

TIROS AND RADAR OBSERVATIONS OF A THUNDERSTORM COMPLEX OVER FLORIDA*

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ABSTRACT

An east-west line of thunderstorms passed southward into the Gulf of Mexico and the Florida peninsula. A large complex with an extensive anvil developed over the Gulf. The cold air outflow to the south of this storm was visible to TIROS as a thin line of cumulus clouds. When the line passed over the northern Florida peninsula, very active convection cells developed which subsequently penetrated to heights near 50,000 ft. No new cells developed over the Atlantic so that the line ended near the eastern coast of Florida. North of the line on the Florida east coast, the west-northwest gradient wind, the sea breeze effect, and the thunderstorm outflow caused renewed convection which developed a secondary line. South of the primary line the sea breeze prevailed, causing a line of cumulus clouds quite apparent on the TIROS photographs.

TIROS Channel 2 radiometer readings indicated that the storm over the Gulf had the highest cloud tops whereas radar measurements showed the towers over Florida were considerably higher than those over the Gulf. The apparent discrepancy is resolved by considering the field of view of the radiometer.

1. INTRODUCTION

In the study of mesoscale phenomena, satellite observations may be used to considerable advantage. The photographs provide a view of the entire system not generally available in any other way. The infrared measurements may be used to determine heights of cloud tops; the reflected solar radiation measurements give an indication of the reflectivity of the cloud systems. However, in interpreting these observations care must be taken because of the different scale from that of observations taken near the surface. Blackmer [2] has pointed out the difficulty of determining the extent or stage of development of precipitation within clouds from satellite photographs. In the satellite radiation measurements, the 5° aperture of the radiometer integrates over a relatively large area so that cloud top heights may differ appreciably from those measured in other ways.

In this paper, satellite, radar, and surface observations are used to provide a more complete analysis of a line of thunderstorms extending from the Gulf of Mexico into the Florida peninsula on August 11, 1963. The information available from the different scales of observation is compared. In addition interpretations of various physical features of the thunderstorm complex are made.

2. TIROS PHOTOGRAPHS

A TIROS VII photograph from orbital pass 788 at 1714 GMT, August 11, 1963, taken almost vertically, shows a large thunderstorm complex extending across the Florida

peninsula (fig. 1). The eastern portion consists of an L-shaped pattern extending from Lake Okeechobee north-eastward to the eastern Florida coast and then bending westward to mid-Florida. The sharp boundaries, the large cellular structure, and the relative brightness of this cloud system suggest a storm in an active growing stage. A larger cloud mass extending from the mid-Gulf across the western coast of Florida appears to have fuzzy boundaries and is probably an anvil canopy indicative of a cluster of mature storms past their prime in growth. Some cirrus blowoff is apparent over the northeastern Gulf extending to the western Florida coast. However, the presence of active cells over the Gulf is indicated by the rounded appearance of cloud masses which may be indicative of cumulus clouds extending through the cirrus canopy or visible through thin cirrus. Another cluster of cells in an earlier stage of development lies across the western Florida coast to the south of the main cloud mass. An isolated group of thunderstorms may be seen over Key West.

The eastern Florida coast south of the storm area is made more visible by some coastal cumulus clouds, probably congestus. These clouds are evidently associated with the sea breeze which, during days of light synoptic winds, tends to cause cumulus clouds to ring the peninsula as an almost stationary semipermanent cloud "front" (Cunningham [5]).

To the north of the storm some coastal cumulus clouds are only faintly visible. Cumuli are also visible inland both north and south of the storm. Along western Florida there is no coastal line of cumuli.

An additional interesting feature in figure 1 is a long, wavy, thin line of clouds over the Gulf about 10 mi. to

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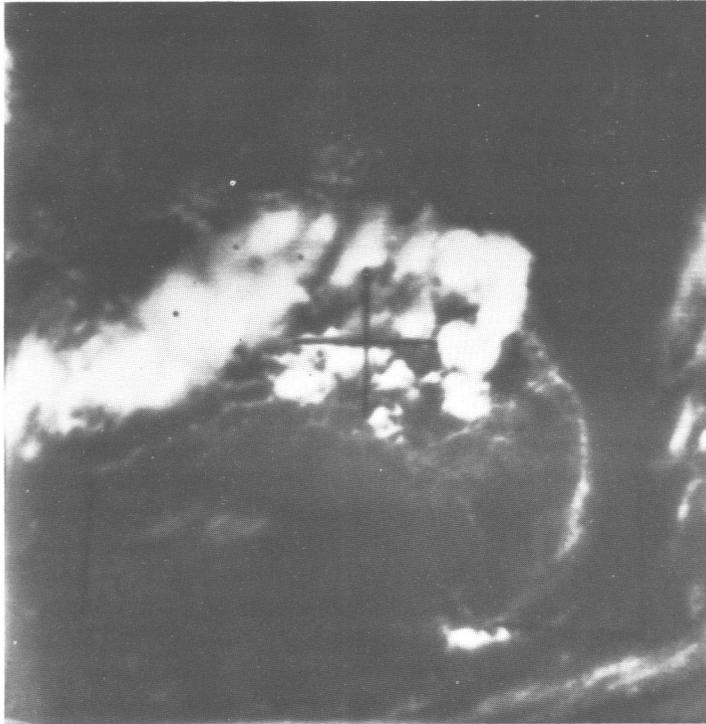


FIGURE 1.—TIROS VII photograph, orbital pass 788, 1214 EST, August 11, 1963. Note anvil and thin line over Gulf, new cells over Florida, and east coastal cumulus clouds.

the south of the western portion of the thunderstorm complex. The line is parallel to the southern boundary of the storm and the waves appear to follow the indentations of the cumulonimbus. The thin line may be small cumulus-type activity occurring along the cold air outflow from the storm. Other cumuli north and south of the storm are not as well organized. It appears possible that the thin line of cumulus clouds is similar to thin lines (without clouds) observed by radar in regions where they could reasonably be interpreted as the cold air outflow from thunderstorms (Brown [3]). In this case no radar echoes of a thin line were observed as will be discussed below.

3. SYNOPTIC SITUATION

The thunderstorm activity occurred in advance of an east-west cold front extending across southern Georgia. At 500 mb. a broad trough extended southward along the Atlantic coast into northern Florida. However, as was pointed out by Byers and Rodebush [4], thunderstorms occur in northern Florida on about two-thirds of the days in July and August, and are probably associated with the almost daily release of convective instability resulting from the convergent sea breeze effects from the Atlantic and Gulf.

Surface winds of moderate intensity were from the west-northwest and were observed at 1800 GMT on the northern half of the Florida east coast (Daytona Beach and Jacksonville) where normally a sea breeze prevails.

However, much farther south a coastal sea breeze prevailed, as shown by observations at West Palm Beach and Miami. The sea breeze in this area was probably responsible for the line of coastal cumuli so prominent in figure 1.

Erickson [6] found good agreement between cirrus flow from cumulonimbus clouds observed by TIROS IV over Florida and the wind shear vector between 700 and 200 mb. Winds at 700 mb. over central northern Florida (Tampa and Jacksonville) were west-northwesterly at about 8 m. sec.⁻¹ At 200 mb. winds were from the west or west-southwest at about the same speed. There was thus a wind shear vector of 5 to 8 m. sec.⁻¹ from the south or south-southwest between 700 and 200 mb. This direction is consistent with the interpretation of cirrus blowoff on the northeastern portion of the Gulf storm in figure 1.

4. RADAR PPI PHOTOGRAPHS

PPI photographs of the storm were taken continuously on August 11, 1963 with WSR-57 10-cm. radars located at Daytona Beach, Tampa, and Apalachicola, Fla. A composite photograph from Apalachicola and Daytona Beach radars¹ at 1500 GMT (fig. 2) shows a line of thunderstorms extending across the Gulf and ending at the eastern Florida coast where there is a northward extension of new cells. At 1714 GMT or at about the same time as figure 1, the composite photograph (fig. 3) shows the line to have moved southward with the eastern end over Lake Okeechobee. From this area new cells extend northeastward to the coast and then westward in a line to form the L-shaped pattern. Over the Gulf the rain area is more continuous, and is evidently due to the amalgamation of a group of mature cells accompanied by the development of the cirrus canopy visible in figure 1.

A persistent feature of the thunderstorm complex is its inability to extend any appreciable distance into the Atlantic. In order to study this phenomenon, the behavior of individual small cells observable on the Daytona Beach radar was investigated. The lifetimes of cells ranged from about ½ hr. to 2½ hr. depending on their size. There did not seem to be any appreciable difference in lifetimes between those cells which had a trajectory completely over land and those with a partial trajectory over the sea. It was concluded that the sea had no appreciable dissipating effect on existing cells. However, new cells were continually forming over the land but none formed over the sea. Hence, the inability of the line to extend appreciably into the Atlantic was due to the fact that the sea somehow inhibited the formation of new cells. When the line passed from the mainland to the Gulf of Mexico during the early morning hours 0800-0900 EST, new cell formation was not inhibited, evidently because the sea breeze effect was nonexistent at this time.

No trace of the thin line is evident on any of the

¹ The Tampa radar photographs gave no additional information.

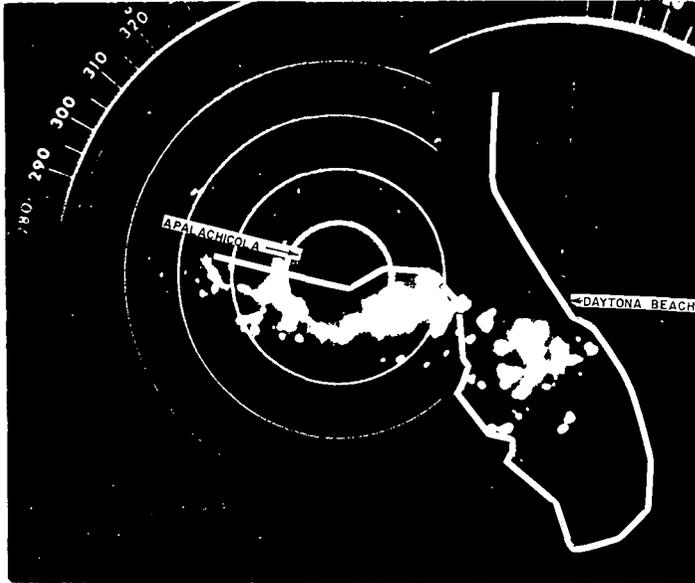


FIGURE 2.—Composite radar photograph from Apalachicola and Daytona Beach radars, 1000 EST, August 11, 1963.

WSR-57 radar PPI photographs. The closest station, Tampa, is about 30 mi. to the east of the end of the thin line. However, the obliqueness of the angle may not be suitable for detection since most thin lines observed by radar have been from a nearly perpendicular line of sight. The distance of the Apalachicola and Daytona radars from the line is too great for detection.

5. COMPARISON OF RADAR AND TIROS PHOTOGRAPHS

The TIROS photograph (fig. 1) gives the appearance of a line of thunderstorms across Florida although one would probably place the primary line through more solid structure to the north. The radar photograph (fig. 3) clearly indicates the primary line and suggests the possible formation of a second line through Daytona. Of course, continuity of the radar photographs over a period of a few hours is the best indication of changes in line structure.

In a study of TIROS I and radar photographs of thunderstorms Blackmer [2] found that only a small portion of clouds contained radar echoes; in addition, he found it "impossible to state exactly the area within a particular cloud where precipitation was occurring." In the present case, one might infer from the appearance of the clouds in figure 1 that rain was occurring beneath the L-shaped storm and the new cells over western Florida. Estimating the occurrence of rain beneath the anvil would be more difficult but the relative brightness and rounded appearance of portions of this cloud from the Florida west coast into the Gulf also suggest rain, whereas the cirrus blowoff over the northeastern Gulf does not suggest rain. Hence, in the present case there appears

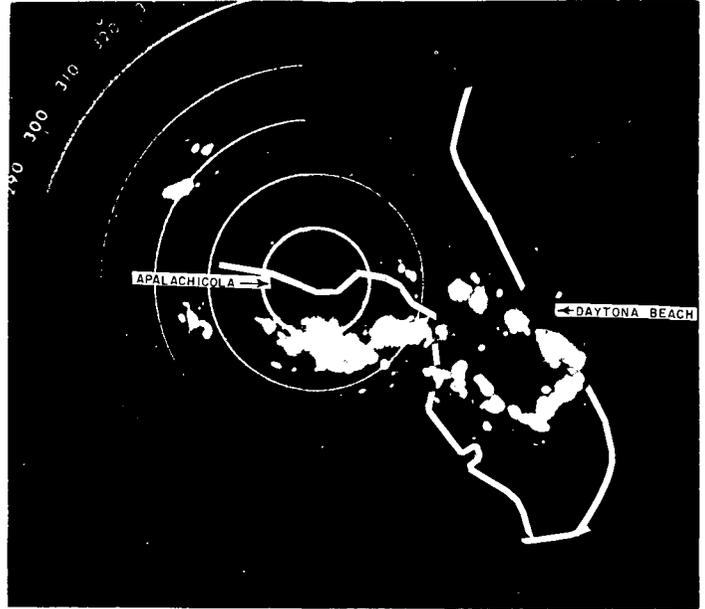


FIGURE 3.—Composite radar photograph from Apalachicola and Daytona Beach radars, at 1214 EST, August 11, 1963.

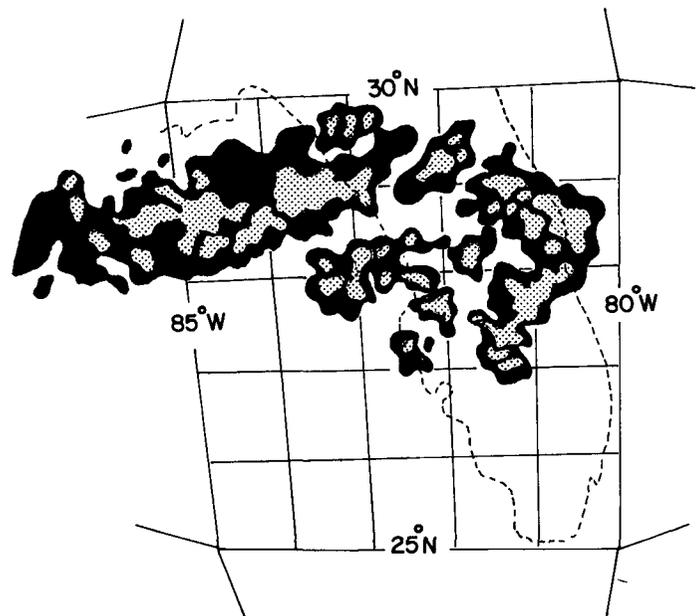


FIGURE 4.—Radar echoes of figure 3 superimposed on cloud system of figure 1.

to be reasonable agreement between expected rain areas as determined from the appearance and relative brightness of the clouds on the TIROS photograph and areas of rain as determined from radar observations. It is also of interest to note that in the present study a relatively large percentage of the cloud visible in the TIROS picture did contain radar echoes in contrast to Blackmer's findings. This is shown in figure 4 in which the radar echoes of figure 3 are superimposed on the cloud system in the TIROS photograph (fig. 1).

6. TIROS CHANNEL 2 PATTERN

Figure 5 shows the Channel 2 ($8-13\mu$) radiation pattern of equivalent blackbody temperature as observed by TIROS VII on pass 788 during the period 1712-1716 GMT or at about the same time as figures 1 and 3.

During the period of observation the radiometer was in a closed mode of operation which often causes serious errors in the location of the viewed area as given on the final meteorological radiation (FMR) tape (Allison and Warnecke [1]). In this case the values plotted directly from the FMR tape showed that considerable discrepancy existed between the location of the cloud areas as determined from the radiation pattern, and that determined from the photographs. Correction of these errors was attempted from the data on the FMR tape by rotating swaths in the clear areas in such a way that temperature discontinuities between land and ocean along the Atlantic coast occurred approximately at the proper location. For swaths in the cloudy areas of the storm, correction was estimated by extrapolation. The resultant diagram (fig. 5) shows a far better fit with the photograph (fig. 1) than that originally prepared from the FMR tape.

In figure 5 the coldest area of 219°K . equivalent temperature is in the storm just west of the Florida Gulf coast. This minimum corresponds to a height of about 32,000 ft. as determined from the 1200 GMT Apalachicola sounding. A secondary minimum of 230°K . is over the more active storm over the Florida east coast.

Heights of echo tops as measured by radar at the different stations during the period 1600-1800 GMT are as follows:

Apalachicola—found maximum heights of 37,000 to 43,000 ft. and average heights near 30,000 ft. for the Gulf storm.

Tampa—observed a maximum of 41,000 ft. and an average of 30,000 ft. for the Gulf storm. Over the central Florida region, 57 mi. east-southeast of the radar, a maximum of 46,000 ft. was observed.

Daytona Beach—observed a maximum top of 49,000 ft. over the eastern Florida coast.

Hence, the radar observations showed that the maximum cloud top heights were over the Florida Atlantic coast, while Channel 2 observations indicated a lower equivalent temperature, presuming higher tops, over the Gulf storm. The reason for this apparent discrepancy is to be found in the field of view of the radiometer. The aperture of the radiometer is 5° . With the satellite height at 628 km. above the earth, the field of view straight down is a circular area 55 km. in diameter. For a nadir angle of 40° , which is more appropriate to the present case, the field of view is an elliptically shaped area about three times the circular area. The towering cumuli over Florida cover only a small portion of this relatively large area so that the cloud height integrated over the entire field of view, is considerably smaller. On the other hand, the more extensive anvil over the Gulf covers practically

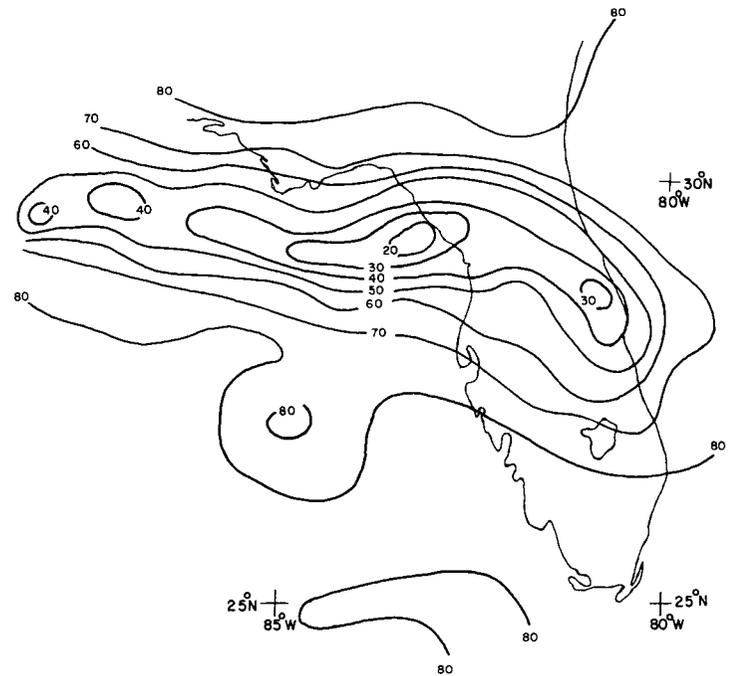


FIGURE 5.—Channel 2 radiation pattern from TIROS VII, 1212-1216 EST, August 11, 1963. Units are in $^\circ\text{K}$. ($80 = 280^\circ\text{K}$).

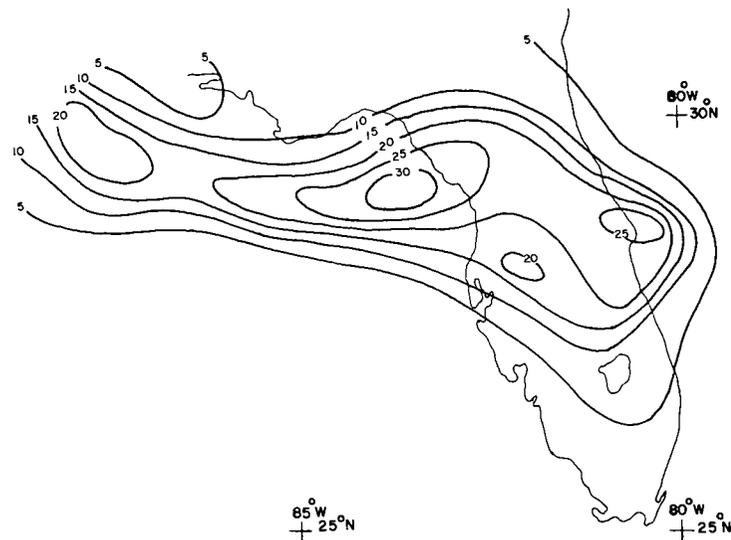


FIGURE 6.—Channel 3 albedo values (percent) from TIROS VII, 1212-1216 EST, August 11, 1963.

the entire field of view so that the integrated cloud height is greater than that over Florida.

7. ALBEDO

Figure 6 shows the albedo pattern as determined from Channel 3 (0.2 to 6μ), pass 788 of TIROS VII during the period 1712-1716 GMT. The values were converted to albedo by the formula:

$$A = \frac{I}{S \cos Z}$$

where I is the energy measured by the sensor; S is the effective solar constant or the amount of energy which would be measured by the sensor from an isotropic perfectly reflecting surface illuminated by the sun without intervening attenuation (as provided by NASA, the value of S for Channel 3 is given by 484 W./m.²); Z is the zenith angle of the sun. Absolute values are too small because of calibration errors and sensor deterioration so that only relative values are useful.

The pattern is similar to that given by Channel 2 and shows a maximum albedo of 31 percent over the Gulf coast and about 26 percent over the Florida Atlantic coast. A strong gradient of albedo exists on the south side of the thunderstorm over the Gulf and to the east of the storm over the Atlantic coast. The albedo is greater over the anvils of the mature storm over the Gulf than over the growing thunderstorm cells to the east, despite the fact that the latter appear brighter on the photographs. Again the reason is that the bright growing cells cover only a small portion of the field of view of the radiometer whereas the more extensive anvil over the Gulf gives a larger average reflectance.

Over the clear areas of the Gulf of Mexico indicated albedo values are very low, in the vicinity of 1 percent. It is probable that the absolute values are 5–10 percent over these areas. Likewise, the albedo from the anvil is probably 60–80 percent instead of the indicated 30 percent (cf. Wexler [8]).

8. CONCLUSIONS

This study of the August 11, 1963 thunderstorm complex over Florida illustrates the different types of information on the mesoscale available from satellite and radar data. The satellite photograph reveals the entire cloud system within which is the precipitation detectable by the radar. In this case a relatively high percentage of the visible cloud contained radar echoes. The satellite radiometer can determine heights of cloud tops, integrated over a relatively large area, while the radar can determine the cloud top heights of individual towers.

Interesting features observed by the satellite include (1) a thin line of cumulus clouds over the Gulf which is interpreted as the cold air outflow of the thunderstorm complex to the north, and (2) a coastal band of cumulus clouds in the region of sea breeze influence on the Florida east coast south of the storm.

The line of thunderstorms had developed over the mainland and pushed southward over the Gulf during the early morning hours. Continued development occurred

over the Gulf and by mid-morning the line extended over the Florida peninsula. The line failed to penetrate into the Atlantic, evidently because new cell development was inhibited over the sea.

Thunderstorm lines of this nature propagate by the development of new cells just ahead of the existing line. This problem has been considered by Newton and Fankhauser [7] who showed that for a wind configuration which veers with height new cell development tends to occur on the right flank of the existing storm. On August 11, 1963, the winds over the Florida peninsula veered with height up to about 400 mb.

On the Florida east coast new cell development occurred to the north of the existing line thereby causing the L-shaped patterns and a secondary line some 20 mi. back of the primary line. It appears probable that the sea breeze effect and the gradient wind configuration were factors in this development. To the north of the line where the westerly gradient wind was relatively strong the sea breeze effect may have caused strong convergence inland from the coast and divergence off shore. South of the line the westerly gradient wind was relatively light and the sea breeze prevailed on shore causing the coastal cumuli. Further investigation appears desirable on the influence of the sea breeze effect on the propagation of line storms.

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