NOAA-3 Satellite Observations of Thunderstorms in Alaska

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ABSTRACT

The very high resolution radiometer imagery from the NOAA-3 satellite is used to obtain the spatial and temporal distribution of thunderstorms in Alaska. Although the observations presented here are confined to only one summer, they show 1) the capability of NOAA-3 very high resolution radiometer imagery for thunderstorm studies, and 2) that the widespread thunderstorm development is the result of the interaction of large-scale motion with topography of certain areas in the interior of Alaska.

1. Introduction

The interior of Alaska has a continental type climate, hence during the summer intense convective activity is prevalent during the day. These convective clouds often develop into thunderstorms and the resulting lightning is believed to be the cause of many forest fires in Alaska (Barney, 1971). The cumulus activity is an important part of the summer weather in the region.

Climatological studies in this region are mainly confined to specific locations, while few or no studies of the climatology of large areas exist. The main reason for this is the small population and hence the sparse network of meteorological observations for the state. In Fig. 1 the network of upper air observation stations is shown.

In this paper we show that the very high resolution radiometers of the NOAA-3 satellite, although restricted by a limited number of observations per day, are capable of locating the position of thunderstorms. Thus it is possible to use the satellite imagery for the purpose of obtaining thunderstorm climatology in remote areas where logistic make routine observations difficult. Study of the location of thunderstorms in relation to topography and to satellite observed weather conditions also allows some inferences regarding the mechanism of thunderstorm development in Alaska.

2. Previous studies

Purdom (1973) discussed the uses of ATS-3 Satellite imagery for locating the meso-high boundary and hence the region of consequent thunderstorm development, which may escape detection by radar. Weiss and Purdom (1974) have mentioned the use of GOES satellite images as a tool for forecasting the region of afternoon thunderstorm development as a result of the early morning cloud cover. In addition to such special studies using satellite imagery, the geostationary satellites (GOES) are routinely used to track and locate the positions of thunderstorms and study their formation. These satellites with their regular half-hourly observations provide time lapse observations of the life cycle of thunderstorms. The polar orbiting weather satellites, such as the NOAA-3 and the Air Force DMSP satellites, have sensors with similar resolution and capability as those of the GOES. However, because of the limited observations possible with polar orbiting satellites, it is often not possible to obtain imagery within the active stages of thunderstorm development. The main application using the imagery from these polar orbiting satellites for the study of thunderstorms, so far, has been to supplement those from GOES satellites (Purdom, 1973; Ernst, 1975).

In Alaska, the NOAA-3 satellite passes over the interior of Alaska near noon and in the evening around 1700 AST. Since these times correspond to the periods where cumulus activity begins and ends in the interior of Alaska, it has been suggested by Jayaweera and Ahlnas (1974) that it is possible to use the imagery to locate the regions of thunderstorm activity. Such information was found useful in locating possible areas of forest fires, as an aid in their early detection and management. Apart from this there are no other reports indicating the regular use of polar orbiting satellites for detection of thunderstorms.

On the other hand there are other studies attempting to relate the meteorological conditions to the formation of thunderstorms in Alaska. The first published study is by Sullivan (1963), who tried to relate the areas of low-level convergence to thunderstorm occurrence. The other studies were performed by Comisky (1966) and Sierra Research Corporation (1973) as a part of the Bureau of Land Management fire control efforts. These

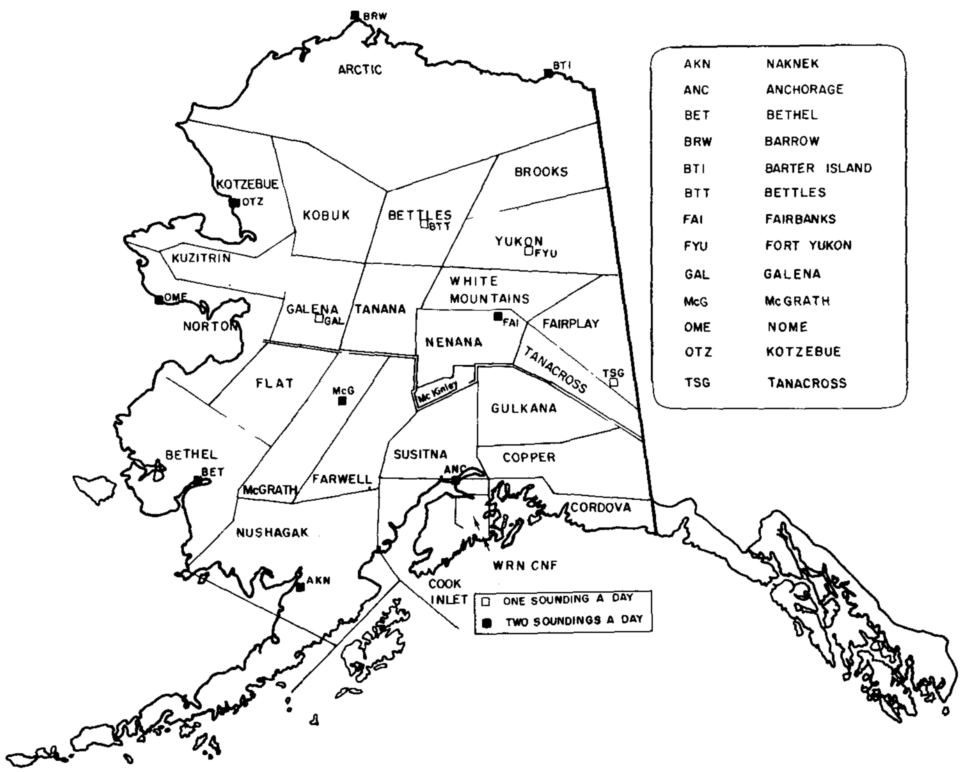

FIG. 1. The network of upper air weather stations and fire-weather districts of Alaska. The weather stations are abbreviated as practiced by the National Weather Service. Their actual names are shown on the right-hand side of the figure.

reports ascribed the main cause of convective development to the destabilization of the air mass in contact with the strongly heated surface, and classified the thunderstorms in Alaska into the broad category of air mass thunderstorms, i.e., those that are formed in the absence of any major large scale circulation, such as cyclonic disturbances or frontal overrunning (Byers and Rodebush, 1948). The reason these past studies were not able to arrive at more conclusive meteorological factors for thunderstorm formation than those suggested is due to the lack of observational data. We hope to show that information of satellite imagery will bridge this necessary data gap. The possibility of obtaining spatial and temporal distribution of thunderstorms will provide data useful in drawing important conclusions as to the topographical factors that give rise to the development of thunderstorms.

3. Satellite observation of thunderstorms

During the summers of 1973 and 1974 we have used the NOAA-2 and NOAA-3 very high resolution satellite imagery for locating thunderstorms. The very high resolution radiometers (VHRR) abroad the NOAA polar orbiting satellite are sensitive to the reflected solar radiation in the 0.6 to 0.7 μm band and to the emitted thermal radiation in the water vapor "window" region of 10.5 to 12.5 μm; and have a resolution of 0.9 km at nadir. In order to distinguish the thunderstorm from other clouds and from land features both these images are necessary.

At the outset, the existence of thunderstorms may be inferred from discrete clouds that appear bright in both infrared and visible and have a fibrous anvil in the visible (see Jayaweera and Ahlnas, 1974). A more accurate determination of cumulus clouds that are most likely to produce lightning could be made by enhancing the infrared imagery in such a way that the gray scale from black to white corresponds to a temperature scale as shown in Fig. 2. The photography of imagery with this gray scale will have two black regions corresponding to a temperature range from $-20°$ to $-28.8°$C and below $-40°$C. Since cumulus clouds colder than $-28°$C may be considered to be thunderstorms, these cumulus clouds can be easily distinguished in the imagery. An example is shown in Fig. 3. The dark clouds surrounded by a medium gray correspond to cumulus with tops between $-20°$ and $-28.8°$C that may subsequently form thunderstorms. The gray scale at the warmer end is chosen to preserve some of the land features and low clouds. The existence of anvils in the cumulus could be distinguished by the appearance of a black area at the colder end of the gray scale for temperatures colder than $-40°$C.

Most of the satellite coverages are around 1000, 1200,

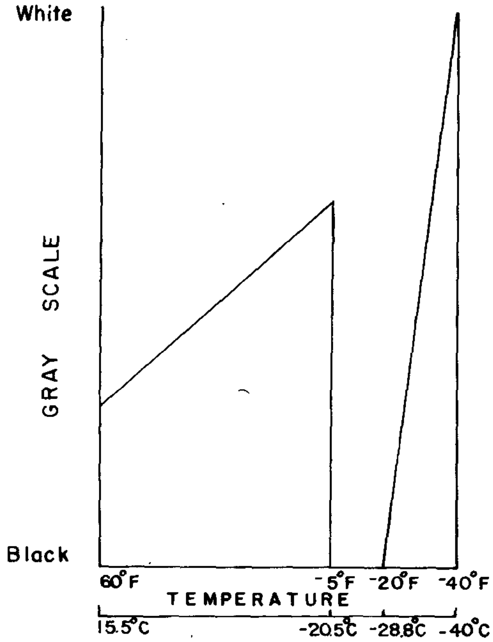

FIG. 2. The temperature scale corresponding to the gray scale of the infrared enhanced image.

and 1700 AST, departure from these times being less than one hour either way. So, these images provide the thunderstorm development and distribution over the entire state, more or less during the initial and final stages of convective activity. Because of the limitation in the number of possible observations by polar orbiting satellites, it is not possible to study the entire sequence of the life cycle of a thunderstorm; but the satellite observations provide locations of thunderstorm activities, their lateral dimensions as viewed over the cloud top, and other associated features, such as anvils and cloud distributions, that may help to identify the thunderstorm type, i.e., squall line, frontal, or air mass.

4. Spatial and temporal distribution of thunderstorms

The locations of thunderstorms on the satellite imagery were determined using a rectangular grid $\frac{1}{2}°$ in latitude and 1° in longitude. The positions of those thunderstorm cells from morning and evening images were then plotted on an Alaska fire-weather map divided into 26 fire-districts. The division of the state into such fire-districts was shown in Fig. 1. In this study, we have considered 23 out of the 26 fire-districts and left out the three districts Cordova, Artic, and WRN CNV, since no thunderstorm activity was observed over these districts. The pattern of distribution of the thunderstorm occurrence for different periods during summer as well as for various regions has been expressed through thunderstorm days. A thunderstorm day for any fire-district is defined as a day having at least one thunderstorm observed in any part of the district. So according to the above criterion, the maximum number of thunderstorm days possible over the entire state during one calendar day is 23. The choice of defining thunderstorm days in relation to each fire-district is quite arbitrary, but the use of the same may yield extra information on the thunderstorm climatology useful to the Bureau of Land Management.

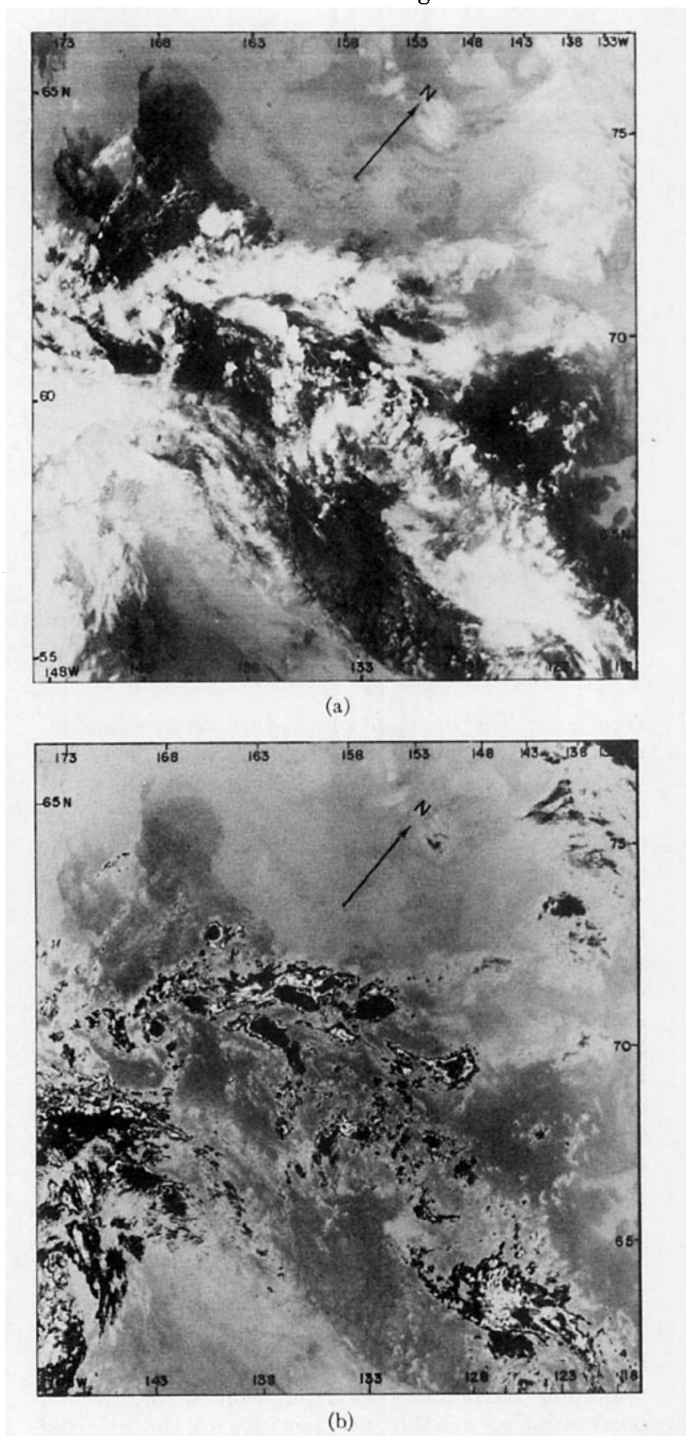

FIG. 3. An example of the application of image enhancement of infrared imagery showing the existence of thunderstorms: (a) unenhanced, and (b) enhanced infrared imagery.

Using the above criterion of thunderstorm days, a histogram of cumulative thunderstorm days for two-week intervals for the entire state was obtained and shown in Fig. 4 for the period from 1 June to 9 August 1974. The thunderstorm distribution for this period shows a peak in the latter part of June and an increasing trend again after the first week of July.

From the daily locations of thunderstorm development, most of the activity has been found to take place at some higher altitudes rather than over the river flats, with the exception of the Tanana flat southwest of Fairbanks. All other river flats were found to have a very low level of activity or none at all. In general the preferred areas of thunderstorm development are shown in Fig. 5a. These are regions between the west to southwest of Lake Minchumina and northwest of the Kuskokwim river over the Kuskokwim mountains (A); Kokrines Hills region and north to northwest of the Koyukuk River (B); Davidson Mountains and Porcupine River (C); and the entire mountainous area between the Tanana and Yukon Rivers extending south to southwest of Nenana (*D*). The locations of preferred areas on mountain slopes with open water surfaces probably indicate the importance of the slopes where the solar heating is stronger than that on the plains. This effect is similar to that observed in the eastern Rocky Mountains at much higher elevations (approx. 12,000 ft) (See Henz, 1972).

Of these four regions, the most persistent cumulus activity was found to be in region D. This was evident when daily locations of thunderstorms were superimposed, one over the other, for the entire season. Within this region, it is possible to further delineate five areas where thunderstorm activity is highly prevalent. These areas are shown in Fig. 5b. Over these five areas together, widespread developing cumulonimbus were observed on the morning satellite imagery for 70% of the days that had thunderstorm activity over any part of the state. This does not mean that 70% of the total thunderstorm occurrences in Alaska were observed in these regions, because thunderstorms could develop anywhere over these regions as well as other parts of the state on the same day. These five regions are apparently the area where most of the thunderstorms developing over the east central part of the state originate. Topographically, this area is at an elevation between 1000 ft and 2000 ft on mountain slopes which extend up to 5000 ft. Although no particular orientation of the mountain slopes could be identified because of the large grid scale, a major part of this region as located on the Alaska topography map is on the slopes with river valleys to the south, southwest, and west.

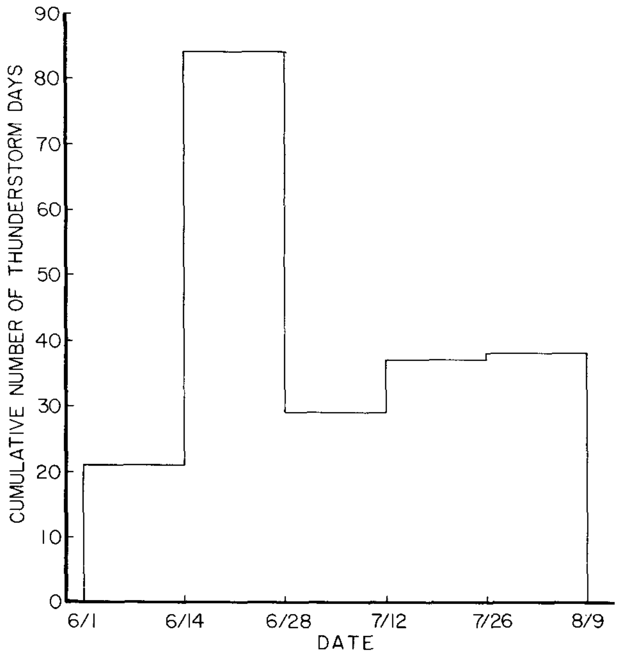

FIG. 4. The temporal distribution of cumulative thunderstorm days for two-week period for the 23 fire districts of Alaska. A thunderstorm day for any fire district is defined as a day having at least one thunderstorm observed in any part of the district.

5. Discussion

Because of the sparse network of meteorological stations it is not feasible to relate the spatial and temporal distribution of thunderstorms to various meteorological conditions such as solar heating, moisture advection, or low-level convergence. However, the satellite imagery by itself provides sufficient clues for a good understanding of the type of weather conditions that give rise to small scale and wide spread thunderstorm activity.

Satellite imagery often indicates isolated thunderstorms in certain areas with little or no clouds elsewhere. This type of formation is most likely due to intense solar heating in the interior of Alaska. These thunderstorms occur in preferred areas such as mountain slopes and suggest the importance of interaction of solar heating and topography on their development. Hence they may be classified into the category of air mass thunderstorms.

On many occasions, satellite imagery indicates widespread and intense activity in Alaska (Fig. 6). These are the situations where intense lightning and heavy rainfall occur. In such cases, the satellite imagery shows a line formation of cold top cumulonimbus (see boxed area of Fig. 6). Furthermore the line of thunderstorms separates a clear area from that of a cloud-covered area, suggesting that these storms are formed along a dry line. Often we can recognize the jet stream in the vicinity of thunderstorms and the associated cirrus covering the cumulonimbus clouds. This type of thunderstorm formation is different from the air mass type, being associated with large scale weather systems. Hence, we may conclude that widespread thunder-

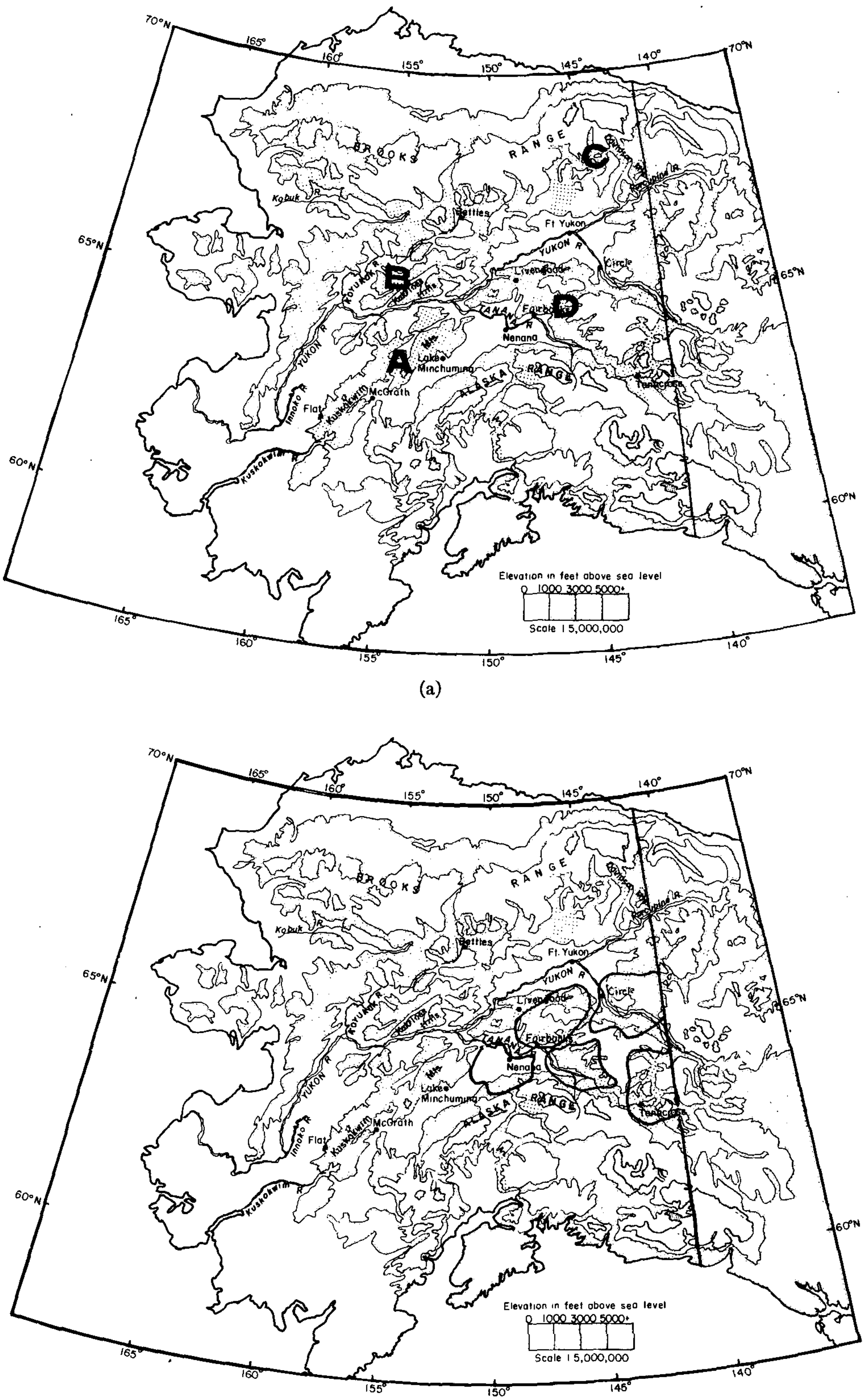

FIG. 5. (a) Preferred areas of thunderstorm development. (b) The region of most frequent convective development where cumulonimbus developed in the morning on 70% of days that had thunderstorm activity over any part of the state.

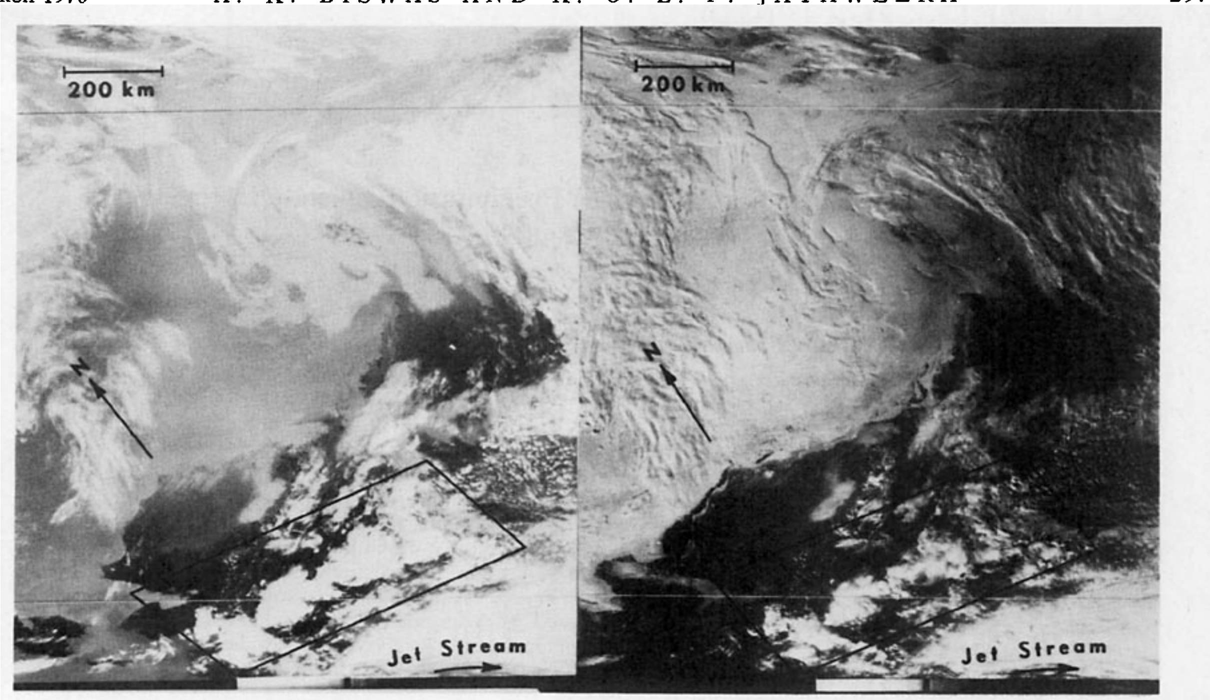

FIG. 6. The VHRR imagery at 1704 AST for the active thunderstorm day, 24 June 1974. The boxed area indicates the region of thunderstorm activity, and the axis of the jet stream is also shown. The infrared image is on the left-hand side and the visible is on the right-hand side of the figure.

storms in Alaska are related to synoptic or subsynoptic scale influences.

Information in this paper shows that satellite imagery from the very high resolution radiometer aboard the NOAA environmental satellites provided an excellent opportunity to locate the positions of thunderstorms in areas where other types of conventional observations such as radar and aircraft surveillance are not available or are logistically difficult. Information on the location of thunderstorms taken over a period of few years together with relevant weather data could give a better understanding of thunderstorm climatology for Alaska and the pertinent meteorological conditions for their formation.

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