Mesoscale Convective Complexes [1]

Robert A. Maddox

NOAA, Environmental Research Laboratories, Office of Weather Research and Modification, Boulder, Colo. 80303

and

Department of Atmospheric Science, Colorado State University Ft. Collins, Colo. 80523

Abstract

A particular class of weather system, the Mesoscale Convective Complex (MCC), is identified, defined, and contrasted with other types of convective weather systems. It is found that MCC systems frequently occur over the central United States, grow to tremendous areal extent, and often persist for periods exceeding 12 h. In addition to widespread beneficial rains, a wide variety of severe convective weather phenomena attends these systems.

The development and evolution of MCC systems is not explicitly predicted by operational numerical models even though they are shown to be organized in a distinctly non-random mode on scales that cannot be considered subgrid. The MCC is a convectively driven weather system whose physics are not yet understood, much less incorporated into operational parameterization schemes. A preliminary conceptual model of the life cycle of these systems is presented using enhanced, infrared satellite imagery in conjunction with conventional surface and radar data. The outlook for further study and ultimately for the prediction of MCC systems is encouraging since their time and space scales—coupled with their frequent occurrence over the central United States—make them highly amenable to detailed investigation.

1. Introduction

Each year during late spring the primary forecast problem for much of the continental United States gradually shifts from prediction of traveling cyclones, with their broad shields of stratiform cloud and stable (nonconvective) precipitation, to prediction of smaller-scale weather systems characterized by deep convective clouds. Operational prediction of convective precipitation has traditionally been perceived as a sub-grid scale problem that can best be handled using statistical techniques in combination with numerical model output [see, for example, papers by Glahn and Lowry (1972); Klein and Glahn (1974); and Bermowitz and Zurndorfer (1979)]. However, satellite images during warm season months (March–September) show a high frequency of organized, meso-α scale[2], convective weather systems over the central United States. It is believed that these systems, which have been named Mesoscale Convective Complexes (MCCs), are a class of convective weather system heretofore unrecognized in the literature. Numerous examples are shown and a definition and hypothesized life cycle (based upon physical characteristics and associated circulations) for MCC weather systems are presented in the following sections.

2. Mesoscale Convective Complexes

a. Definition

A definition that was used for the midlatitude MCCs studied is presented in Table 1. This definition is based upon physical characteristics that are observable in enhanced, infrared (IR) satellite imagery. Two MCCs, typical of those that often occur over the central United States, are captured in the satellite

[1] A shortened version of this paper appeared in the Preprints of the AMS Eighth Conference on Weather Forecasting and Analysis.

[2] Meso-α scale is defined here as length of scales of 250–2500 km with durations $\geq$ 6 h. See Orlanski (1975) for more detailed definitions of mesoscale terminology.

TABLE 1. Mesoscale Convective Complex (MCC) (based upon analyses of enhanced IR satellite imagery).

Physical characteristics	
Size:	A—Cloud shield with continuously low IR temperature $\leq -32°C$ must have an area $\geq 100\,000$ km^2 B—Interior cold cloud region with temperature $\leq -52°C$ must have an area $\geq 50\,000$ km^2
Initiate:	Size definitions A and B are first satisfied
Duration:	Size definitions A and B must be met for a period ≥ 6 h
Maximum extent:	Contiguous cold cloud shield (IR temperature $\leq -32°C$) reaches maximum size
Shape:	Eccentricity (minor axis/major axis) ≥ 0.7 at time of maximum extent
Terminate:	Size definitions A and B no longer satisfied

photograph shown in Fig. 1. The size and duration criteria (refer to Table 1) ensure that large (meso-α scale) and persistent convective systems are being considered and that (at least over the central United States) the system's circulations are likely to be sampled (at some point in its life cycle) by several synoptic upper-air soundings. The requirement that a large portion of MCC cloud shields have an IR black-body temperature $T_{BB} \leq -52°C$ (the MB enhancement curve is considered throughout the paper) ensures that the system is active and that precipitation is falling over a significant area [note that Scofield and Oliver's (1977) satellite rainfall estimation scheme begins accumulating precipitation after T_{BB} reaches $-32°C$]. The shape criterion in Table 1 was arbitrarily specified to preclude classification of linear type systems as MCCs.

The scale of an MCC system is huge in comparison to individual thunderstorms. For example, IR depictions of mature, air mass thunderstorms indicate an average cold cloud shield area $\leq -32°C$ of approximately 700 km^2. Reynolds and Vonder Haar (1979) documented 38 multicell thunderstorms over eastern Montana and found that the average total cloud top area was about 1400 km^2. According to the Table 1 definition the cold cloud top area of an MCC is 100 000 km^2 or greater. Thus, the size of an MCC cold cloud shield exceeds that of an individual thunderstorm by *more than two orders of magnitude!*

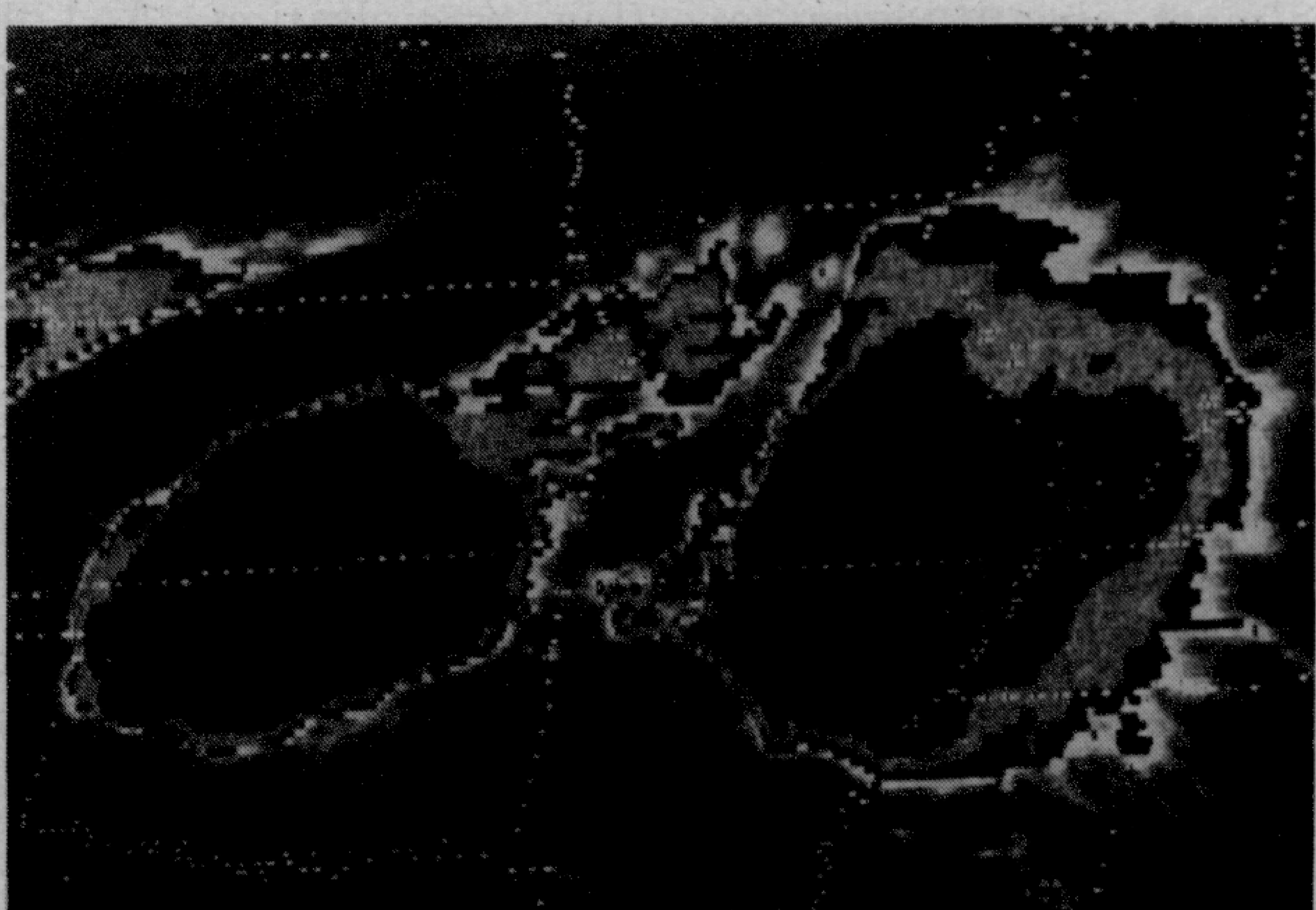


FIG. 1. Enhanced infrared satellite image for 0630 GMT 20 May 1979. Black, gray, and white contours indicate increasingly lower infrared temperatures (refer ahead to Fig. 2).

b. Data used

The studies of mesoscale convective weather systems (and particularly MCCs) reported here utilized sequences of enhanced IR satellite images from Geostationary Operational Environmental Satellites (GOES). This particular type of display of satellite data provides contrasting shades of black, gray, and white to indicate specific ranges of T_{BB}. An example of an enhanced IR satellite image is shown in Fig. 2, along with the T_{BB} range indicated by each shading level. Sequences of enhanced IR images are particularly useful for studying the development and evolution of convective weather systems.

c. Mesoscale convective weather systems

Meso-α scale, convectively driven weather systems can be classified according to their physical charac-

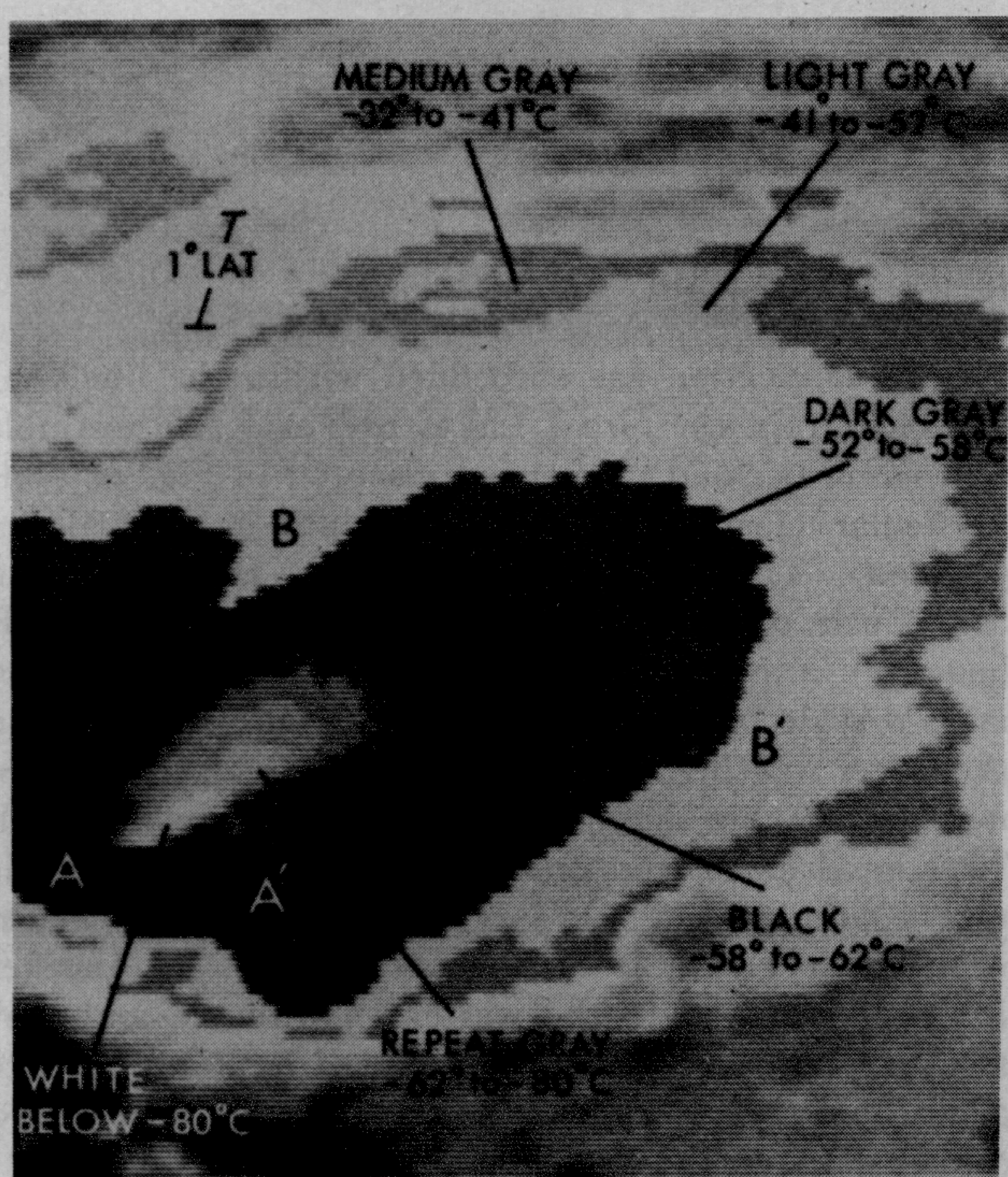


FIG. 2. Infrared image showing the MB enhancement curve temperature ranges that correspond to the various shades of black, gray, and white. (Courtesy of Dr. R. Scofield, NOAA-NESS.)

TABLE 2. Classification of meso-α scale, convectively driven weather systems according to physical characteristics, organization, and location.

Mesoscale convective weather systems

[Meso-α scale.......... 250–2500 km length scales and time scales $\geq$6 h]

- Linear type
  - Tropics: TROPICAL SQUALL
  - Midlatitudes: SQUALL LINE
- Circular type
  - Tropics: CLOUD CLUSTER; TROPICAL STORM/CYCLONE; Mesoscale Convective Complex (MCC)
  - Midlatitudes: Cloud Cluster; Mesoscale Convective Complex (MCC)

teristics, organization, and location of occurrence. Such a classification scheme is presented in Table 2 (note that meso-β scale[3] convective weather systems may be similarly classified). Capital letters indicate types of systems that have been frequently considered in the literature.

Figure 3 presents satellite images that depict several types of meso-α scale convective weather systems. A large MCC system over the central United States is shown in Fig. 3a—note the nearly circular, continuous shield of cold cloud top that characterizes the MCC. A linear-type midlatitude squall line is depicted in Fig. 3b. Regions of colder cloud top and intense convection are embedded within the line that stretches from the Great Lakes to Texas. An example of a tropical cloud cluster is presented in Fig. 3c (this particular cluster had developed into a tropical depression). The cluster (located over the Caribbean Sea south of Cuba) presents (in the enhanced IR imagery) a chaotic cloud shield with a number of meso-β scale convective components embedded within the larger weather system. Hurricane Frederic is shown moving onshore along the Gulf Coast in Fig. 3d. The hurricane's conterminous cold cloud shield is nearly circular, but this intense tropical system is not nearly as large as the MCC shown in Fig. 3a. Another MCC, this one over the western Caribbean and portions of Central America, is pictured in Fig. 3e—once again note the continuous, nearly circular, large shield of cold cloud top.

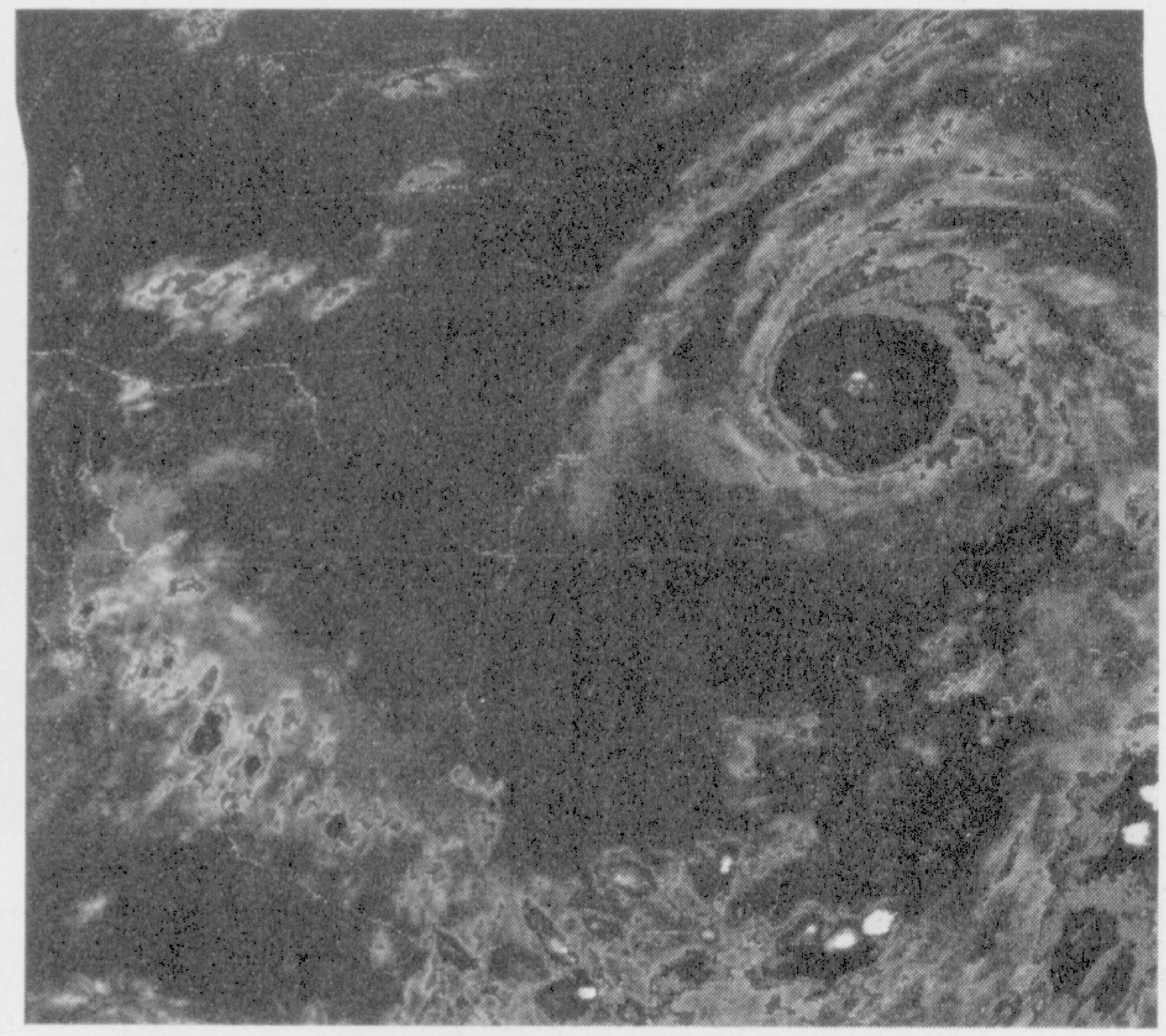
[3] Meso-β scale is defined here as length scales of 25–250 km with durations <6 h.

d. Comparison of MCCs and a midlatitude squall line

The satellite image of Fig. 4a captures an MCC weather system over the central United States at 1130 GMT on 20 May 1979. A nearly concurrent (1135 GMT) radar summary chart (Fig. 4b) shows that the highest echo tops were coincident with the region of coldest cloud top indicated in Fig. 4a. A large region of weaker echo attended the system and the shape of the echo area was similar to that of the cold cloud shield depicted in the satellite image. The thick, cold cirrus shield extended north and east of the echo area, indicating that the IR $T_{BB} \leq -32$°C region does not exactly correspond with active precipitation areas. However, it was noted that surface stations located beneath cloud regions with $T_{BB} \leq -52$°C almost always were reporting precipitation. A 1200 GMT surface analysis (Fig. 4c) shows that the MCC was occurring with a larger-scale environment characterized by weak pressure gradients and light winds and that it was producing a significant area of general precipitation (note the reports of steady light rain).

The enhanced IR image in Fig. 5a shows a large MCC over the Northern Plains at 0900 GMT 12 July 1979 that produced widespread rains of up to an inch or more. The radar summary chart for 0835 GMT (Fig. 5b) indicated that the system's echo configuration was quite similar to that of its cold cloud shield. An analysis of surface conditions at 0900 GMT (Fig. 5c) shows that this MCC was also occurring within a weak large-scale environment and that the important surface features were the outflow boundary, pressure trough, and mesohighs directly associated with the convective system. A time series of surface observations from Huron, S. Dak., is shown in Fig. 5d.

a



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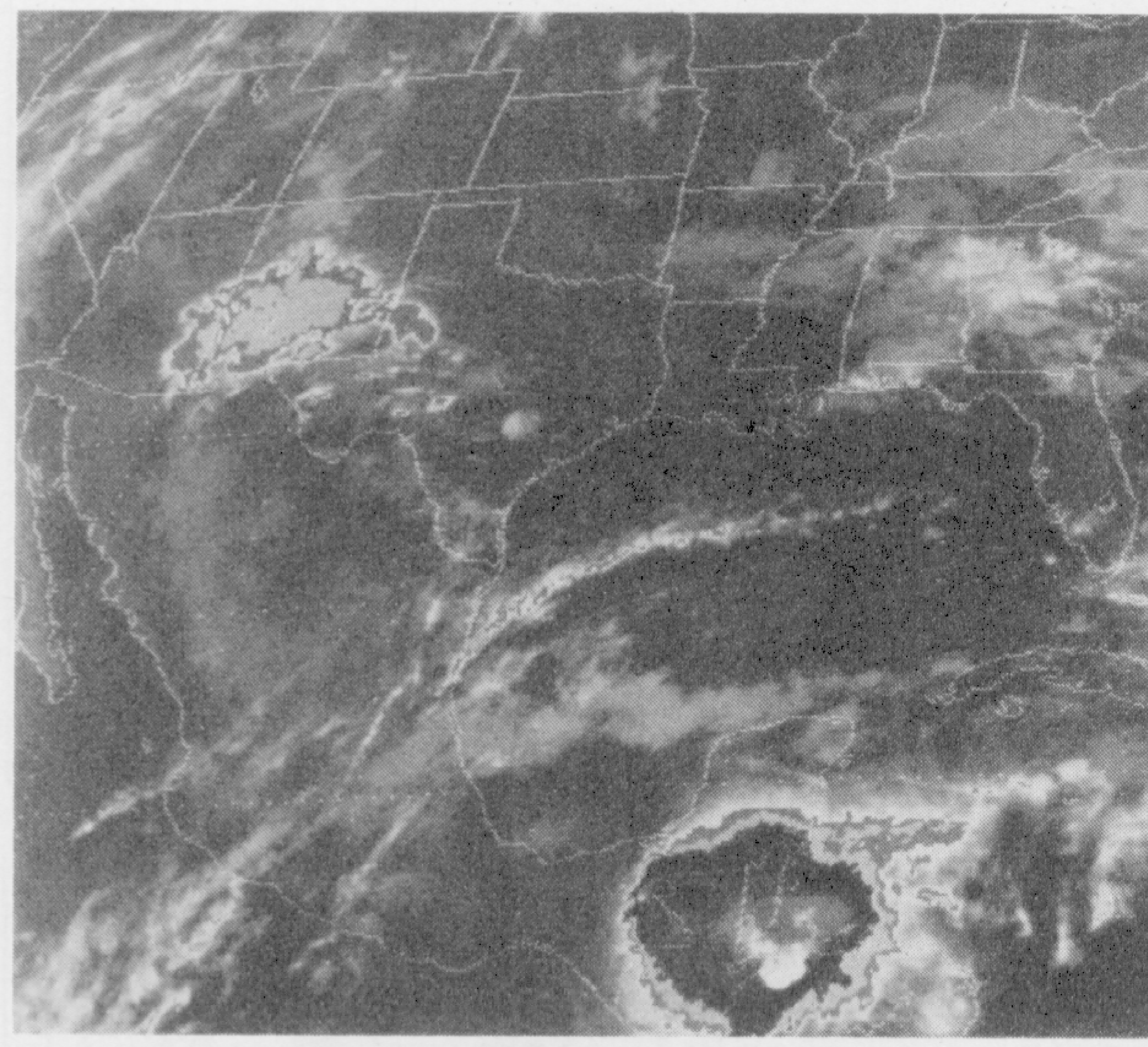

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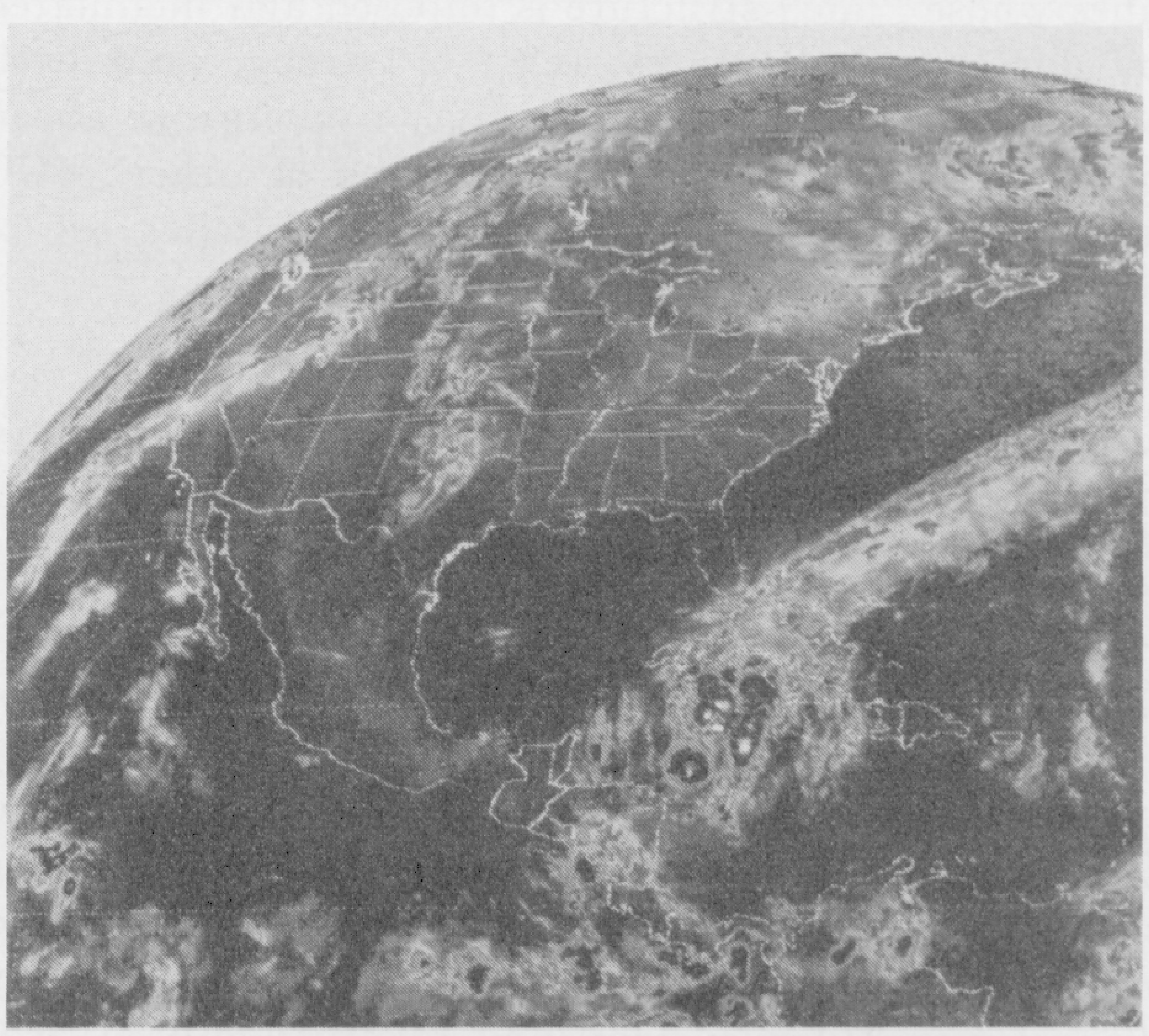


c

FIG. 3. Enhanced infrared satellite image for a) 0200 GMT 4 May 1979, b) 0300 GMT 11 May 1979, c) 0930 GMT 15 October 1979, d) 0232 GMT 13 September 1979, and e) 1102 GMT 3 May 1980.

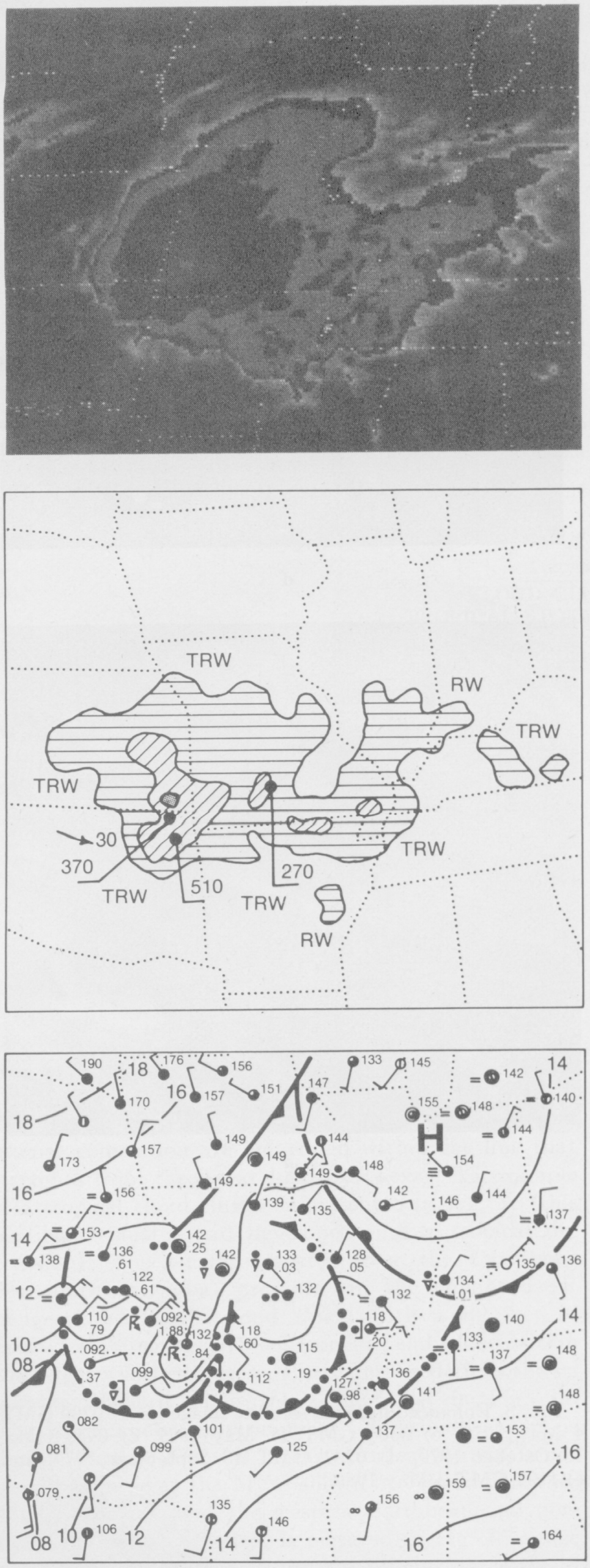


FIG. 4. a) Enhanced infrared satellite image for 1130 GMT 20 May 1979. b) Radar summary chart for 1135 GMT 20 May 1979. c) Surface analysis for 1200 GMT 20 May 1979. Surface features are indicated, along with 2 mb isobars. Winds are in kt (full barb: 10 kt) and squall symbols with frontal barbs indicate positions and movements of cold-air outflow boundaries. Three-hourly precipitation amounts, in inches, are also shown.

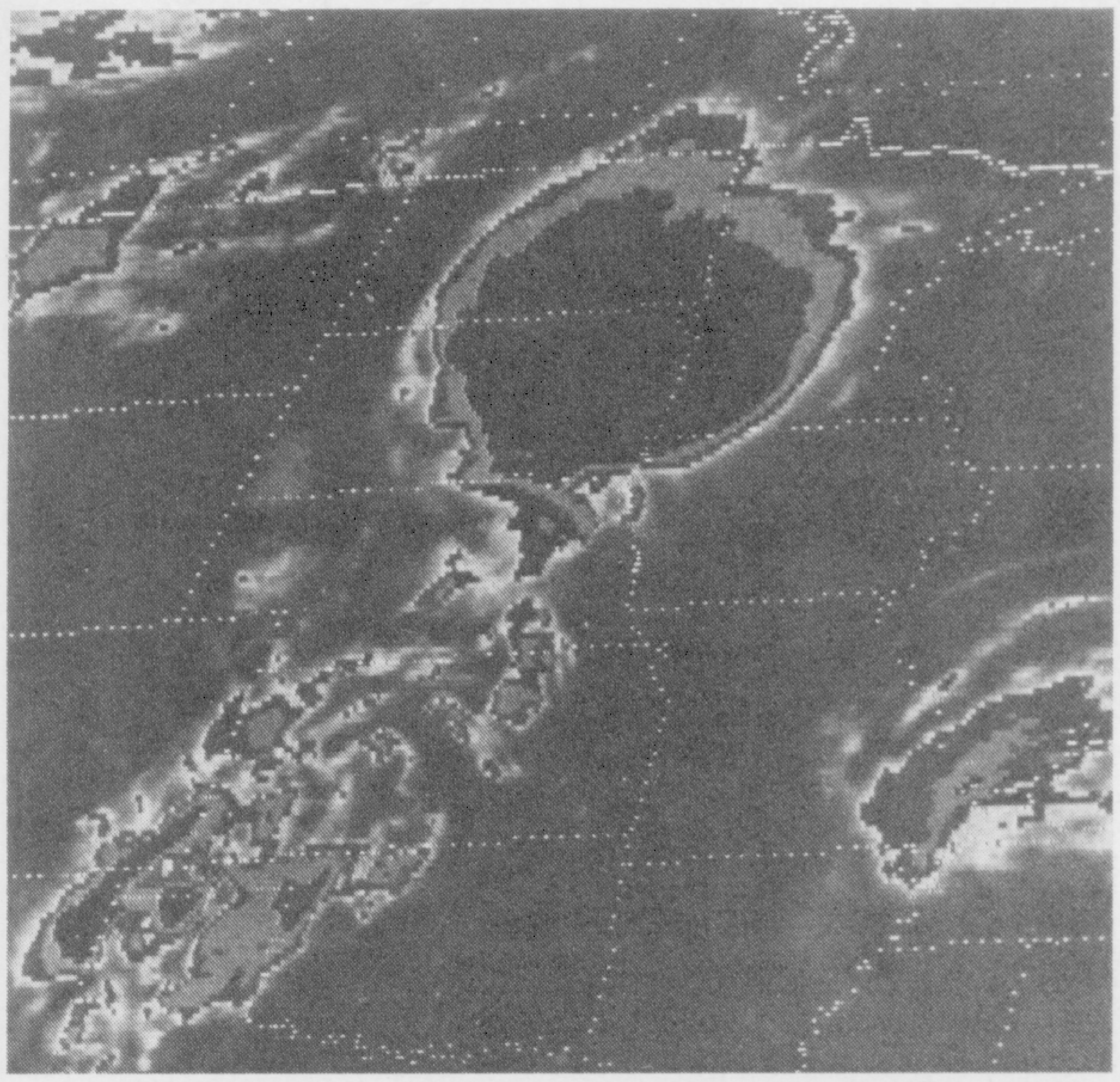
It shows that the temperature and dewpoint temperature dropped rapidly when the leading edge of the system moved across the station. The wind shifted briefly to the southwest and gusted to 32 kt before becoming light and variable for the duration of the event. The pressure rapidly rose and then fell about 2 mb, after which it remained almost steady. An initial burst of heavy rain was followed by more than $4\frac{1}{2}$ h of continuous light rain and thunder.

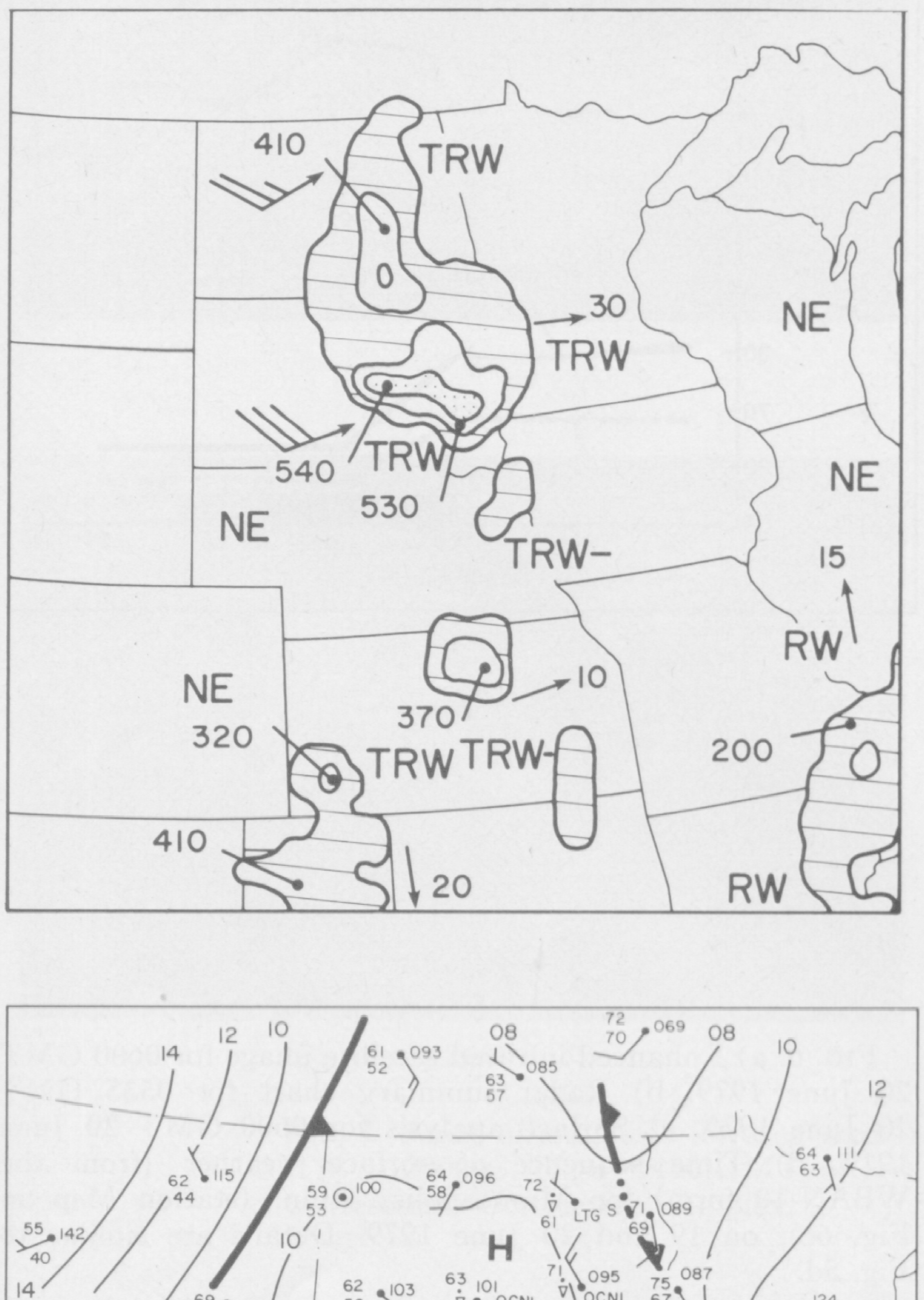
In contrast, the enhanced IR image in Fig. 6a (0600 GMT on 20 June 1979) shows a severe squall line over the north-central United States. This squall line produced tornadoes, large hail, and straight-line winds exceeding 75 kt. A radar summary chart for 0535 GMT (Fig. 6b) illustrates the "linear-type" characteristics of the system (compare with Figs. 4b and 5b). The 0600 GMT surface analysis of Fig. 6c (compare with Figs. 4c and 5c) shows that the squall line was occurring within the warm sector of an intense, large-scale cyclone that was centered over the Dakotas. A time series of surface observations for Minneapolis, Minn., depicts, in Fig. 6d, the sequence of weather events as the squall line moved across the station. As the squall hit, the temperature and dewpoint dropped rapidly while the pressure rose rapidly ($\sim$6 mb). The wind shifted to the west-southwest and gusted to 49 kt. A thunderstorm-associated mesohigh, followed by a wake depression, passed the station as precipitation persisted for about $2\frac{1}{2}$ h and the wind gradually backed to the east-southeast. Although this sequence of events is much different from that produced by the MCC (see Fig. 5d), it is typical of squall lines (see Williams, 1948; Newton, 1950; Brunk, 1953).

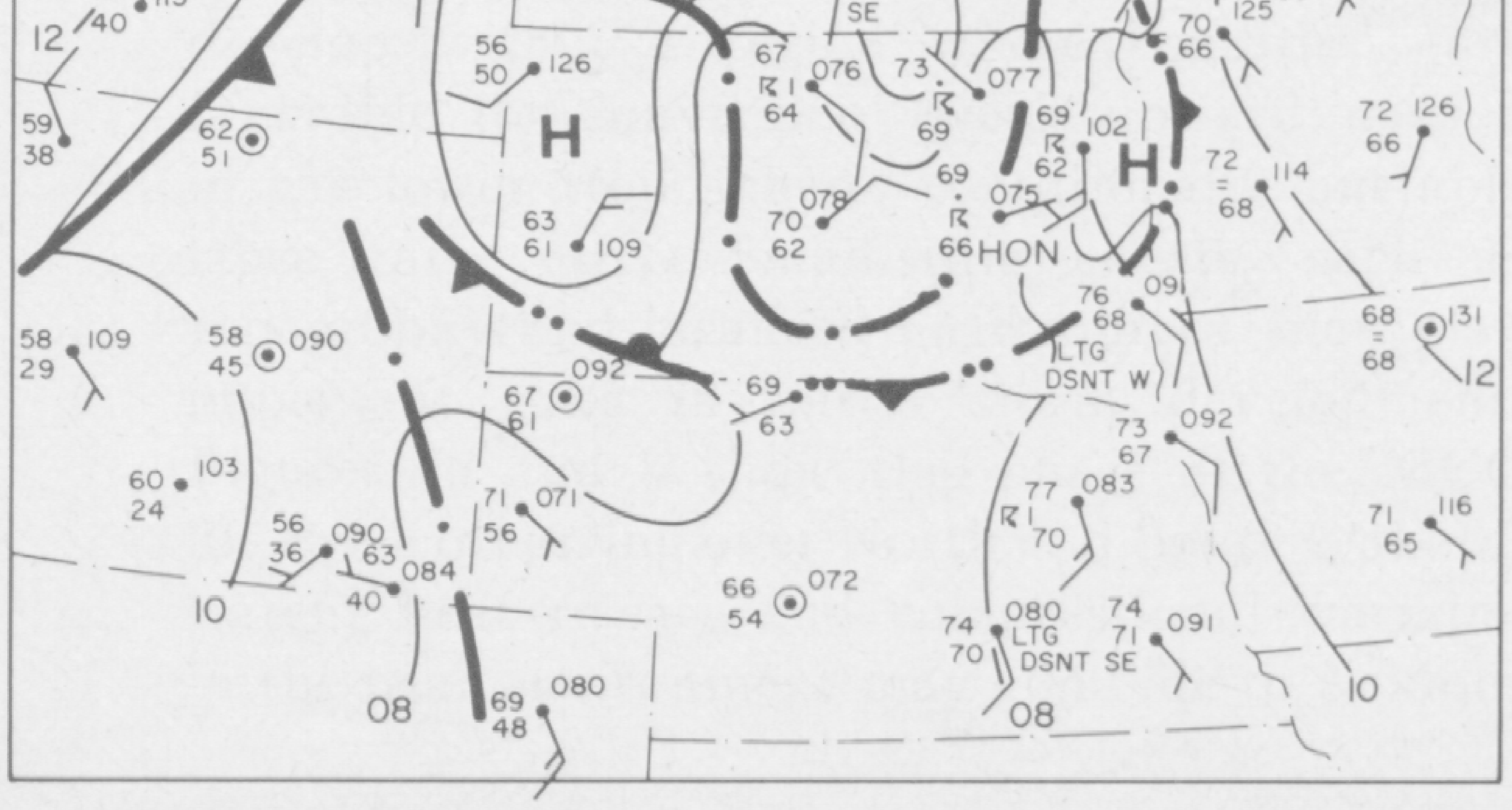
Comparison of the two sequences of surface weather events demonstrates that, in these particular cases, the MCC and the squall line weather systems manifested themselves, both at the surface and in satellite imagery and radar data, as different types of convective weather systems. It is hypothesized that the circular cloud shield of MCCs indicates that convectively driven, mesoscale circulations are predominant. This is in contrast to severe, prefrontal squall lines whose "line" structure is imposed and modulated by larger-scale features (e.g., a strong, mid-level, short-wave trough; boundary layer convergence ahead of the surface front; etc.). Analyses of other MCC and squall line events also showed a similar set of different characteristics.

e. MCC life cycle and circulations

Enhanced IR images in Fig. 7 illustrate the development and life cycle of a large MCC that moved slowly eastward across the Dakotas. This system produced several reports of funnel clouds, tornadoes, and strong winds; however, it principally produced widespread rains of up to an inch or more. Satellite imagery (along with radar, surface, and rawinsonde data) was examined for a number of MCC weather systems and the following hypothetical life cycle was developed.







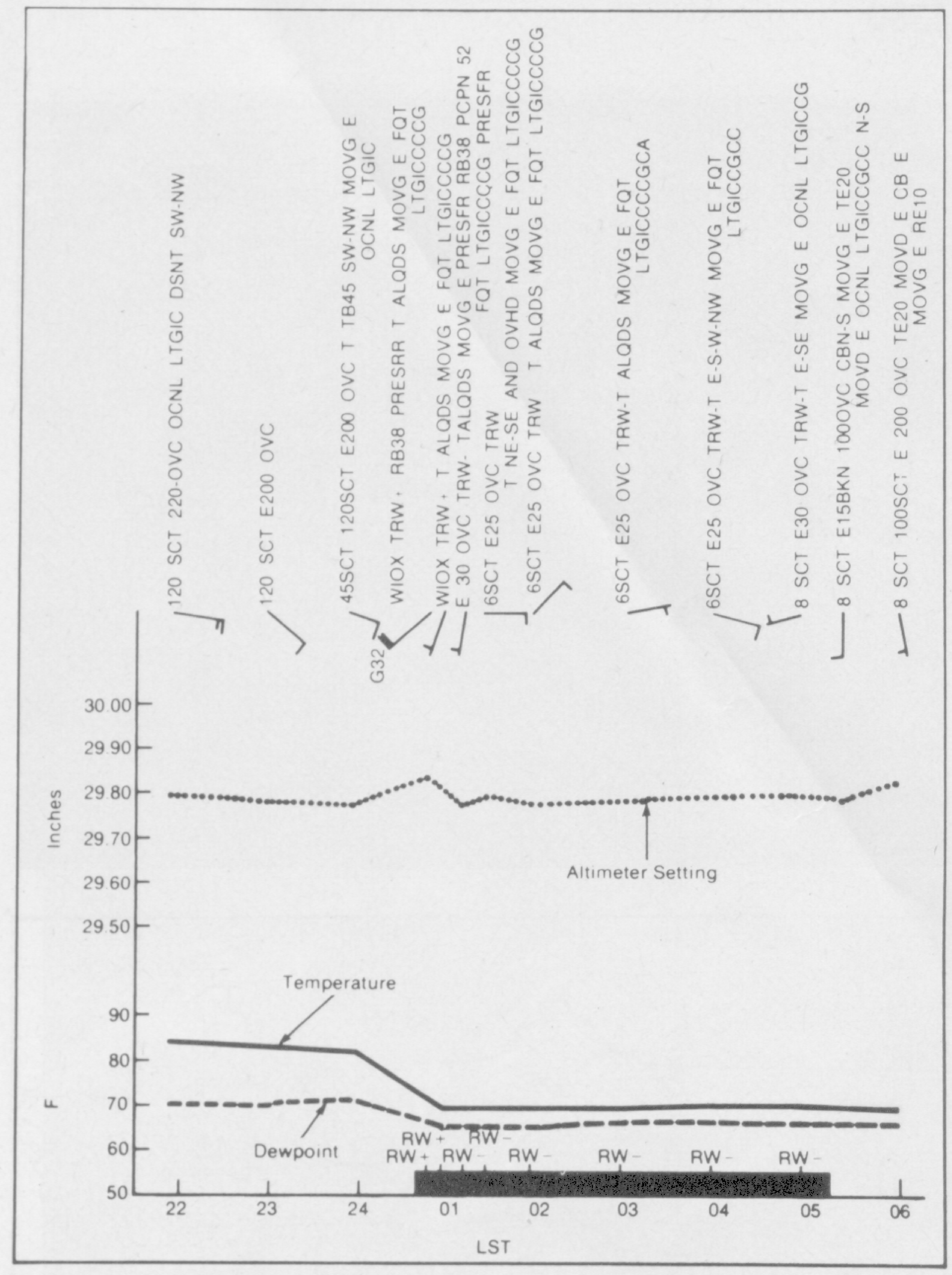
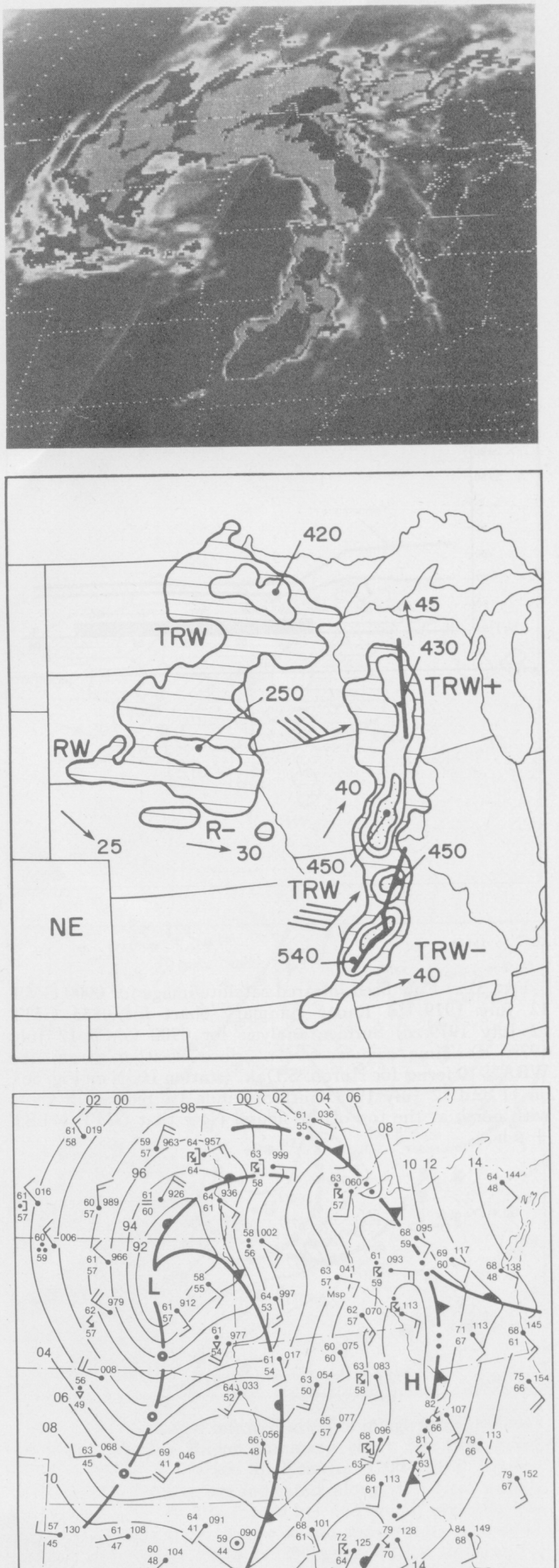


FIG. 5. a) Enhanced infrared satellite image for 0900 GMT 12 July 1979. b) Radar summary chart for 0835 GMT 12 July 1979. c) Surface analysis for 0900 GMT 12 July 1979. d) Time sequences of surface weather (from the WBAN-10 form) for Huron, S.Dak. (station HON on Fig. 5c), on 11 and 12 July 1979. Surface winds are plotted in knots with north at the top of the figure. Note that GMT = LST + 6 h.



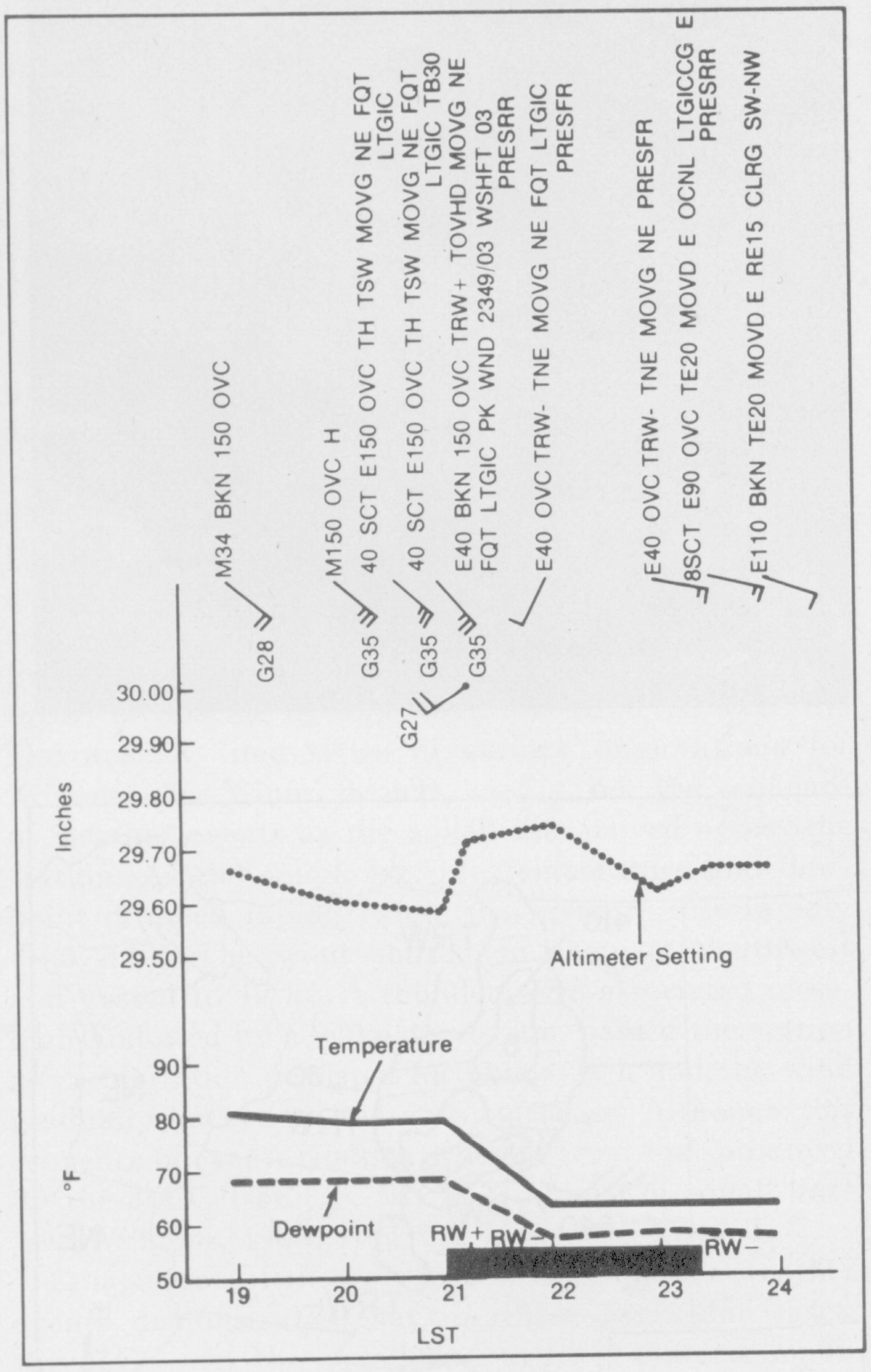


FIG. 6. a) Enhanced infrared satellite image for 0600 GMT 20 June 1979. b) Radar summary chart for 0535 GMT 20 June 1979. c) Surface analysis for 0600 GMT 20 June 1979. d) Time sequence of surface weather (from the WBAN-10 form) for Minneapolis, Minn. (station Msp on Fig. 6c), on 19 and 20 June 1979. Details are similar to Fig. 5d.

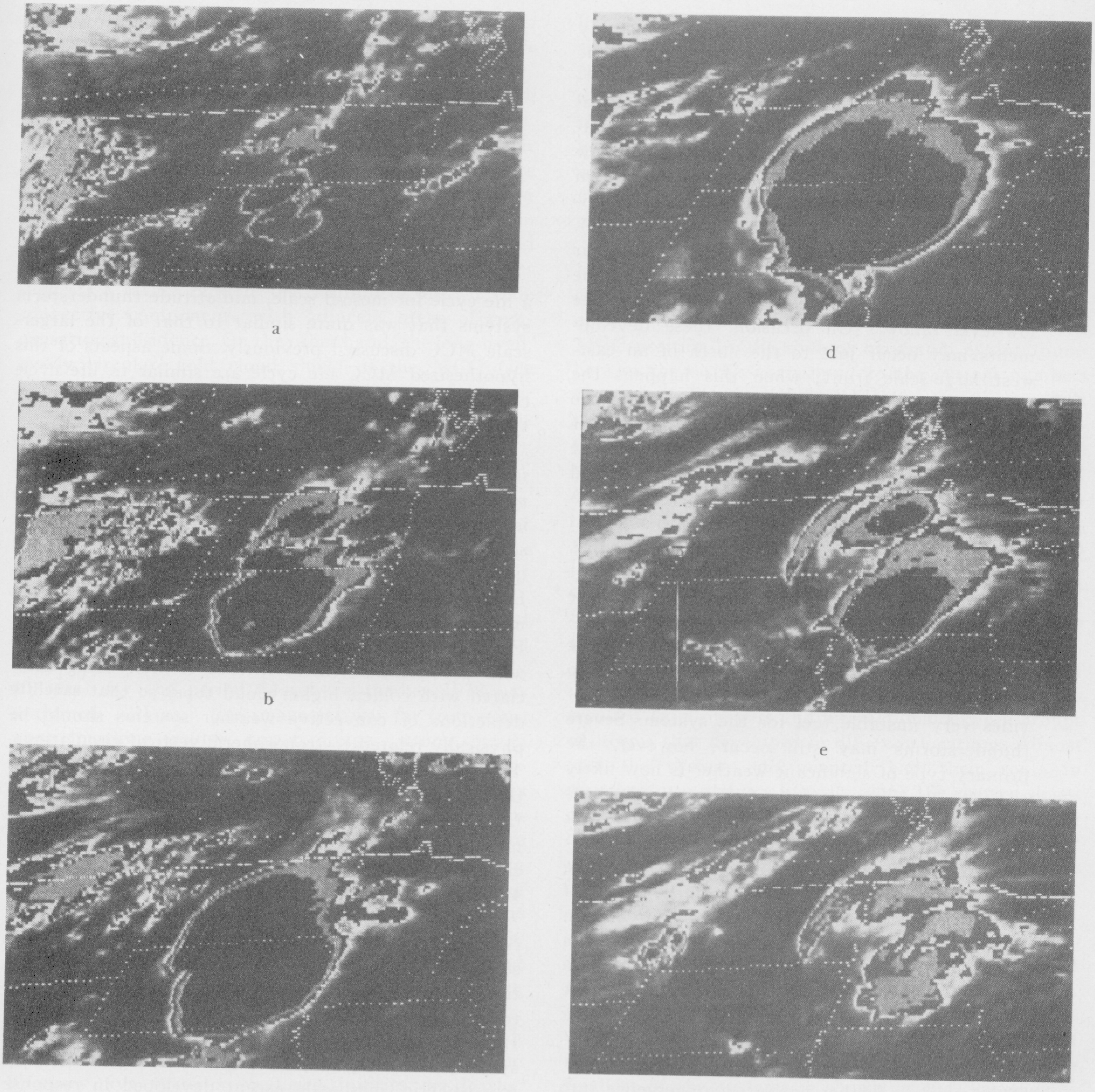


FIG. 7. Series of enhanced infrared satellite images for a) 0030 GMT, b) 0300 GMT, c) 0600 GMT, d) 0900 GMT, e) 1430 GMT, and f) 1630 GMT on 12 July 1979 showing the life cycle of a Mesoscale Convective Complex.

1) *Genesis*—A number of individual thunderstorms develop within a region where conditions are favorable for convection (weak upward motion in the lower troposphere, conditionally unstable lapse rate, etc.). Small-scale effects, such as topography and localized heat sources, may play important roles in initial storm development. Figures 7a and b show this phase of the MCC life cycle occurring over North and South Dakota. Latent heat release and compressional warming in the near environment may combine to produce a meso-β scale region of anomalous warming similar to that hypothesized by Fritsch (1975). The thunderstorms often produce significant severe weather (tornadoes, hail, and strong winds) during this phase. At mid-levels, entrainment of potentially cool environmental air produces strong, evaporationally driven downdrafts with mesohigh pressure systems and cold-air outflows occurring within the surface boundary layer.

2) *Development*—The larger-scale environment be-

gins to respond to the presence of the anomalously warm region and a layer of mid-tropospheric (e.g., 750–400 mb) inflow develops. At the surface, gust fronts and outflows from the individual storms merge to produce a large mesohigh cold-air outflow boundary. Strong, low-level inflow of moist, unstable air continues and the system grows rapidly (eventually reaching the size criteria specified in Table 1; refer to Figs. 7b and c). The most intense convective elements occur along the convergence zone produced by the interaction of the outflow boundary and the low-level inflow. (On occasion, these developments may occur just to the north of an east-west large-scale front; when this happens the thunderstorm outflows act to strengthen the frontal zone and the MCC develops and moves eastward on the cool air side of the surface front.) In response to thunderstorm-produced warming, mid-tropospheric air converges into the system, where it is incorporated into a central region of mean, mesoscale ascent. Eventually, this region should become saturated and exhibit a moist adiabatic, warm core structure relative to the surrounding environment.

3) *Mature*—During the mature stage (see Figs. 7c and d) intense convective elements continue to form in the region where low-level inflow provides very unstable fuel for the system. Severe thunderstorms may still occur; however, the primary type of significant weather is now likely to be locally heavy rainfalls. Convective elements occur within a moist environment, with weak vertical wind shear, and are very efficient precipitators. The dominant characteristic of the mature system is likely to be the large extent of the mid-tropospheric, upward mass circulation and the attendant large area of precipitation (as indicated by the large shield of cloud with $T_{BB} \leq -52°C$; see Fig. 7d). The warm core nature of the mesocirculation may produce a mesolow aloft, just above the mesohigh associated with the shallow layer of cool surface air. This mesolow further enhances convergence into the system. By this time a large mesohigh is present at upper levels over the system (see Fritsch *et al.*, 1979; Maddox, 1980).

4) *Dissipation*—The dissipation stage is marked by a rapid change in the character of the MCC that commences when intense, convective elements no longer develop (see Figs. 7e and f). The system's fuel supply has been cut off, or modified, and it loses its mesoscale organization and appears chaotic in the IR imagery. The MCC might begin its decay for a variety of reasons: the cold air dome beneath the system may become so intense that the surface convergence zone moves away from the region of mean mesoscale ascent into a region of mid- and upper-level subsidence; the system might move into a different larger-scale environment so that relative flow fields change and low-level moisture convergence is significantly reduced; or it might merely move into a drier, more stable, large-scale environment. Although the MCC rapidly loses its meso-α scale organization, the cool air and outflow boundary at the surface, middle and high cloud debris, and light showers may persist for many hours.

As early as 1962, Pedgley (1962) had proposed a life cycle for meso-β scale, midlatitude thunderstorm systems that was quite similar to that of the larger-scale MCC discussed previously. Some aspects of this hypothesized MCC life cycle are similar to life cycle characteristics of tropical, meso-β scale, convective systems discussed by Zipser (1979).

Probably the most significant feature of the MCC is its associated region of mid-tropospheric convergence and mean, mesoscale ascent. The development of this feature is particularly important because it reflects meso-α scale organization, structure, and dynamics that are quite different from other types of weather systems. Evidence for the existence of this region of mean mesoscale ascent comes from a number of sources. For example, cold cloud top regions correspond well with precipitation (more intense rainfall being associated with colder, higher cloud tops) so that satellite depictions of convective weather systems should be physically related to tropospheric vertical circulations. The distinctive, continuous shield of very cold cloud that characterizes MCCs indicates upward motion (at least in the middle and upper troposphere) on meso-α scales. This cold cloud shield is usually associated with large areas of steady rain (refer to Figs. 4 and 5).

Zipser (1977) found a persistent region of steady rainfall associated with two meso-β scale tropical squalls, and Houze (1977) noted that steady precipitation accounted for a large portion (~40%) of the total rainfall produced by a tropical convective system[4]. In a numerical simulation of a tropical convective system, Brown (1979) found that a region of mid-tropospheric, mesoscale ascent developed in response to parameterized convection. Similar results were obtained by Kreitzberg and Perkey (1977) and Fritsch and Chappell (1980). Other evidence for the tendency of the atmosphere to produce mean, mesoscale ascent in response to convective forcing can be found in the studies of Fankhauser (1969, 1974), Sanders and Paine (1975), Sanders and Emanuel (1977), and Ogura and Chen (1977). These investigators diagnosed mesoscale,

[4] Houze (1977) and Zipser (1977) have called this steady precipitation "anvil rain"; however, MCC physical characteristics (especially the apparent meso-α scale of the regions of mean ascent and steady precipitation) indicate that this appellation may not be particularly appropriate for the type of systems being considered here.

vertical circulations attending convective systems that moved across the National Severe Storms Laboratory's sounding network in Oklahoma.

The tremendous areal extent of cold cloud shield associated with the mature MCC also indicates that, although these systems may be qualitatively similar to meso-β scale tropical systems, their circulations are organized much differently from those of a meso-α scale cloud cluster (i.e., contrast the MCCs shown in Figs. 3a, 3e, and 7d with the cloud cluster depicted in Fig. 3c). The chaotic cloud shield of the cluster suggests a rather random distribution of meso-β scale convective components with adjacent areas of compensating subsidence. On the other hand, the long-lived, nearly circular, cold cloud shield of the MCC (see Fig. 7) indicates a focused, central region of meso-α scale upward motion in the middle and upper portions of the troposphere.

3. Central U.S. MCCs during 1978

A set of enhanced IR satellite imagery (operational data routinely available from the Kansas City Satellite Field Service Station at intervals of approximately 30 min) for the period March–September 1978 was examined. Although this image set was far from complete (machine trouble, power outages, wrong sectors available, etc.), the life cycles of 43 MCCs were documented. Specific information for these systems is presented in Table 3 (refer to Table 1 for the terminology definitions). The areas of these systems were computed by outlining the boundaries encompassing $T_{BB} \leq -32°C$ and $\leq -52°C$ onto maps and then fitting a number of rectangles to each region. Significant weather (from the NOAA, EDIS publication *Storm Data*) that each system produced during the period between initiation and termination is also listed in Table 3. Severe thunderstorm phenomena (tornadoes, wind, and hail), as well as torrential rains and flash floods, were often associated with the systems. One of every five systems produced injuries or deaths. The data shown in Table 3 indicate that the MCCs studied were truly significant convective weather systems that spawned a variety of severe convective weather phenomena.

Although the first thunderstorms typically developed during the afternoon, the transition to large, highly organized mesosystems usually did not occur until early evening. Most systems grew to maximum size (as indicated by the satellite imagery) after midnight and persisted into the morning hours. It seems likely that MCCs are, in large part, responsible for the nocturnal maxima in thunderstorm and precipitation frequencies over the central United States (Wallace, 1975). Maddox *et al.* (1979) found that significant flash floods in the eastern two-thirds of the United States usually occurred during nighttime hours, and it is hypothesized that MCCs are also largely responsible for this nocturnal flash flood characteristic (note that at least 17 of the 43 systems produced heavy rains). An average of 16½ h elapsed between first thunderstorm development and the time that the MCC began to decay (terminate). The extent of the systems was indeed huge, with an average cold cloud shield ($T_{BB} \leq -32°C$) of more than 300×10^3 km^2 at the time of maximum extent.

The paths that these MCCs followed are shown in Fig. 8 (tracks are for the centroid of the $\leq -32°C$ cloud shield). The triangles indicate the position of each system when it initiated; the circles denote the MCC position at the time of maximum extent (numbers in the circles correspond to the system numbers shown in Table 3); and the "X"s indicate the system's position at termination (refer to Table 1 for definitions of MCC terminology). The dashed lines indicate the region in which the first thunderstorms developed and their movements prior to the time that the MCCs initiated. Once the systems developed, their movement tended to be with the mean flow in the 700–500 mb layer. The tracks also seem to indicate that many of the systems moved eastward to, or just beyond, the large-scale ridge positions before they began to decay.

The 1978 satellite imagery illustrates a number of interesting aspects of MCCs. Many of the systems resulted from mergers and interactions between groups of storms that developed in different locations. Almost half the systems documented had their roots in thunderstorm activity initially along the eastern slopes of the Rocky Mountains, whereas the remainder grew out of storms that developed over the Plains (probably along fronts or dry lines). Some of the systems were initially linear-type developments that acquired MCC characteristics as they grew in size. As the warm season progressed the favored region of MCC occurrence shifted slowly northward, so that by July and August the systems primarily affected the north-central states.

Examples of the satellite IR depiction of several of the 43 MCCs studied are presented in Fig. 9. The smallest of the systems is shown in Fig. 9a. Figures 9b and c illustrate typical systems and Fig. 9d shows the largest of the documented systems. Detailed examples of thermodynamic and kinematic modifications of the large-scale environment produced by the 7 May system (Fig. 9d) have been presented by Fritsch *et al.* (1979) and Maddox (1980). Some of the important effects included: development of pronounced cooling and a mesohigh pressure perturbation within the upper troposphere, strong anticyclonic outflow in the vicinity of this mesohigh aloft, and a difference between observed 200 mb winds and 12 h Limited Fine Mesh (LFM) forecast winds of 30–50 kt over the system (with an anticyclonic circulation also apparent in this difference field). The LFM quantitative precipitation forecast (QPF) called for about an inch of rain over portions of Louisiana and Mississippi, while local

TABLE 3. 1978 Mesoscale Convective Complexes.

No.	Date	Time (GMT) First storms	Initiate	Maximum extent	Terminate	Cloud top area at max. extent × 10^3 km^2 ≤−32°C	≤−52°C	Significant weather
1	22/23 Mar.	2200	0200	0600	1430	281	89	None reported
2	22/23 Apr.	1700	2100	1500	2200	568	243	Wind, hail, tornado
3	2/3/4 May	1600	2200	1230	UNKN	612	352	Wind, hail, tornadoes, 4–13 in rains, and flooding 7 deaths, 103 injuries
4	6/7 May	2230	0200	1200	2230	924	456	Wind, hail, tornadoes, 5–10 in rains, and flooding 2 deaths, 8 injuries
5	11/12 May	1800	2200	0300	0800	574	260	Wind, hail, tornadoes 10 injuries
6	17/18 May	1500	1800	2330	0400	218	86	Wind, hail, tornado, 5 in rain, and flooding
7	18 May	0300	0730	1330	1600	224	87	None reported
8	18/19 May	2200	0130	0600	1000	212	130	Hail, tornado
9	19 May	0230	0730	1130	1530	188	112	None reported
10	26/27 May	1800	2200	0600	1000	198	78	Wind, hail, tornadoes, 10 in rains, and flooding 4 deaths, 15 injuries
11	26/27 May	2100	0300	0600	1000	166	59	Wind, tornadoes
12	30/31 May	2030	2330	0900	1500	405	225	Wind, hail, tornado
13	2/3 Jun.	2200	0000	0600	1500	391	243	Wind and 3 in rains
14	3/4 Jun.	2200	0600	1230	1430	174	56	Hail, tornado
15	5/6 Jun.	2100	0200	0615	1330	230	96	Hail, wind
16	13/14 Jun.	1930	0500	1100	1400	235	105	Hail
17	19/20 Jun.	1930	0030	0630	1430	546	228	Wind, hail, tornadoes, heavy rains
18	21/22 Jun.	1200	1500	2100	0000	185	79	Wind, hail, tornado
19	23 Jun.	0600	1200	1700	2000	164	80	Wind, rains 4–6 in
20	23/24 Jun.	1800	2230	0500	0800	300	129	Wind, hail
21	24/25 Jun.	2000	0030	0500	0830	250	72	Hail, tornadoes, heavy rains
22	24/25 Jun.	2100	0130	0400	0730	167	106	Hail, tornadoes
23	24/25 Jun.	2030	0430	1000	1915	446	165	Hail, wind, heavy rains, 1 death, 1 injury
24	27/28 Jun.	1800	2200	0430	0900	382	180	Hail
25	29/30 Jun.	2200	0330	0630	1030	125	66	Heavy rains
26	29/30 Jun.	1800	0000	0630	1100	322	146	None reported
27	30 Jun./1 Jul.	2000	0030	0500	1000	262	149	5–8 in rains, flooding 4 deaths
28	1/2 Jul.	1900	0030	0800	1030	271	88	Wind, very heavy rains, flooding, 2 deaths
29	3/4 Jul.	2000	0030	0500	1000	262	149	Tornado
30	5/6 Jul.	1830	2300	0430	0800	454	222	Wind, hail, tornadoes, 6–7 in rains, and flooding 5 deaths
31	6 Jul.	0100	0700	1100	1330	233	98	Wind, hail
32	8/9 Jul.	2000	0330	0630	1200	190	107	Wind, 4 in rains
33	13 Jul.	0130	0700	1100	1600	186	74	None reported
34	14/15 Jul.	1700	0000	0500	0830	326	150	Wind, hail, 3+ in rains, and flooding
35	19/20 Jul.	1900	0300	0800	1630	238	92	None reported
36	20/21 Jul.	1830	0200	0630	1300	243	106	Tornado
37	21/22 Jul.	1930	0000	0630	1100	429	132	Winds, 2 injuries
38	17 Aug.	0100	0730	1100	1800	216	89	None reported
39	17/18 Aug.	1700	0130	0430	0830	382	107	None reported
40	22/23 Aug.	1800	2130	0500	0800	338	171	3–7 in rains
41	22/23 Aug.	1930	0100	0730	1700	365	173	3–7 in rains
42	23/24 Aug.	1730	0230	0730	0900	150	73	Wind, hail, heavy rains, and flooding
43	25/26 Aug.	1200	2130	0130	0930	239	123	Wind
Average Values		2000	0130	0730	1230	308	139	

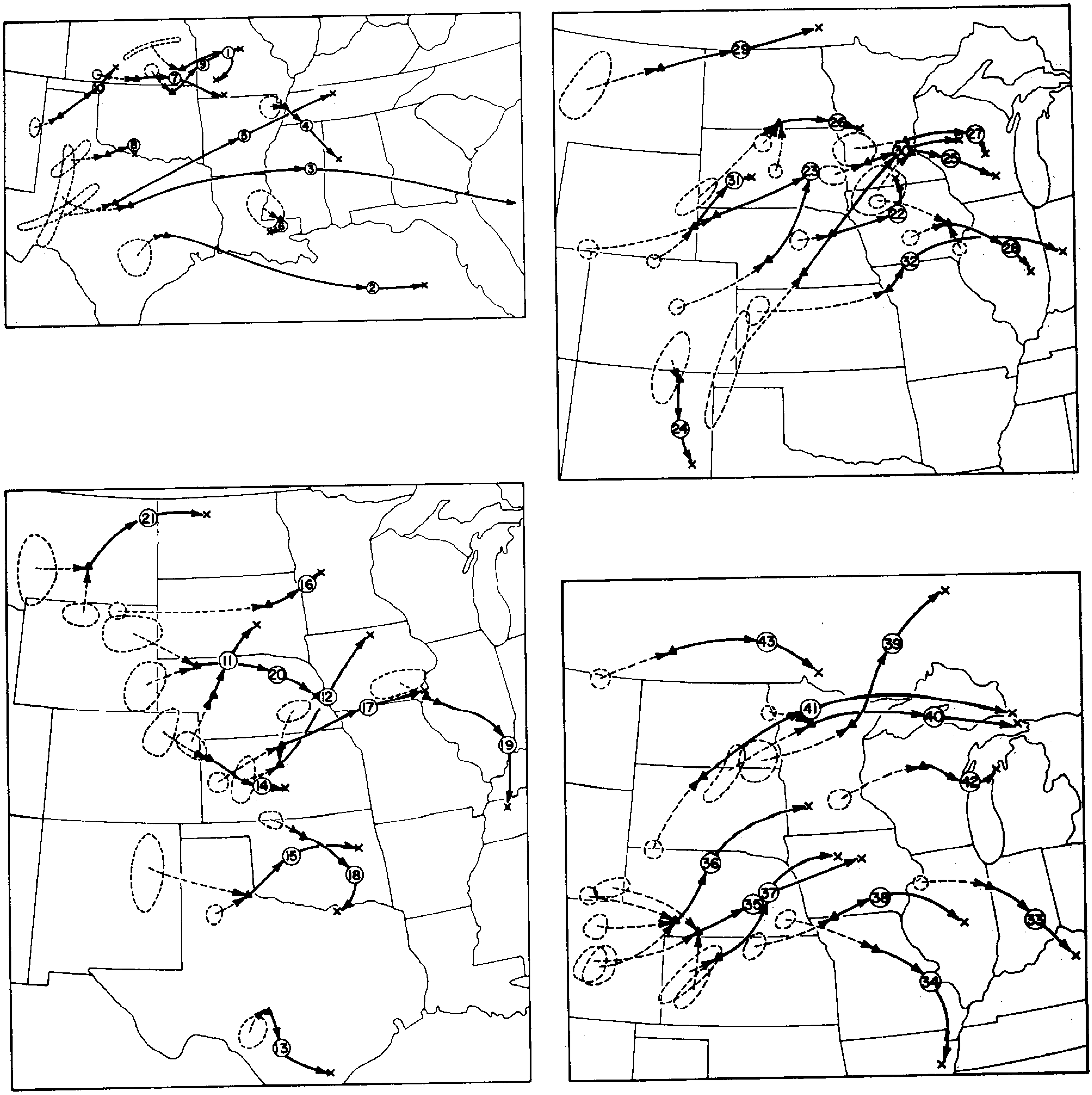


FIG. 8. Tracks of 1978 Mesoscale Convective Complexes. Dashed lines indicate regions and movements of the first thunderstorm developments. The triangles show the position of the system at "Initiate," circles at "Maximum Extent," and "X"s at "Terminate" (refer to Table 1). The numbers correspond with the system numbers shown in Table 3.

reports indicated amounts that exceeded the QPF by 5–10 times. Preliminary studies indicate that these types of operational forecast errors are not unusual when MCC weather systems develop. Therefore, these systems crucially affect state and local forecasts over the central United States and it is important that forecasters recognize developing MCCs, monitor their movement, and interpret forecast guidance accordingly.

4. Discussion

An important type of mesoscale convective weather system, the Mesoscale Convective Complex (MCC), has been identified utilizing enhanced IR satellite imagery. Their organization, size, and attendant mass circulations distinguish MCCs from other types of convective weather systems. A physical definition of

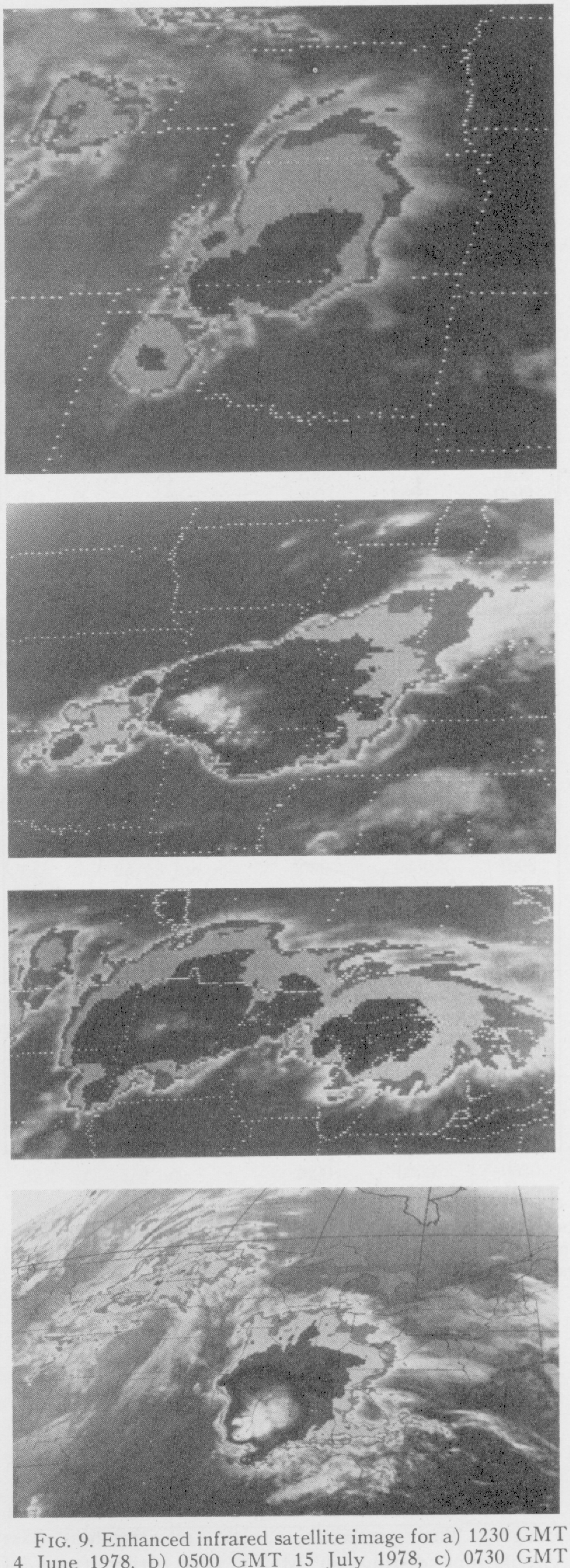


FIG. 9. Enhanced infrared satellite image for a) 1230 GMT 4 June 1978, b) 0500 GMT 15 July 1978, c) 0730 GMT 23 August 1978, and d) 1230 GMT 7 May 1978.

the MCC has been developed to facilitate further documentation and study of the characteristics and life cycles of these weather systems. Satellite imagery from the warm season of 1978 was used to study 43 midlatitude MCC systems that occurred over the central and eastern portions of the United States. These systems produced a wide variety of significant convective phenomena that included tornadoes, hail, wind, destructive flash floods, and intense electrical storms—in addition to widespread beneficial rain. In fact, it is possible that MCC systems dominate the precipitation and convection climatologies for the growing season over the United States wheat and corn belts.

Mesoscale Convective Complexes interact with and modify their larger-scale environment in ways that may affect the future evolution of meteorological features over much of the United States. MCCs are organized in a distinctly nonrandom manner on scales that are definitely not subgrid in nature. However, the phenomena and effects attending MCC weather systems are not forecast by operational numerical models. This is because MCCs are convectively driven, organized weather systems whose physics are not yet understood, much less included in operational convective parameterization schemes.

A hypothetical life cycle model for MCCs has been developed and ongoing studies of the meteorological conditions associated with a number of MCCs will be utilized to refine and substantiate this conceptual model. An understanding of the life cycles, meteorological characteristics, and up- and down-scale environmental interactions of MCC weather systems may help elucidate many aspects and problems of convective weather phenomena (ranging from physically realistic convective parameterizations to beneficial modification of convective weather systems). The prospects for realizing such understandings are quite bright, since the time and space scales of these systems—coupled with their frequent occurrence over the central United States—makes them highly amenable to detailed investigation.

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