Quantitative Temperature Data from Direct-Readout Infrared (DRIR) Pictures

FRANCIS R. VALOVICIN
Air Force Cambridge Research Laboratories, Bedford, Mass. 01730

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ABSTRACT

The Scanning Radiometer System aboard the new meteorological satellites transmits infrared radiation data directly to APT stations for local use. By controlled processing of the direct readout data and by taking reflective density measurements with a densitometer on the infrared imagery, quantitative temperature data may be obtained. It is shown that, in general, the quantitative temperature measurements are quite representative and have immediate application to users of APT data.

1. Introduction

The new generation of operational meteorological satellites such as NOAA's environmental satellites provide the meteorologist with Direct Readout Infrared (DRIR) data. Since May 1966, these data have been intermittently transmitted directly to Automatic Picture Transmission (APT) ground stations for immediate use. In general, these data have received limited utilization in the field because most APT facsimile recorders were not modified to produce imagery from the DRIR signal and those that were provided a low quality picture. The ability to separate relatively cold from warm clouds and the surface was about the only information that could be derived from the quality of the imagery received at the APT station.

As the National Satellite System phases out of the use of vidicon imaging and into the use of the two-channel scanning radiometer system in 1972, the requirement to optimize the presentation (both visual and IR) will become increasingly important. The work discussed in this paper is an attempt to demonstrate that useful quantitative information can be extracted from DRIR data at remote sites which do not have elaborate computer facilities to digitize and process the data.

At the Air Force Cambridge Research Laboratories, considerable effort has gone into the improvement of the processing of direct readout products. Techniques for the controlled processing of direct readout data from meteorological satellites have been developed at AFCRL (Myers et al., 1970). Basically, their techniques allow matching the range of the satellite signal containing meteorological information to the full dynamic range of the photographic paper and controlling the slope of the signal/photographic density (gray level) curve. Their techniques were designed primarily for operational use by the APT ground stations that have a photographic recorder capability. When these procedures are carefully followed, the resulting image has neither bleached-out clouds nor blacked-out surface features. In the DRIR mode, the ability to control the signal/photographic density relationship has implications beyond producing a high quality picture. Since the signal in the DRIR mode is related to equivalent blackbody temperature, the photographic density is also related to temperature. Therefore, by knowing the signal/photographic density relationship, it is possible to use measurements of the photographic density to obtain equivalent blackbody temperatures. Thus, this functional relationship allows an individual to interpret the infrared imagery in terms of temperature.

The Muirhead M115 B/1 Recorder has been used in this work. It is a photofacsimile recorder which produces a 8X8 inch (20X20 cm) APT picture or a scanning radiometer (DRIR) image that is 5½ inches (13 cm) wide and about 16 inches (41 cm) long for a typical satellite pass. When the satellite is in the scanning radiometer mode, two sheets of paper must be used to get the complete pass.

2. Procedure to extract quantitative temperature data

In order to extract quantitative temperature data from the DRIR picture, certain procedures are followed as outlined in Myers et al. (1970). The new operational meteorological satellites transmit a 7-step calibration wedge between each scan across the earth. The steps of this wedge are equivalent to voltage outputs of the radiometer. In turn the voltage outputs are related to equivalent blackbody temperatures according to the internal housing temperature of the radiometer. When the procedures for controlled processing are carried out
carefully, the IR signal being received at the APT station will be processed in a calibrated and reproducible fashion.

Under normal settings and using the entire 7-step calibration wedge, land and water surfaces that are cloudless appear black to dark gray, low clouds appear dark gray, middle clouds appear light gray, and thick high clouds appear white.

Many options are possible with the 7-step calibration wedge. If the entire 7-step wedge is utilized, equivalent blackbody temperature values range below 200K to above 330K which is more than adequate for meteorological purposes. By adjusting the photographic or reflective density of the step wedges, any desired thermal feature may be highlighted. Fig. 1 shows examples of temperature, reflective-density relationships for highlighting a few temperature ranges. Reflective density from a photograph or paper print is defined as the logarithm of the ratio of incident to reflected light. A densitometer is used to measure a wide range of reflective densities. On the IR photograph, a reflective density value of approximately 0.15 is selected to represent “white” and 1.50 is selected to represent “black.” A value of 0.15 representing “white” will retain the details in extremely bright clouds while details are lost where reflective densities are greater than 1.50.

The photographic result of some of the temperature, reflective-density settings is shown in Fig. 2. For example, if one wanted to measure cloud and surface temperatures on the same IR photograph, either calibration A or B would be chosen. The thermal resolution of the features in the DRIR presentation A or B is retained. Presentation A in Fig. 2 appears dark because the majority of clouds are generally not colder than 215K. By adjusting the reflective density from calibration A to B, the clouds appear brighter and there is more contrast between land and water surfaces. On the other hand, it is possible to limit the reflective-density range between steps 2 and 6 at the warmer end of the calibration wedge. This is shown by DRIR presentation C in Fig. 2. This setting is ideal for studying low clouds and surface temperatures. Clouds colder than 250K are washed out or paper white and the temperature span of interest is between 250–330K.

3. DRIR measurement technique

On 21 May 1970, orbit 1481 of ITOS-1 crossed the equator at 71.5W northbound. The satellite was pro-

![Fig. 1. Temperature, reflective-density relationships for various temperature ranges.](image)

![Fig. 2. DRIR imagery made with calibrations A, B and C of Fig. 1.](image)
grammed to operate in the scanning radiometer infrared mode. In this mode, emitted energy in the 10.3–12.5 μ spectral region, perpendicular to the path of the spacecraft, was measured and transmitted in real time.

Fig. 3 shows the infrared imagery from orbit 1481 of ITOS-1 that was received by AFCRL at Bedford, Mass. Bright areas (white) correspond to low emitted energy values associated with clouds. In the infrared imagery, the brighter the cloud, the lower is its equivalent blackbody temperature. Thus, a knowledge of the temperature-height relationship for a particular area allows one to assign a cloud top height value as a function of temperature with the assumption that overcast areas radiate as blackbodies. The dark areas (dark gray–black) correspond to high emitted energy values and are generally cloud free, and this in turn may be related to surface temperature patterns.

In an expanded DRIR picture on the Muirhead M115 B/1 Recorder, the 7-step calibration wedge does not appear on the picture because of the blanking of the radiometer housing portion of the scan. It is necessary to shift the picture right or left in order to display the wedge. At the end of the recording of the DRIR picture, the calibration wedge was inserted on the photograph (top of Fig. 3) by shifting the picture left. The reflective density of each step was measured with a densitometer. The equivalent blackbody temperature values corresponding to the controlled voltage levels of each wedge step for ITOS-1 were obtained from a calibration table provided by NOAA. The relationship between the reflective density of each wedge step and the corresponding calibration temperatures for Fig. 3 is shown in Table 1. In addition, Table 1 contains the standard deviation of 25 reflective-density measurements taken over a period of 6 weeks. As seen from the value of the standard deviations, little change occurs

![Fig. 3. ITOS-1 DRIR 21 May 1970 orbit 1481. Gridded manually in accordance with APT Users Guide (1969).](image)

![Fig. 4. Linear temperature, reflective-density relationship as determined from wedge densitometer measurements.](image)

<table>
<thead>
<tr>
<th>Radiometer step number</th>
<th>Equivalent temperature (°K)</th>
<th>Reflective density</th>
<th>Standard deviation (reflective density)</th>
<th>Standard deviation (temperature)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porch</td>
<td>(188)*</td>
<td>0.16</td>
<td>0.01</td>
<td>1K</td>
</tr>
<tr>
<td>1</td>
<td>216</td>
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<td>1K</td>
</tr>
<tr>
<td>3</td>
<td>279</td>
<td>1.16</td>
<td>0.01</td>
<td>1K</td>
</tr>
<tr>
<td>4</td>
<td>300</td>
<td>1.36</td>
<td>0.01</td>
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<tr>
<td>6</td>
<td>333</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

* Equivalent temperature of “porch” using a linear least-square fit of a line. See text.
in the measurements of the reflective densities on the
IR photograph over a period of weeks. Thus, it is
possible to repeat measurements on the same picture
even over a relatively long period of time provided the
photographs are protected from direct sunlight.

To determine the temperature, reflective-density
relationship for all values of reflective density on the
photograph, either a graphical or algebraic interpola-
tion can be used. The graphical method is illustrated in
Fig. 4 where the reflective density of each wedge step is
plotted on the appropriate horizontal line correspond-
ing to the temperature of the wedge step. The coldest
wedge step (white) in the DRIR photograph is called
the “porch” and is uncalibrated. However, if the rela-
tionship is linear, a temperature equivalent for the
“porch” may be obtained. For this wedge-step, reflec-
tive-density relationship, the temperature equivalent
for the “porch” is 188K. For the algebraic interpo-
lation, the linear least-square equation for the wedge
densities and corresponding temperatures for Fig. 3 is

\[ Y = 92.6X + 173.4, \]  

where \( Y \) is the effective temperature (°K) and \( X \) the
reflective density.

In this study, a modified Macbeth Reflection
Densitometer, Model RD 107, was used. It was physi-
cally and permanently attached to a drafting machine.
Thus, a fixed \( x-y \) coordinate system can be tied directly
to any photograph. Fig. 3 was attached to this \( x-y \)
coordinate system and reflective-density measurements
were made at certain pre-set intervals. In the \( x \) direc-
tion, measurements were made at \( \frac{1}{8} \) inch (0.16 cm)
intervals and in the \( y \) direction at \( \frac{1}{16} \) inch (0.254
cm) intervals. This corresponds to 160 readings per
square inch (25 per square cm) on the DRIR photo-
graphs. The densitometer has a \( \frac{1}{8} \) inch (0.32 cm)
diameter spot for measuring the average reflective
density on the IR photograph. On the expanded IR
photograph, this sampling area corresponds to an
elliptical area of approximately 25 by 35 n mi (46 by
65 km) on the ground along the satellite subpoint.

Fig. 3 was sectioned off on the \( x-y \) coordinate system
in \( \frac{1}{8} \) inch (1.27 cm) squares. The center of the picture
is designated at 0 and the sectors are marked off in
\( \frac{1}{8} \) inch (1.27 cm) segments. These sector designations,
A to J, appear both at the top and bottom of Fig. 3.
The numbers appearing on the left and right side of
Fig. 3 refer to the lines on the \( y \) axis. The number 20
refers to line 20 and is 2.0 inches (5 cm) from the start of the picture.

The spatial resolution of the ITOS-1 Scanning Radiometer System on the expanded DRIR picture plane is 4 n mi (7 km) at the picture center; 5 n mi (9 km) in sectors C, D and G, H; and 15 n mi (28 km) in sectors B and I. In terms of the densitometer, in these same sectors, the elliptical sampling areas are 25×30 n mi (46×56 km), 25×40 n mi (46×74 km), and 25×120 n mi (46×222 km), respectively. Each scan of the radiometer perpendicular to the orbit track is 3600 n mi (6667 km) long and covers the earth’s surface from horizon to horizon.

At approximately the same time, ESSA-9 with the Advanced Vidicon Camera System (AVCS) aboard was taking television pictures of the cloud cover in the visible part of the spectrum in the same general area. Figs. 5 and 6 were taken by ESSA-9 in the same general area as the DRIR of ITOS-1 in Fig. 3. As you can see, the DRIR presentation of ITOS-1 is similar to the television picture of ESSA-9. Both IR and visible presentations emphasize or highlight the same large-scale features but in the IR presentation, the shades of gray are directly related to cloud temperatures, and is thus an added dimension.

A comparison of the infrared with the television picture of the cloud cover shows many interesting features. On 21 May 1970 at approximately 2000 GMT, tropical storm Alma was located just south of Cuba. Farther north between 35–40N and 80–85W air mass thunderstorms were in progress. Along the coastal area of the Middle Atlantic States and in New England, some fog was being reported. Finally, a stationary front was located in the vicinity of the Great Lakes. Further discussion in this paper will be limited to the four aforementioned weather features.

4. Results


On 21 May 1970, tropical storm Alma had weakened to a tropical depression and the center was located at 19N, 80W (Simpson and Pelissier, 1971). The center or eye of the storm is easily seen south of Cuba in the AVCS presentation of ESSA-9 (Fig. 5). The DRIR from ITOS-1 (Fig. 3) shows a slightly different presentation of Alma. The eye of Alma, clearly seen in the AVCS
presentation cannot be distinguished in the DRIR presentation. It must be emphasized at this point that although there is much similarity between the whites, grays and blacks of both pictures, each represents a different physical property. The AVCS picture represents reflective energy in the visible spectrum. In the DRIR presentation, emitted energy in the 10.5-12.5 μm region has been converted to shades of gray in the infrared picture. Using the technique previously described, representative reflective-density measurements were made at 19N, 80W on the DRIR photograph and converted either graphically (Fig. 4) or algebraically [Eq. (1)] to an effective temperature of 277K. The 0000 GMT 22 May 1970, Miami, Fla., radiosonde was used to assign temperatures to constant pressure surfaces and/or height. The 277K temperature is representative of a cloud top at 650 mb. The lightest and therefore the coldest spot measured on the DRIR photograph, 209K, was located at 20N, 78W some 130 n mi (241 km) NE from the center. This is representative of a cloud top at 160 mb or 43,000 ft (13 km). Unfortunately, no reconnaissance aircraft was flying above 10,000 ft (3 km) on this day and no verification of the cloud tops is possible.

A continuous radiation-implied temperature and cloud top heights for a few selected lines over Alma are shown in Fig. 7. The temperature on the left ordinate scale has been inverted to give the effect of cloud topography, i.e., the whiter the cloud, the colder the temperature and the higher the cloud top. Fig. 7 may be compared directly with the DRIR photograph to see how the temperature changes across Alma. Also, the temperature changes across water, land and clouds may be seen in sectors D, E and F of line 50.

The means and standard deviations based on 40 measurements for each 1/2 inch (1.27 cm) sector in the area of Alma is shown in Fig. 8. Again, the temperatures on the ordinate scale have been inverted, to give an effect of cloud topography. It can be seen that sector F, lines 30-34, contains the coldest temperature, 218K, and that there is an increase in equivalent blackbody temperature and therefore a decrease of cloud heights in all directions from this sector. The strongest gradient of both temperature and cloud heights is located in the western sectors, i.e., C, D and E. The cloud heights in the coldest sector are near 200 mb or 40,000 ft (12 km).

The effect of sampling homogeneous or non-homogeneous areas of clouds and/or surface with this densitometer technique on the DRIR photograph also may be seen in Fig. 8. Homogeneous area is defined as an area that appears to consist of a single gray shade over the size of the aperture sampling area (1/2 inch or 0.32 cm). A non-homogeneous area is defined as an area that has many different shades of gray over the same sampling area. In the case of homogeneous clouds, e.g., sector F, lines 30-34, the mean was 219K with a standard deviation of 4K. To the west and south of this sector are examples of non-homogeneous cloud areas. Standard deviations of 22-24K are found in sectors E, lines 25-29 and 30-34, and F, lines 20-24. The cloud top heights in these sectors go from 800 mb to about 200 mb. The homogeneous clear areas with the smallest standard deviations of 2K are usually found over the sea surface, e.g., sectors F and H, lines 60-64. In the case of homogeneous clear land areas, the standard deviations are 4-6K. Northern Florida, sector E, lines 60-64, is a good example of a homogeneous clear land area.

Florida, which is located in sector E, lines 48-65, appears clear in the DRIR photograph. Shelter temperatures were 305K to 300K from northern to southern Florida at 2100 GMT. In addition, northern Florida was clear to about 28N while south of this area there were reports of scattered cirrus and developing cumuliform clouds. Temperature measurements made with the
densitometer technique gave values of 315±4K in northern Florida and 306±7K in southern Florida. In general, ground surfaces will appear dark gray–black and therefore relatively warm on the daylight infrared imagery. In view of these temperature measurements, any attempt to relate radiative ground temperature directly to shelter temperatures can be misleading. In general, DRIR shows the land to be warmer by 10–15K than the shelter temperature, and this may be explained as the result of solar heating during the day. The effect of scattered cirrus and cumuliform clouds over Florida may be evaluated by examining both the shelter and radiometric temperatures. Northern Florida which is clear had a shelter temperature of 305K and a radiometric temperature of 315K. Southern Florida had a shelter temperature of 300K and one would expect a radiometric temperature of 310K. In actuality, the radiometric temperature measured from the IR photograph over southern Florida was 306K, and this 4K decrease in temperature may be explained by the presence of scattered cirrus and cumuliform clouds that were being reported in southern Florida.

In a previous study on jet stream cirrus, the ambient temperature of the cirrus, $T_e$, and the cirrus height estimate could be improved by categorizing the radiation measurements, $T_{RB}$, and using an effective cirrus emission-transmission factor $e_e^*$ (Valovcin, 1968). Table 2 shows the cirrus classification based on the observed values of $T_{RB}$ and the $e_e^*$ values assigned for each category.

The radiometric temperatures, $T_{RB}$, measured on the

<table>
<thead>
<tr>
<th>Category</th>
<th>Thin</th>
<th>Average</th>
<th>Thick</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{RB}$ (K)</td>
<td>≥260</td>
<td>252±8</td>
<td>&lt;244</td>
</tr>
<tr>
<td>$e_e^*$</td>
<td>0.20±0.15</td>
<td>0.50±0.15</td>
<td>0.80±0.20</td>
</tr>
</tbody>
</table>
DRIR photograph over Alma were classified as radiometrically thin, average or thick according to Table 2. Using the Miami radiosonde and the categorized $T_{BB}$ measurements, the cirrus cloud tops would have temperatures representative of those found at the following levels: thick cirrus at 27,000-43,000 ft (8-13 km); average cirrus at 20,000-27,000 ft (6-8 km); and thin cirrus 14,000-20,000 ft (4-6 km).

Following the procedure outlined in the previous study, the adjusted or corrected ambient temperature of the cirrus, $T_e$, may be computed from

$$T_e = \frac{(3+\epsilon_*)}{4} T_{BB}.$$  \hspace{1cm} (2)

The $T_{BB}$ values measured from the DRIR photograph over Alma were categorized, and using $\epsilon_*$ values assigned for each category, $T_e$ was computed according to Eq. (2). The result of categorizing the $T_{BB}$ values and assigning an $\epsilon_*$ value is shown in Fig. 9. The frequency distribution as a function of actual $T_{BB}$ and $T_e$ values for 1 inch (2.54 cm) squares on the DRIR photograph over Alma indicates that the cirrus shield is more extensive than indicated by the temperatures derived from the IR photograph and the top of the cirrus level should be adjusted upward. Using the actual $T_{BB}$ values, the top of the cirrus level would be found at 14,000-43,000 ft (4-13 km). If these $T_{BB}$ values were corrected, according to Eq. (2), the top of the cirrus level would be found at 39,000-46,000 ft (12-14 km).

Thus, height adjustments of 25,000-32,000 ft (8-10 km) should be added to the original estimate of the top of the cirrus level.

b. Air mass thunderstorms

Air mass thunderstorms can be seen in Figs. 3 and 5 located between 80-85W and 35-40N. In general, the appearance of actively growing thunderstorms are very similar in the IR and video presentation. Densitometer readings were made on the DRIR photograph in sectors E, F and G between lines 76-85. The lightest spot was found in sector F, lines 76-80. Converting the density readings to a temperature value gave 232K. Relating this temperature value to the radiosonde observations in this area gave a cloud top at 300 mb or 30,000 ft (9 km).

c. Thin cirrus and/or haze

A warm homogeneous sector is found in sector G, lines 76-80, in the vicinity of the thunderstorm area. The infrared temperature values gave a mean of 306K with a standard deviation of 7K. Although it is difficult to differentiate by eye, temperatures as low as 290K, which is representative of the 850-mb level, were measured. A look at the video presentation (Fig. 5) shows a grayish appearing mass along the coastal area in the vicinity of 35N. Synoptic surface reports in the area indicated that both thin cirrus and/or haze were being observed by stations in that area and shelter tempera-
tures were around 300K. In the IR photograph, this area appears clear although the radiometric temperature measurements taken from the photograph are slightly colder than expected in a clear area. A comparison of the video and IR presentation, along with the inherent information obtained from both photographs, may give a clue to the presence of thin cirrus and/or haze. The IR photograph alone does not show these conditions directly.

d. Coastal area

In order to study the land, sea-fog contrast with this technique, reflective-density measurements were made in sectors H and I between lines 70–95. In this area of the DRIR photograph, the spatial resolution of the TTOS radiometer decreases from 5 n mi (9 km) in sector H to 15 n mi (28 km) in sector I. Fog conditions were being reported along the coast and by ships from 37 to 45N. This fog condition may be seen at the edge of Fig. 5, north of 37N. A better view of the clouds along the coast and farther east may be seen in Fig. 10. Although this picture was taken 5 hr earlier, the APT from ESSA-8 shows the extent of the cloudy condition over the ocean. Along with the fog conditions over the ocean, many of the land stations in the northeast from northern Maine to Pennsylvania were reporting thin cirrus. On the DRIR photograph (Fig. 3) the thin cirrus appears slightly gray and barely visible in sector H between lines 86–95. The range of temperatures as deduced from the density measurements were 289–315K. The actual shelter temperatures reported in this area were between 297–303K. On the assumption that the temperature of land surfaces measured from the DRIR image are generally 10–15K warmer than the shelter temperatures, then any temperature less than 307K (297K+10K) on the DRIR photograph may be suspect of cirrus contamination.

An attempt was made to discriminate between sea-surface temperatures, stratus and fog conditions. Unfortunately, the sea-surface temperatures north of 35N were reported at 280–296K and the top of the fog or low clouds were found at a level where the temperatures were being reported at 285–290K. Since the sea-surface and the low cloud top temperatures were within 5–10K of each other, it is almost impossible to distinguish the two above line 75 in sectors H and I. A grayish contrast is evident along the coast north of 35N and can be seen in Fig. 3. This type of thermal contrast as indicated by shade of gray along the coast is also indicative of the northern and/or western boundary of the Gulf Stream. Consequently, the thermal contrast on the IR photograph could be either the edge of the fog bank or the Gulf Stream.

In sector H lines 71–75, the sea-surface temperatures were reported at 296–300K. This sector was generally clear and the mean temperature as deduced from the reflective density measurements was 299K with a standard deviation of ±6K.

e. Great Lakes area

At 2100 GMT, a stationary front was located in the Great Lakes area. Surface synoptic reports showed that thin Ac, Ci and Cs was widespread from Michigan to the New England states. Little or no activity was being reported along this front east of 85W.

Reflective-density measurements were made in sectors E–H from lines 95–115. The coldest spot, 239K, was found at the border of sectors G and H, lines 100–104. Relating this temperature to the radiosonde sounding at Sault Ste. Marie (72734), indicates that the cloud tops in this area were in the vicinity of the 325-mb level or 29,000 ft (9 km). Another cold spot is found in sector F, lines 105–109, just north of 45N in the immediate vicinity of Sault Ste. Marie. The reflective density converts to a temperature of 246K. Again, relating this temperature to the radiosonde sounding for Sault Ste. Marie indicates that the cloud tops in this area were located near the 375-mb level or 26,000 ft (8 km). As was previously mentioned, no activity was being reported along the stationary front. Four hours after the IR data were observed, rain showers and thunderstorms were reported in the area where the lowest density values or coldest temperatures were measured.

Reflective-density measurements made at Lake Michigan gave a temperature of 294K. In contrast, the land areas around the lake had a radiometric temperature of 312K. Even with thin Ac, Ci and Cs being reported, this is still about 8K above the shelter temperatures that were found in the immediate area. This is another example of the difficulty of relating radiometric and shelter temperatures in areas that appear clear in the satellite imagery of this resolution.
5. Summary and conclusions

The Scanning Radiometer System aboard the new meteorological satellites transmits infrared radiation data directly to APT stations for local use. These data transmissions may be displayed on a photorecorder receiver as a strip of IR imagery. A calibrated 7-gray-step wedge can be generated on the IR picture. By controlled processing of the direct readout data and by taking reflective-density measurements with a densitometer on the picture, quantitative temperature values may be obtained. These quantitative temperature values may be obtained in real-time for immediate operational use.

Although the IR display is quite similar to the visual display, each one has an entirely different characteristic. The IR display is a function of radiant energy while the visual is a function of reflective energy. The infrared display can generally distinguish between low (dark gray), middle (light gray) and high clouds (white). These changes in the grayish appearance are due to the amount of radiant energy that is transmitted to the satellite radiometer sensor. Regions on the photograph show up dark or dark gray where it is relatively warm and white where it is relatively cold.

Clear land appears black in the daytime view at this time of the year and radiates at a temperature 10-15K warmer than shelter temperatures. The brightest areas delineate the active weather which in turn suggests cumulonimbus activity. This is true within a tropical storm, frontal zones, and air mass thunderstorm complexes.

Semi-transparent clouds such as thin cirrus or alto-cumulus are difficult to detect because of the warmer thermal emission from below. Also, clouds near the surface such as fog are not discernible in the infrared display. A comparison must be made between the visual and IR display in order to distinguish fog conditions.

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