housing, space, and the earth, as well as containing calibration signals and a start tone. Also, the IR data has no picture beginning or end, but is simply a continuous stream of data from local horizon-to-horizon as the satellite passes overhead. Thus, the first scan line is simply the first signal recorded on the tape and rather than building an array in the computer of possibly several thousand lines, each line is treated independently.

Figure 4a shows the separate elements of each IR scan line, and Figure 4b shows their sequence. Three separate checks are made on each scan line in the computer to insure that the line is useable and that the earth-scan portion of that line can be found. First, the data is searched for the 7-pulse start signal, then the high space reading at the end of the earth scan, and finally the 7-step calibration wedge. Each of these portions of the line should be a specific number of digital points away from the beginning and end of the 600 earth-scan points. The exact number of points separating each feature is, of course, a function of the digitization frequency. With these tests then, the earth view portion of the scan line can be located with respect to the rest of the signals in the line.

In addition to the foregoing procedures for locating the earth view portion of the scan within each line, the following procedure was used to convert each data point of the earth-scan into equivalent black body radiating temperatures.

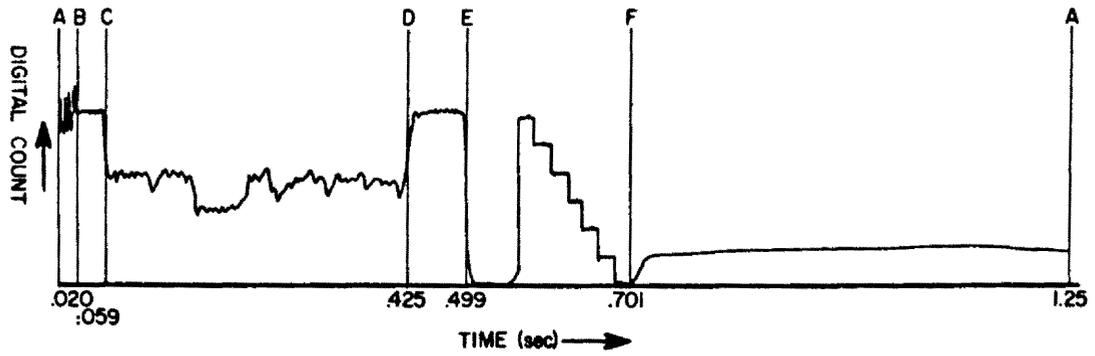


Figure 4a. Schematic drawing of one line of NOAA I.

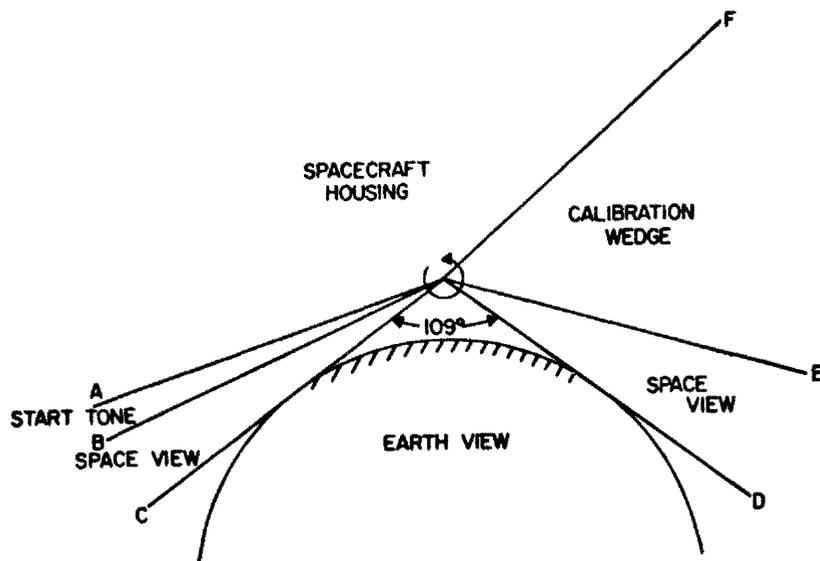


Figure 4b. Sequence of NOAA I scan.

As designed and tested in the laboratory, the scanning radiometer output voltage is linear with input energy. Hence, the system can be described by Eq. (5.1):

$$E = mV + b \quad (5.1)$$

where E is energy, V is output voltage and the m and b are constants that linearly relate the voltage to energy. The analog output voltage is then digitized in terms of counts, C , with the linear relationship:

$$V = nC + k \quad (5.2)$$

Substituting Eq. (5.2) into Eq. (5.1) gives:

$$E = m(nC+k) + b \quad (5.3)$$

Performing the indicated multiplication, collecting terms, and letting $mn = m_1$, and $mk+b = b_1$, we obtain:

$$E = m_1 C + b_1 \quad (5.4)$$

A value for m_1 can be calculated using Eq. (5.5):

$$m_1 = \frac{E_2 - E_1}{C_2 - C_1} \quad (5.5)$$

where E_2 and E_1 are the energies output by two black body sources at known temperatures, and C_2 and C_1 are the digital counts recorded while the radiometer looked at these black body sources. If we choose the radiometer housing and space as our black body sources, the Eq. (5.5) becomes:

$$m_1 = \frac{E_{\text{housing}}}{C_{\text{housing}} - C_{\text{space}}} \quad (5.6)$$

since E_{space} is nominally zero.

The APT TBUS bulletin contains a radiometer calibration temperature T_{hs} , from which E_{housing} can be calculated. The algorithm for this calculation is:

$$E_{\text{housing}} = \int_{\lambda_1}^{\lambda_2} B(\lambda, T_{\text{hs}}) \phi(\lambda) d\lambda \quad \text{cal cm}^{-2} \text{min}^{-1} \quad (5.7)$$

where $B(\lambda, T_{\text{hs}})$ is the Plank radiance for T_{hs} , $\phi(\lambda)$ is the radiometer, relative system spectral response function (see Fig. 5), and λ_1 and λ_2 are the limits of the spectral response function. T_{hs} for our experiments was constant at $+13^{\circ}$ Centigrade, thus the value for E_{housing} was:

$$E_{\text{housing}} = 0.052593 \quad \text{cal cm}^{-2} \text{min}^{-1}$$

A value for b_1 can be calculated since:

$$E_{\text{space}} = 0 - m_1 C_{\text{space}} + b_1 \quad (5.8)$$

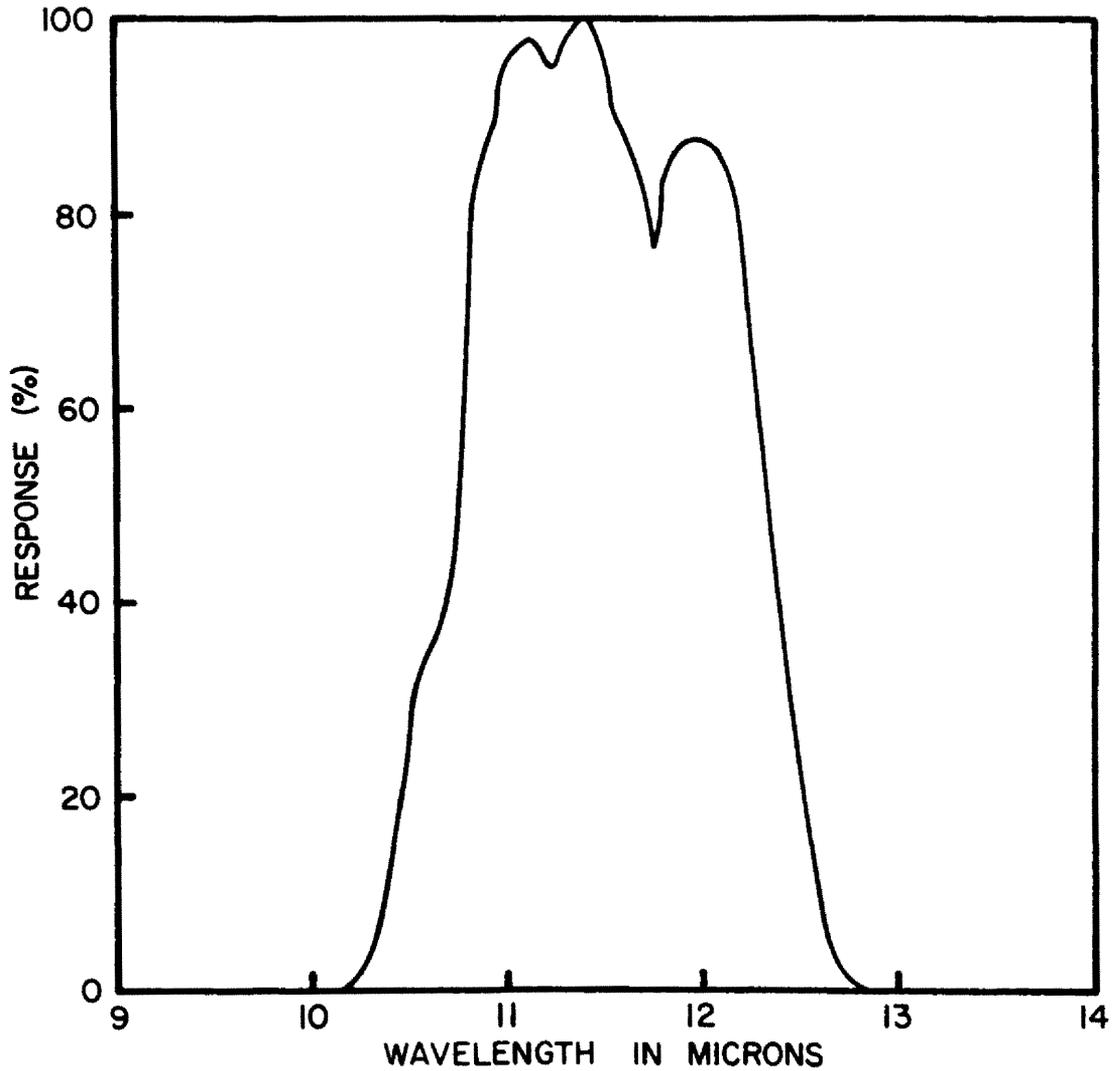


Figure 5. NOAA scanning radiometer relative spectral response (infrared channel). Courtesy E. Conlan, National Environmental Satellite Service, Washington, D.C.

or

$$b_1 = -m_1 C_{\text{space}} \quad (5.9)$$

The final form of the equation converting digital counts to energy values is:

$$E_{\text{scene}} = \frac{0.052593}{C_{\text{housing}} - C_{\text{space}}} (C_{\text{scene}} - C_{\text{space}}) \text{ cal cm}^{-2} \text{ min}^{-1} \quad (5.10)$$

These values of E_{scene} cannot be directly converted to black body radiating temperatures. Note in Figure 5 that the relative spectral response curve is given as a ratio of the measured energy to the incident energy, normalized to the maximum response of the instrument. Thus the curve represents only the percent of the amount of energy that is measured versus the maximum amount that can be measured. The energy values calculated in Eq. (5.10) are on a scale that is based upon this response ratio and what the instrument system "sees" when it looks at space and the radiometer housing, and the absolute value of the incident radiation remains unknown. Thus we must remain within this relative framework in calculating the equivalent black body radiating temperatures from the E_{scene} values obtained from Eq. (5.10). To convert these E_{scene} values to equivalent black body radiating temperatures, a table of E_{scene} vs T_{scene} was generated in the computer using Eq. (5.7). Since each scan line contains values for C_{scene} , C_{housing} , and C_{space} , E_{scene} for each data point of the earth portion of the scan was calculated; by using the table, the equivalent temperature of each point was then found. These values were then fed into an array which, when filled, was the earth view portion of one scan line of the IR sensor.

4.3b Computer Analysis and Display

With the preliminary data handling accomplished, programs were written for processing and display of the satellite data. These programs included:

1. Grey-scale programs
2. Earth location programs
3. Display programs

A description of each of these programs is given in the Appendix to this paper and the complete programs themselves will be published in an accompanying Atmospheric Science Technical Report (Madden et.al., 1972).

Figures 6 and 7 are examples of the type of display produced by the APT system alone and the APT system plus computer.

Figure 6 is an ESSA VIII APT picture taken 1742z June 23, 1971. The center of the picture is located at 30.2 N, 112.5 W on the eastern shoreline of the Gulf of California.

Figure 7 is the same APT picture after being digitized, gridded, and grey-scaled. The latitude and longitude lines are represented by series' of /'s, with the longitude lines being labeled at the top of the page in degrees East and nearly vertically down the page. The latitude lines are labeled at the left side and they slant upward toward the upper right-hand corner of the picture. The time values listed down the right hand side of the figure are the times of each scan line.

The data itself in Figure 7 is low resolution APT data in a 16-level grey-scale from black, represented by A , to white, represented by P . The apparent outlines of the Gulf of California and west coast of the U. S. have been drawn in to make it easier to recognize known geographical features. Comparing Figure 7 with Figure 6 we can

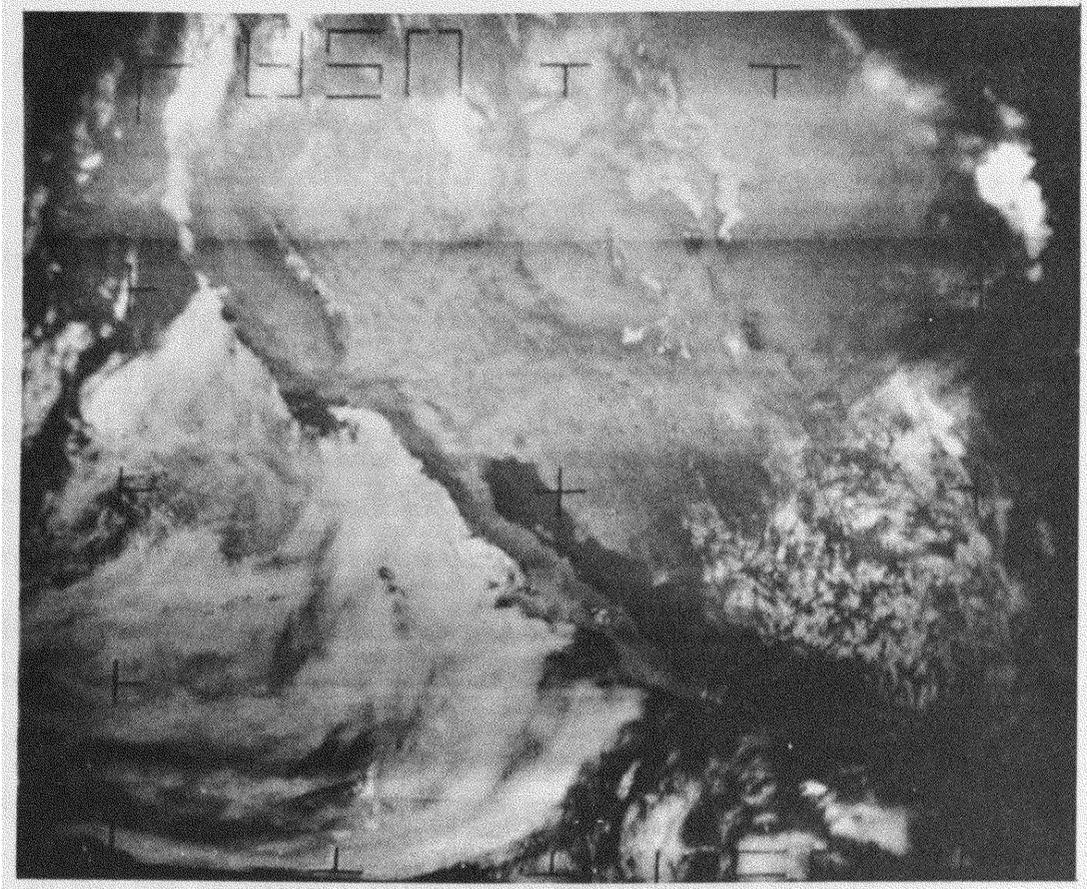


Figure 6. ESSA 8 APT picture 1742z, June 23, 1971.

APT DATA FROM ORBIT 1550.. TIME OF FIRST SCAN IS 17.39. 4. DATE 6/23/71

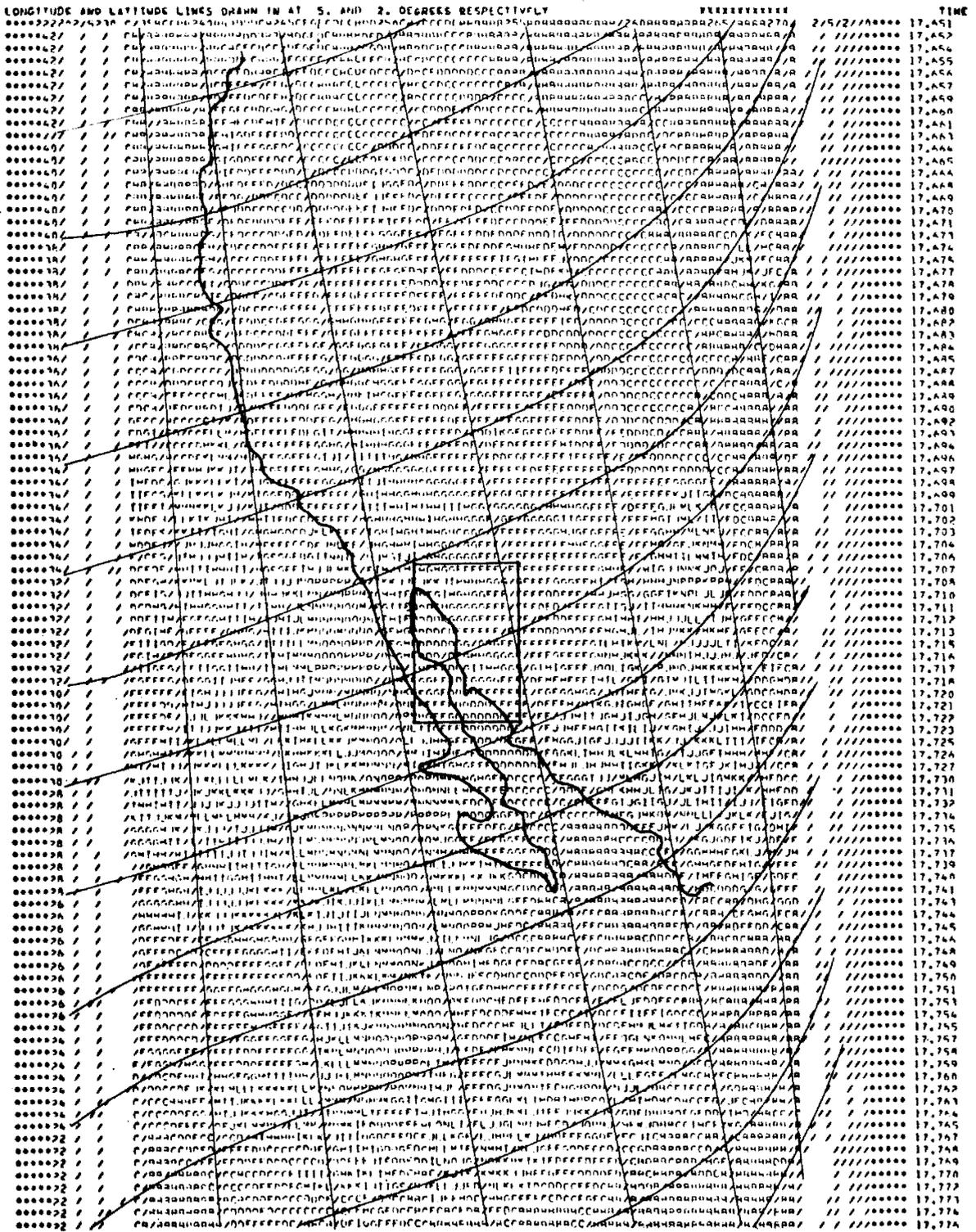


Figure 7. Digitized ESSA 8 APT picture 1742z, June 23, 1971.

see we have an identical picture except that now we have an earth located picture and relative values assigned to the various shades of grey.

Other examples of the display possibilities are given in the Appendix and in the section on specific project support which follows.

5.0 SPECIFIC PROJECT SUPPORT EXAMPLES

This section is designed to provide some examples of how direct read-out satellite data can be used and how this data can be specifically tailored to meet the unique needs of the experimental or operational project being conducted.

5.1 Environmental Research Program

One of the most pressing, and perhaps the most challenging problems facing mankind today is to determine his effect on his environment. However, before any determination of man-made changes in the environment can be made, a better understanding of ecological systems is required.

Increasing numbers of scientists are becoming involved in the attempt to understand how ecosystems function. Biologists, hydrologists, meteorologists, physicists, and chemists are all involved in some way, and are participating in an ecosystem analysis program as part of the United States' participation in the International Biological Program.

This ecosystem analysis program is an effort to model the behavior of these systems and thus to understand their response to man-made stresses. In order to cope with the diversity and tremendous complexity of ecological relationships, the research is focused on empirical analysis and greatly simplified models. Five major habitat types or biomes are presently being studied. These are: grasslands, deciduous and coniferous forests, deserts, and arctic tundra. In each biome, intense studies are being made to identify the processes involved in the dynamics of the system and to measure the flow of energy and materials

through the system. This data is then used in the construction of the mathematical models used to simulate each of the separate ecosystems.

Crude as these models may be, and it is not the purpose here to critically review any of them, they are producing some important initial results. One of the initial results indicates that a primary driving force in almost every biome is surface temperature; particularly as it affects plant growth. Another result shows direct beam solar radiation to be an important factor in the balance of an ecosystem through its effect on photosynthesis.

If surface temperature and solar radiation are to be used as primary inputs to an ecosystem model, then extensive measurements of these variables must be taken over the area of interest. This is where direct read-out satellite data, and a system for processing and display of this data can be of use to a project of this kind.

For surface temperature measurements the highest resolution possible would be desirable and only data taken under clear sky conditions would be valid. Figure 11 is a high resolution map of surface temperatures over an area including the Pawnee National Grasslands of northern Colorado (40.5 N to 41.0 N, 103.6 W to 104.7 W). This particular map is a night-time IR pass on June 25, 1971. The grey-scale used to represent temperature values was chosen such that A represents 0 and 1°C, B represents 2 and 3°C, etc. This grey-scale was chosen for two reasons. First, climatologically, the surface temperature in this area has never been below freezing at this time of year, thus any areas of data below 0°C would probably be due to cloud cover and would be displayed as blank areas on the print. Second, the 2 degree interval of the scale is probably the best precision possible with this data, as mentioned before.

This surface temperature map, although restricted in the ways mentioned above, would still be a useful product. The diurnal temperature variations, of course, could not be measured, but the day-to-day changes could be. The approximate 4 km resolution and 2°C precision is possibly too coarse for many studies, but as the area of observation increases the cost-benefit ratio of a fine mesh grid of ground based sensors would soon become prohibitive and the satellite data then becomes very good indeed.

The application of satellite video data to the direct beam solar radiation measurements is not as straight forward as is the IR data. The primary value of the satellite in this area is in giving accurate accounts of cloud cover. Thus the use of high resolution video data over the biome can be used as at least an input to the calculation of solar radiation, even if it cannot be used to directly measure this quantity. The video data can also be used to estimate the day-to-day changes in albedo of the surface caused by changes in plant cover, etc. Figure 12 is a high resolution APT photo again over the Pawnee National Grasslands (boxed off area) on June 25, 1971. The grey-scale used on this data is simply a 16 level brightness scale from black, represented by A , to white, represented by P .

The use of the satellite data on a daily basis could provide the ecosystem analyst with fast, accurate, and economical inputs into his biome model; and the use of the system designed in this paper for the processing and display of this satellite data would reduce the number of man-hours required for its use tremendously.

APT DATA FROM ORBIT 1678. TIME OF FIRST SCAN IS 19. 20. 17. DATE 6/28/71

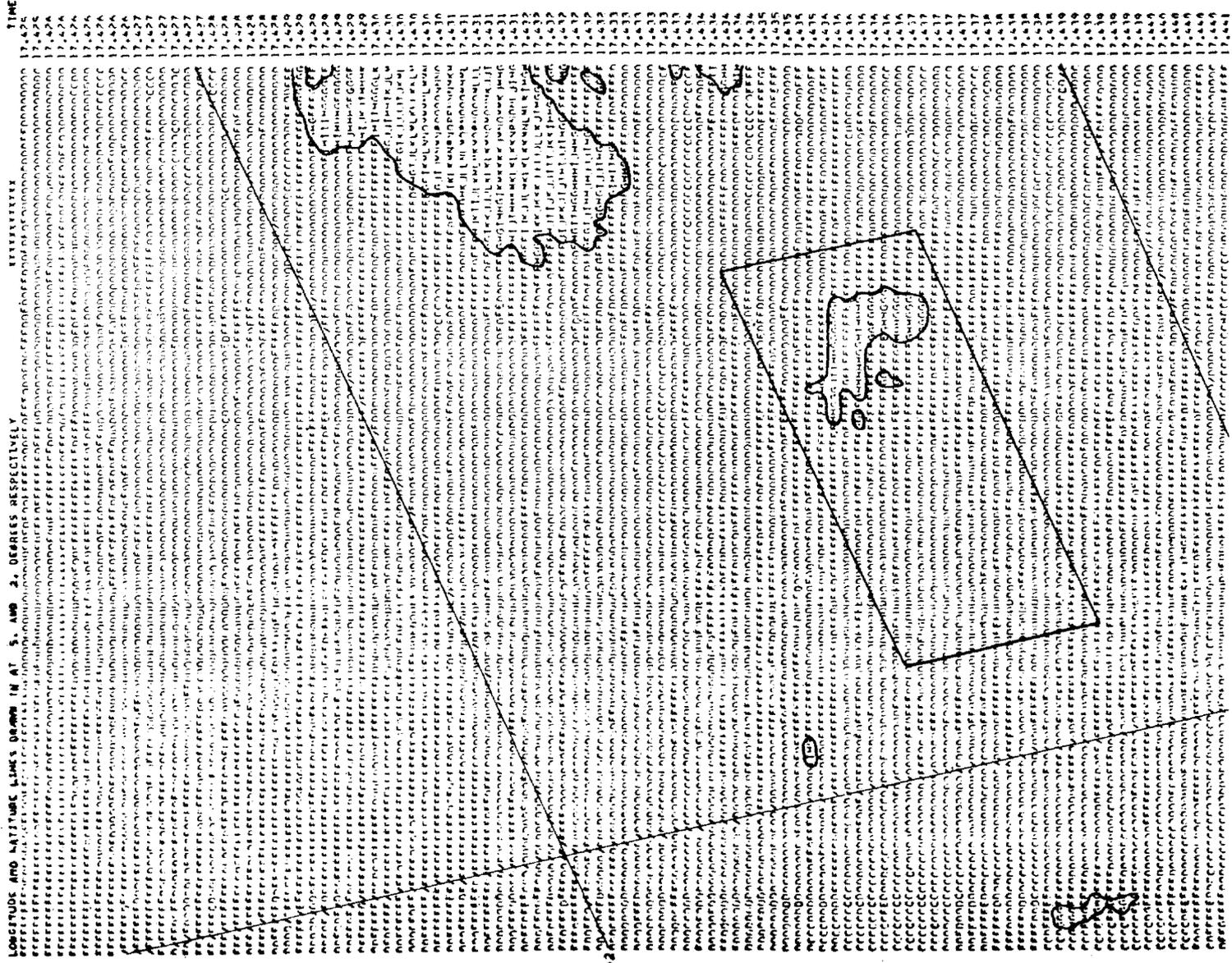


Figure 12. Digitized ESSA 8 APT picture 1724z, June 25, 1971. High resolution.

5.2 Severe Weather Watch

Virtually every operational weather forecaster has, at some time in his career, been involved in a severe weather watch. For many meteorologists it is very much a part of their full time job, and during active seasons, a significant portion of every forecast day is spent in simply trying to locate and track synoptic disturbances of potential danger to aircraft, crops, cities, etc.

Frequently, during such busy periods, data such as that received from satellites takes too much time to assimilate, earth locate, and analyze and is thus simply ignored or, at best, used to paper the walls. A system such as presented in this paper could, by alleviating the forecaster of the tedious and time consuming task of assembling the satellite data, contribute heavily to the efficiency and success of a forecaster conducting a severe weather watch.

Most successful operational meteorologists do much of their forecasting based on empirical rules they have developed through experience and familiarity with the actions of synoptic disturbances in their local area. This is particularly true when dealing with severe weather disturbances. These rules range from the very large and complex severe weather threat (SWEAT) indexes used by the National Severe Weather Central in Omaha, Nebraska, which include thousands of real time weather reports as well as statistical parameters derived from climatological records, to relatively simple rules-of-thumb which may use only a few real-time observations and a lot of experience. The important point is that these empirical rules work to some degree or they wouldn't be in use.

This is another area where our data handling routines can help. By displaying the data in terms of numbers, the forecaster can then use these quantitative values in his forecast "formulas". For example, he may correlate potentially severe weather with cloud top temperatures below 250°K in his local area. He may also want to include the lateral extent of clouds with tops below this temperature. Many such correlations can be made with the video data also. It must be remembered, however, that the brightness values given in the video data are not an absolute scale and any use made of this data must be in a relative sense. For example, if the brightness of a cloudy area on the picture is significantly higher than the surrounding clouds and the temperature of this area is below 250°K , the forecaster may be alerted for possible thunderstorm activity.

Of course, satellite data alone is not sufficient in a severe weather watch operation, but, when displayed in a useful and convenient manner, can be easily combined with other sources of data such as conventional weather reports and weather radar reports.

Figures 13, 14, and 15 are a sequence of contoured satellite data on the 24th and 25th of June, 1971. On the 24th, a strong frontal system began moving across the northwest United States and the three figures are of satellite data over this area as the front moved in.

Figure 13 is APT video brightness contours valid 1827z, June 24. The picture covers an area from approximately 140 W to 100 W and 48 N to 37 N. The brightness contours were drawn on an 8 level grey-scale with an interval of .16. Recall that the brightness values are based on the brightness of the line sync signal which varied from picture-to-picture from about 1.0 to 0.9. Thus the actual brightness values

ESSA 8 APT DATA FROM ORBIT 1563. TIME OF FIRST SCAN IS 18/23/59Z, DATE 6/24/71
 VALUES ARE MEASURED BRIGHTNESS WITH CONTOUR INTERVAL OF .16

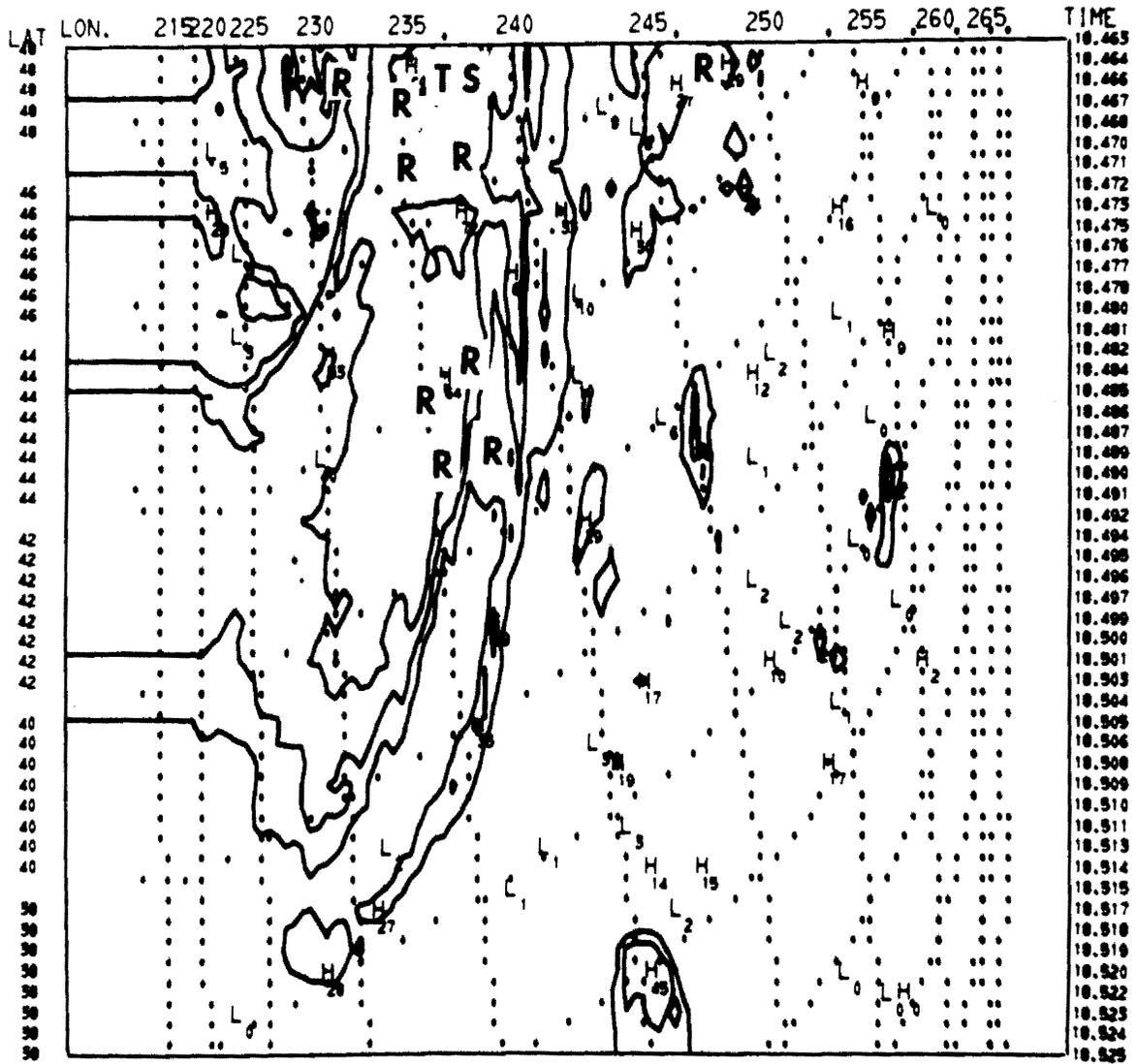


Figure 13. Digitized ESSA VIII APT picture 1827z, June 24, 1971.

NOAA I IR DATA FROM ORBIT 2456. TIME OF FIRST SCAN IS 11/51/00Z, DATE 6/25/71
 VALUES ARE IN DEGREES KELVIN WITH CONTOUR INTERVAL OF 20 DEGREES

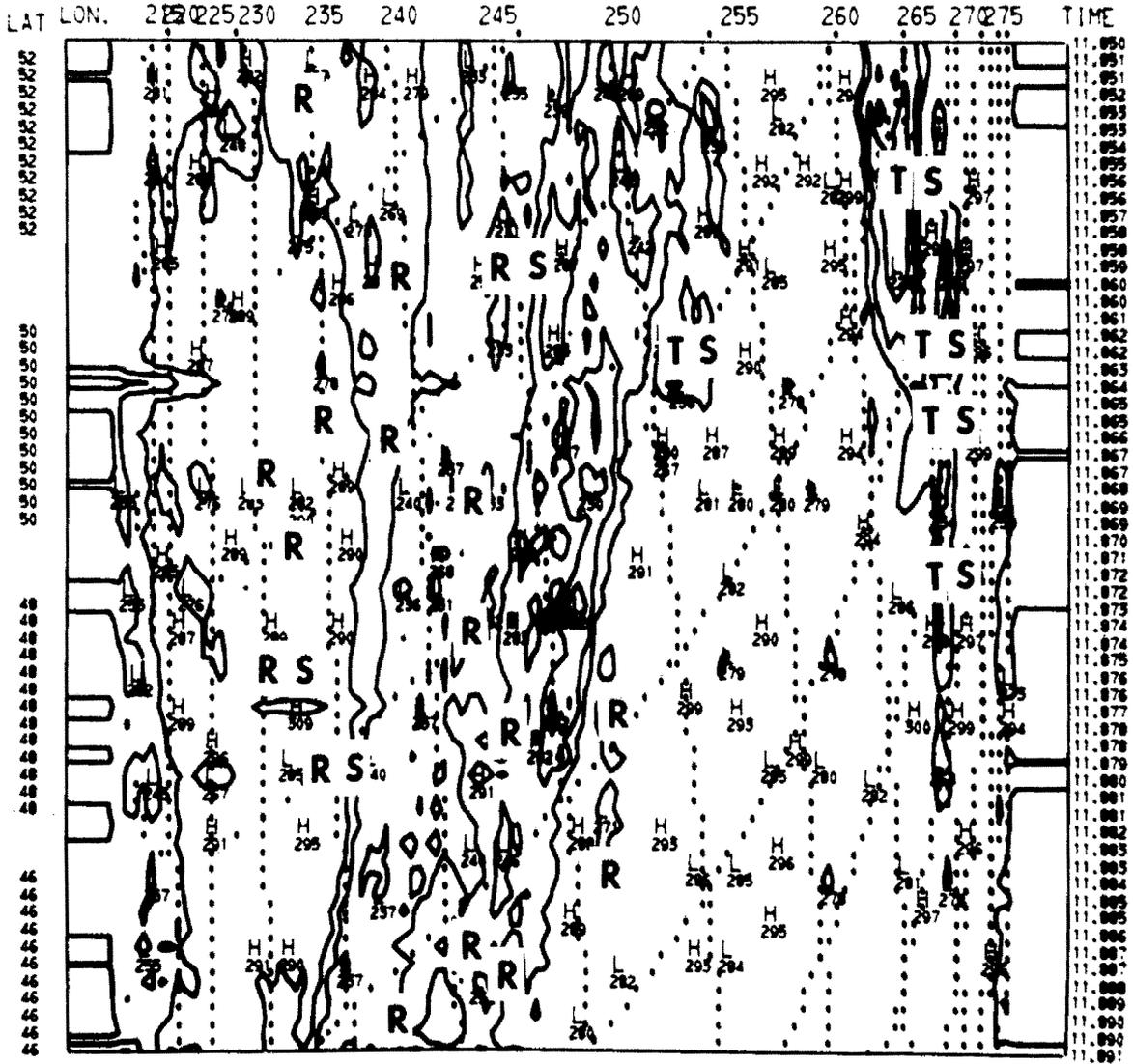


Figure 14. Digitized NOAA I IR picture 1151z, June 25, 1971.

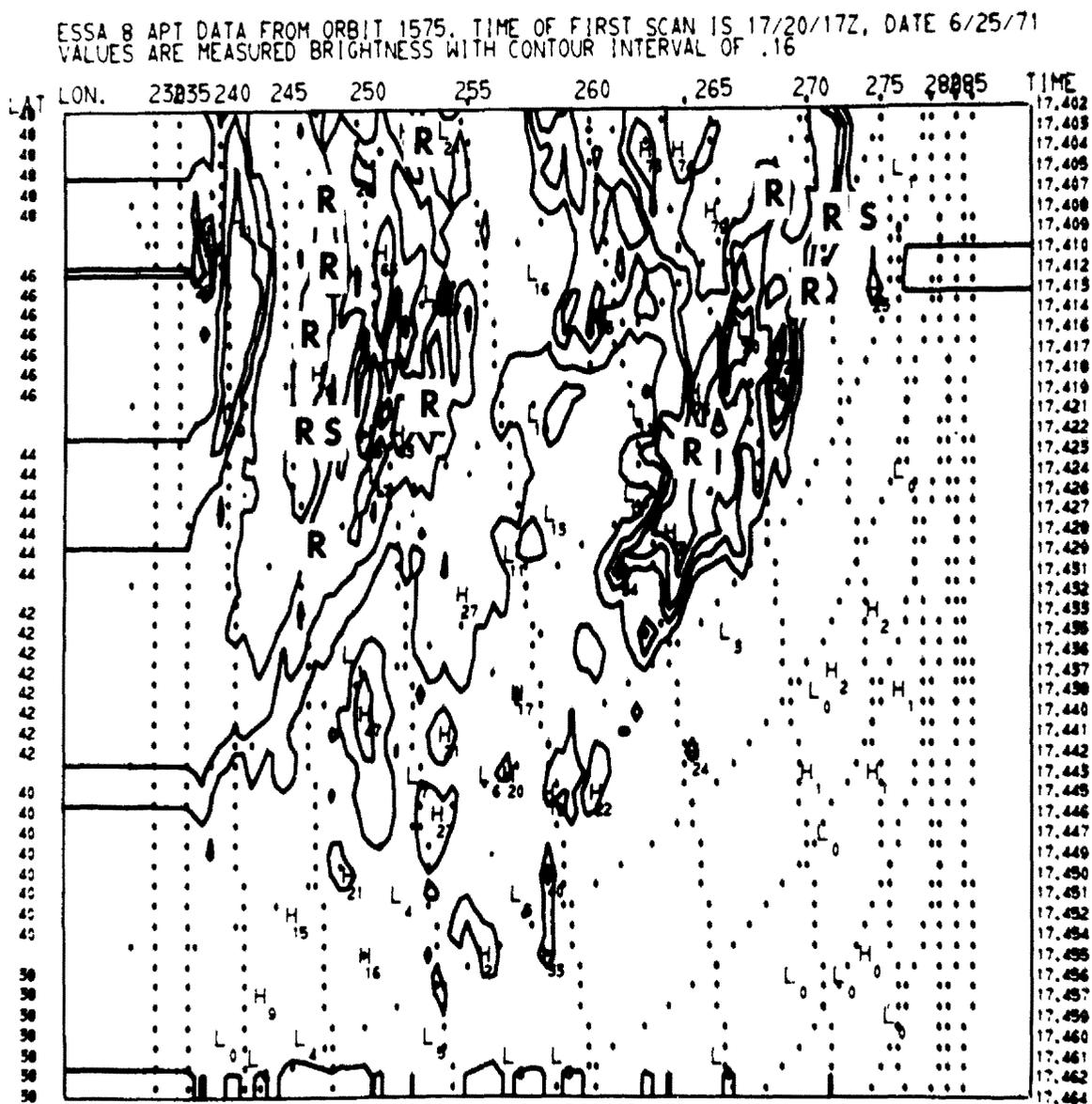


Figure 15. Digitized ESSA VIII APT picture 1724z, June 25, 1971.

plotted are valid only in a relative sense within each picture. Inter-picture comparisons of brightness values can only be done when the change between pictures is quite large (e.g., greater than 0.1).

The contour pattern shows quite well the areas of active synoptic conditions and potential severe weather. The high values in the left center of the picture show the cloud pattern associated with the frontal system as it enters the west coast of the U. S. Superimposed on this contour pattern have been plotted the surface weather taken from the NMC maps. Only those areas reporting significant precipitation have been shown. The code for the surface weather is: R = rain, RS = rain showers and TS = thunderstorm activity.

Figure 14 is an IR temperature contour map over the same general area, valid near 12z, June 25, 1971.

The contour pattern shows that the frontal system has entered the coast and is now at about 115 W. The weather pattern has now expanded somewhat and moved inland also. Some stations in Washington and Oregon have reported new rainfall records. Note the cold temperature pattern on the right side of the figure running down 95 W. This is an extensive area, in the upper midwest, of thunderstorm activity, with many stations reporting heavy rains and one report of damaging hail.

Figure 15 is an APT video brightness contour valid 1724z, 25 June, 1971. The frontal system can now be seen to be approaching 105 W. The cloud pattern and associated weather appear to be dissipating somewhat. The active thunderstorm area seen in the previous figure can now be seen to be moving eastward and is centered at about 42 N, 95 W with no thunderstorms being reported any longer.

With these few examples it can be seen that satellite data, when conveniently and accurately displayed, can indeed be used in conducting a severe weather watch. Undue amounts of time need not be spent on simply assembling the data and thus more time can be spent utilizing the product. Even if the satellite data were only to be used to draw the attention of the forecaster to potentially active weather areas, I believe the satellite data products of this display system would serve a useful purpose.

5.3 Weather Modification

Weather modification programs have, in the last decade, become increasingly important in terms of time, money, and facilities dedicated to them. Both operational and experimental weather modification programs are being tested and run in a variety of different synoptic situations and geographical areas. One of the most extensive and long-term programs being conducted is Professor L. O. Grant and associates' experiments on the seeding of cold orographic clouds over the Colorado River Basin. This study is now in its eighth year and large amounts of observations have been statistically treated to determine not only the effects of cloud seeding, but also the criteria necessary for most efficient "snow-making" operations.

From the results of Grant, et. al. (1971), the following parameters are significant to cold orographic cloud seeding:

1. Wind Direction - This parameter takes into account the local topography, and the conditions producing the most favorable and continuous orographic stream, i.e., wind direction should be more or less perpendicular to the mountain chain

to produce the upslope motion, and should be directed so that the nuclei from the seeding generators will arrive at the target.

2. Wind Speed - This parameter probably optimizes the distances from the generators to the target area taking into account the crystal growth rates, travel times, and fall velocities from the snow.
3. Cloud Temperatures - This parameter shows the dependence of natural nuclei's activation on temperature. As an indicator of cloud temperatures, the temperature of the cloud top (500 mb temps) where artificial seeding increases the snow most is -20°C to -13°C . The least effect of seeding, and sometimes negative effects, are produced with cloud top temperatures colder than -23°C . This is probably due to the presence of adequate natural nuclei and occasional overseeding for the negative effect.
4. Moisture Availability - The largest increases in snowfall occur when the moisture supply is largest.
5. Lapse Rate - Lapse rates near or less than moist adiabatic are most conducive to artificial increases of snow.

Satellite observations are not only well suited to weather modification programs, but also, in some cases, better than other sources. The satellite can measure directly the presence and extent of cloud systems over mountainous terrain where conventional observations are lacking. It can also measure directly the important parameter of cloud top temperatures. The present system for measuring these temperatures

involves an extrapolation and interpolation of standard level synoptic charts. With the aid of geosynchronous satellite observations, the speed and direction of movement of clouds can be observed and thus wind speed and direction established. With the coming of the newer generations of operational satellites mentioned previously, temperature and moisture soundings, two more important parameters, will become available. Of course, the temperature and moisture soundings can only be taken in cloud free areas, but an important phase of this program includes studies on the cloud system's environment where these observations would be possible.

In an operational cloud seeding program over the Colorado River Basin area, these same parameters and observations would be significant. The primary difference between the operational program and the experimental one being that the satellite data would be used as a "forecast" for determining the seedability of cloud systems rather than strictly as observational data taken for study purposes. If, for instance, the purpose of the operational seeding program was to increase the snowfall, it would be economically ridiculous to randomly seed clouds. A much better approach would be to routinely use satellite data input into the seed or non-seed decision. In this way cloud systems could be observed on a real-time basis for favorable seeding conditions and then only those clouds with the maximum potential would be seeded. The time and money wasted in seeding unproductive clouds would thus be held to a minimum.

Of course, for both operational and scientific weather modification programs, the need for accurate processing and earth locating of the data is mandatory. Although generally less important for the scientific

program than for the operational, speed is important. The operational meteorologist would want the data processed, displayed, and delivered to him as rapidly as possible in order that his personnel and equipment may be dispersed and operating with a minimum of delay.

Having previously shown examples of the capability of this multiple input and display system for producing specialized outputs, such as may be required in a weather modification program, we will elaborate upon the last point mentioned above - speed.

Consider the following hypothetical situation: an operational cloud seeding program is being conducted over the Colorado River Basin with the objective of increasing the snowfall in the area. It is desired that the IR data from NOAA I be received and used as a final seed or non-seed decision maker. The data display should be high resolution and only cloud top temperatures ranging from -15°C to -23°C need be displayed. How soon can this data be in the hands of the program forecaster?

The following list gives the operations required and the approximate times needed to produce the desired product.

ACTION	TIME
Satellite read-out	15 min.
A to D conversion	15 min.
Program set-up (alter grey-scale and select grid location)	10 min.
Program run	5 min.
	<hr/>
TOTAL	45 min.

This rapid conversion from satellite observation to data display makes possible a real-time operation. With the use of this display system, the operational weather modification program no longer need rely solely on conventional weather forecasts made over sparse data regions, but can assume a wait-and-see attitude before launching their planes or starting their seeding generators. Thus, time and money are saved rather than being wasted on an operation based on a too optimistic forecast.

6.0 SUMMARY

This study has shown that with the aid of a direct read-out satellite receiver and a small computer, any meteorological field project or small weather group could receive and display satellite data on a real-time basis.

To prove the feasibility of constructing such a system, an existing APT satellite read-out set, originally designed to only produce Polaroid pictures, was expanded and improved to a multiple input and display system by adding an analog-to-digital converter and a computer. This system proved to be fast, accurate, and flexible enough to produce highly tailored satellite data displays designed to suit a variety of user needs.

Direct read-out satellite data, as received and displayed on the standard APT set, is frequently of little operational or scientific use because of the qualitative nature of the display and the time consuming procedures necessary to collect, process, and earth-locate the data. The use of a system such as presented in this paper not only eliminates the man-hours needed for the processing, but also improves the data usefulness by providing the user with a digitized, earth-located data base with which to work.

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APPENDIX

COMPUTER ANALYSIS AND DISPLAY PROGRAMS

A1. Grey-Scale Programs

For the video data, the digital values were linearly placed into 16 groups, representing a grey-scale from black to white. The lower end of the scale, representing black, was simply a zero value of the digital count. The upper value, representing white, was based upon the digital count of the line sync signal. Since the vidicon camera system was designed such that the maximum amplitude of the data signal is 70 percent of the amplitude of the sync signal; the digital count representing white, and thus the high end of the grey-scale is simply 0.7 of the sync signal count.

For the infrared data, the grey-scale was already created in the conversion of energy values to equivalent black body temperatures. In the preceding section it was pointed out that the calculated energy values were converted to temperatures by use of a table. This table was generated using a 1°K interval. Thus, the values of equivalent temperature produced were already in a grey-scale with a precision of $\pm 1^{\circ}\text{K}$. Further grey-scaling, when desired, was accomplished by grouping the data into categories which included a range of temperatures similar to what was done for the APT data.

A2. Earth Location Programs

The program used for earth locating the data was one written by Madden (1971). This program was specifically designed for use with scanning radiometer data only; however, in this study, it was adopted for use on APT video data also.

The program uses as input the orbital parameters taken from the APT TBUS bulletin with the additional information of satellite altitude, direction of motion, rate of scan of the sensor, and the time of the first scan line. Using this information, and assuming the scan line is along a great circle through the satellite sub-point, the program calculates the latitude and longitude of the satellite sub-point and the latitude-longitude intersections with the scan line. The latitude-longitude lines are then placed in their proper positions in the earth-scan data array and the line is printed out. Then the next data line is brought in and the whole process repeated.

In order to use this program for earth locating the video image data the assumption was made that each raster line of the APT picture could be equated to a great circle scan through the satellite sub-point. Since the time of the APT picture corresponds to the time the satellite sub-point was at the center of the picture, then the time of the first scan line can be found by calculating the number of seconds it would take the satellite to move through the distance covered by the top one-half of the picture and subtracting this from the APT picture time. The distance on the ground between the top of the picture and the center is 1711 km. The ground velocity of the satellite is 7.5 km/sec. Thus the time it would take the satellite to move over this distance is 228 seconds, and the time of the first scan is equal to the APT picture time, minus 228 seconds. Of course, we must also simulate a scanning rate which agrees with this time and distance calculation. The vidicon camera produces 400 lines of data while "flying" over the top one-half of the picture, thus the scan rate is simply the ratio of

this number of lines to the time of flight ($400/228 \text{ sec}^{-1}$ for the ESSA VIII). The new scan rate for APT pictures is then about 105 rpm. Thus, for mapping purposes, we have created the effect of a satellite orbiting over the area with a scanning type instrument rather than a "snap-shot" type instrument.

The only other modification that had to be made was one involving the side-to-side scan angle. The IR sensor, of course, scans from horizon-to-horizon corresponding to a scan angle of about 109° . The vidicon tube, however, only "sees" over an angle of 90° from side-to-side. Thus the limits of the computed data array in the program had to be modified to account for this narrower field of view.

A3. Display Programs

The display programs actually are not separate programs at all, but simply data handling and print routines necessary for the presentation of the computer output in a useable and convenient manner. These routines provide the means by which the preliminary data handling, grey-scaling, and earth location products can be brought together into a final computer output. The display programs were designed to be quite flexible and to output several modes of display, including:

1. Low resolution, large area, mapped display of IR or APT data.
2. Contoured, large area, mapped display of IR or APT data.
3. High resolution, small area, mapped display of IR or APT data.
4. Contoured IR data overlaid on large area, mapped APT data.

Before an explanation of the various resolution and area coverages can be given, note must be made of the limitations imposed on the display by the computer printer. Most computer printers are limited to

approximately 130 print positions (characters) per line and about 60 lines per page. Thus, to display completely an 800 x 800 data point array, such as the APT pictures, would require a display of about 7 pages wide and 14 pages long. This would not only be costly, but in most cases, unnecessary. If we assume that when displaying the complete APT picture or IR strip, the full resolution present in the data is not needed, then we can reduce the volume of output to a manageable level. This reduction of resolution was accomplished by simply taking averages of the data points within each line and between lines.

Allowing for some space at each side of the "pictures" for printing times, latitude labels, etc., the program for earth location of the data is left with 108 print positions available for data values. For the APT picture at our digitization frequency, we have approximately 760 data points per line; thus if we represent every 7 data points by their average value, we can print a full data line across one page of output. To maintain proper perspective and to make this reduction in resolution meaningful, the same averaging technique must be applied between the separate data lines also. It follows that the definition of low resolution, large area display of APT data is a complete APT picture at a resolution of about 25 km.

For the IR data, approximately 600 points per line need to be reduced to 108 points, thus about 5-point average across the line is necessary. This produces an east-west resolution of about 20 km. To produce this resolution in the north-south direction, consideration must be given to the ground velocity of the satellite versus the scan rate of the radiometer. Since the scan rate is 1.25 seconds/line and

the satellites velocity is about 7.5 km/sec., each line is separated by a distance of about 10 km. We have seen before that the instantaneous field of view of the radiometer produces a resolution of about 7.7 km. If this is added to the distance between lines, then it can be seen that only 2 lines of data would have to be averaged to produce an 18 km resolution. Thus the definition of low resolution, large area display of IR data is again the full width of the scan line by about 120 scan lines, at a resolution of about 20 km.

High resolution then means the highest resolution permitted by our sampling frequency (3.5 km for APT, 4.7 km for IR) and small area is governed by the number of these data values that will fit on a page of output.

The contouring routine is a program that uses a 4-data-point grid for the calculation of the position of the lines. Basically, all the program does is to set up a grid of 4 data points and interpolate the entrance and exit positions of the contour. Then a line is drawn between these two points. The program loops through this process enough times to draw the number of contours desired, then proceeds to the next 4 data points. Finally, all data points are searched for high and low values relative to the surrounding data, and an H or L is printed along with the central value of the high or low. The output from this program was done on the micro-film printer since lines are much easier drawn on this device than they are on a paper printer. Also, data overlays are possible on the micro-film and not on the printer. This is done by plotting each data field separately and not advancing the micro-film frame between plots. Several examples of the types of output from these programs are presented in figures 8, 9, and 10. An

APT DATA FROM ORBIT 1550.. TIME OF FIRST SCAN IS 17.39. 4. DATE 6/23/71

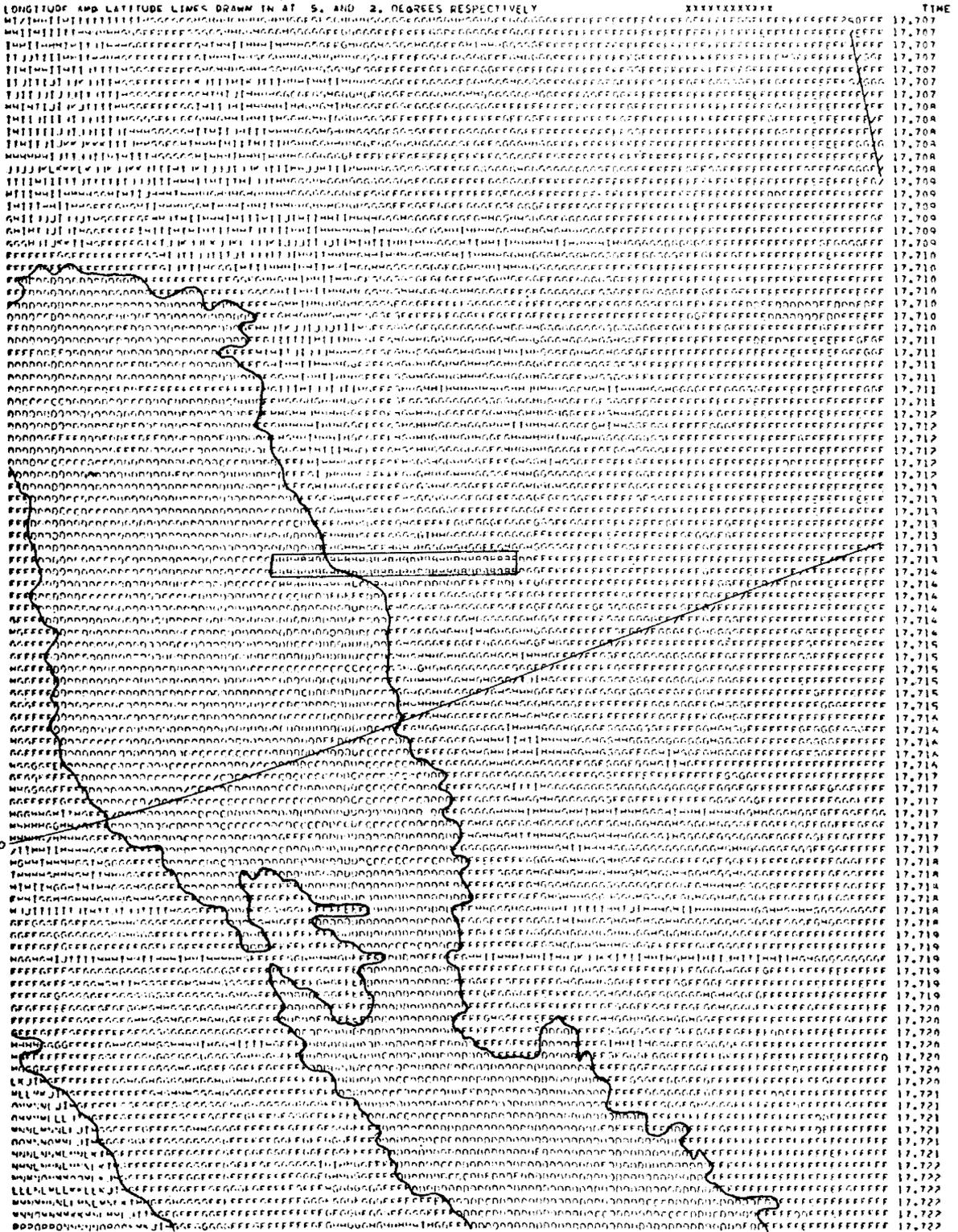


Figure 8. Digitized ESSA 8 APT picture 1742z, June 23, 1971. High resolution.

NOAA 1 IR DATA FROM ORBIT 2278. TIME OF FIRST SCAN IS 06/51/00Z, DATE
 VALUES ARE IN DEGREES KELVIN WITH CONTOUR INTERVAL OF 10 DEGREES

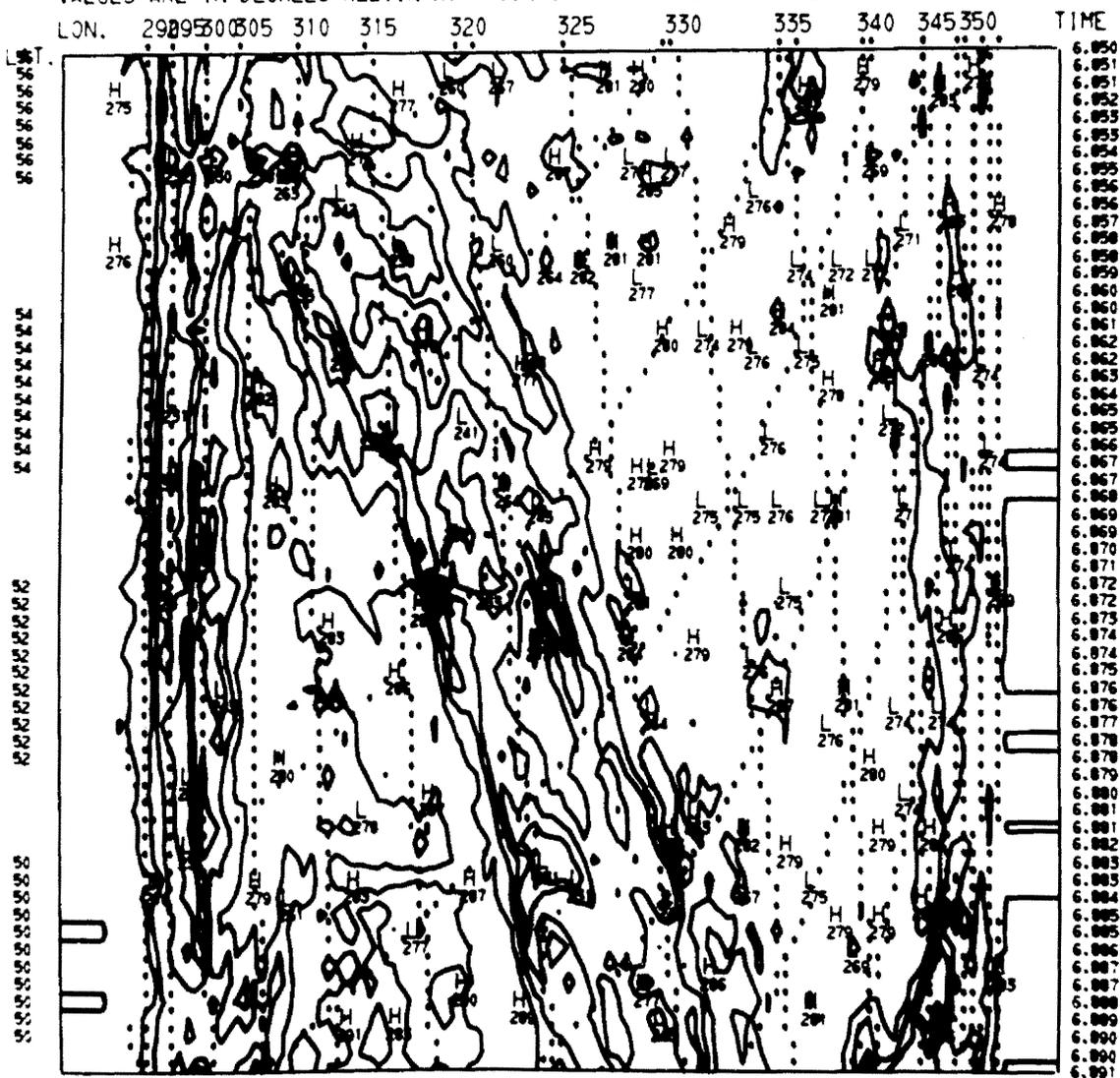


Figure 9. Digitized NOAA I IR picture 0651z, June 11, 1971.



Figure 10. Nimbus III MRIR total infrared radiant emittance ($10^{-2} \text{ cal cm}^{-2} \text{ min}^{-1}$) superimposed on ESSA 9 photographic cloud average over the same period (16-30 June 1969). (after Vonder Haar, 1970).

example of a low resolution, large area, mapped display of APT data has already been shown in Figure 7. The boxed-off area in Figure 7 is presented again in Figure 8 as a high resolution display. We can now see this small area at the full 3 km resolution permitted by the sensor. The outline of the Gulf has again been drawn in. Note how the small island just south of 30° N (Guard Angel Is.) is now distinguishable as an island, where in Figure 7 it was not. Shark Island, directly across the Gulf still appears as part of the coast since the separation between coast and island is less than 3 km. Also, the center fiducial mark is now partially visible just north of 30° N.

Figure 9 is contoured low resolution IR data from NOAA I at 07z, June 11, 1971. The latitude-longitude grid is similar to the one explained in the previous figures. The data itself is given in degrees K with a contouring interval of 10° K, based at 200° K.

Note the narrow band of cold temperatures slanting down from the upper left hand corner of the picture and then curving back and spreading toward the bottom center. This band is associated with a large occluded frontal system over the North Atlantic just south of Greenland.

Figure 10 is not a product of this display system. The figure was taken from one produced by Vonder Haar (1970) as representative of the type of product that can be produced by overlaying APT data with contoured IR data. The reason this figure was used was because of the early failures of both the ITOS and NOAA satellites; no direct read-out IR and video data, valid at the same time and place, was available. The program necessary to produce this type of display has been written. All that is necessary is to produce the APT picture first, followed by the IR contours without advancing the micro-film frame. The programs

need not be changed at all. Of course, instead of the photographic type APT background, the display would be a digital representation such as in Figure 7.

This combined data display aids in the mutual interpretation of the individual data fields. For example, the two bright areas over Central America; both these areas might be interpreted as areas of high thick cloudiness if the video data alone were used. But the character of these clouds is seen to be quite different when the IR data is added. The Central American clouds have low temperatures and thus probably have significant vertical extent, while the clouds off the South American coast have warm tops and thus are probably low stratus or fog.