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POTENTIAL VALUE OF SATELLITE CLOUD PICTURES IN WEATHER MODIFICATION PROJECTS

By: K. R. Biswas

CASE FILE COPY

Prepared for:

National Aeronautics and Space Administration
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NGL 42-001-004

Institute of Atmospheric Sciences

South Dakota School of Mines and Technology

Rapid City, South Dakota 57701

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ABSTRACT

Satellite imagery for one project season of cloud seeding programs in the northern Great Plains has been surveyed for its probable usefulness in weather modification programs. The research projects and the meteorological information available for the same are described. A few illustrative examples of satellite imagery analysis are cited and discussed, along with local observations of weather and the seeding decisions made in the research program. This analysis indicates a definite correlation between satellite-observed cloud patterns and the types of cloud seeding activity undertaken, and suggests a high probability of better and/or earlier decisions if the imagery is available in real time. Infrared imagery provides better estimates of cloud height which can be useful in assessing the possibility of a hail threat. The satellite imagery appears to be of more value to area-seeding projects than to single-cloud seeding experiments where the imagery is of little value except as an aid in local forecasting and analysis.

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1. INTRODUCTION AND CONCLUSIONS

This is a report on a simple but revealing investigation of the potential value of satellite cloud pictures in weather modification projects.

The value of any source of information to a meteorologist depends upon many factors, including his training, the timeliness of the data presented, and the other sources of data simultaneously available to him. One method of evaluating the worth of satellite cloud pictures in weather modification projects would be to make the pictures available to meteorologists conducting such projects, and let them work out by trial and error the weight which they should assign to the cloud pictures in relation to their other sources of information. If they seized upon satellite pictures in the manner in which meteorologists late in World War II seized upon weather radar, we could be certain of the value of satellite cloud pictures in weather modification projects.

So far the weather modification projects of the Institute of Atmospheric Sciences have not had weather satellite data available in real time, apart from APT pictures read out on a facsimile machine. These are of lower quality than the present state-of-the art products and therefore do not provide a fair test of the potential value of satellite cloud pictures. An alternative approach has been followed here. The author has examined cloud pictures obtained by the ATS-III and NOAA-1 satellites covering two experimental cloud seeding projects in the western Dakotas and several commercial cloud seeding projects in the same general region. These projects were particularly valuable for the present study in that some of them had the dual objectives of increasing rainfall and suppressing hail, and slightly different seeding procedures were used for the two objectives. Hail threats were determined by the project meteorologist on the basis of actual hail reports and of radar observations of storm heights and maximum reflectivity factors. Conditions in the area as determined from the satellite photographs have been compared with other weather data and with the operational logs for the seeding projects.

The present study has shown that there is a definite correlation between the cloud patterns observed by the satellites and the types of cloud seeding activity undertaken in the various regions. We conclude that a meteorologist having access to the satellite cloud photographs and no other sources of information could have specified the appropriate type of activity for each region on a given day. Furthermore, he might have made his decisions earlier in the day than did the meteorologists actually on the projects who did not have satellite cloud photographs available and relied principally on the short range radar and conventional weather data from a teletype. This conclusion will be amplified in the final chapter of the report following a description of the procedures and presentation of some illustrative examples.

2. DESCRIPTION OF THE STUDY

2.1 Background Information

During the last decade abundant literature has appeared on relationships between satellite observed cloud patterns and descriptive features of synoptic meteorology such as fronts, troughs, ridges, and jet streams. This literature provides a useful background for interpreting satellite-observed video pictures. Good summaries illustrating meso and synoptic scale cloud features and patterns have been reported by, among others, Widger et al. (1965), Anderson et al. (1966), and Anderson et al. (1969). A good amount of work has also gone into interpreting satellite data in relation to mesoscale structure in specific situations (e.g., University of Chicago, Satellite and Mesometeorology Research Project). Satellite data are also being used in thunderstorm and hurricane research, operational forecasting, and forecasting research. Real-time infrared imagery has also become routinely available in recent times. Together, the daytime video and nighttime IR meteorological satellite displays can give continuity and information on the vertical as well as the horizontal structure of the atmosphere (Ashman et al., 1971; Rao, 1970; Anderson and Smith, 1971).

2.2 Purpose of the Study

Until now there has not been any attempt to assess the possible value of the satellite data in aiding weather modification projects, except in the research on modification of hurricanes. The purpose of the present study was to survey the satellite imagery for one project season of cloud seeding programs in the northern Great Plains, and to evaluate any possible application of satellite imagery as an aid, in real time, to the operation of weather modification programs such as the state-wide weather modification project now planned for South Dakota. The satellite pictures were used to help identify the cloud type, cloud cover, and the tendency of the cloud system in and around the area of interest (during the seeding period). Special attention was given to the areas around the North Dakota Pilot Project in McKenzie County and the Rapid City area where Project Cloud Catcher is conducted, together with the entire three-state area of North Dakota, South Dakota, and Nebraska.

2.3 Description of Seeding Projects

There were a number of cloud seeding projects operating in this area during the summer of 1971 including two federally funded research projects, the North Dakota Pilot Project and Project Cloud Catcher.

The North Dakota Pilot Project was primarily concerned with the effects of silver iodide seeding on rainfall and hailfall from stratiform and convective clouds. The target area for the project was McKenzie County, an area of roughly 2700 mi^2, with a field office located near Watford City (Fig. 1). The project was conducted on a seven-day week basis from May 1 through August 15, 1971 (Schock, 1971), seeding operations being performed mainly during daylight hours. The operational period was broken into a series of time blocks consisting of eight consecutive 24-hour periods. Out of each eight-day block, a two-day block was chosen by chance in advance of the project for control purposes and left unseeded. The operational day started at 1000 CDT and lasted 12 hours. An M-33 10-cm acquisition radar, slightly modified to increase its effective range, was used for storm detection, for monitoring storm development and motion, and as an aid in directing seeding aircraft. There were two other private projects operating in North Dakota, the Bowman Slope Project and the Ward County Project (Fig. 1).

The only research project in South Dakota was Project Cloud Catcher. It differed from the North Dakota project in that it involved experimental seeding of convective clouds only, and the seeding effects were evaluated with the aid of data collected by radar and instrumented aircraft. The main objective was to increase the ability to detect seeding effects in convective clouds using movable target areas. Two alternative ways to modify convective clouds were used: First, the stimulation of cloud growth by heavy silver iodide seeding to release latent heat and, second, the release of collodial instability through seeding with finely ground sodium chloride. In the summer of 1971 a further specific objective was the introduction of numerical cloud modeling (Dennis, 1971) into the decision framework of the project. The models were used to determine the effects of salt seeding upon precipitation from vigorous convective clouds and to determine if small convective showers could be intensified through dynamic effects of silver iodide seeding. The project was operated five days a week from Monday, June 7, 1971, to Friday, August 12, 1971.

There were a few other private cloud seeding projects operating in this state (see Fig. 1), of which the Grand River Project and the Western South Dakota Rain Increase Corporation Project are worth mentioning.

2.4 Information Available and Procedures for Forecast and Decision Making

Daily meteorological information available to the meteorologists of the two research projects was more or less the same as that at a Class A weather station of the National Weather Service. This included facsimile and teletype information of surface and upper air observations and charts, prognostic charts, severe weather forecasts, etc. Teletype sounding data were not available to Watford City but a local sounding was taken each day.

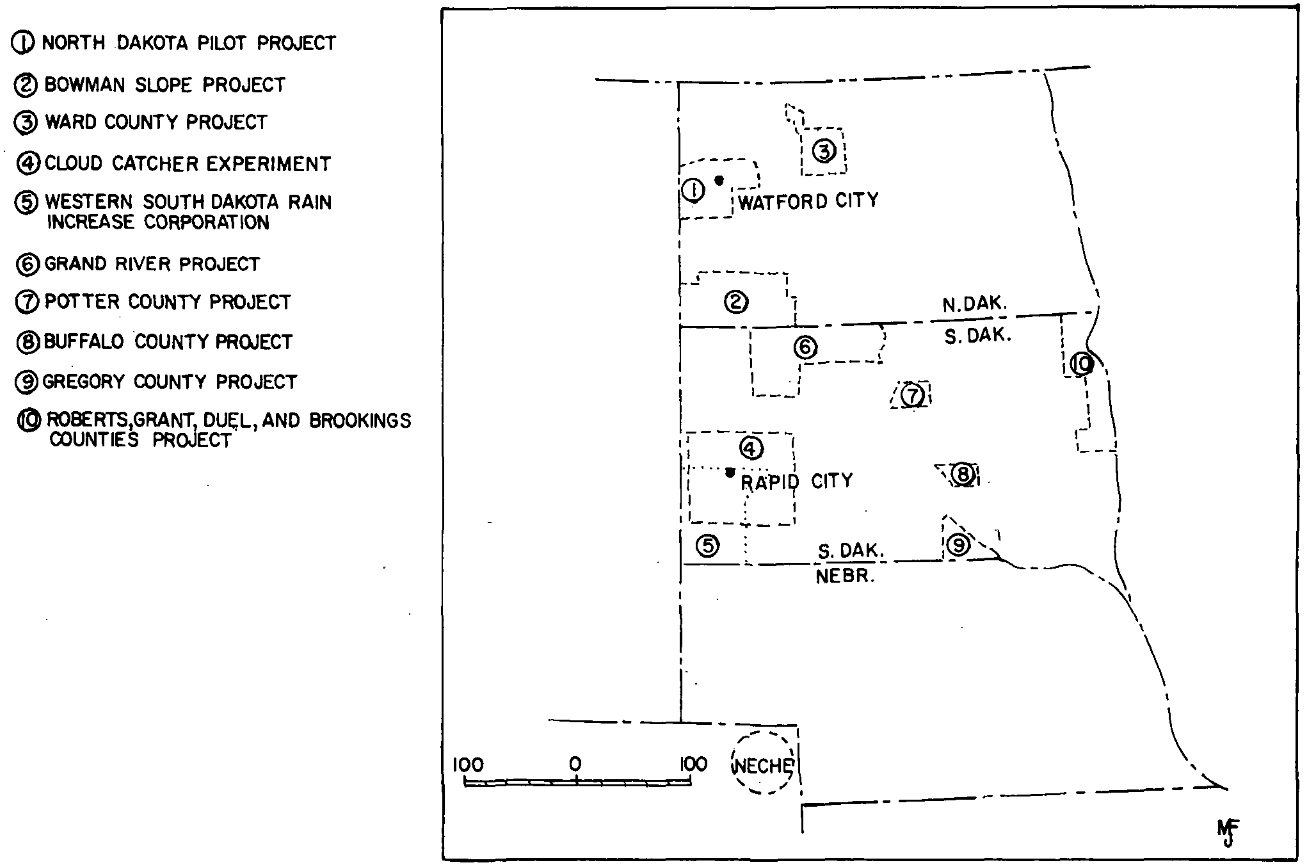

Fig. 1. Cloud seeding projects in the three state area, 1971.

The North Dakota Pilot Project meteorologist stood by for seeding operations if he expected precipitation development within the next few hours. Seeding to increase rainfall was initiated on the sign of developing (visual or radar) towering cumulus and/or rain showers. Decisions for hail suppression were primarily based on radar observations, hail suppression starting when the maximum echo height exceeded 40,000 ft MSL, or when the radar reflectivity factor was 55 dBz or greater. If there was no expectation of any development within the next 12 hours, no operation was conducted on that day. Days were stratified in several ways to aid the analysis in determining seeding effects as a function of meteorological conditions (Fig. 2). Precipitable water was the total from surface to 500-mb level taken from local morning soundings. Vorticity advection was taken from the morning analysis and the corresponding 12-hour prognostic chart prepared by the National Weather Service.

In the Cloud Catcher Project around Rapid City, additional information available included radiosonde data from Circuit "C" teletype and the output of a computer cloud model based on the morning sounding and indicating the suitability of the day for seeding and the type of seeding preferred. This included the maximum expected updraft for unseeded clouds and the increase in cloud height that would result from silver iodide seeding (Dennis, 1971). For 1971, the condition was that if the model output indicated updraft in excess of 10 m sec^{-1} with a minimum updraft radius of 1 km in an unseeded cloud, the decision was for salt seed. When this criterion was not met, but the model indicated that silver iodide seeding could result in height increase of 500 m or more with an updraft radius of 2 km or less, the decision was for silver iodide seed. When none of the above conditions were fulfilled the decision was for no operation. Occasionally APT satellite pictures were also available. Local forecasting was further aided by mesoscale surface maps drawn locally with the latest observations received on teletype. Pertinent soundings of the six upper air stations around the region were analyzed for stability, precipitable water, convective cloud base, etc., and extensive use was made of the 500-mb prognostic chart for shortwave location, vorticity advection, etc.

2.5 Procedure Followed in This Study

The primary purpose of the present study was to determine whether the availability of imagery from weather satellites in real time might have helped the project meteorologist to do his job better. As such imagery was not actually available to us in real time, we had to obtain and examine it after-the-fact and then attempt to infer its probable value in the real-time situation.

Attempts were made with several organizations to obtain the satellite imagery covering our desired period from June to mid-August 1971.

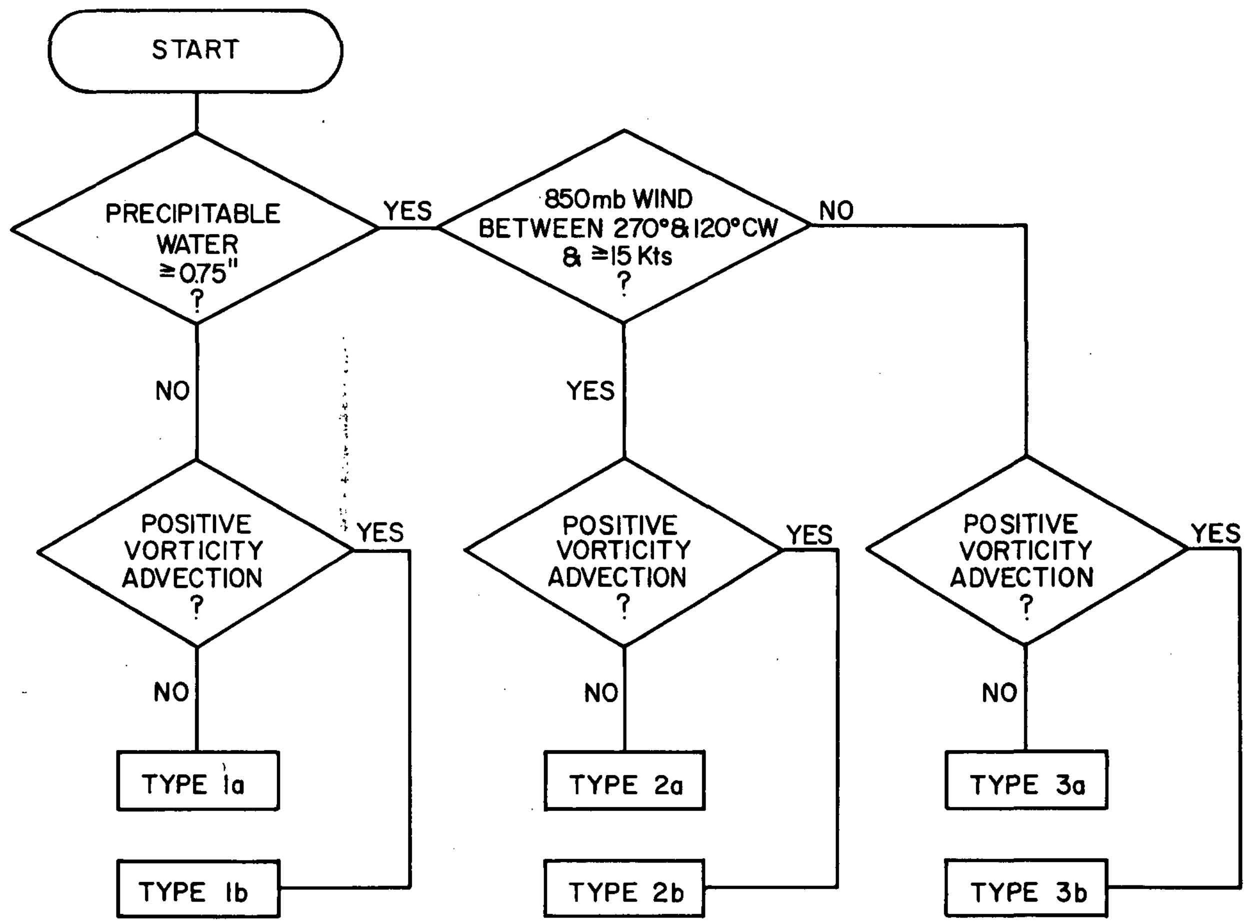

Fig. 2. Flow chart for objective typing of days for the North Dakota Pilot Project.

National Environmental Satellite Service, Washington, D. C., offered to supply the same free of cost. The imagery was provided from two sources. One source was NASA Application Technology Satellite ATS-III. This geosynchronous satellite, positioned roughly 80°W during mid-June to August 1971, had the northern Great Plains well within view and provided the desired morning coverage. The other source was the polar-orbiting NOAA-1 spacecraft equipped with vidicon camera and scanning radiometers. It provided IR imagery for our desired area near about 0300 hours local time and vidicon pictures for the afternoon at about 1500 hours.

Enlarged views (maximum possible) of the area around the State of South Dakota, both for ATS-III and NOAA-1 imagery, were most helpful in identifying cloud type and cover over the desired area. The prints were properly gridded with latitude and longitude lines and state boundaries. When state boundaries were not properly shown, a prepared transparency showing state boundaries was superimposed over the prints for identification of location.

Most individual clouds could not be seen in the pictures because of their small scale and so were not identified. The resolution of the camera also does not permit detection of many small scale features and it is from the gross features that the natures of the clouds are identified. In identifying the cloud type and pattern, general guidance has been taken from the relevant literature (e.g., Widger et al., 1965; Anderson et al., 1969; and Ashman et al., 1971). It is mainly the subjective analysis and interpretation of satellite cloud pictures that have been followed. The characteristics such as brightness, pattern, structure, texture, shape, and size have been used to detect the presence of cloud layers and to identify the type of cloud wherever possible, and make some inferences about temperature, wind, and stability fields of the atmosphere. In large scale features the vorticity, troughs, fronts, ridges, etc., have also been identified when related to the local cloud pattern over the area of interest.

With the few IR images obtained a similar procedure has been followed except that the higher clouds were identified mostly by their relative brightness. It is possible to use the same procedure with proper calibration of the shades to obtain specific cloud top heights.

ATS-III photographs covering the morning period were available for the majority of the days during June and July 1971, with blown-up views of the desired area available in most cases. NOAA-1 vidicon pictures covering the afternoon period, with enlarged views for the northern Great Plains, were also available from June 6 through August 14, 1971. NOAA-1 IR photographs covering the early morning period were available for a few days in June 1971 only.

3. ILLUSTRATIVE EXAMPLES*

The cloud description along with the satellite pictures for a few days are cited here to illustrate the possible use of the satellite imagery as an aid to weather modification programs. The examples selected refer particularly to the North Dakota Pilot Project. We have chosen a few days that represent, for this area, days of little activity, days for rain increase operation, and days for hail suppression.

June 8, 1971: According to the random selection, this was a seed day for the North Dakota Pilot Project, but seeding was not carried out for lack of suitable clouds. Observations indicated mostly layer type stratiform clouds over the area. The forecast for the Rapid City area was partly cloudy with a few showers on the Black Hills, and observations indicated rain showers late in the afternoon in some portion of the area.

Satellite photographs for three different times were available for this day. The prepared transparency showing state boundaries has been used over an enlarged view to identify locations. The early morning IR photograph (0402 MDT, Fig. 3a) indicated high cloud coverage over a large area in the extreme eastern part of South Dakota extending over to the neighboring eastern states. This suggests a severe storm in that area. To the south and west are clouds of lower heights. Central and southwest Nebraska also have high cloud cover associated with convective activity. There seems to be thin cirrus or perhaps low cloud cover all over North Dakota, part of South Dakota, and Nebraska.

The late morning (1153 MDT) ATS-III video picture (Fig. 3b) indicates a quite active frontal cloud pattern (the same pattern was seen on the previous day) extending over a major part of North Dakota and South Dakota with severe activity in eastern Nebraska. Comparatively little activity appears around the Black Hills area but there is probably some cumulus development north of it.

The afternoon (1459 MDT) NOAA-1 vidicon picture (Fig. 3c) indicates weakening of frontal activity around North and South Dakota with probably some clouds dissipating (in higher levels). A few severe local storms are visible in southwest Nebraska. The whole cloud pattern over North and South Dakota is a part of the large cloud system showing the vortex-form in the northwest.

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*Weather observations and forecasts were obtained from operational and weather logs of project meteorologists of the two areas.

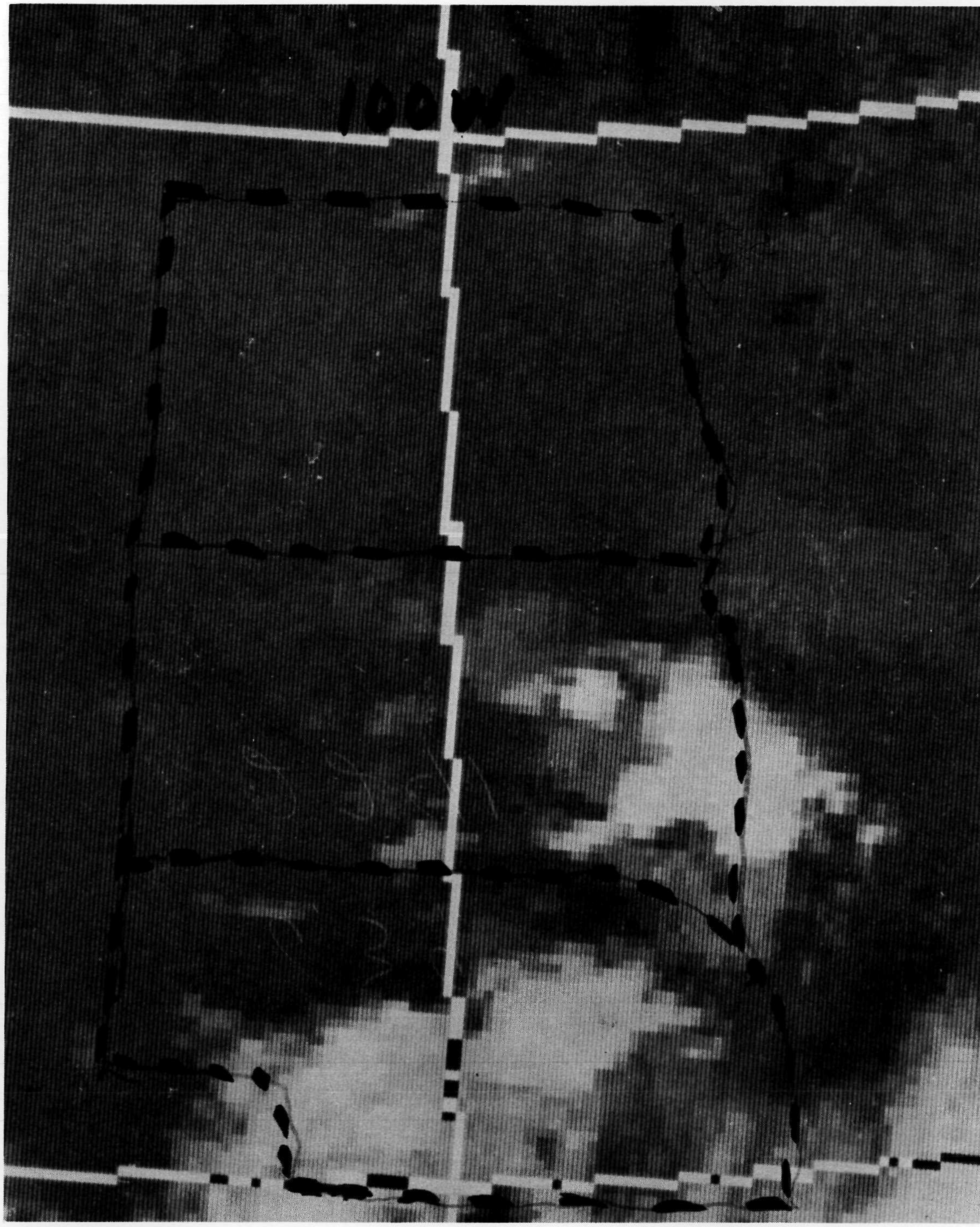

Fig. 3a. June 8, 1971, 0402 MDT: NOAA-1 IR photograph.

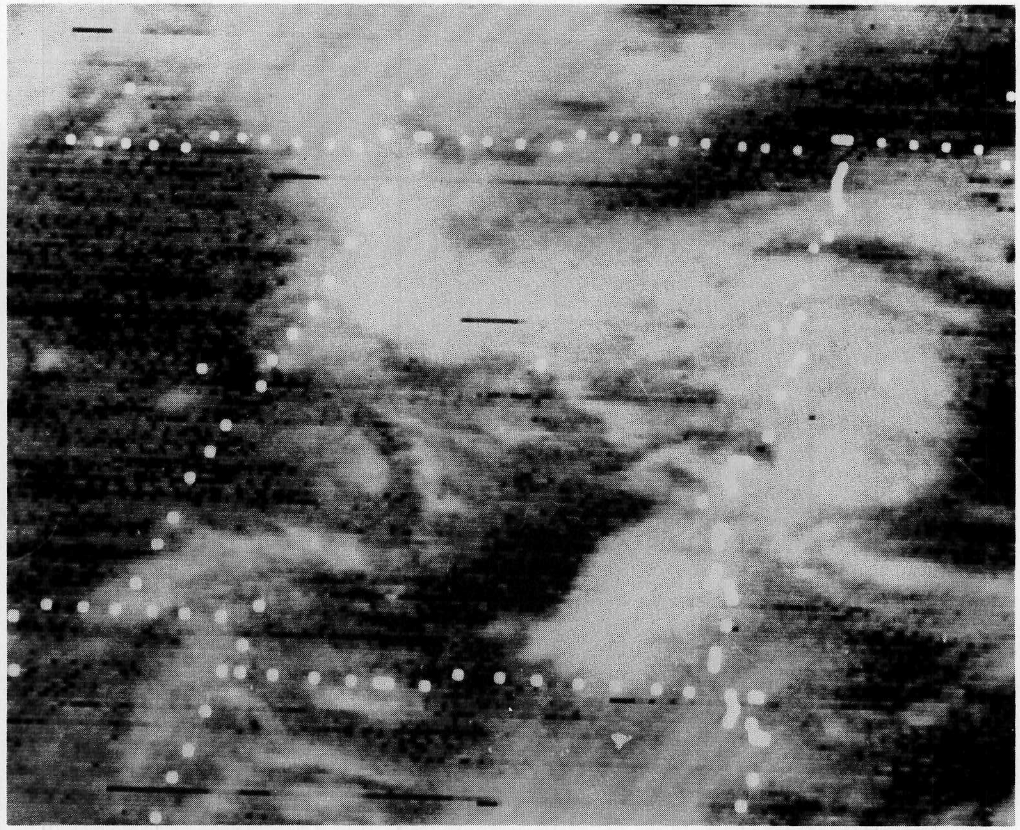

Fig. 3b. June 8, 1971, 1153 MDT: ATS-III picture.

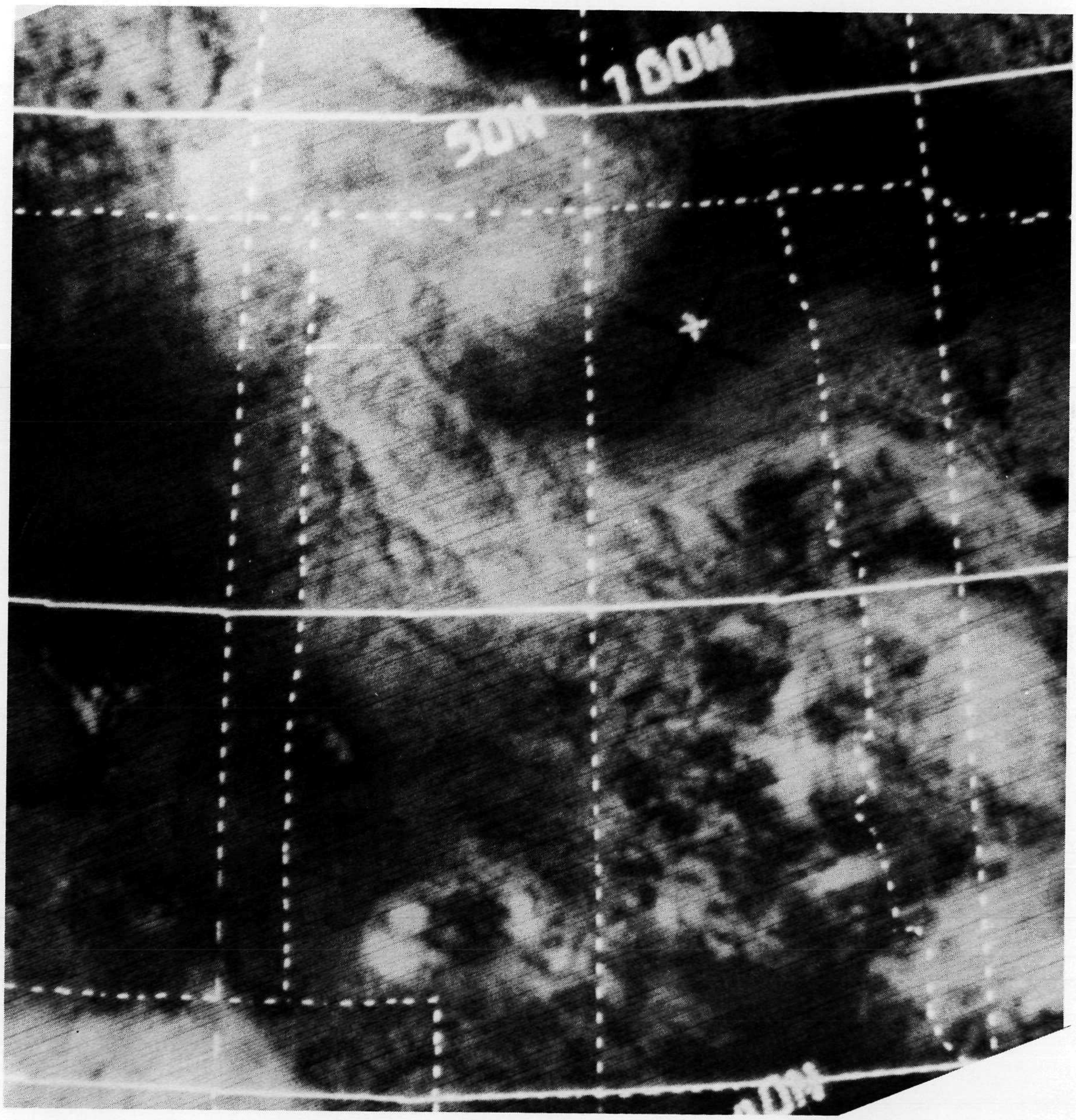

Fig. 3c. June 8, 1971, 1459 MDT: NOAA-1 video picture.

As can be seen, except for early morning convective activity over southeastern South Dakota, both North and South Dakota were filled with frontal clouds that had very little convective activity. The western part of North Dakota in particular was not suitable for any seeding operations over a large area. The eastern part of South Dakota seems more suitable for operations for rain increase, and a number of places in southwestern Nebraska seem appropriate for hail suppression activity.

In Project Cloud Catcher, the decision to stand by for the day perhaps could have been avoided from the satellite observation of little activity over the Black Hills and the weakening tendency around the area.

June 12, 1971: This was another seed day for the North Dakota Pilot Project, but seeding was not carried out for lack of enough cloudiness over the area. Most of the day was clear in McKenzie County with some scattered cumulus in the afternoon. It was a non-operational day in the Rapid City area.

Early morning (0349 MDT) IR photographs (Fig. 4a) indicate that most of the southeastern part of South Dakota is covered with high clouds, with the most severe activity around the south central part of the state. The activity has extended slightly into Nebraska and also to the east. Central North Dakota also has some high cloud cover probably associated with storm activity.

The late morning picture (1150 MDT) from ATS-III (Fig. 4b) indicates that the severe activity has moved slightly southeast. Major cloud cover is now over the southern part of South Dakota and Nebraska, with more severe activity over eastern Nebraska and south of it. Less dense and scattered clouds cover the rest of North and South Dakota with slightly more dense clouds over northeastern North Dakota. There is not much cloudiness around the Black Hills. By afternoon (1445 MDT) the NOAA-1 photograph (Fig. 4c) shows a severe local storm (hail likely) south of the Black Hills area. Other large storm areas are over central and eastern Nebraska; the latter has extended into the extreme southeastern corner of South Dakota. North Dakota has cumulus activity in the northwest with a large cell on the northern border. The Black Hills area also has some cumulus activity and there is scattered cloudiness all over North and South Dakota.

Although the area around McKenzie County had no suitable clouds for seeding operations, the region north of it seems, from the satellite photographs, to be quite suitable for rain increase operations during the afternoon. Cloud developments and movement over South Dakota (as observed from satellite photographs) indicate that, barring the Black Hills area, the remaining portion of the state might have been suitable for rain increase operations during early hours only. No enlarged view of the morning ATS-III photograph for the area was available to judge

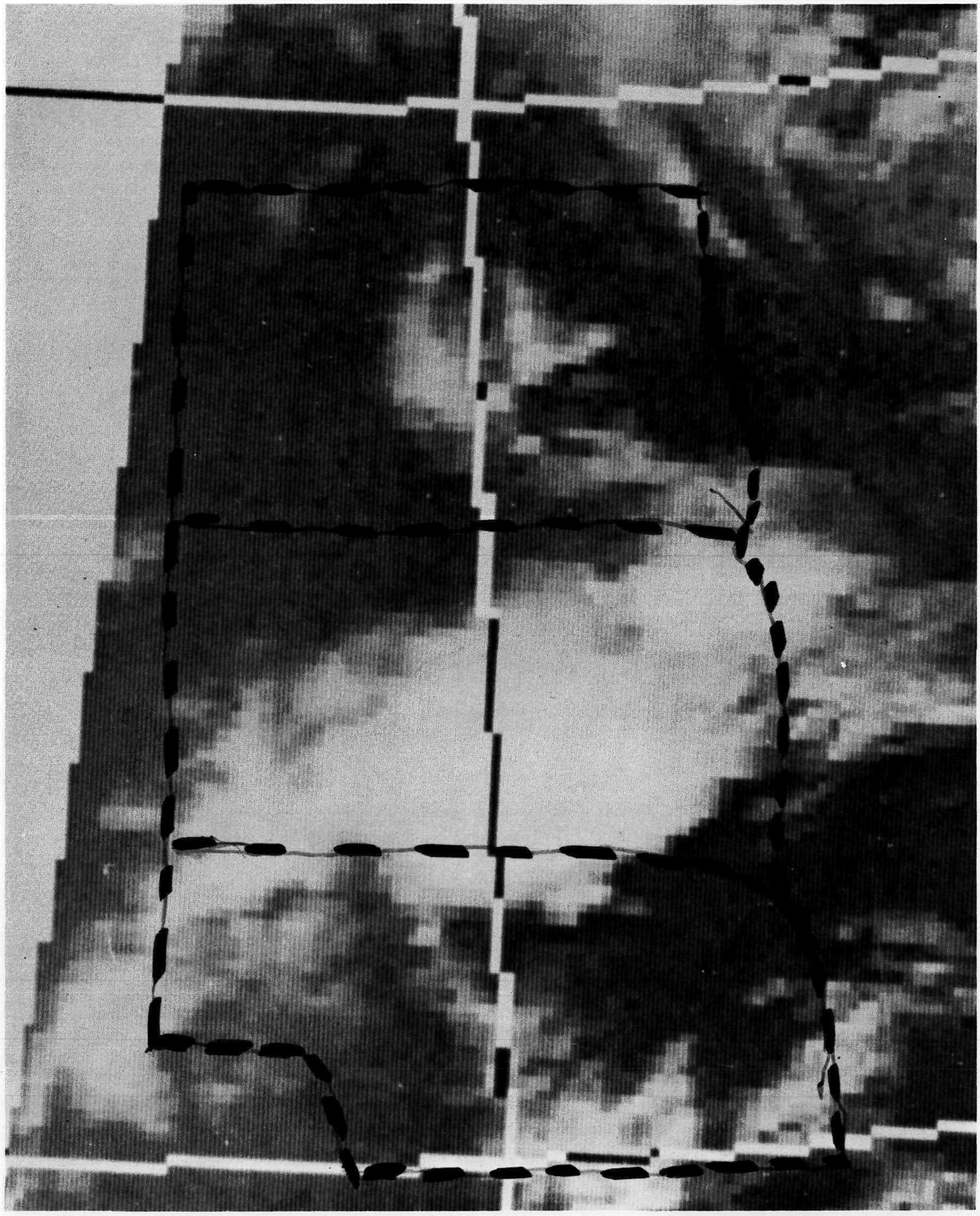

Fig. 4a. June 12, 1971, 0349 MDT: NOAA-1 IR photograph.

Fig. 4b. June 12, 1971, 1150 MDT: ATS-III picture. (No enlarged view was available.)

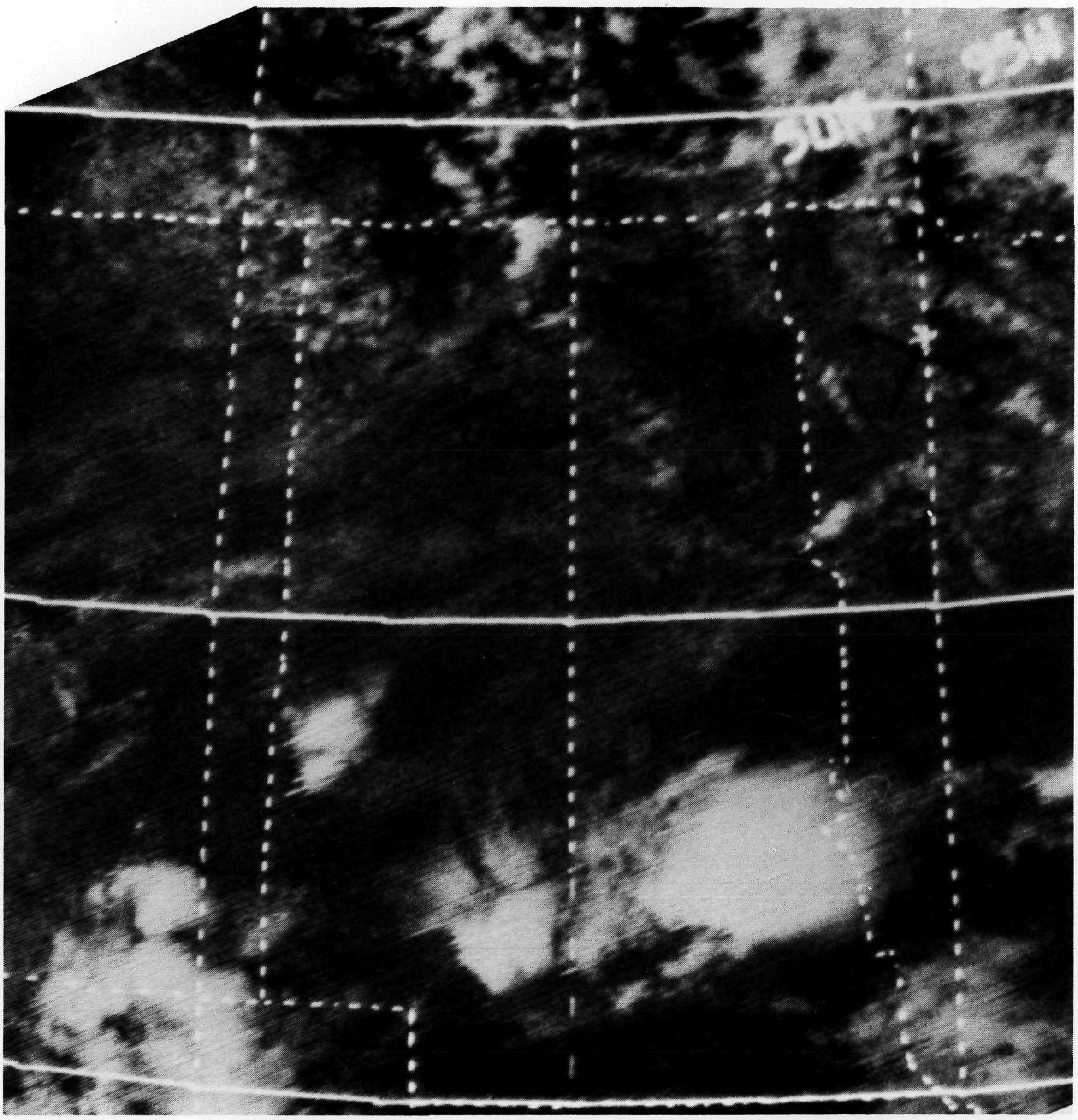

Fig. 4c. June 12, 1971, 1445 MDT: NOAA-1 video picture.

better the convective nature of the cloud cover. In the afternoon a localized hail suppression activity could have been conducted south of the Black Hills area. The eastern storm zone of Nebraska could have been treated in the early hours. By afternoon extensive cirrus cover has developed over the region, whereas the storm zone in central Nebraska seems to be in proper stage for hail suppression activity at this time.

June 18, 1971: This was a no-seed day in the North Dakota Pilot Project. There were a few light showers in the morning over McKenzie County, mostly from stratiform type clouds. In the afternoon hail was predicted when the radar echo-top began to reach 45,000 ft in height. A hail shower occurred over the area at about 1630. For the area around Rapid City, the forecast was for numerous heavy thunderstorms in the afternoon and early night with a few severe thunderstorms with hail and possible tornado activity. Observations also indicated heavy thunderstorms that moved through the northern part of the area in late afternoon. Severe weather also occurred in the southwestern part of North Dakota.

No early morning IR photograph was available for this day. The late morning (1159 MDT) ATS-III picture (Fig. 5a) shows one severe storm area (probably with hail) over northeastern Nebraska; cirrus cover of the same extends northeast. North and northwest North Dakota have cloud cover that seems more of a scattered nature and is probably composed mostly of layer-type clouds (enlarged view was not available). Some cloudiness also appears over the western sides of South Dakota and Nebraska.

The afternoon (1425 MDT) NOAA-1 picture (Fig. 5b) indicates that the severe storm seen earlier in Nebraska has weakened and moved south with its cirrus top extending into Iowa. Severe storms have developed in the southwestern part of North Dakota and extend into extreme northwestern South Dakota. There are two distinct storm zones here with a clear area in between; both are in the developing stages and indicate hailstorm or tornado. This storm development was not seen in the morning ATS-III picture. Convective cloud developments are also seen over most of western North Dakota in the region north and northwest of the severe storm area.

This was a most suitable day for hail suppression activity over western North Dakota and northwestern South Dakota. The early detection of large storms can facilitate proper operation of the hail suppression activity. It is unlikely for radar (that detects precipitation cells only) to observe the extent of the severe activity region. Furthermore, early detection by radar would not have been possible from Watford City, which was away from the severe storm region. The convective activity of northwestern North Dakota as detected by afternoon satellite imagery also seems suitable for conducting seeding operations for rain increase.

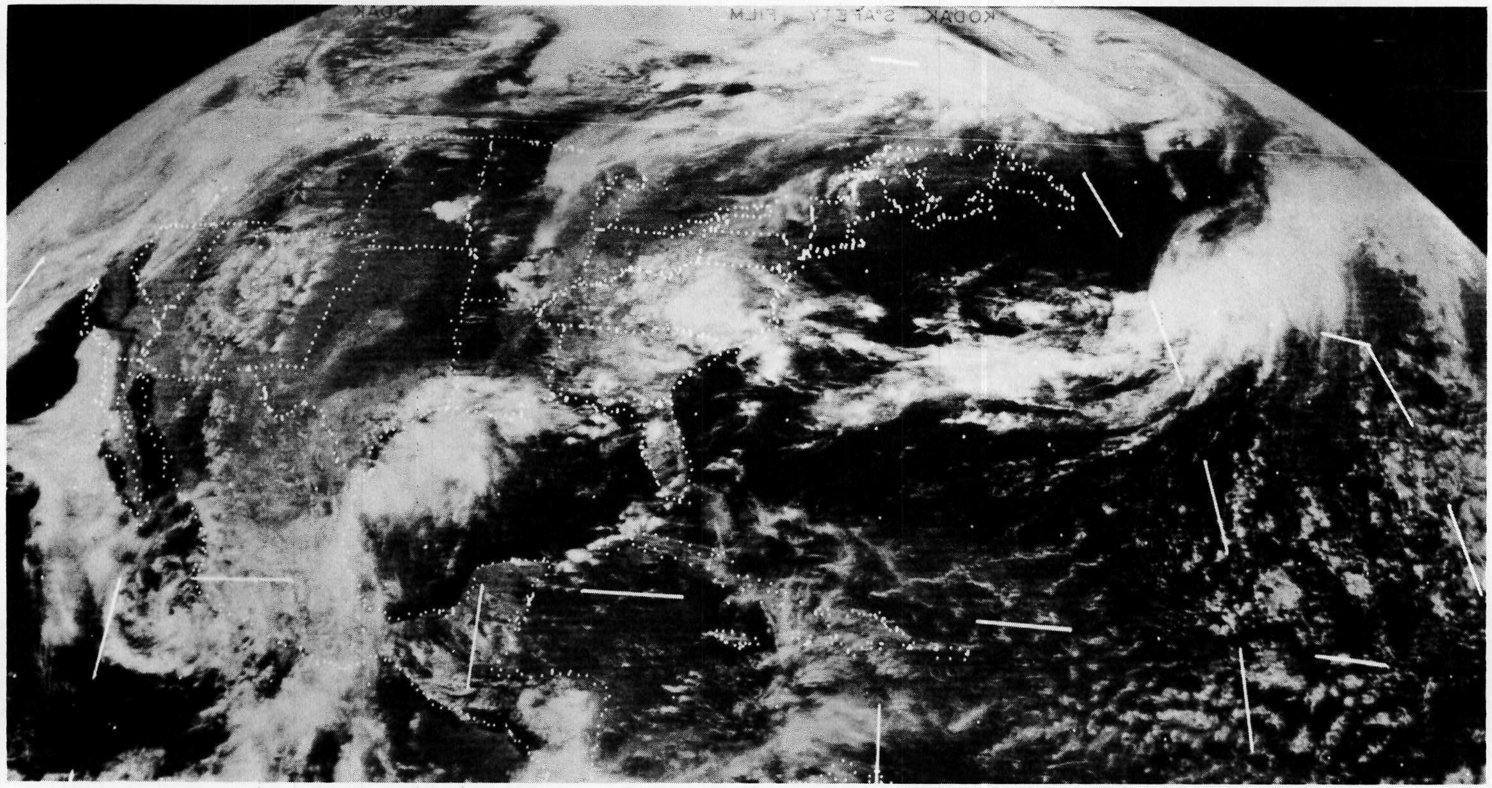

Fig. 5a. June 18, 1971, 1159 MDT: ATS-III picture. (No enlarged view was available.)

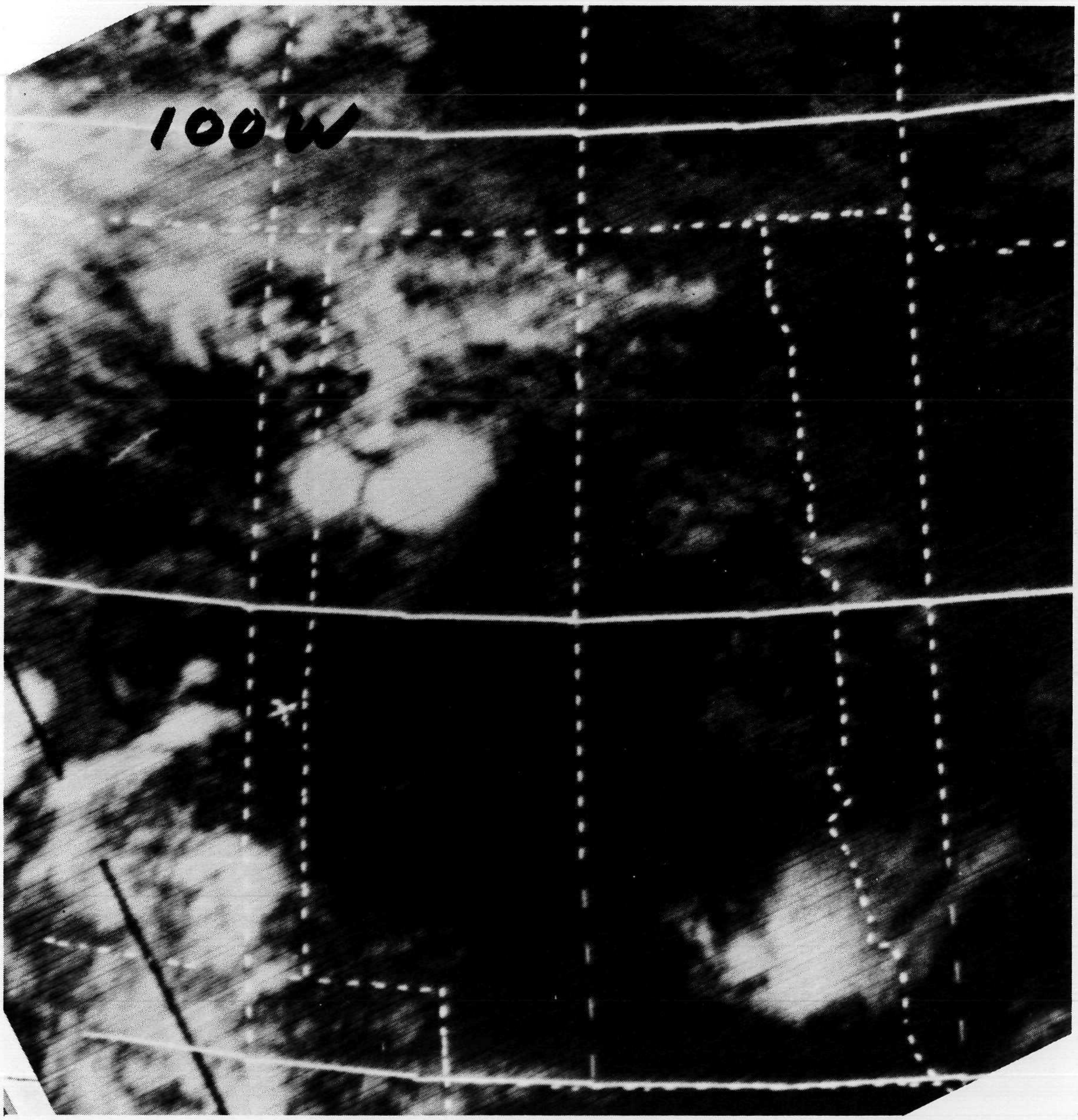

Fig. 5b. June 18, 1971, 1425 MDT: NOAA-1 video picture.

June 20, 1971: For the North Dakota Pilot Project this was a seed day and seeding was carried out for rain increase. McKenzie County had mostly convective clouds. There was a shower at about 2000 hours, and the maximum radar echo height observed was 24,000 feet. It was a non-operational day in the Rapid City area.

There was no early morning IR photograph available. The late morning (1204 MDT) ATS-III picture (Fig. 6a) shows cloud cover (with convective activity) over a large region east of the Black Hills that extends both to North Dakota and Nebraska. Apparently the Black Hills area is clear. (No enlarged view was available.) Part of northeastern North Dakota seems covered with thin middle or high clouds.

In the afternoon (1418 MDT), NOAA-1 picture (Fig. 6b), the convective activity seen earlier over a large region has moved southeast with cloud cover extending across Nebraska. There are signs of cumulus activity around the Black Hills area; some clouds are large and towering. Some large cumulus are also seen over northwestern North Dakota; otherwise most of North Dakota and part of South Dakota are covered with clouds of cumulus or stratocumulus type.

As can be seen, most of North Dakota is covered with clouds of small development. Even the main cloud cover area (over South Dakota-Nebraska) does not show very severe activity except for a few large cells over southeastern Nebraska. Although generally a suitable day for seeding throughout North Dakota, not much result can be expected from rain increase operations over this region. A much better situation exists over the area around the Black Hills. However, the most suitable situation is in southern South Dakota and Nebraska, and it is quite probable that southeastern Nebraska clouds are also suitable for hail suppression activity.

July 10, 1971: This was a seed day for the North Dakota Pilot Project. Seeding was carried out around noon for rain increase and later for hail suppression. McKenzie County had mostly convective clouds with associated stratocumulus, altocumulus, and cirrus. Thunder was heard over the area and the maximum echo height observed by radar was 45,000 feet. It was a non-operational day in the Rapid City area.

No early morning IR photograph was available for this day. The late morning (1155 MDT) ATS-III photograph (Fig. 7a) indicates cloud cover over the eastern part of North and South Dakota that is part of the large system lying over the states to the east. Some cloudiness appeared east of the Black Hills area. The rest of the three states is clear but another cloud system is approaching North Dakota from the northwest with severe activity just north of North Dakota.

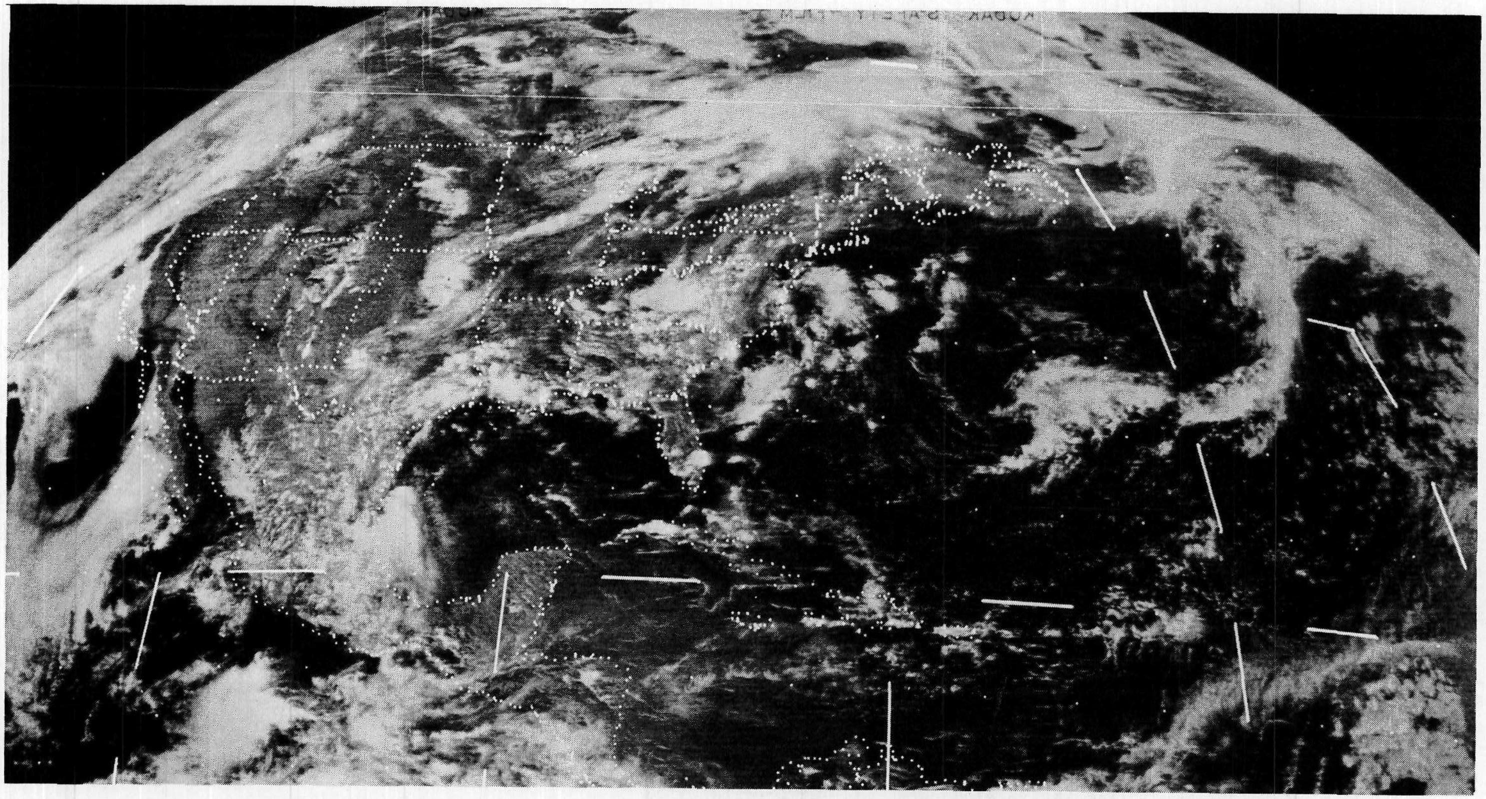

Fig. 6a. June 20, 1971, 1204 MDT: ATS-III picture. (No enlarged view was available.)

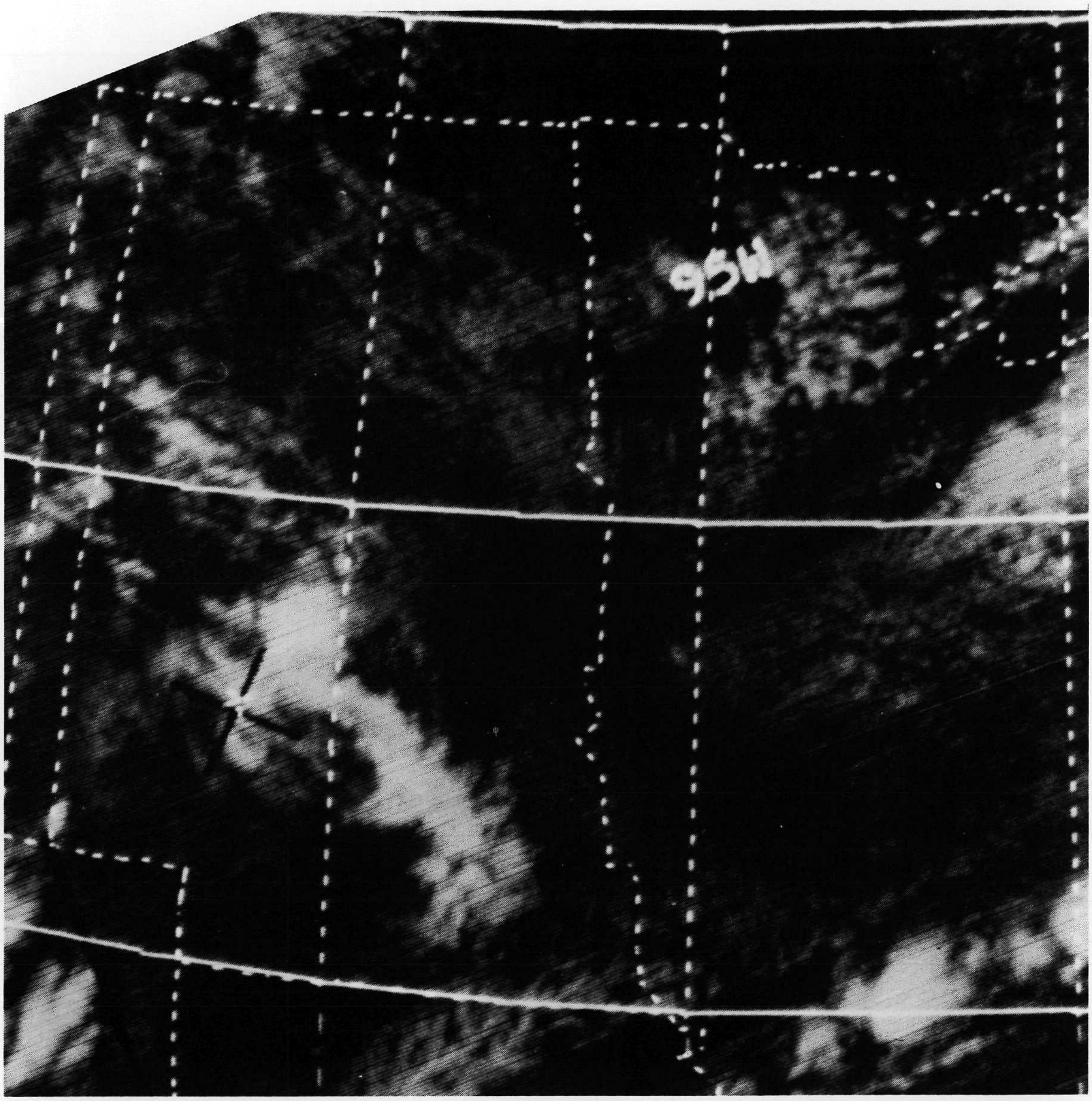

Fig. 6b. June 20, 1971, 1418 MDT: NOAA-1 video picture.

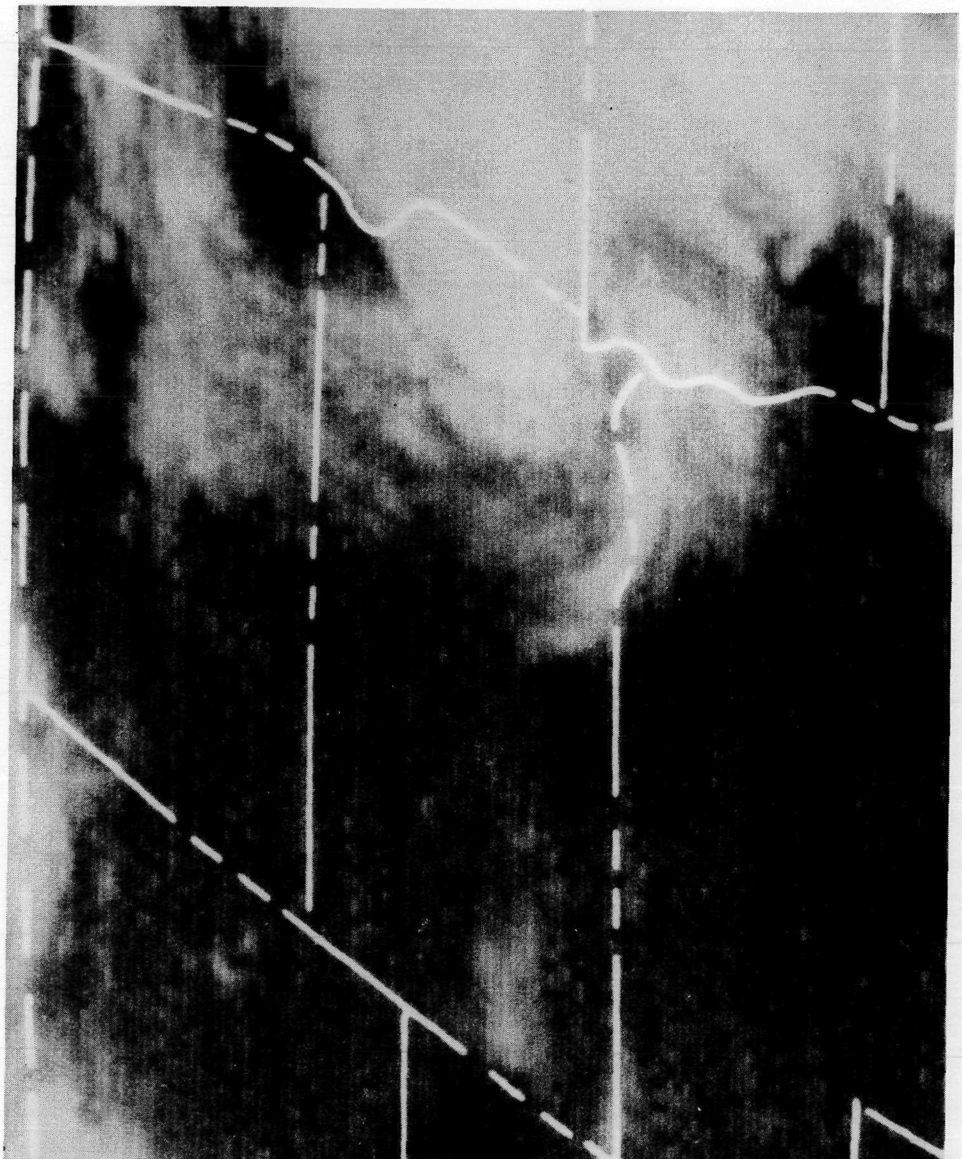

Fig. 7a. July 10, 1971, 1155 MDT: ATS-III picture.

Afternoon (1440 MDT) NOAA-1 photographs (Fig. 7b) indicate a severe storm in northwest North Dakota near McKenzie County that has already developed extensive cirrus cover. There is another severe storm developing just west of McKenzie County in Montana. Both of them seem to be hailers and are part of the large frontal system in the north. The eastern parts of North and South Dakota have cloudiness of cumulus nature with more towering clouds in North Dakota. The remainder of the three states, including the Black Hills area, is clear.

It is a most suitable day for hail suppression activity over the northwest region of North Dakota. Since the storm in the north is in the mature stage it would be proper at the time of the photograph to give more emphasis to the storm in the west that is developing and approaching McKenzie County. It would be appropriate also to have some operation for rain increase in the eastern part of North Dakota.

July 27, 1971: This was also a seed day in the North Dakota Pilot Project and seeding was carried out for rain increase. Observations around McKenzie County indicated convective clouds over the region and there were nice showers through the eastern part. In the Rapid City area it was cloudy with a few sprinkles; the decision was for a no-seeding operation in the absence of any indication of a possibility of low level convective clouds.

There was no early morning IR photograph available. Observations with late morning (1211 MDT) ATS-III photographs (Fig. 8a) indicated overcast skies over most of the three-state region. Clouds are more dense over the Black Hills area and northeastern South Dakota. Cloud cover is light and spotty over the major part of Nebraska. Convective development is embedded in clouds over most of the region and particularly over North Dakota. As can be seen this semicircular cloud pattern is part of a large system that has its vortex center in the north.

By 1400 MDT the NOAA-1 afternoon photograph (Fig. 8b) shows that the main pattern has moved east and shows a decrease of cloud cover over the three states. The wide semicircular band of cloud cover still runs along the southern part of South Dakota extending from southeast to northwest through the Black Hills area and seems composed mainly of stratiform clouds. North Dakota throughout is covered with cumulus and stratocumulus clouds, of which a few in the north may be towering and probably a few cumulonimbus cells in the extreme east. A few stormy clouds can also be seen in southeastern Nebraska but the main severe activity is further east.

Most of South Dakota had clouds of stratiform type with little or no instability and seems unsuitable for any seeding operation, but a major part of North Dakota with clouds of more convective nature had a better chance for rain increase with seeding. None of the clouds of the three states were suitable for any hail suppression activity.

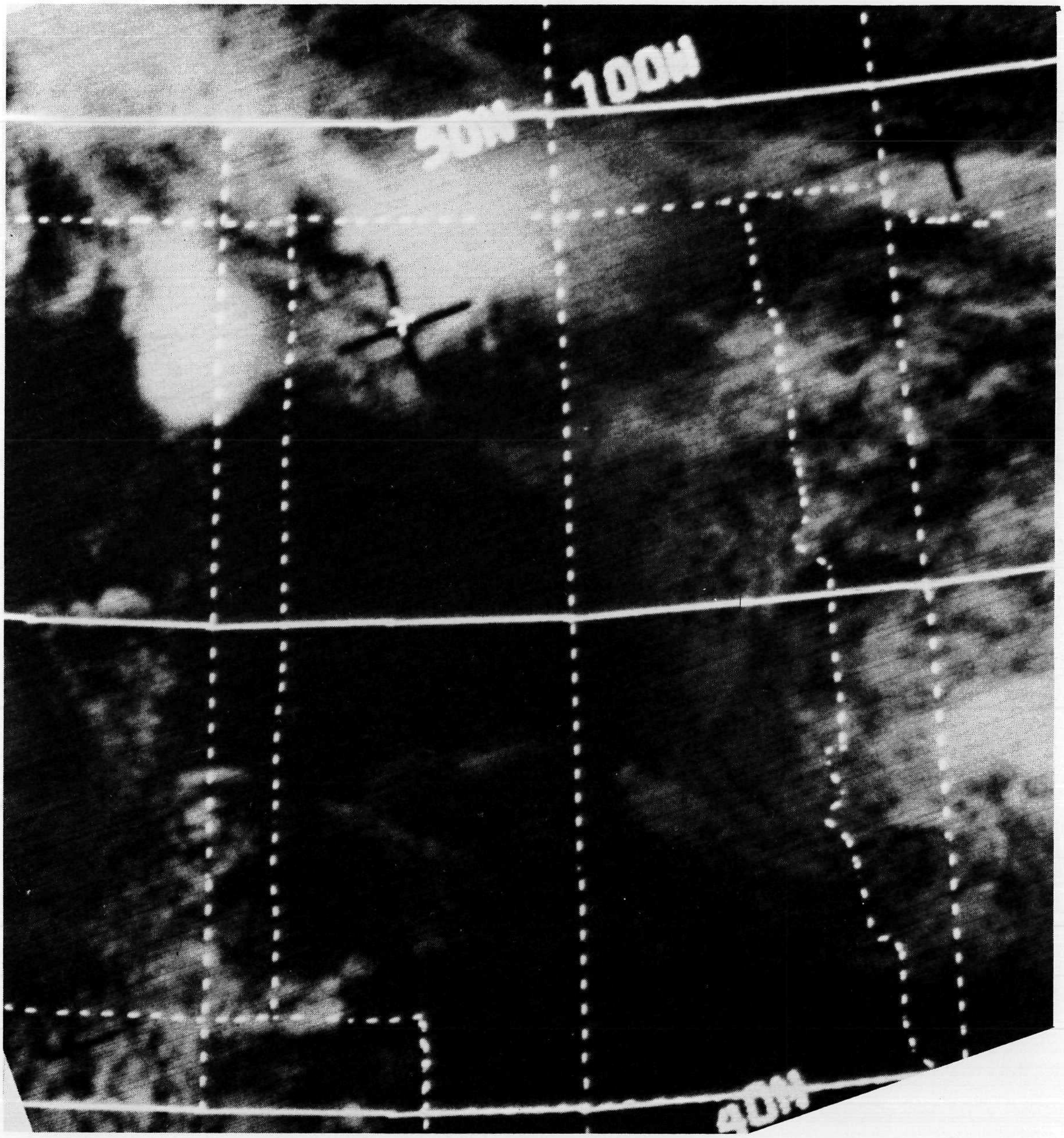

Fig. 7b. July 10, 1971, 1440 MDT: NOAA-1 video pictures.

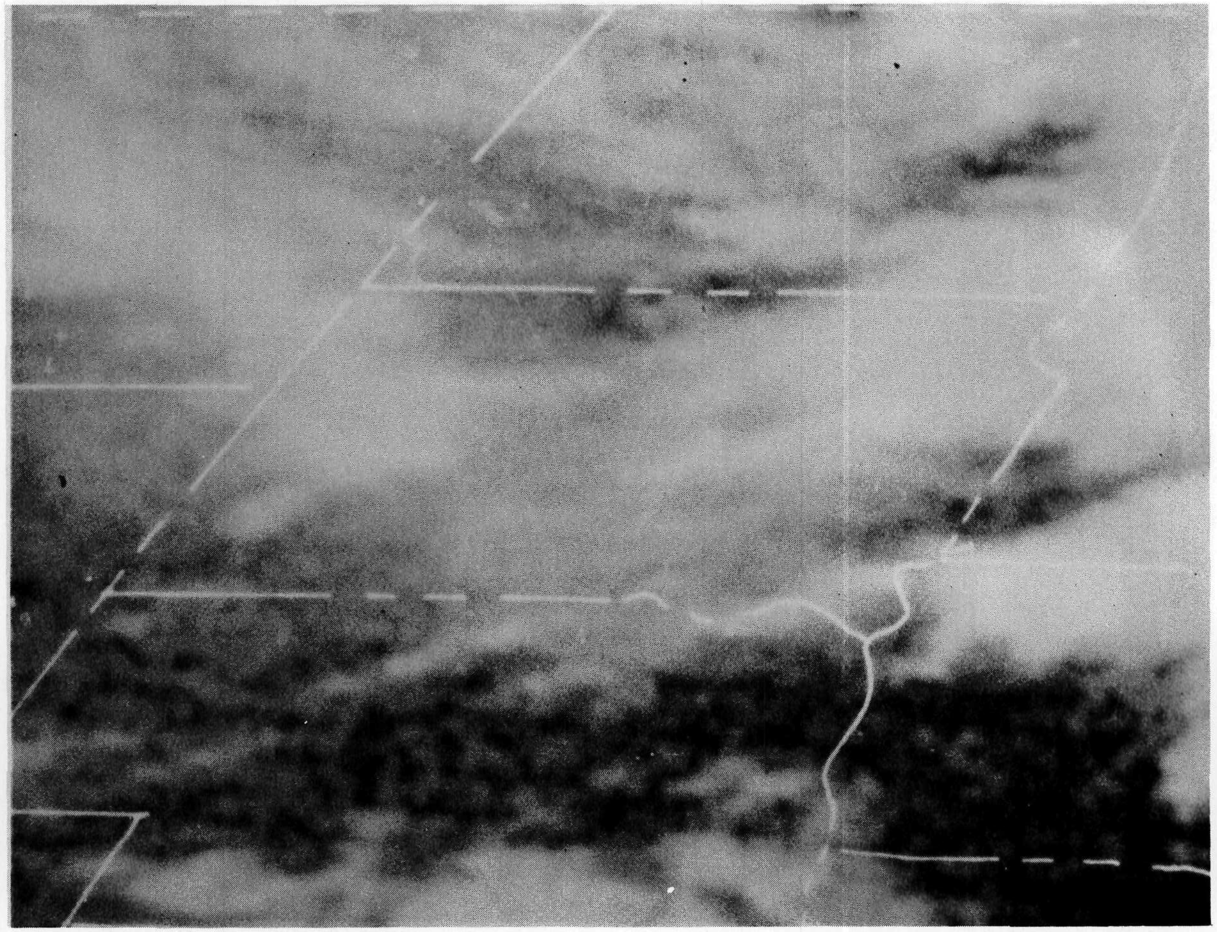

Fig. 8a. July 27, 1971, 1211 MDT: ATS-III picture.

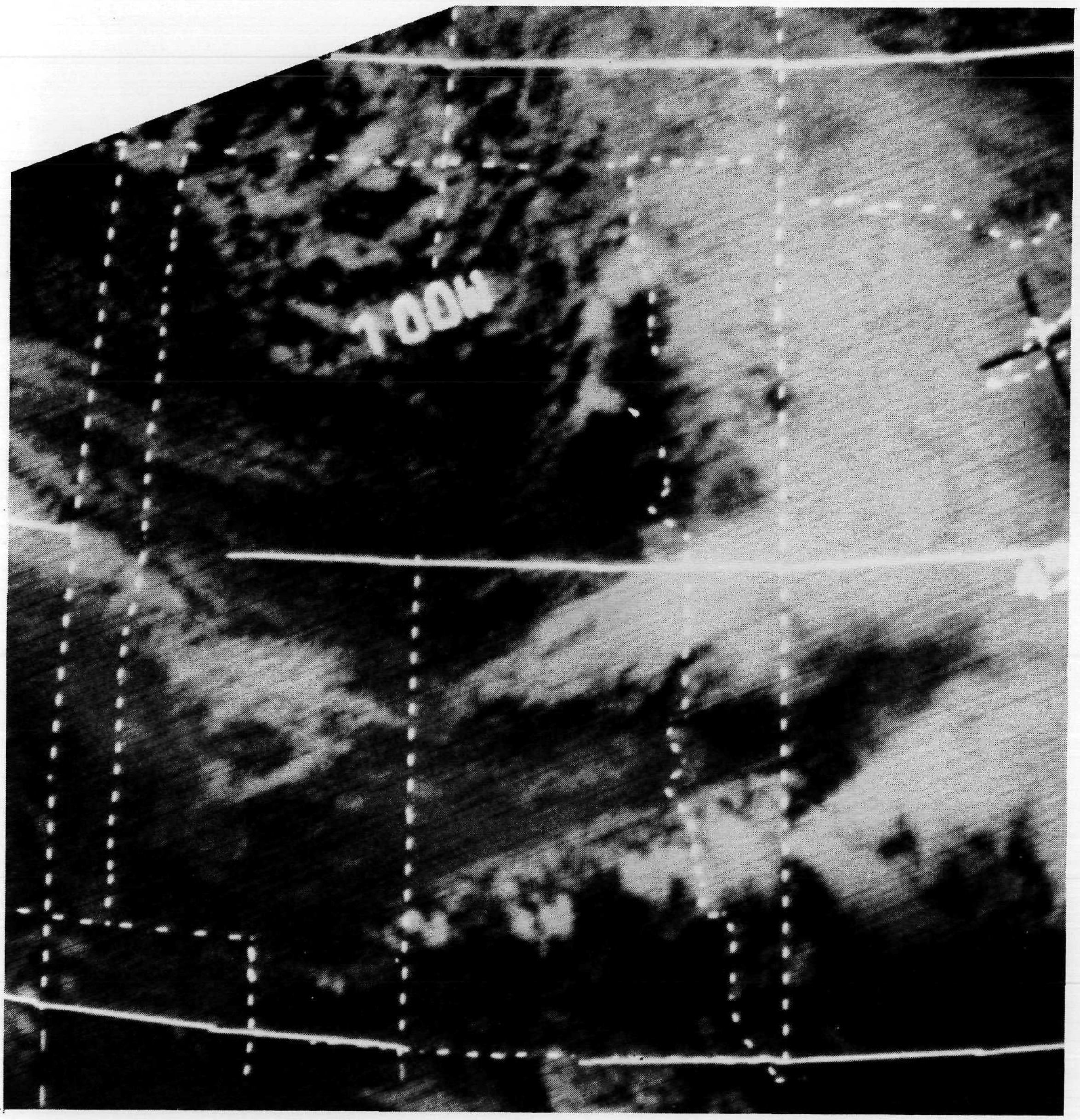

Fig. 8b. July 27, 1971, 1400 MDT: NOAA-1 video picture.

4. FURTHER DISCUSSION AND CONCLUSIONS

This survey has demonstrated that weather satellites can now provide timely views of cloud conditions that provide additional intelligence for weather modification programs, even over land areas where conventional observations are dense. In order to realize the maximum value of these data, it is essential to have correct interpretation of the cloud photographs. One must at the same time be aware of some gross limitations and the capabilities of the different types of imagery. Some of the characteristics that were obvious from the present survey can be summarized as follows:

1. Individual clouds are not seen in the pictures because of their small scale and cannot be identified as when they are seen from the ground. In their place, groups or clusters of clouds are seen. This seems likely to limit the usefulness of the satellite imagery in single-cloud or cloud-cluster seeding experiments such as our Project Cloud Catcher.

2. The resolution of the satellite camera and IR sensors does not permit detection of many small scale features that identify the cloud types to the ground observer.

3. The nature of the clouds can often be deduced from the gross features, particularly when an enlarged view of the region of interest is available.

4. Large scale convective cloud features, if not embedded in other clouds, are easy to identify, and large thunderstorms easier, although sometimes cloud layers or debris obscure the cumuliform structure.

5. Local severe storms are characteristically separated from other cloud cover and, although each pattern is observed as a large unit with little internal detail, their convective nature is easily identified.

6. Identification of stratiform cloud layers is not so easy. In general, they are identified by their amorphous sheet nature, particularly when they are two or more layers thick, but it is impossible to distinguish between separate layers or cloud elements.

7. Height estimations are better in IR pictures. When simultaneous daytime video and IR photographs are available, it will be possible to better judge the phase of the convective developments.

One season's survey has brought out the possibilities and usefulness of satellite imagery in weather modification programs. As was said earlier, satellite-observed cloud type, pattern, and coverage have a definite relation with the type of operational decision made over a particular region. Perhaps we may restate the conclusions that:

1. When available in real time, proper decisions for many weather modification projects could be made with the satellite imagery alone. Incorporated with the other meteorological information normally available, it makes the decision making much easier.

2. IR nighttime imagery, together with daytime pictures, would provide continuity and identify changes in cloud pattern with a better estimate of cloud height.

3. Satellite pictures would be of little direct value for detailed identification of separate cloud elements as essential for single cloud seeding experiments but can aid in local forecasting and analysis for these projects also.

Weather satellites provide another tool for precise weather analysis in weather modification programs and also can provide better insight into the mesoscale features prevailing over a region of interest. The potential value has further increased with the advent of geo-synchronous satellites that can provide imagery at regular short intervals that add the capability of observing motions and developments in cloud pattern. Such information could be of enormous value when available to the weather modification programs in real time like any other meteorological information.

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