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CLOUD AND CONVECTION FREQUENCIES RELATIVE TO SMALL-SCALE GEOGRAPHIC FEATURES

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January, 1990

CIRA Cooperative Institute for Research in the Atmosphere

Colorado
State
University

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ABSTRACT

CLOUD AND CONVECTION FREQUENCIES RELATIVE
TO
SMALL-SCALE GEOGRAPHIC FEATURES

Visible and infrared data of GOES West were collected for nine hours each day during the summer of 1986. Cloud frequency charts were computed for the area from Mississippi east to Georgia and the Gulf of Mexico north to Tennessee for each of the nine hours as well as convection frequency charts to four convection intensities as defined by the temperature of the cloud top. Strong diurnal tendencies were noted. As was expected, these charts show that over the land areas cloudiness is at a maximum during the early afternoon hours with convection at a maximum in the late afternoon and evening. Cloudiness and convection are at a maximum during the nocturnal hours over the Gulf of Mexico.

Cloud frequency shows a strong relationship to small terrain features. Small fresh water bodies have cloud minima in the afternoon hours relative to the surrounding terrain while higher terrain, especially if there is a sharp slope, have cloud maxima. The adjacent lower terrain exhibits afternoon cloud minima due to divergence caused by the valley to mountain breeze.

The sea breeze-induced convergence causes relative cloud maxima over near-shore land areas with the stronger maxima over peninsulas. It is shown that the sea breeze results in convergent low level flow regardless of the whether over a peninsula or over land adjacent to a bay or inlet. Cloud frequencies tend to be larger both in magnitude and areal extent over peninsulas. Small scale geographical features show no relationship to convection, but larger peninsulas and extensive higher terrain show late afternoon convection maxima.

ACKNOWLEDGEMENTS

Without the support (and maybe even a bit of nagging - just to keep my spirits up) of my wife of 39 years, Virginia Tenbrook-Gibson, I would never have completed my undergraduate work in 1955, much less return to graduate school upon my retirement from the National Weather Service. During this past year I have experienced problems of non-academic origin which ordinarily would have caused me to withdraw from Colorado State and also isolate myself from society. Her encouragement and support turned these problems into an asset.

Prof. Thomas H. Vonder Haar has been my graduate student advisor. When I was not satisfied with my progress in research or in class studies he has been a source of encouragement. Most important, his expectations and confidence in his graduate students are high. No student, whether in Kindergarden or on a Post-Doctorate Fellowship, performs higher than the expectations of his teachers. Though many give verbal support to this, very few people have the confidence that Prof. Vonder Haar has in his students.

Prof. William Cotton and Prof. Thomas Brubaker are members of my Graduate Advisory Committee. Suggestions for expanding the horizon of my research have proved particulary helpful and added measurably to the results.

It would have been impossible for me to complete this research without the help of John F. Weaver of NOAA NESDIS and Frank Kelly, Air Weather Service, U. S. A. F. The COMTAL is not a user-friendly system, nor was I computer-friendly. When I arrived at

CSU my knowledge of satellite data was limited. They converted me into a computer-compatible person. Through their instructions early in this research and continued well-placed hints I have learned of the great potential of computer systems. They have been particularly helpful in acting as a sounding board to discuss ideas for research procedures. Every idea which had merit was always improved upon following these lengthy discussions.

On the floor of every hospital one can always locate one nurse who is the organizer for an entire floor. Without her the efforts of everyone would be haphazard and little would be accomplished. Nan McClurg, Computer Operator, is that person at the Atmospheric Science Department. Without her organizing efforts, her oversight of the computer systems, her availability to give hints as to how one can get the computer to do what, and most of all, without her encouragement, I would have accomplished little.

A remarkable spirit of cooperation has developed at the Colorado State Universitty Department of Atmospheric Science. Every graduate student will go to great lengths to aid another who may be having problems. Quite frequently this aid is given at a large cost of a graduate student's most valuable asset --time. There is no hesitation. I do not know what individual on the Atmospheric Science faculty managed to develop this remarkable trait in the students. This person and the Atmospheric Science graduate students have my admiration.

Loretta Wilson is responsible for the final formal and printing of this manuscript. Discussions of the layout of text and figures lead to ideas other ideas which were explored before the text reached its final form. Together we attempted to learn a new language and thought processes - that of Macintosh computer systems.

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TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

Figure Number and Title | Page No

1.0 INTRODUCTION

1.1 *Background from a 35 Year Career*

In a lecture to his Physics 101 class during the summer of 1950 Prof. Robert F. Paton of the University of Illinois exaggerated considerably, but never-the-less made an excellent point, when he said,

> "Fifty percent of what you learn in college is either inaccurate or incorrect. When you learn which half belongs to which fifty percent, then you can consider yourself educated."

It sometimes seems that this statement was a little optimistic when applied to the science of meteorology, but with further thought one realizes that it wasn't so much inaccuracies as it was a lack of knowledge of the initial state of the atmosphere. When Dr. Paton made this statement meteorology was near the beginning of an explosion of new knowledge - largely based on expanded observing systems.

My career in meteorology began a few years earlier with my training in the Weather Observer Courser and later the Enlisted Forecast Course of the U. S. Army Air Force at Chanute Field, Illinois. Instruction was of the highest quality. The subsequent growth in knowledge in this science can be partly attributed to the inspiration initiated by instructors of this and similar institutions who trained meteorologists for the military during and after World War II. Their students later formed the nucleus of every operational, research, and teaching organization in the field of meteorology.

An instructor attended a seminar on the east coast while on a break from his duties. On his return he gave the class several detailed reports on the presentations at the meeting. Of most interest was his description of experiments in the seeding of clouds with dry ice which were being conducted by Vincent Schaefer. This was the beginning of modern day cloud physics.

There was a multitude of misconceptions in this science at that time, largely due to the inadequate observing system. For example, until recently it was believed that there were three principal mechanisms in initiating precipitation in the atmosphere: 1) lifting of air parcels as they moved along isentropic surfaces and up the slope of a warm front; 2) forced wedge-like lifting of air parcels by a cold frontal surface; and 3) the space-random thunderstorms resulting from heating of the surface atmospheric layer releasing conditional instability. It is true that these processes do have an effect, but they are seldom the overriding forces as was once believed.

It was generally accepted that squall lines were initiated by the wedge-like lifting of air parcels at a cold front which released convective instability. The line of thunderstorms was assumed to propagated eastward, away from the frontal surface, by the stronger upper level winds. With the development of radar observation systems it became known that the squall lines usually develop at varying distances east of the cold frontal boundary.

It was also a widely-held, though not a universal belief, that the dew point front over the western plains was of no synoptic significance. When serious research and forecasting of severe thunderstorms and tornadoes began it was immediately recognized that this dew point front was the initiating point of many intense squall lines. In the 1980's it remains a focus of attention in the research and prediction of meso-meteorological scale events.

This brings to mind a trivial, but interesting event. Shortly before I received my undergraduate degree in 1955 an American Meteorological Society employment bulletin listed a research position in meso-meteorology. From the wording it was obvious that it had to do with thunderstorms, but nobody on campus knew the meaning of the term meso-meteorology, and for good reason. It was a new field -- and I got the job.

Many subjects which are widely taught and researched in the 1980's received only limited attention in the 1940's and 50's. A cursory review of meteorology texts and reference books of the 1940's show that there was a knowledge of the effects of radiation on the atmosphere and on weather systems. However, in these texts the treatment was usually quite brief. The reason is quite simple. At that time an adequate method of measuring radiation over the globe was a dream waiting to be fulfilled by satellite observations. The theory was in place, but application was not yet possible.

The world-wide surface and upper air observing network was put into place during World War II. An adequate weather radar network for the Lower 48 States was put in place by the Weather Bureau during the early 1960's. This was followed closely by the launching of the first weather satellites. Knowledge continues to be gleaned from these and many more measuring systems too numerous to describe here.

When the first weather satellite was launched, Donald C. House, Meteorologist in Charge of the Weather Bureau Regional Forecast Center in Kansas City, was quoted in a local newspaper, "It is the best thing that has happened for weather forecasting since they cleaned our windows." This was a very accurate description of the value of the data. Before the launch of the first weather satellite the vision of a meteorologist was limited to the horizon -- plus that which could be implied from teletype messages.

Within ten years of this first launch satellite imagery had expanded our vision to include the entire globe. Perhaps of even greater importance, these satellites also expanded our observations into the non-visible portions of the spectrum. This first weather satellite images proved two things quite conclusively. First, cold fronts and warm fronts do exist

Many people, including myself, were beginning to question their authenticity. There was no question in anyone's mind that air masses, and therefore boundaries between air masses, did exist. However, data from the dense synoptic-scale network, if carefully analyzed, made it apparent that the precipitation models attributed to a developing wave cyclone were inadequate. This became even more apparent with the study and forecasting of meso-scale systems beginning in the 1950's. Second, these satellite images, with other available data, made it obvious that precipitation and cloudiness have their genesis in a system much more complicated than simple lifting of an air parcel as it moves up an isentropic surface at a warm or cold front or by the release of convective instability due to surface heating.

Satellite data have been used to aid in flash flood forecasting for several years. Techniques using satellite data to estimate the rainfall rate which were developed by Scofield and Oliver (1977) together with forecast procedures to help the forecaster recognize flash flood threatening situations developed by Maddox, et.al.(1979) have proved to be lifesaving and invaluable. Fifteen months after assuming the Flash Flood Warning responsibility for northern New Jersey, Ben Scott, Official in Charge of the National Weather Service Office in Newark, NJ reported that during the period from June 1, 1981 to September 10, 1982 every flash flooding event in northern New Jersey was preceded by a Flash Flood Watch. Every flash flood was preceded by a Flash Flood Warning. Every Flash Flood Warning issued for that area was succeeded by a flash flooding event. Ten years previous to this geostationary satellite data were not available to field offices. Such an excellent record for forecasts and warnings would not have been possible.

1.2 *Goals of the Study*

When I retired as Meteorologist in Charge of the National Weather Service Forecast Office in New York City, the New York Times printed that I was returning to college at Collorado State University to learn the difference between mostly sunny and partly cloudy. I agree that this is a fine witticism, but it is also close to the truth. Before satellites images were available the knowledge of cloud distribution was severely lacking. Routine aviation weather observations estimate cloudiness as scattered (1/10 to 5/10 coverage), broken (6/10 to 9/10 coverage), or overcast. Accuracy is therefore no better than 2 to 3 tenths. Further consider the spacing of observation points and this accuracy falls even further. Also consider the lack of maritime observation sites and one begins to believe than our ignorance of cloud formations is greater than our knowledge. It is the purpose of this research to make a contribution, even if it is small, to our knowledge of cloud cover.

Prehistoric man must have recognized many of the effects of a sea breeze, especially on a hot day. Regardless of this, an adequate explanation of this phenomena was not made until the introduction of the circulation theorem (Bjerknes, V., 1918). Influences of this small-scale circulation system on other atmospheric processes are not fully understood and continues to be the object of considerable research. The Florida peninsula has been a favorite target of this research because of the possible enhancement of the sea breeze-induced convergence field as a result of the geography and also because of the high frequency of thunderstorms in that area.

It has been established for several years that the sea breeze has a significant contribution toward the development of cloud systems and thunderstorms (Byers and Rodebush, 1948). This work was supplemented by V. Plank (1965). He related cloud physics events in the Florida area to the daily variations of 1) the advection of low level moisture, 2) transport of pre-existing cloudiness across the area, 3) low-level convergence associated with the "orographic barrier effect" of the peninsula, 4) synoptic-scale forcing, and 5) precipitable water in the lower atmosphere. Evidence suggested that the first of these factors, advection of low-level moisture, was the more important. This implies that, given a sufficient moisture supply, there will usually be sufficient convergence to develop cloudiness and shower activity. The third factor is of particular interest in this study. Plank did not consider convergence produced by a sea breeze. Instead, the Florida peninsula is considered a barrier to larger scale flow. It was proposed that the increase in surface friction experienced as the air moves from ocean to land results in an increase in convergence over the land areas and thus contributes toward an increase in cloudiness and shower activity.

Frank, et. al. (1966) using the frequency of radar echoes noted the showers tend to form during the morning hours over the windward side of the Florida peninsula and then move toward the leeward side, reaching a maximum near the leeward sea breeze front during the afternoon hours. This afternoon maximum is coincident with the time of maximum convergence. The Lake Okeechobee area had a minimum of echoes particularly during the afternoon hours which was attributed to the divergence caused by a lake to land breeze.

The output of an eight-level three-dimensional primitive equation model was compared to the observed radar data (Pielke, 1973). This showed that on synoptically undisturbed days the sea breeze circulations are the dominant control of the location of thunderstorms. Pielke also noted that a convex coastline tends to accentuate the horizontal convergence caused by the sea breeze. He confirmed the findings of Frank in that a subsidence region and a persistent cloud-free region was noted over Lake Okeechobee. This lake breeze circulation also accentuated the magnitude of the convergence caused by the larger scale sea breeze circulation.

Using satellite data McQueen and Pielke (1985) investigated the daily trend of convection over south Florida. They reported that well-developed convection had a frequency of less than 1.9 percent at 1200EST on synoptically undisturbed days which increased to 9.5 percent by 1400EST. A maximum greater than 15 percent was reached by 1600EST. There was more deep convection during the morning hours on disturbed days with the maximum occurring at 1400EST. The frequency dropped sharply during the evening hours for both disturbed and undisturbed situations. Early morning deep convection frequency over adjacent waters was correlated positively with the percent of convection at 1400EST over the land areas of south Florida. They confirmed Pielke's earlier findings that a convex coastline curvature enhances the sea breeze convergence and created preferred convection areas. It was also shown that a preferred area for convective development was where the Lake Okeechobee lake breeze met the inland penetration of the sea breeze.

This study will look at the climatology of cloudiness and convection in areas which are known to be subject to sea breeze convergence/divergence patterns. The time and location of areas of cloud frequency maxima and minima will verify these low level convergence/divergence patterns produced by the sea breeze. The reports of research which have been quoted indicate that cloud frequencies will be highest during the afternoon hours over peninsulas with smaller maxima over other coastal areas. At this same time there should be cloud minima over bays and inlets and the near shore areas of the Gulf of Mexico. There is a question of scale. Will all bays and inlets, regardless of size, show an afternoon cloud minima? Will all peninsulas, regardless of size, show and afternoon cloud maxima? Related to this, do relatively small fresh water bodies have any significant effect? The relationship of large mountains to cloud frequency and to convection has been show by a number of studies (Klitch and Vonder Haar, 1982; Klitch, et.al., 1985). One of the goals of this study is to determine if smaller terrain features in the southeast United States have a significant effect on the development of cloudiness and convection.

There is no question that satellite data are an invaluable aid in recognizing excessive precipitation events. But can satellite data be used to estimate rainfall for longer periods? Can satellite data be used as a replacement to or to supplement the rain gage for climatological purposes?

I am particularly interested in any knowledge which would be a help to an operational forecaster resolve the problem of thunderstorm forecasts in coastal areas. Timely and accurate warnings of strong gusty winds associated with thunderstorms were issued by my staff at the National Weather Service Forecast Office in New York City on the afternoon of June 24, 1975. In spite of this, no corrective action was taken by aircraft control personnel. Thunderstorm-related wind shear caused an aircraft to crash and burn at JFK International Airport, killing 113 people. The thunderstorm was at a sea breeze front which was near the approach end of the runway (Gibson, 1975 and Fujita, 1976). This was not the first known crash of an aircraft caused by thunderstorm related horizontal wind shear, but it was the impetus of major research efforts in the effects of thunderstorm-initiated horizontal wind shear on aircraft safety. Since that date I have continued to seek knowledge which can be passed to the aircraft controllers and pilots which will give them the confidence to take corrective action when this occurs again.

2.0 DATA COLLECTION AND PROCESSING

2.1 *Data Collection*

Images from the GOES West satellite were collected for the months of June, July, and August 1986 at each hour for 0700CST and 1000CST through 1800CST. The Colorado State University Interactive Satellite Ingest System was used for this collection process. The 1800CST data were not used in this study because there was not sufficient visible light to distinguish the cloudy areas from those which were cloud free.

The GOES East satellite became inoperable early in 1984. GOES West was temporarily moved eastward during successive hurricane seasons so that there would be adequate satellite data available over a larger portion of the Atlantic Ocean. The eastward move of the satellite took place during the collection period of this study. It caused major problems in processing the data.

The collected data were visible and infrared images which covered the contiguous 48 states. It was stored on magnetic tape for additional processing. The first step of this processing was to read from the tape that portion of each image which covered the selected area of study. In order to do this an image sector and an image structure for this sector had to be defined. The sector description is the latitude and longitude coordinates of the northwest and southeast corners of the desired area. The structure is the number of north-south as well as the number of east-west pixels of the sector in the collected image. A pixel is a single picture data unit.

Early in the collection the GOES West satellite viewed the area of study near its eastern horizon. As a result the subtended angle was quite small and relatively few pixels covered the area. With the eastward movement the area of study came nearer the center of view. Thus, the area of study was further from the horizon and it subtended a larger angle than previously and more pixels covered the area. The structure of the image had to be changed frequently so that each image would be geographically compatible with every other image. Eight different structures were required for this data collection..

Processing of the data was completed using the Interactive Research and Imaging System (IRIS) of CSU. The computer system is a DEC VAX 11/780. Image processing was done on a COMTAL Vision one/20. This is described by Klitch, et.al. (1985) and by Green and Kruidenier (1982).

An image made on a nearly cloudless day was used as a base image. A base graphic was made which showed state outlines, coastline, larger rivers or lakes, or any geographical feature which is visible on a satellite image. The other visible images were then entered onto the COMTAL screen and ROAMed, i. e., moved on the screen, so that geographic features matched the base image and base graphic. Infrared images were ROAMed to match this visible image. This ROAMing process corrected errors in navigation parameters or for satellite wobble. This was especially important during the period when the satellite was being moved. After renavigation the images were saved on the computer disk and on tape for further processing.

The initial intent was to limit this study to the area of northern Alabama and central Tennessee which was the subject of the COHMEX Project during the summer of 1986. It soon became obvious that the area had to be expanded. Such a small area is often almost totally cloud covered. Under these conditions there is not enough recognizable landmarks to properly ROAM the images. The area was expanded so that the northern coastline of the Gulf of Mexico from the Florida Panhandle to the Louisiana Delta would be visible. This new area also included the Mississippi River near Memphis, TE. With this larger area no images had to be discarded because it could not be navigated accurately.

Accuracy of this renavigation of the visible images is estimated to be ±2.5km. Figures 1a and 1b illustrate this accuracy. These are cloud frequency images. No terrain was included in these images, but note the areas near the coastal islands to the south of Mobile Bay in Alabama and eastward along the Florida Panhandle. Relative to the surrounding water there are cloud frequency maxima over these coastal islands. The islands average 2 to 3 km in width. The area covered by the minimum visible cloud frequency is slightly larger and approximate the shape of the islands. These islands were never used for renavigation if any type or size of clouds were nearby. When it is considered that the low level wind tends to increase the areal coverage of the cloud frequency images by spreading the cloudiness toward the lee side of the islands, these charts instill a great deal of confidence in the accuracy of the navigation. Cloud frequency charts will be discussed in detail later.

2.2 *Image processing*

The COMTAL Vision One/20 has the capability of masking that portion of any image which is brighter (or darker) than some threshold value. The threshold value can vary from 0 to 255. A value was selected for each visible image such that all cloudy areas were brighter than the threshold value. Cloud-covered areas were converted to a brightness value of 255 and non-cloudy areas to a value of zero. These were saved on tape as cloud-no cloud images. The threshold value varied from day to day and hour to hour due to the variability of the sun angle and cloud reflectivity. Cumuliform clouds tend to be bright while stratiform clouds tend to be relatively darker.

There was a possibility that there could be contamination of the cloudiness by the brighter land areas. The brightness of the coastal islands as well as other consistently bright areas was measured during cloudless conditions at each of the nine times of data collection. In all cases the brightness of the land areas, on a scale of 0 to 255, was about 10 units less than the minimum brightness of the clouds.

The cloud-no cloud images were used to make cloud frequency charts. Each image has 512 pixels east to west and 512 pixels north to south. With proper navigation a given pixel location on one image has the same geographical location as the same pixel location on another image. The cloud frequency for a given set of cloud-no cloud images at any given pixel location can be made by counting the number of images with a brightness count of 255 at the location of the pixel. This cloud frequency at the given pixel location can then be assigned a brightness count such that zero frequency has a brightness count of zero increasing linearly to a brightness count of 255 for 100 percent frequency. A complete cloud frequency composite can be made by making this frequency computation for every pixel location of the 512 by 512 images.

It is the nature of convective cloudiness that the cloud tops are high and therefore cold. They also reflect considerable light and are therefore bright in the visible spectrum. Using these characteristics, convective cloudiness was determined by using a combination of brightness of the visible image and the cloud top temperature as indicated by the brightness count of the infrared image. Since visible brightness varies with sun angle, a different brightness count was needed for each of the nine hours when images were made. A brightness level was selected such that all stratiform cloudiness had a lower brightness count and cumuliform clouds a higher brightness count. This brightness count was determined subjectively. The count for any given time was never changed throughout this study, but it was closely monitored to insure that the natural change in sun angle did not result in a significant change in cloud brightness. Using this brightness count, a graphic was made for each visible image which masked all but the brightest areas. This graphic was then placed over the infrared image of the same time and date. Four separate images were then made considering only the infrared data in the unmasked area. These four images outlined areas where the cloud top temperature was -15 deg C and lower, -41 deg C and lower, -57 deg C and lower, or -75 deg C and lower. On each graphic the low temperatures were assigned a brightness count of 255 and other areas a brightness count of zero. Each of the images indicate convective processes of varying strength.

Cumulus clouds which develop a little beyond the "fair weather cu" classification are described by the convection to -15 deg C. At the other end of the spectrum, convective cloudiness extending to -75 deg C is exceptionally strong. Only a few thunderstorms reached this level. The four convection images give an excellent measure of the varying intensity of the convection. Convection frequency charts were prepared using the same methods as those used for the cloud frequency.

Cloud-No Cloud Frequency composite charts were prepared for each of the nine times for the three month period of study and for each individual month; June, July, and August 1986. Convection Frequency to -15 deg C and Colder and to -41 deg C and Colder composite charts were prepared for these same periods. The other convection frequency composite charts, i.e., -57 deg C and colder and -75 deg C and colder, were prepared for each of the nine times, but only for the full three month period, not for individual months.

Hour to hour changes in cloud frequency for the summer of 1986 were computed These charts are not a measure of cloud motion, but are a measure of the sum of development, dissipation, and/or motion between successive times of collection.

3.0 DATA ANALYSIS

3.1 *Precipitation-Cloud Relationships*

The summer of 1986 was a very dry period over portions of the southeastern United States. Monthly mean 700mb charts (Halbert and Ropelewski, 1987) show a ridge extending westward from the Atlantic across the Gulf Coast. During the months of June and August the flow immediately north of the area of study tended to be west to west-southwesterly while in July the flow was more west-northwesterly. As a result there was almost no convection triggered by synoptic scale mechanisms in July, but during the other two months convective activity often formed to the north and west of the study area and moved eastward into the area of study during the nocturnal and early morning hours.

The mean precipitation of those NOAA observation stations in Alabama which also report departures from normal was computed. This is shown in Table 1. Also included in this table is the mean cloud frequency of each summer month for the hours of study and the mean frequency of convective clouds with cloud top temperatures of -15 deg C or colder.

Table 1. Alabama mean precipitation per gage, mean cloudiness, and mean frequency of convective cloud tops -15 deg C or colder over the state during the summer of 1986.

	Mean Precip. (Inches)	Departure from Normal	Mean Cloudiness (Percent)	Mean Frequency of Convective Cloud Top -15 deg C or Colder
June	2.75	- 1.34	40.2	9.1
July	4.17	- 1.28	28.9	4.9
August	4.62	+0.56	45.1	8.3

July precipitation was greater than that of June even though there were fewer clouds and less convective cloudiness with cloud top temperatures of -15 deg C or colder. Precipitation increased in August as did the cloudiness and the convection.

It is apparent that the parameters in Table 1 are not those proper to relate precipitation and clouds. When studying eastern Montana, Klitch (1982) also noted that there was little change in cloudiness during 1979 as compared to 1980 even though the latter year had a marked decrease in precipitation. Our lifetime experience tells us that there is a relationship between cloudiness and precipitation, but the results of this study and that of Klitch show that this relationship goes beyond the mere presence of clouds. It is evident that there must a triggering mechanism to initiate precipitation within the clouds and to initiate vertical growth of the clouds.

Bergeron theorized that most raindrops begin as ice crystals in supercooled clouds (Bergeron, 1933). Since the vapor pressure relative to ice crystals is lower than that relative to water droplets, the ice crystals should grow at the expense of the droplets. Ice crystals then grow into snowflakes through collision and aggregation.

Crystal habit is a function only of temperature (Kobayashi, 1961 and Mason, et. al., 1963 as cited by Braham, 1968). The temperature range from -12 deg C to -17 deg C is particularly suitable for the formation of dendritic crystals. Combining observations from a variety of sources Braham also noted a strong dependence of the growth of the size of ice crystals to the temperature with a very strong maximum near -15 deg C. Thus, the temperature favorable for the maximum rate of growth is also favorable for the formation of dendritic crystals. It was noted by Braham that, "in any cloud extending from 0 deg C to -20 deg C crystal growth in the -12 deg C to -17 deg C region will overshadow that of all other levels."

In this study the frequency of convective cloudiness to -15 deg C and colder is an indirect indication of the proper environment for ice crystals to develop and enlarge. Frequency of convection to even lower temperatures is an indication of vertical motions and vertical cloud development, thus further enhancing the development of additional ice crystals through adiabatic cooling.

Data used to compile the figures in Table 1 were only cloud frequency or frequency of convection to -15 deg C and colder. Duration of the cloudiness or convection was not a consideration. Convection to -15 deg C, though important in the development and growth of ice crystals, does not indicate a significant vertical development of the clouds. It follows that a good correlation should not be expected.

The total rainfall for the three months of the study for hours ending at 0700CST and 1600CST were tabulated for each Alabama observation location published in Hourly Precipitation Data. These two times were selected because one is near the time of minimum convective activity and the other near the maximum. The correlations of this hourly precipitation to the various cloud or convection frequencies are illustrated in Table 2.

Table 2. Correlation coefficients between hourly precipitation and cloud frequency or frequency of convective cloud tops at the indicated temperatures or colder.

Time	Cloud Frequency	Convective tops Colder Than			
		-15 deg C	-41 deg C	-57 deg C	-75 deg C
0700CST	.10	.04	.76	.66	-.16
1600CST	.49	.37	.15	.20	.51

Cloud tops sensed by the satellite were several kilometers above the surface of the earth. The satellite was never directly above any cloud of which an image was made and used in this study. An extension of the line of view from the satellite to the cloud top would not intersect the surface of the earth beneath the cloud, but at some distance to the north and east. From this it is evident that cloud convection frequencies are not exact plots. A navigational correction for every pixel in the vicinity of every rain gage for every cloud and convective cloud image would have to be made in order to have the proper spacial relationship between rain gages and convection frequency composites. The difficulty in making these computations is compounded by the eastward movement of the satellite during much of the period of study. Though the task is not impossible, the extent makes it impractical to accomplish. There are also other problems which may be of comparable magnitude.

Even if the satellite data were perfectly correlated with the precipitation which was falling at the time the image was made, it would not necessarily be a measure of the precipitation falling into a rain gage beneath the cloud. The atmosphere is in constant motion. This motion is imparted to the falling raindrops, thus the raindrop trajectory is rarely vertical. The distance between reporting points of hourly precipitation is 30 to 50 km, much greater than the size of a thunderstorm cell. As a result of the scale problem and the geographic inaccuracy inherent in the observation, relatively low correlations were expected.

The correlation between rainfall at 1600CST and frequency of convective tops of -75 deg C and colder, though relatively high, is not reliable in this case. Only two of the 23 observed convection frequencies were greater then zero. The negative correlation of the 0700CST hourly rainfall to frequency of convective top to -75 deg C and colder is also not believable. Only one of the 23 observations had a convection frequency greater than zero and this had no associated precipitation.

Precipitation at 0700CST during the summer was reported at nine of the 23 observation sites, ranging from 0.10 to 1.60 inches. At 1600CST the rainfall recorded at 21 of these 23 sites ranged from 0.10 to 4.50 inches. The 1600CST reports and satellite data appears to be a better sample, but note in Table 2 that the correlations at 1600CST are very low while those at 0700CST are relatively high. This illustrates that these data cannot be used to draw mean isohyetal charts in an objective manner.

Plots of monthly precipitation were made on composites showing the monthly frequency of convective tops of -41 deg C and colder. These are shown in Figures 2 through 4. Higher precipitation values tend to be in the general area of higher convection frequency, but the correlation is poor. An inspection of precipitation data showed that 30 percent of the precipitation fell at hours not considered in these convection frequencies. Precipitation during these off-hours was subtracted from the June data and replotted. There was no significant improvement in the pattern. This approach was therefore abandoned.

As a result of the problems associated with not considering the duration of the convection, navigational errors caused by non-vertical views of the convective clouds, and the horizontal displacement during the fall of precipitation, convection frequency composites are of no objective help in the analysis of the monthly isohyetal pattern.

3.2 *Areal Cloud/Convection Trends and Relationships.*

The average cloudiness and the average convection of four different intensities was computed by considering the brightness of 773,926,160 pixels in 3,815 images. Between 0700CST and 1100CST (Figure 5) there is an 11 percent increase in the average cloudiness over the area. By noting the areas of steeper slope of terrain (Figure 6) as well and the coastline areas and comparing these to the areas where there is an increase in cloudiness during the morning hours (Figures 7 and 8), it is quite apparent that the increase in cloudiness is largely due to convergence associated with the sea breeze and with vertical motion caused by the valley to mountain breeze. The area of increasing clouds over northern Mississippi and western Tennessee is a notable exception. During the months of June and August there was a tendency for the development of convective activity over the Midwest States during the afternoon which then moved eastward and southward into the area of study during the nocturnal and morning hours. The decrease in cloudiness over the Gulf of Mexico is also evidence of a strong sea breeze system.

The morning increase in cloudiness is followed by a two percent decrease between 1100CST and 1200CST. Though there are many areas of change which might be related to or caused by geographic features (Figure 9), there is nothing consistent which can be applied to all areas. Areas which tend toward no change are narrow strips extending northeast-southwest near the Alabama-Georgia-Tennessee triple point. These are reservoirs of the Tennessee River. Another area which tends to show no change is along the Tennessee-North Carolina state line. This a ridge of the Great Smoky Mountains. There tends to be no change in cloudiness near the Mississippi River. It will later be shown that these areas tend to be at a maximum or minimum of cloud frequency. Areas of cloud increase and cloud decrease seem to be scattered over the entire area, showing no obvious relationship to the terrain. It is recognized that this decrease in cloudiness from 1100CST to 1200CST might be geographically related, but these data neither support nor refute such a contention.

This decrease in cloud frequency is followed by a four percent increase between 1200CST and 1400CST (Figures 10 and 11). There does not appear to be a strong geographically-related preference for a positive or negative change other than a continued cloud decrease over the Gulf of Mexico.

Convection frequency of all intensities is low and changes little from 0700CST to 1200CST and then increases, reaching a maximum shortly after 1400CST. In Figure 5 note that the frequency of convective cloud tops of -15 deg C or colder reaches a maximum before the frequency to -41 deg C or colder. There is an additional lag in the maximum convective tops of -57 deg C and colder. This is expected. Developing cumulus clouds must be small before they can become big. The only question to be answered is the slope of this lag. This shows how rapidly, on the average, the deeper convection develops. In this case, during the summer of 1986 over the southeastern United States, the strong convection lags the development of weak convection by about an hour.

Cloudiness over the area decreases almost nine percent between 1400CST and 1600CST (Figures 12 and 13). The decrease in cloudiness appears to be fairly evenly distributed across the land area. Between 1600CST and 1700CST (Figure 14) there is less than a one percent decrease in cloudiness when the entire area is considered, but there are distinct areas of both increase and decrease. Even though gradients of cloud increase to cloud decrease are quite evident, it is difficult to relate these to geographic features. At this time it is assumed, but it is not proven, that this is evidence of the beginning of the effects of the mountain/valley breeze.

It is important to note that, even though the cloudiness decreases significantly between 1400CST and 1700CST, the convective activity remains almost unchanged. Convergent flow and vertical motions of the air mass are essential to initiate and maintain convective activity. However, convergent flow must be equally offset by subsiding air and divergent flow in other locations. This results in dissipation of the clouds in the subsidence area. As the clouds became more extensive vertically there is a corresponding horizontal decrease.

3.3 *Sea Breeze Effects*

Hourly maps of cloud frequency, convection to -15C and colder, convection to -41C and colder, and convection to -57C and colder at 0700CST and 1000CST through 1700CST are shown in Figures 15a, b, c, and d, respectively, through Figures 23a to d.

During the earlier morning (Figure 15) there is a tendency for a cloud minimum over the land areas within 50 to 100 km of the shoreline of the Gulf of Mexico. A land-to-sea breeze is responsible for this. It can be considered only a general trend since there are many small cloud maxima within the general area of cloud minimum. The cloud maximum over the Gulf of Mexico at 0700CST is residual clouds of a nocturnal maxima caused by convergence related to a land to sea breeze.

By 1000CST (Figure 16) the sea breeze-related convergence has resulted in a relative cloud maxima over the land areas which are within 100 to 200 km of the shoreline, whether it be a peninsula or adjacent to a bay or inlet. The area of cloud maximum extends further inland over peninsulas and may be somewhat stronger as compared to those maxima which are inland from bays and inlets. As an example, inland from the peninsula which includes Apalachicola, FL the area of relative maximum extends over 200 km inland. About 150 km to the west, which is a bay area of similar dimensions, the cloud maximum area extends inland hardly a third this distance. Sea breeze-induced cloudiness continues to increase until 1400CST.

The cloud frequency may appear to be a relative minimum over inland areas adjacent to bays and inlets, but this is only relative to adjacent near-shore areas. If the cloud frequency is compared to those which are in a seaward or landward direction, areas near bays and inlets show a strong cloud maximum. This is noticeable when examining the cloud frequency in the 1000CST to 1400CST time period (Figures 16a through 20a). The near-shore area shows a general cloud frequency maximum with the larger magnitude as well as the larger area of increases greatest over peninsulas. There are a few areas, such as north of Mobile Bay, where there is a relative cloud minimum. In these cases the cloud minima are associated with rivers and swampy areas. These will be discussed further in the next section.

Areas of cloud minima develop over water areas as a result of divergence caused by the sea breeze. Hourly cloud frequency and the change in cloud frequency charts show a slow decrease in clouds over the Gulf and bays and inlets. This is in contrast to the rapid changes noticed over the land. These cloud minima are not limited to large water areas such as the Gulf of Mexico. Mobile Bay and Lake Pontchartrain show cloud decreases as do all of the much smaller bays along the Florida Panhandle. The most noticeable relative cloud minima are over the Gulf of Mexico to the south of the Florida Panhandle and also to the southeast of the Mississippi coast (Figure 19a). Both of these are bay areas and are separated by the small peninsula to the east of Mobile Bay. The southern edge of these minima is south of the data area.

The waters of even the smallest bays and inlets from the Gulf of Mexico have a cloud minimum relative to the adjacent land. Many rivers emptying into the Gulf are also evident on the cloud frequency charts. There is the Mobile and Tensaw Rivers emptying into Mobile Bay in Alabama; the Escamba and Choctawhatchee Rivers in Florida; and the Pascagoula River in Mississippi. Note that the Pearl and Bogue Chito Rivers near the peninsula at the Mississippi-Louisiana state line are not associated with a relative minimum.

Convergence attributed to peninsular sea breeze effects dominate to cause a relative maximum cloudiness in that area.

These satellite data show evidence of convergence along the entire shoreline with maximum convergence on peninsulas and minimum convergence near bays and inlets. During those times when there is a sea to land breeze the divergent areas are limited to water-covered areas and are most noticeable over bays and inlets. The increase in cloudiness along the entire shoreline is evidence that the sea breeze always induces convergence over the land areas and never causes divergence, whether associated with peninsulas or land areas adjacent to inlets. Let us now consider the effects of the shape of the shoreline on the magnitude of the divergence.

Assume that boundary layer conditions over land areas are everywhere identical as are the boundary layer conditions over water areas. Further assume that the undisturbed wind is equal to zero. Orient the coordinate system such that the x-axis is perpendicular to the shoreline and positive in the shoreward direction. The sea breeze will be perpendicular to the shoreline and decrease from speed V near the coast to speed zero at a distance L. Under these conditions the x-component of divergence can be written

$$\mathrm{Di}\hat{\mathrm{v}}_{x}\,\underline{V} = -V/L$$

A computation for the y-component of divergence is made by computing the difference in wind speeds in the y direction over a distance L. Because of coastline curvature, the wind vector at a distance L is at an angle ϕ to the vector drawn at distance zero. This angle will be considered positive if counterclockwise. The angle will therefore be positive in inlets and negative over peninsulas. The component of V at distance L in the direction of the y-axis is

$$V_y = V \sin\phi$$

and the y-component of the divergence is

$$\mathrm{Div}_y \underline{V} = (V \sin\phi)/L$$

The horizontal component of the divergence is

$$\mathrm{Div}_H \underline{V} = V(\sin\phi - 1)/L$$

Since the magnitude of the sine is never greater than unity, it is evident that the sea breeze over land is always convergent. Note further that $\sin\phi$ is negative over peninsulas and therefore the magnitude of the convergence is greater over peninsulas than inlets.

Cloudiness associated with the sea breeze begins to dissipate after 1400CST and the dissipation continues beyond 1700CST (Figures 20 through 23). Cloud dissipation during this three hour period is most rapid in the areas of higher cloud frequency. New cloudiness develops over the waters of the Gulf of Mexico as the landward clouds dissipate.

The sea breeze also causes convective cloudiness near the Gulf Shore. At 0700CST there is an offshore convection frequency maximum for all convection intensities up to -57 deg C (Figures 15b, c, and d). The convection maximum which is offshore early in the day begins to move toward the shore by 1000CST (Figures 16b, c, and d). The on shore maxima are well established by 1100CST and continue to increase in magnitude until the 1400CST to 1500CST period (Figures 17 to 21b, c, and d). After 1500CST the magnitude of the convection maxima near the coast decrease rapidly.

The magnitude of the convection frequency is dependent upon the shape of the coastline. The larger maxima tend to be over the larger peninsulas. There are relative convection minima inland from bays and inlets, but this is relative only to the adjacent water-covered areas. If this relationship is between any near-coast area and inland areas there tends to be sea breeze related maxima. This is similar to the patterns shown by the cloud frequencies. There is no evidence of convection over peninsulas which are adjacent to the smaller bays and inlets nor does cloudiness develop over the offshore islands. In most areas one must go inland several kilometers before there is a significant increase in convection frequency.

It follows that there is once again a scale relationship. Thunderstorms are larger than fair weather cumulus clouds in both lateral and vertical extent. More energy is needed to develop a thunderstorm. Sea breeze induced convergence is not strong enough to produce convection over small peninsulas, but convergence associated with the sea breeze is stronger over larger peninsulas, therefore thunderstorms are more frequent.

3.4 *Cloud and Convection Frequencies Relative to Inland Terrain Features*

Note the area near the tri-state triple point of Alabama, Georgia, and Tennessee in Figure 6. This was briefly discussed in Section 3.2. A valley extends in a northeast-southwest direction. The Sequatchie River is in the Tennessee portion of this valley. The Tennessee River and Chickamauga Lake is in the valley about 30 km to the east. The ridge between is the Walden Ridge. The Sequatchie joins the Tennessee near the tri-state triple point. Guntersville Lake is the Alabama portion of the valley. Elevation increases adjacent to the valley range approximately from 500 to 1000 feet.

At 0700CST there is no strong relationship between these terrain features and the cloud frequency pattern. By 1000CST (Figure 16a) the valleys of Guntersville and Chickamauga Lakes and strong cloud frequency minima have a near one-to-one relationship as does the valley of the Sequatchie River. Cloud maxima have a close relationship to the higher terrain to the north and south. Though it is weak at 1000CST in Alabama, an extension of the cloud minimum turns west-northwestward. This minimum area extends toward the northwest corner of Alabama. This coincides with the Tennessee River and Wheeler Lake.

From this area the Tennessee River turns northward into the state of Tennessee, as does the relative cloud minimum, but the minimum is weaker. This broad, weak relative minimum is most noticeable from 1100CST to 1400CST.

At 1400CST (Figure 20a) a weak relative cloud minimum extends as a narrow arc from the Mississippi-Tennessee-Arkansas triple point in a generally southerly direction. This minimum is related to the Coldwater and Yazoo Rivers. There is a slow rise in elevation to the east, but land to the west is quite flat.

Note the five cloud minima about 40 km east of this river system on the 1100CST cloud frequency charts (Figure 17a). The most northerly is about 60 km from the Tennessee state line. This is associated with Sardis Lake. The minimum about 35 km to the south of this is associated with Enid Lake and the next to the south with Grenada Lake. The relative cloud minimum about 40 km to the southeast of this is not related to any body of water. It is associated with no known significant geographical feature. The next cloud minimum area to the south is associated with the Ross Barnett Reservoir.

The cloud minima over the larger fresh bodies of water could be due to downward motions associated with a water-land breeze or because the temperature of the water is not sufficiently high to heat the adjacent air to a point where instability is released. A favorite takeoff point of hot air balloon crews is near a small lake in the southeast of Fort Collins. At times the trajectory of these balloons is across the lake. When this is the case the crewmen have great difficulty in maintaining their elevation and usually sink to the surface. Once on the surface no attempt is made to rise until the lee side of the lake is reached. I have also interviewed several experienced hang glider pilots. Their consensus is that the best that they can hope for over a body of water is zero lift. There is never a positive vertical motion.

Assuming a surface dew point of 20 deg C and temperature of 30 deg C, the base of a cumulus cloud is about 1000 meters above the surface. If the average vertical velocity is 1.5 meters per second, a parcel of air at the surface would reach the cloud base in about 11.1 minutes. If this air parcel had a horizontal wind speed of 3 meters per second it would reach the cloud base after a horizontal movement of 2000 meters. Thus, an over-water trajectory of 2000 meters or more would sharply decrease cumulus cloudiness.

An area of relatively low elevation is located west of the northern section of the Alabama-Mississippi state line. A weak and indistinct cloud minimum develops slowly over this area. It is visible by 1300CST, but it is almost insignificant. This relative minimum develops, not because clouds decrease in the low lying areas, but because clouds develop over the higher terrain to the east and west. There is no large body of water in this lower terrain, but there is a river which has no reservoirs. Cloud maximum also develop over the higher terrain of northern Georgia and adjacent areas of Tennessee, Alabama, and North Carolina.

The 0700CST cloud frequency chart shows a relative cloud minimum in the low terrain area west of the Tennessee - North Carolina state line with a strong relative minimum over the steep slopes near this state line. By the afternoon hours the area of lower terrain is an area of relative minimum which includes small localized maximum areas. These small maximum areas are associated with small terrain variations. The high terrain has become an area of relative maximum cloudiness. It is the highest terrain in the area of this study. Higher terrain throughout northwest Georgia and adjacent areas of Alabama is an afternoon cloud maximum. This nocturnal - diurnal cloud variation is attributed to the variation of winds along the slopes of the terrain.

Even though the development of convection shows a strong relationship to coastal terrain features, no relationship is noted with regard to inland geographic features. Relationships between convection and large terrain features have been known for many years and have been documented with satellite data (Klitch and Vonder Haar, 1982; Klitch, et. al., 1985). It is therefore assumed that the changes is terrain across this area of study are too subtle to cause significant development of convective activity.

4.0 SUMMARY AND CONCLUSIONS

Areas of cloud minima and maxima develop over land areas between the hours of 0700CST and 1300CST. After 1400CST these cloud minima and maxima disappear rapidly. By 1600CST most cannot be distinguished. Development of this diurnal cloudiness is caused by valley to mountain breezes associated with a sloping terrain and by sea breeze affects. Steep slopes of terrain and higher terrain have the strongest affect. The valley to mountain breeze also results in divergent flow and suppression of cloudiness over the adjacent lower terrain.

Areas of low elevation which are also bodies of water are not favorable area for cloud development during the daylight hours. Under the proper conditions they are a mechanism for suppression. The water bodies suppress cloud development due to stability considerations if the water temperature is less than the environmental air temperature. If the water temperature is less than the dew point temperature there is a vapor pressure gradient directed from the air toward the water surface. Condensation results, thus adding to the suppression of cloud development. The valley to mountain breeze also contributes toward divergence in the vicinity of these lakes and rivers.

The scale of the water bodies and the wind speed must also be considered. Small bodies of water such as narrow rivers and small ponds show no significant effect while larger rivers and larger lakes can be important. This is due to the scale of the individual cloud elements as compared to the water body. One must also consider the environmental wind speed. If the flow is such that the area of the developing cloud is over the water for a short time, the water body would have an insignificant effect. If wind speeds are slow, the effect of the body of water increases because the developing cloud is in the suppressing environment for a longer time period. The fresh bodies of water located in the area of study were small as compared to convective cloudiness and therefore had no evident effect on convection.

The smallest inlets and bays adjacent to major water bodies suppress cloud development over the water, but sea breeze induced cloud maxima are observed over the adjacent land. Small peninsulas enhance cloud development associated with sea breeze convergence, but peninsulas must be relatively large in order to have a significant effect on convective activity. A sea breeze is never divergent over land areas.

Any relationship between cloud frequency and rainfall and convection frequency and rainfall over a given point is small. This is due in part to the varying scales of the convection which produces the rainfall and rain gage network density. The convection intensity at a given time is correlated to the rate of fall of precipitation. However, the composite charts which show frequency of convection without regard to the duration of this convection intensity are of little help in the analysis of an isohyetal pattern.

Summertime cloudiness over the area of study reaches a maximum by 1400CST and is followed by a substantial decrease. Convection reaches a maximum about one hour later and there is no substantial decrease until some time after 1700CST. The decrease in cloudiness is caused by divergence which is in response to the strong vertical motions associated with the convective activity. No relationships were noted between small terrain features and convective frequencies of any intensity. Sea breeze and valley to mountain breeze effects enhance the development of convection in areas such as large peninsulas and larger ridges and mountains. When all of the above are considered, it is concluded that there is no such thing as random cloud formations.

Prehistoric man had neither a way to record his observations nor a method of making accurate measurements. But the clouds, the temperature, the wind and the snow, rain and hail were noted by the human senses and their affect was noted in the mind. As it is in the present, the daily weather and changes in weather had a dramatic affect on the mode of life. Routine records were made after man learned to write. Initially the records were crude, but they improved with the development of instrumentation. More parameters were added as instrumentation became more sophisticated. The invention of the wind vane, anemometer, thermometer and barometer all had a major impact. Satellite images are the first significant improvement in cloud observations since the design of the human eye. The massing of these data is in its infancy. This study represents a pinpoint on the globe in a moment of eternity. Statistically no single datum may be important, but the entire data set is significant. One must not lose sight of the fact that a data set is a collection of individual facts. Without individual facts there is no data set. Thus, this insignificant effort is significant.

5.0 RECOMMENDATION FOR FURTHER RESEARCH

The scale-dependence of cloud and convection frequency to geographic features has been noted throughout this publication. Several other researchers examining the characteristics of the sea breeze have made a similar conclusion and been cited (Neumann and Mahrer, 1971 and 1974; Pielke, 1974; Abe and Yoshida, 1982; and Mahrer and Segal, 1985). There is a need for this to be further pursued. The shape as well as size of the geographic characteristic must be considered simultaneous. For example, most peninsulas can be approximated by a triangle. The length of the triangle legs may change and with these changes the convergence caused by the sea breeze cirulation will change. Is there a base-height-size relationship which is most condusive to sea breeze induced convergence? What would be the affect of a sloped terrain? Preliminary answers to these questions may be found in modeling experiments which could then be verified using satellite data.

The time-dependence of cloud and convection frequency with regard to the entire area of study has been shown. This should be further expanded. The times of cloud or convective maxima or minima at significant points should be investigated. Does the sea breeze cloud maximum moves inland with time? A more carefull examination of the data is needed to answer this question. A relative cloud minimum develops during the day over many of the inland waters. These relative minima need to be better defined using the change in frequency per unit distance, i.e., the slope of the frequency adjacent to the relative minima. Once defined, a time-dependence should be determined.

A possible method to invesigate the questions posed in the last paragraph is to construct a cloud frequency versus distance diagram along selected lines drawn on a map of the study area. These could be made for every hour for which data are available. The hour by hour comparison of these charts could possibly answer all of the questions posed.

There is a wealth of meso-scale network, radar, radiosonde and other data available for the northern Alabama-Central Tennessee area during this period of study. Divergence data over the meso-scale network would be of particular interest. The initial question to be answered is whether meso-network data are of a scale comparable to cloud frequency or convection frequency data. Comparing cloud frequency data to the thermodynamic profile as shown by radisonde data should be productive.

Any relationship between cloud and convection frequencies and vetical wind shear should be examined in great detail. Relating vertical wind shear and atmospheric stability to the frequency of convection of the various intensities may be particularly productive.

Though not in this same geographical area, a study which would be of great value is a cloud and convection frequency study in the vicinity of the west side of the Gulf Steam. While with the National Weather Service in New York City, a group representing shipping companies visited my office and requested that on each marine forecast they be furnished the location of the west edge of the Gulf Steam. As meteorologist, those on the staff were aware of the influence of the Gulf Stream on weather system. But until this briefing by shipping personnel we were not aware of the intensity or the rapidity of development of small-scale weather systems in that area. At this time it is my opinion that an investigation of this area would be as scientifically fascinating and productive as meso-scale investigations of the west Texas-Oklahoma dry line. The result would be a major savings of life an property.

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APPENDIX

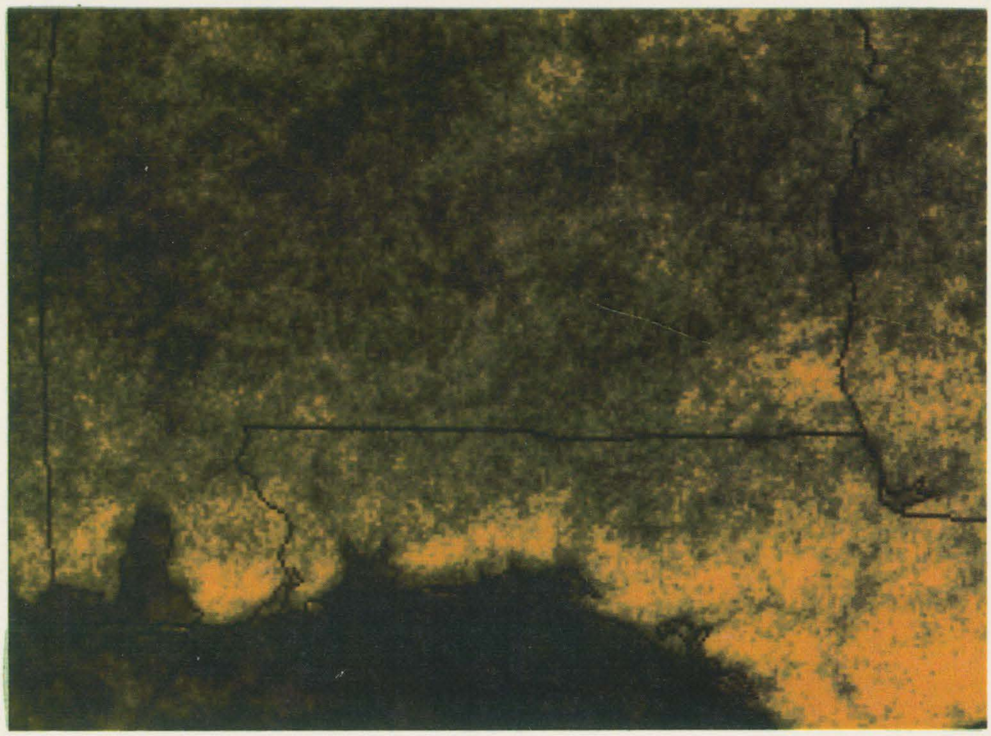

Figure 1a. Cloud Frequency with State Lines

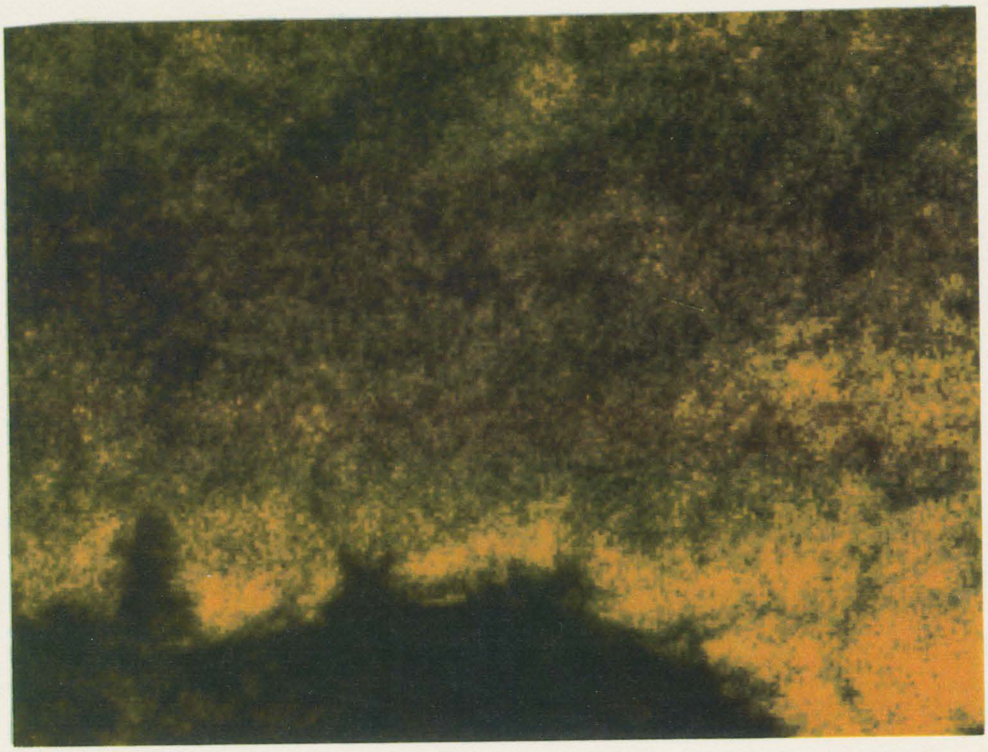

Figure 1b. Cloud Frequency

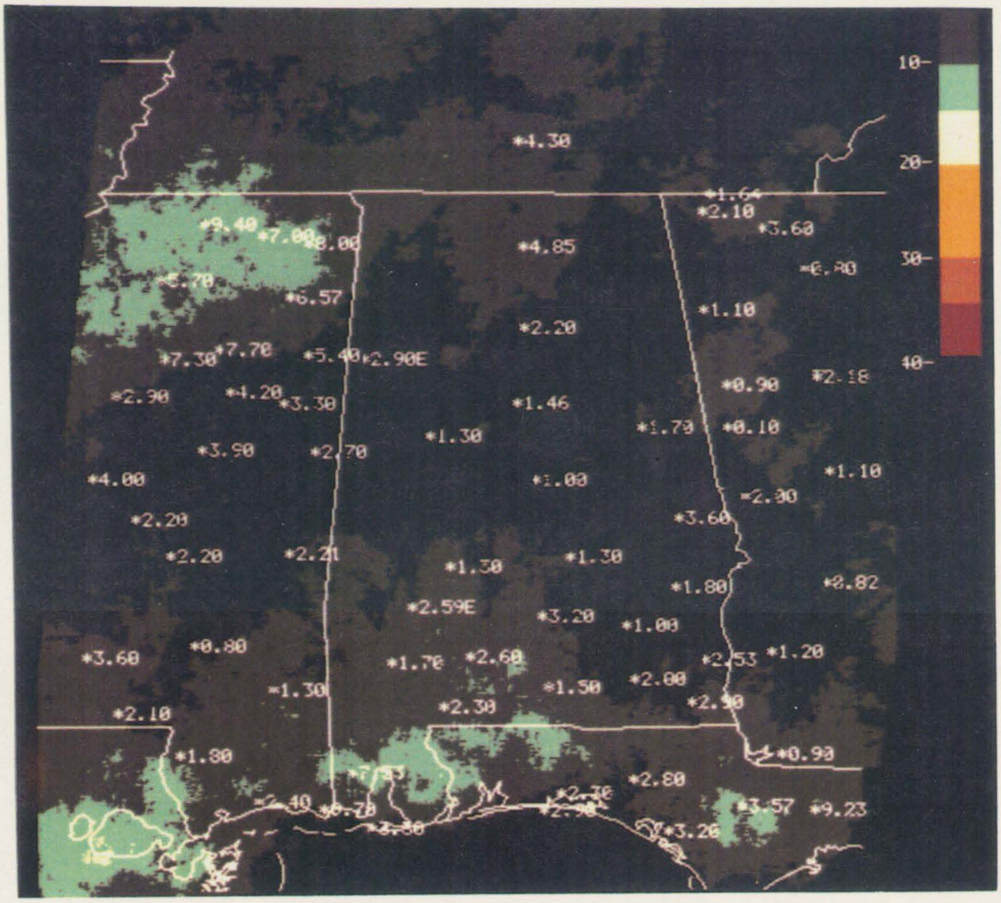

Figure 2. June 1986 Frequency of Convection to -41deg C and Colder and Monthly Precipitation

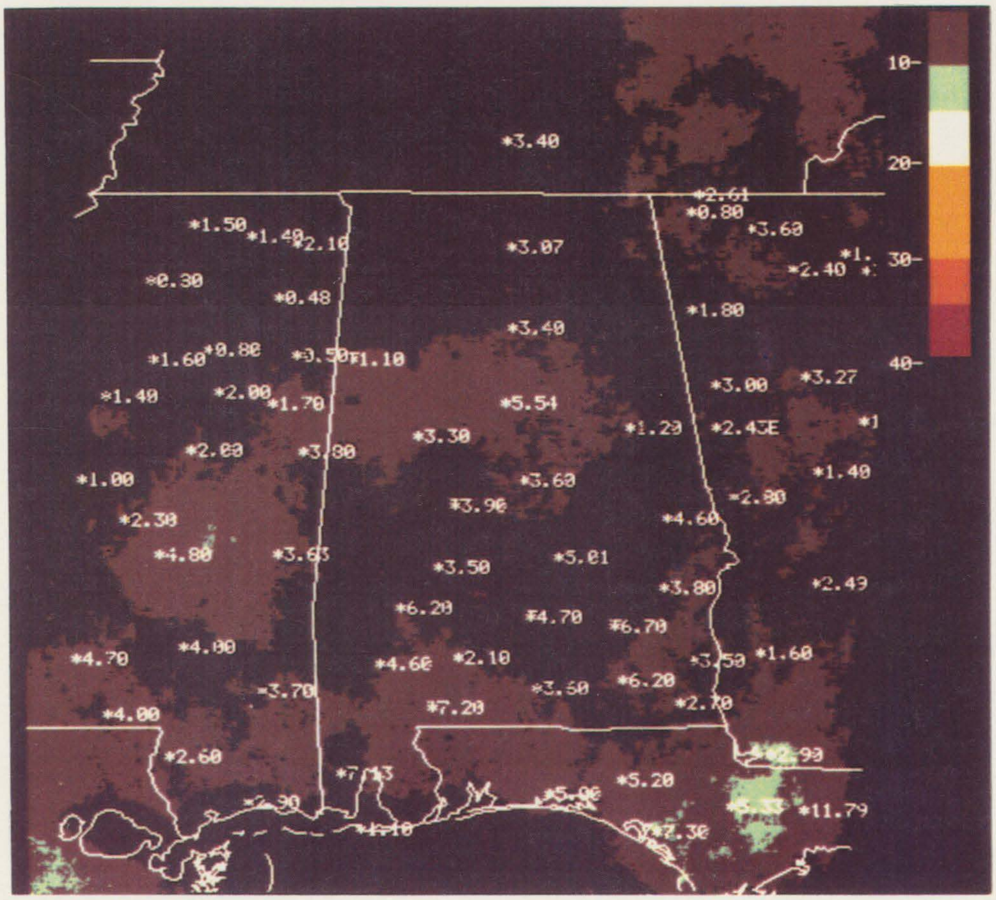

Figure 3. July 1986 Frequency of Convection to -41deg C and Colder and Monthly Precipitation

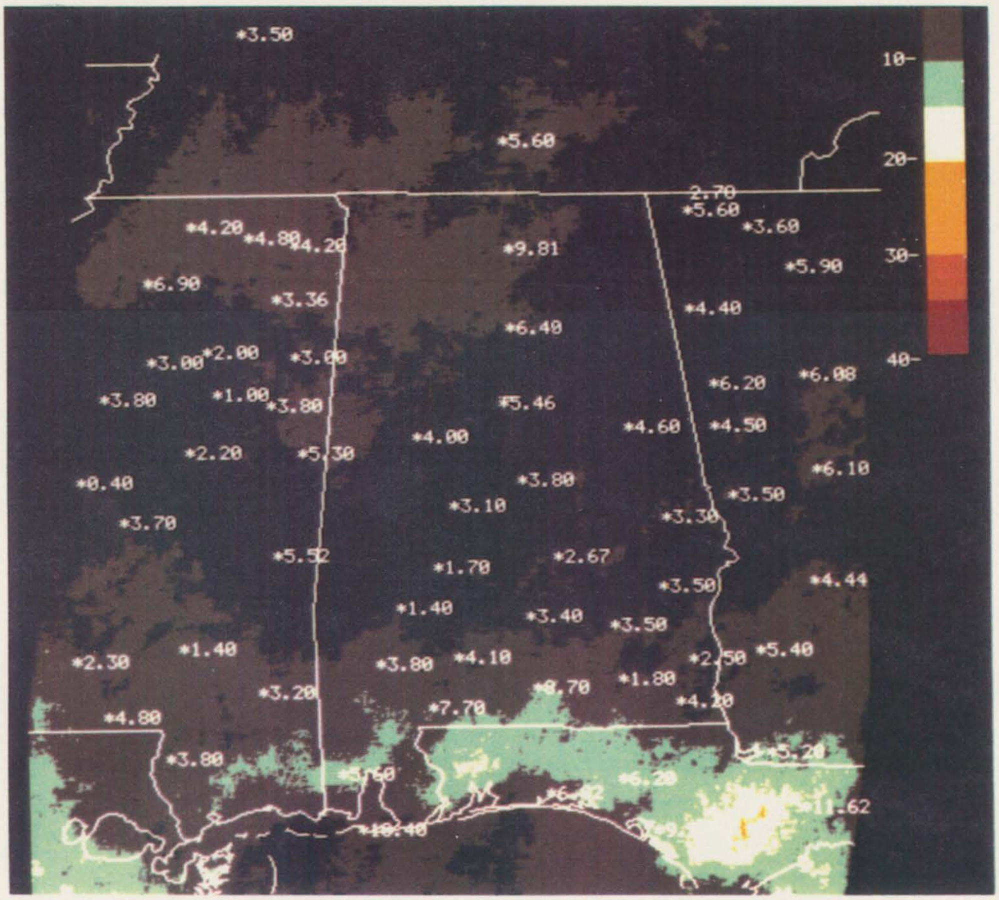

Figure 4. August 1986 Frequency of Convection to -41deg C and Colder and Monthly Precipitation

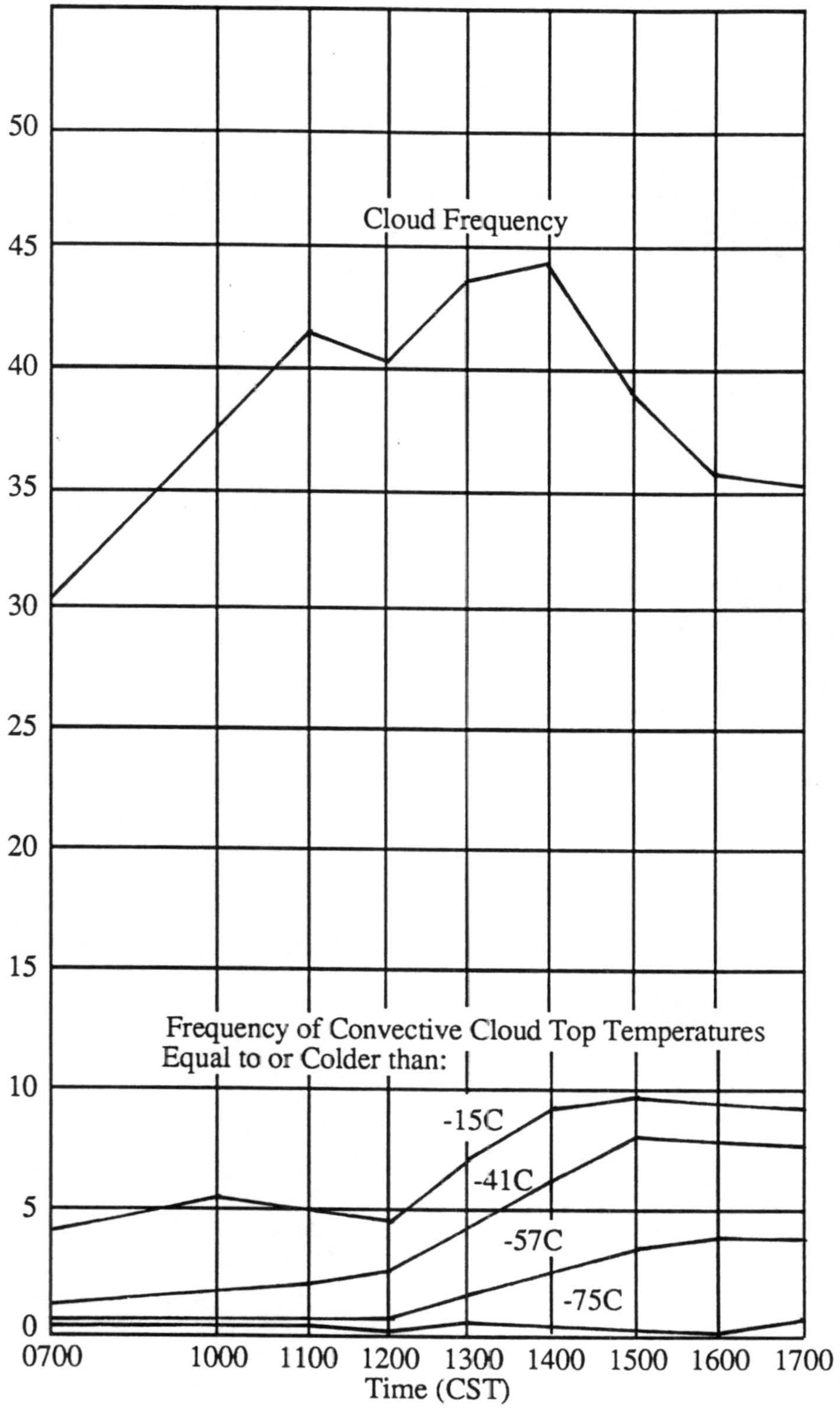

Figure 5. Average Cloud/Convection Frequency for the Summer 1986 Daylight Hours

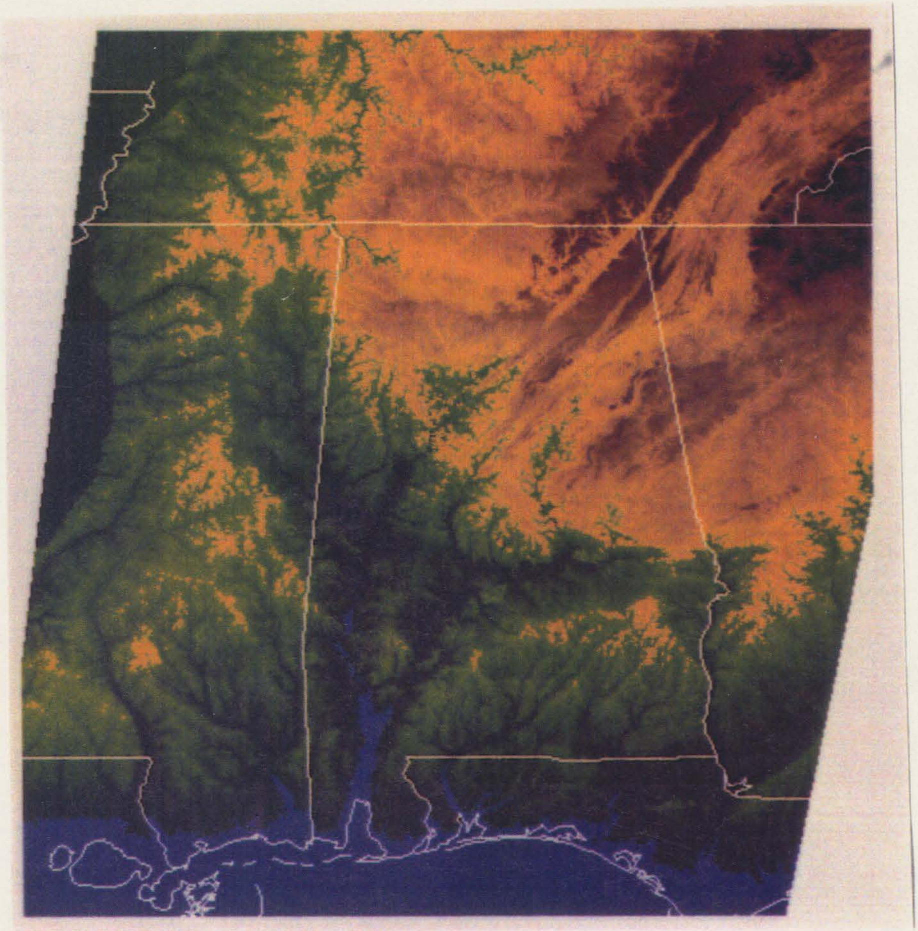

Figure 6. Topgraphy of Area of Study

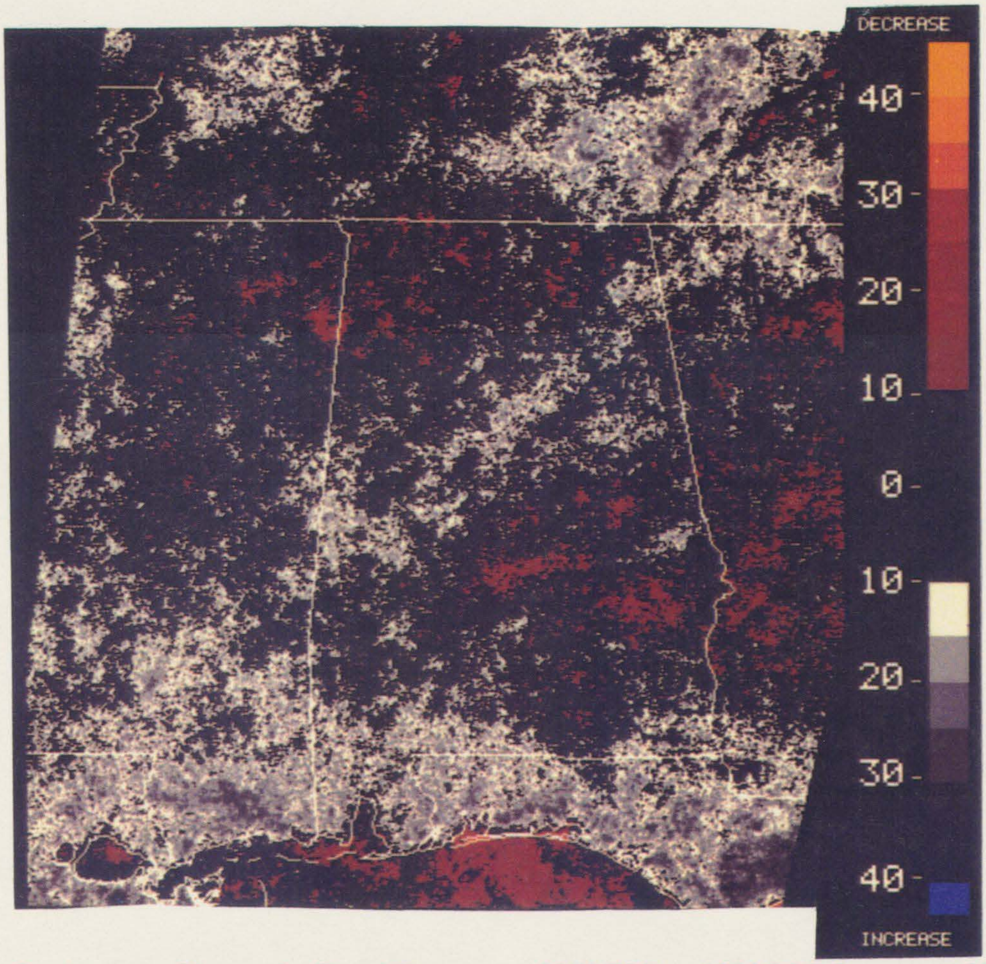

Figure 7. Average Change in Cloud Frequency 0700CST to 1000CST Summer 1986
White - Increase, Red- Decrease

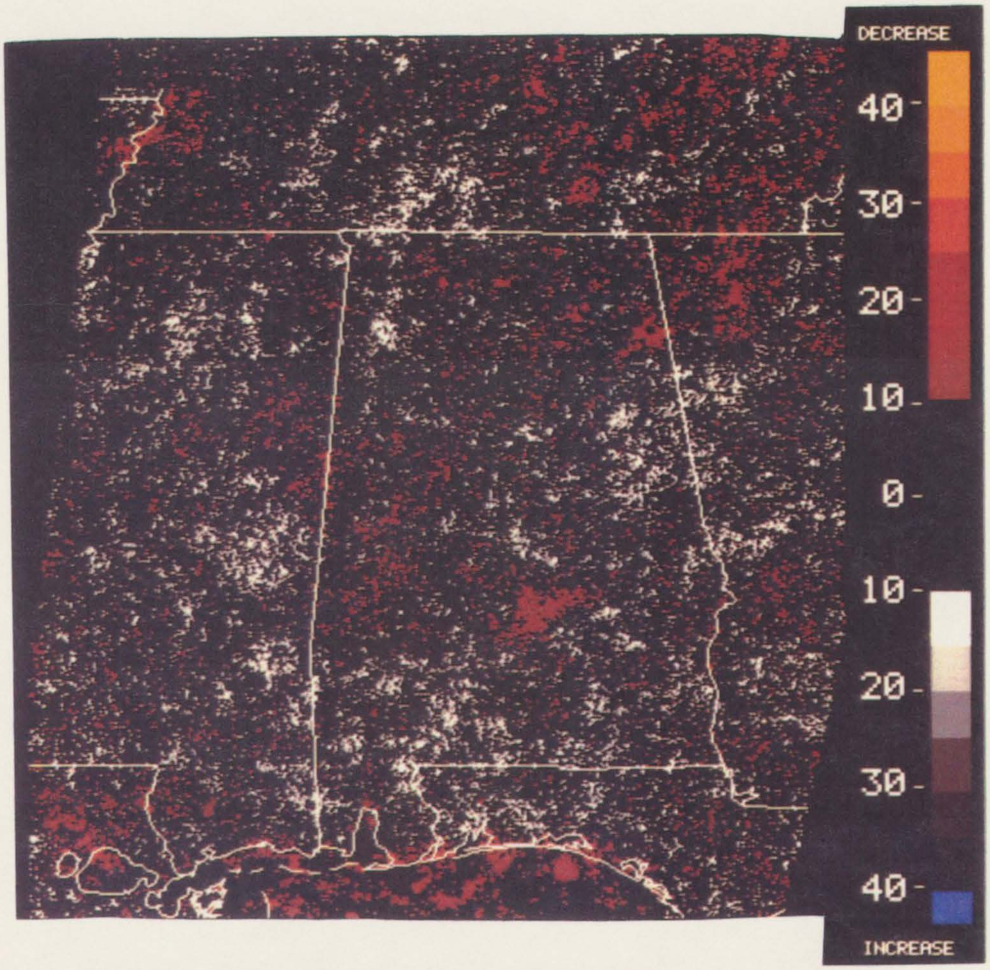

Figure 8. Average Change in Cloud Frequency 1000CST to 1100CST Summer 1986
White - Increase, Red- Decrease

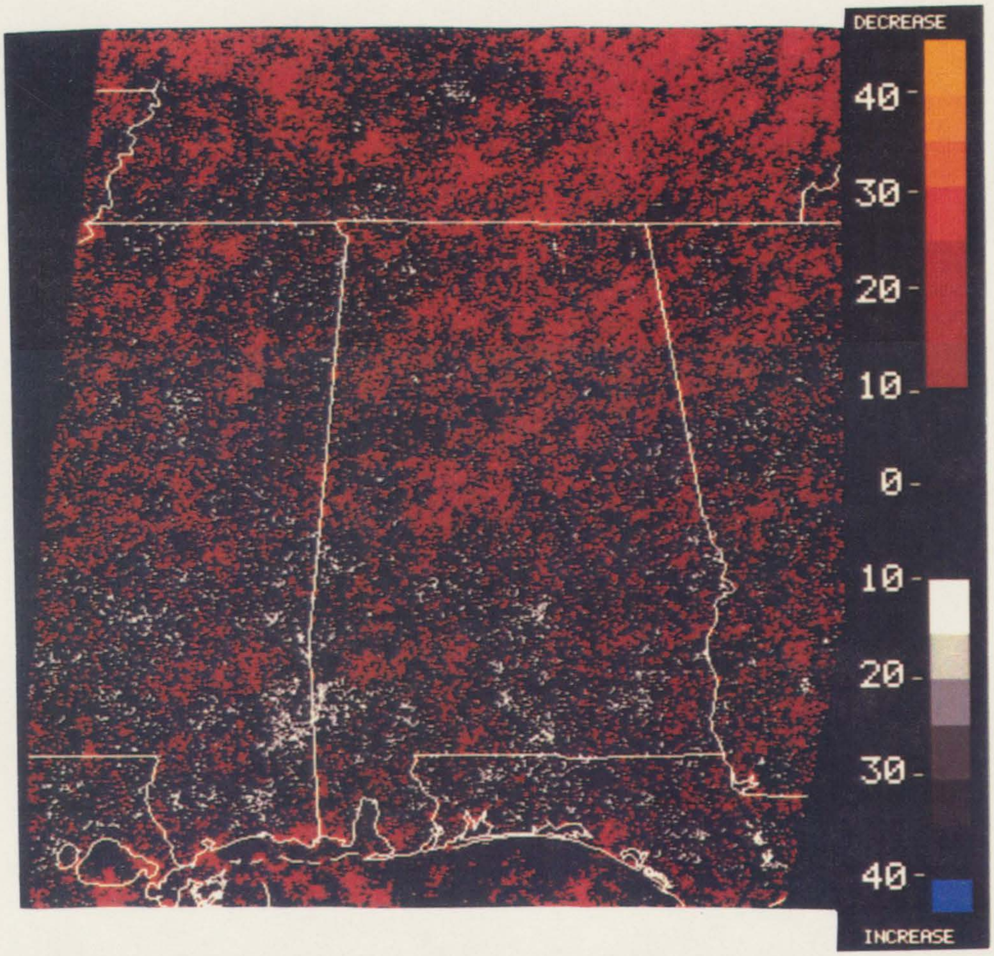

Figure 9. Average Change in Cloud Frequency 1100CST to 1200CST Summer 1986
White - Increase, Red- Decrease

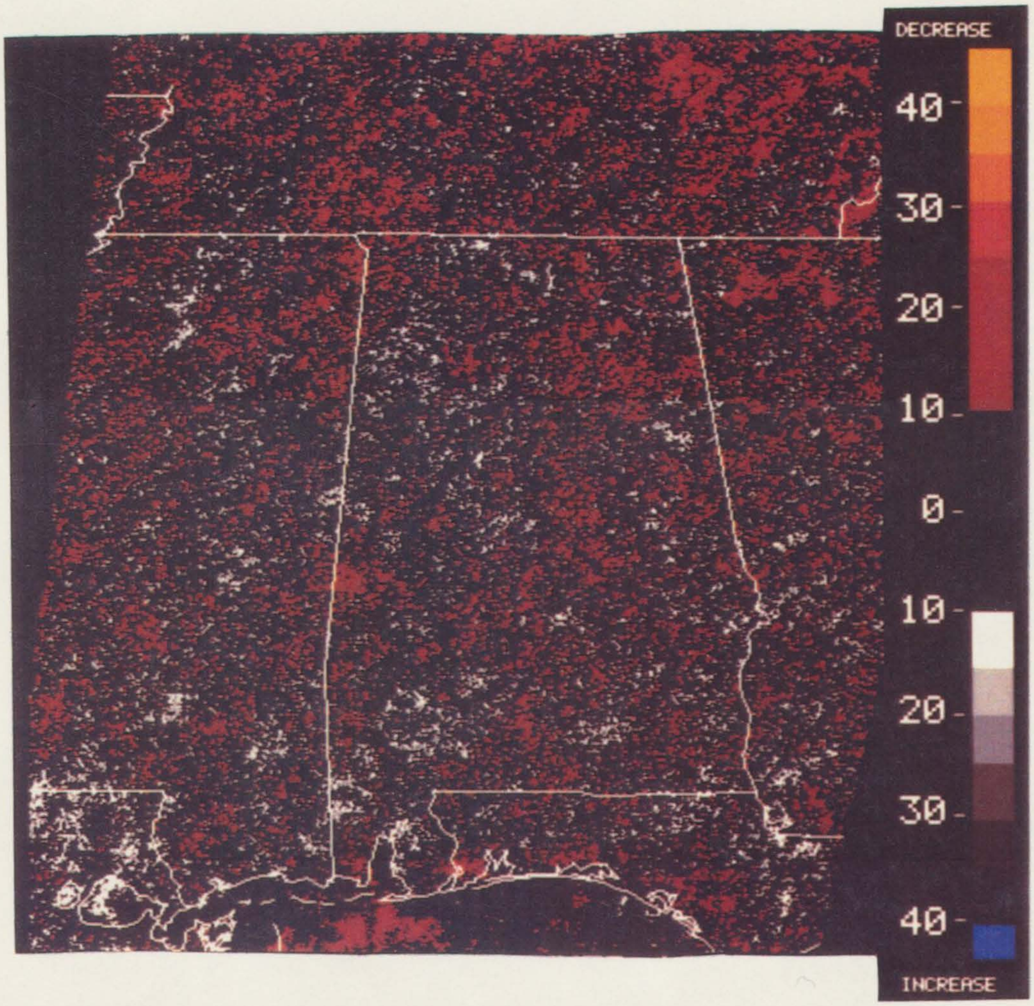

Figure 10. Average Change in Cloud Frequency 1200CST to 1300CST Summer 1986
White - Increase, Red- Decrease

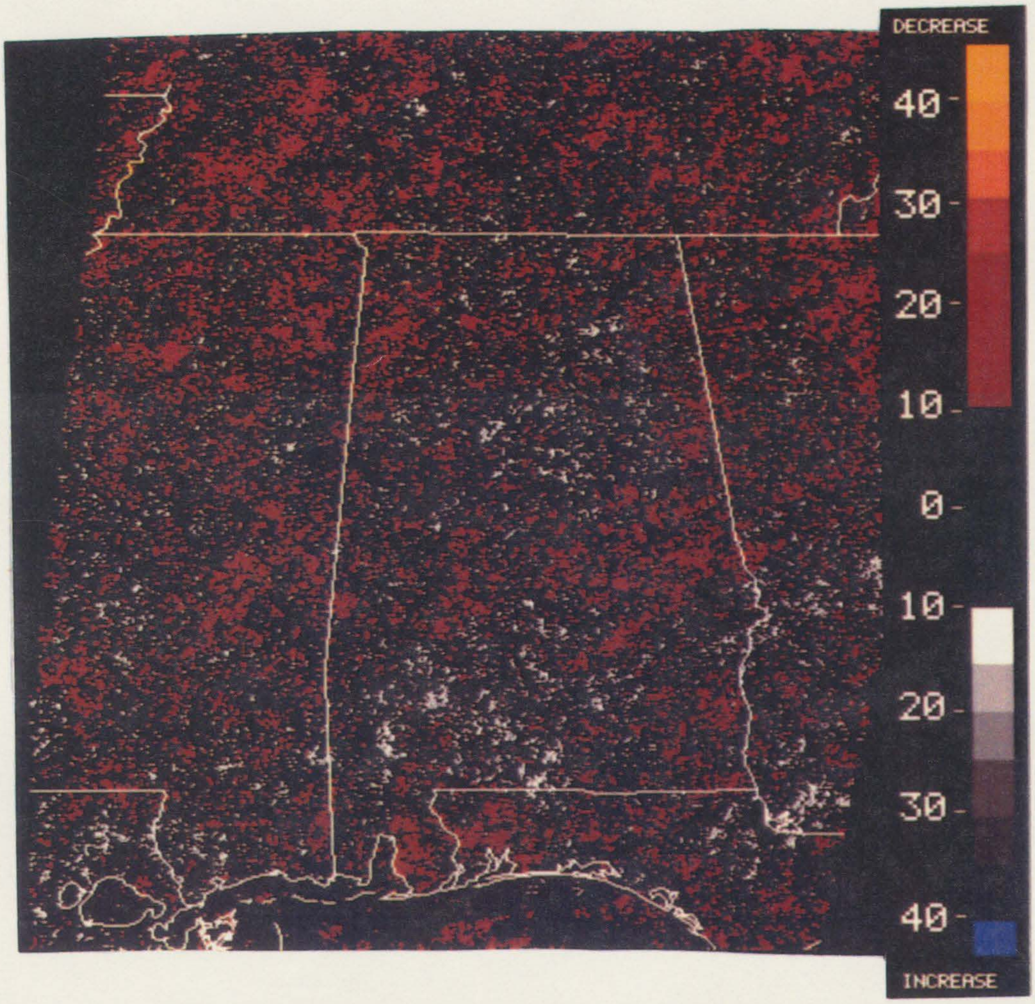

Figure 11. Average Change in Cloud Frequency 1300CST to 1400CST Summer 1986
White - Increase, Red- Decrease

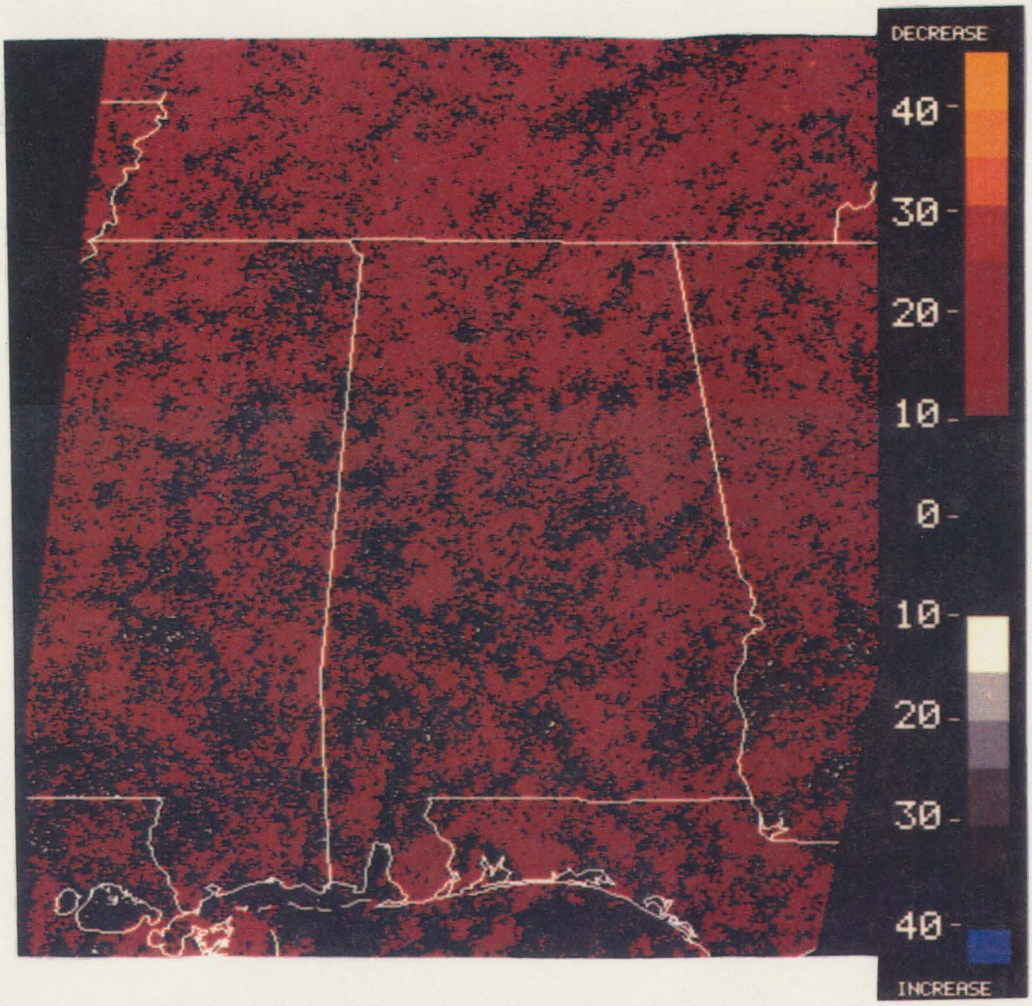

Figure 12. Average Change in Cloud Frequency 1400CST to 1500CSTSummer 1986
White - Increase, Red- Decrease

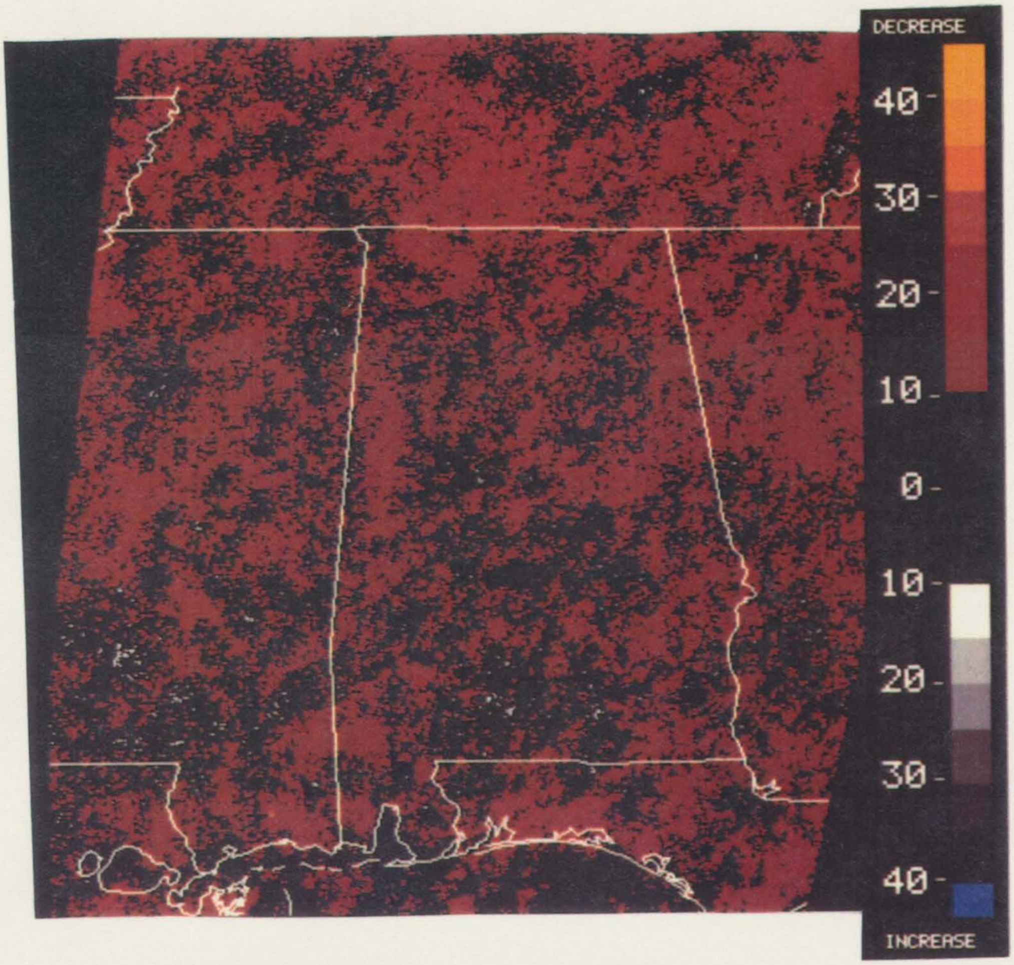

Figure 13. Average Change in Cloud Frequency 1500CST to 1600CST Summer 1986
White - Increase, Red- Decrease

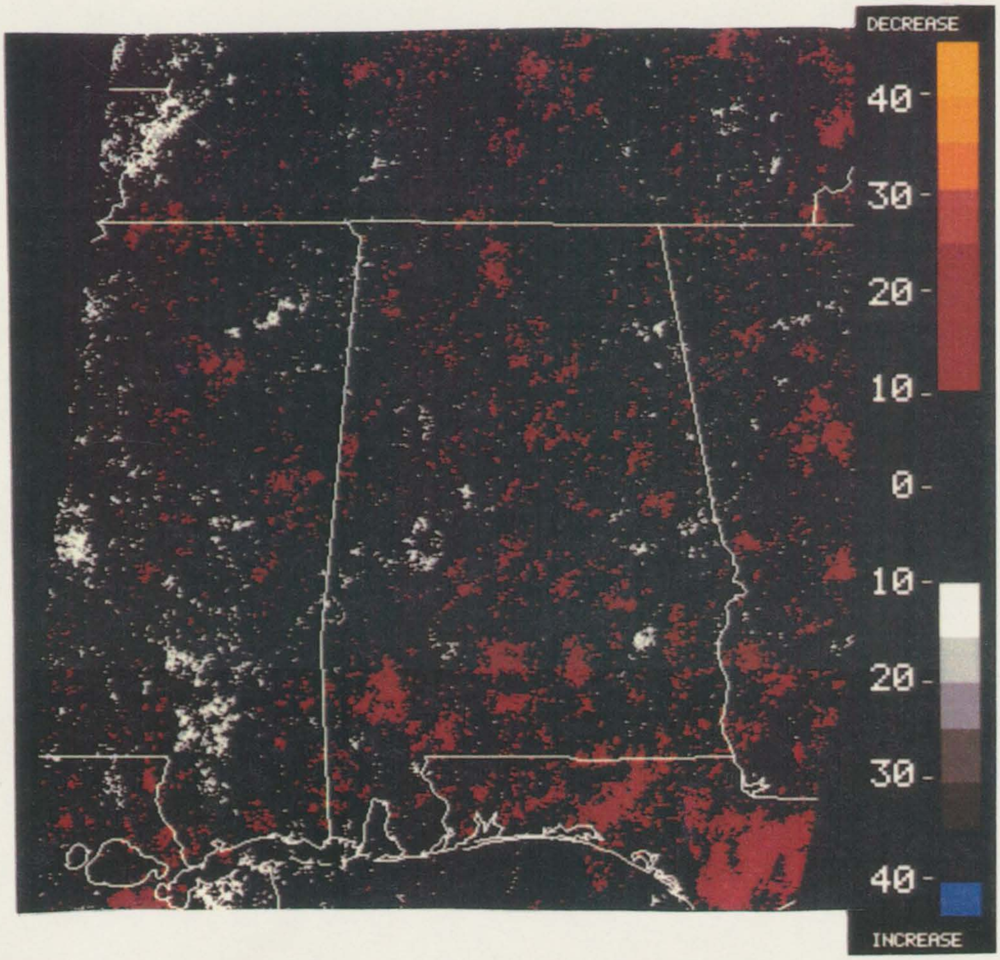

Figure 14. Average Change in Cloud Frequency 1600CST to 1700CST Summer 1986
White - Increase, Red- Decrease

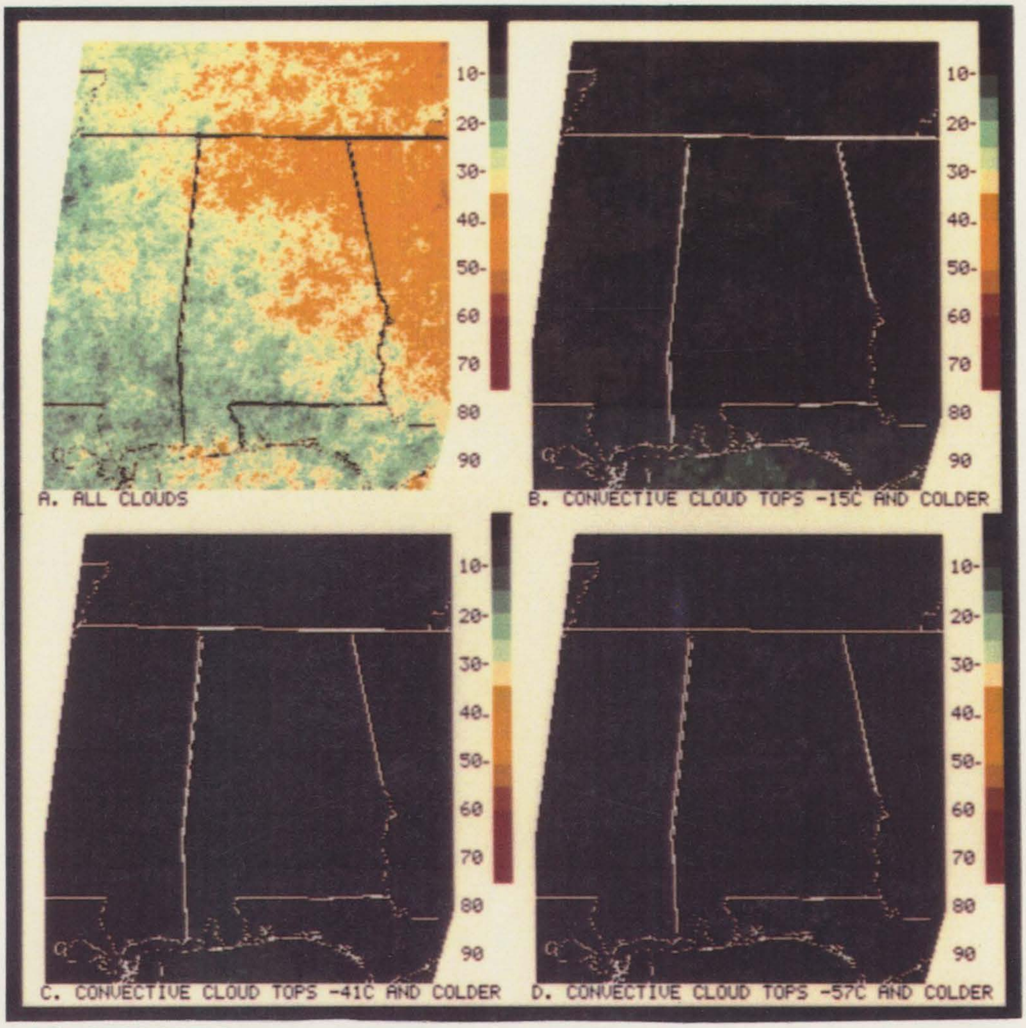

Figure 15. 0700CST Summer 1986 Frequency of Cloudiness and Frequency of Convective Cloud Tops of the Indicated Temperatures or Colder

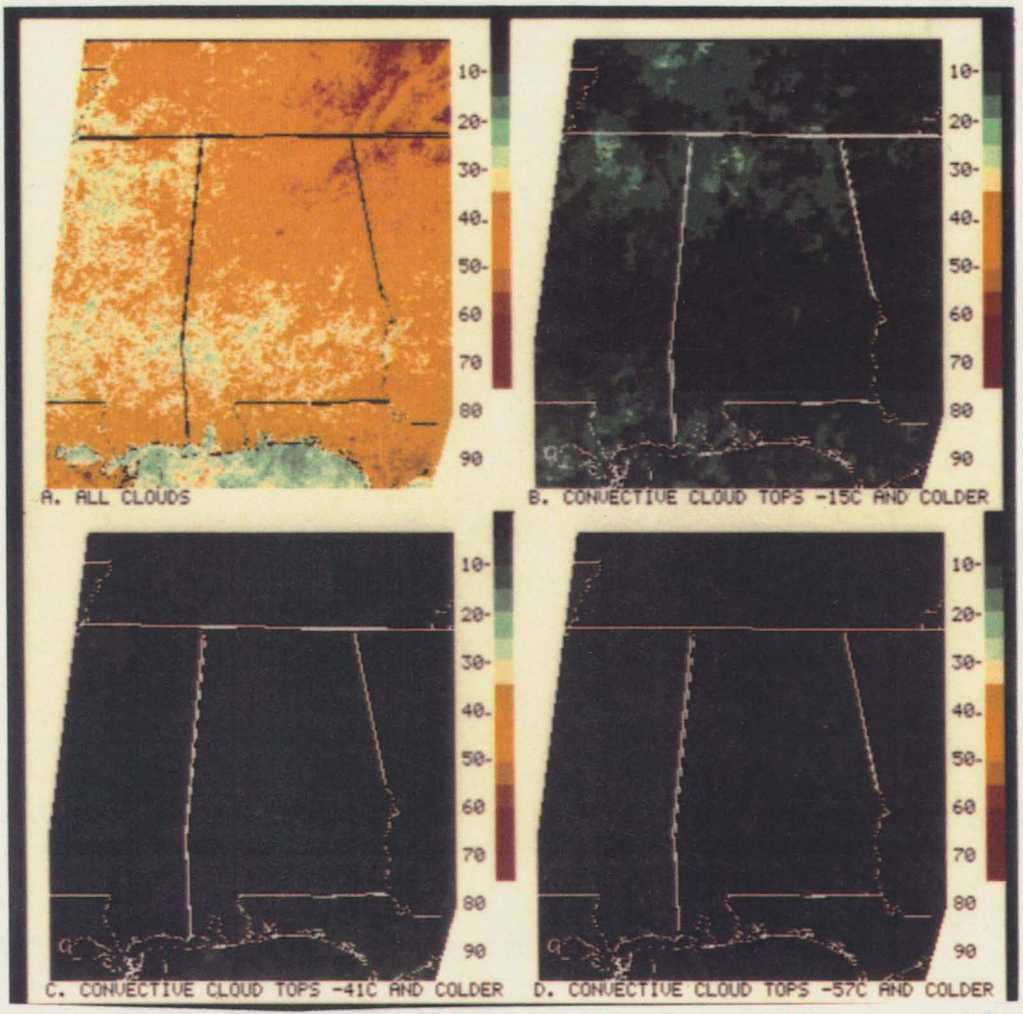

Figure 16. 1000CST Summer 1986 Frequency of Cloudiness and Frequency of Convective Cloud Tops of the Indicated Temperatures or Colder

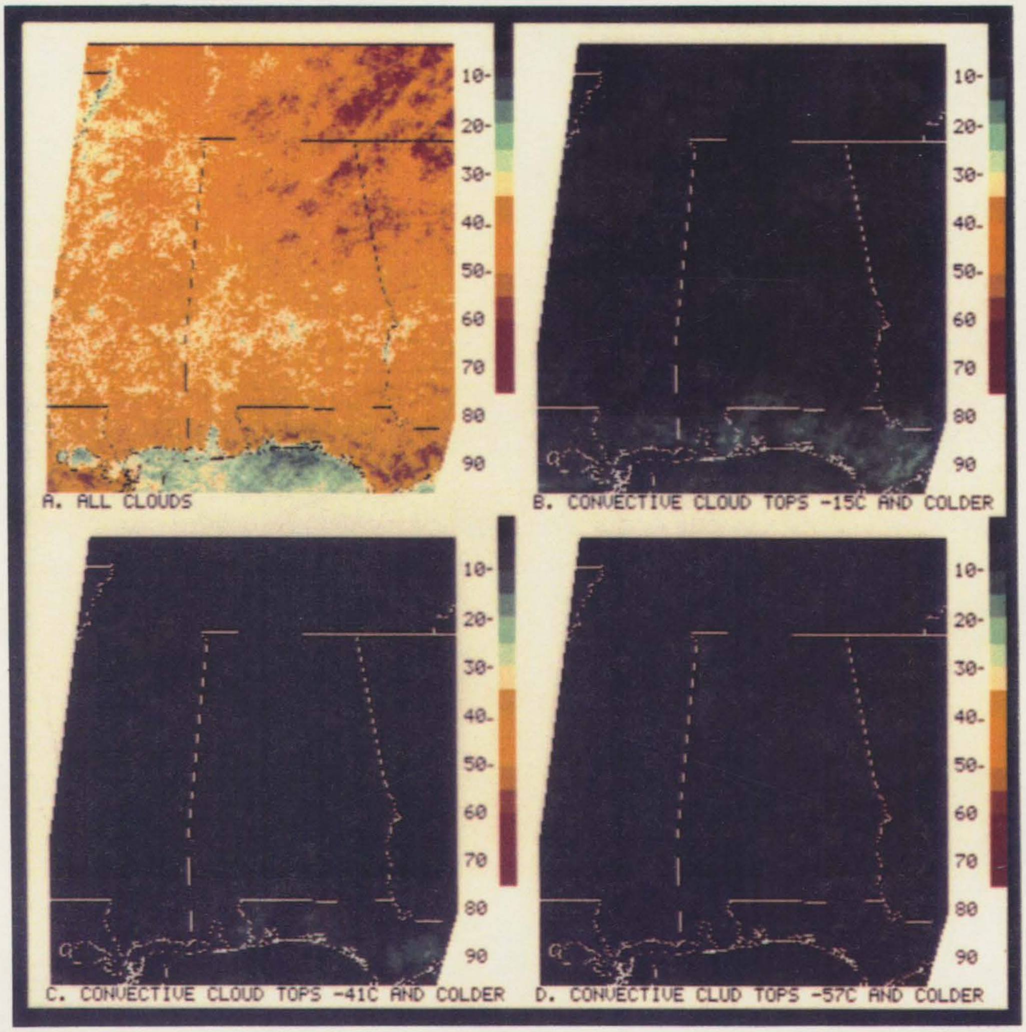

Figure 17. 1100CST Summer 1986 Frequency of Cloudiness and Frequency of Convective Cloud Tops of the Indicated Temperatures or Colder

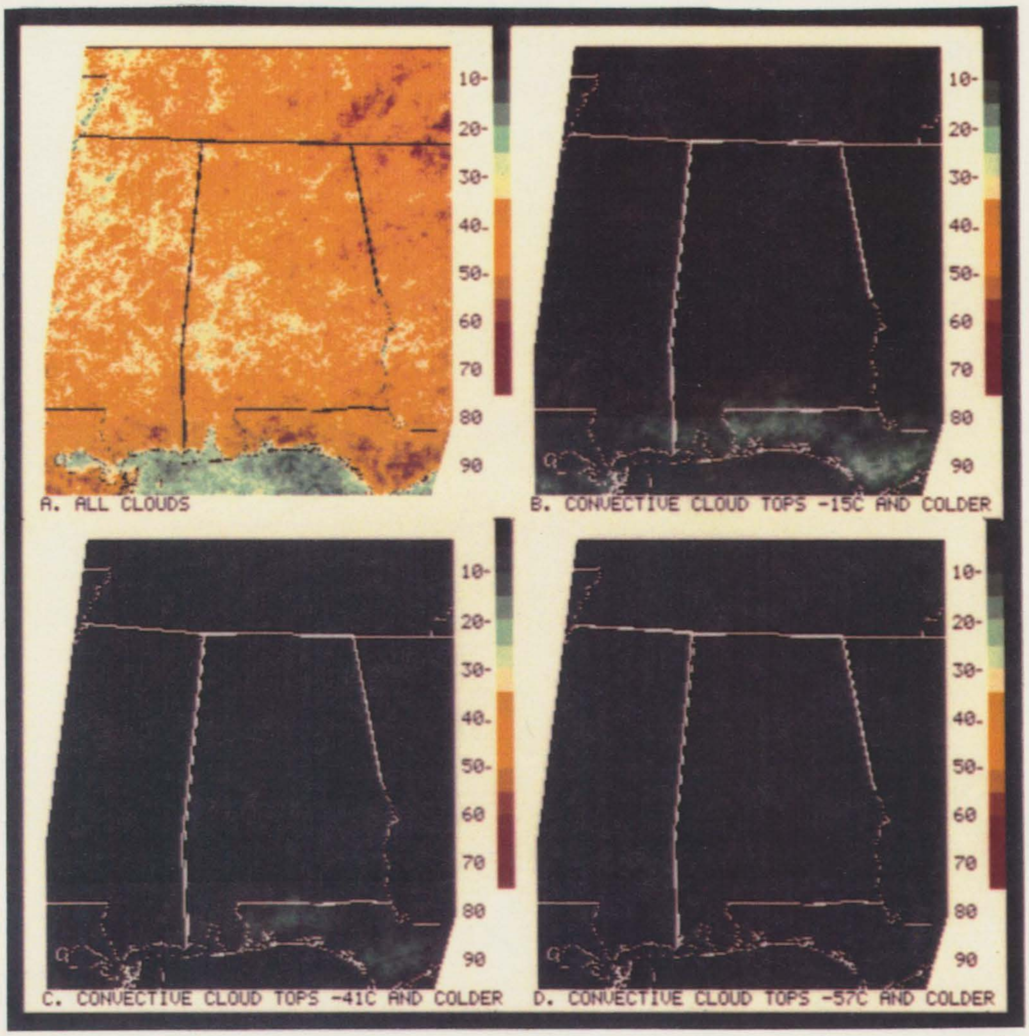

Figure 18. 1200CST Summer 1986 Frequency of Cloudiness and Frequency of Convective Cloud Tops of the Indicated Temperatures or Colder

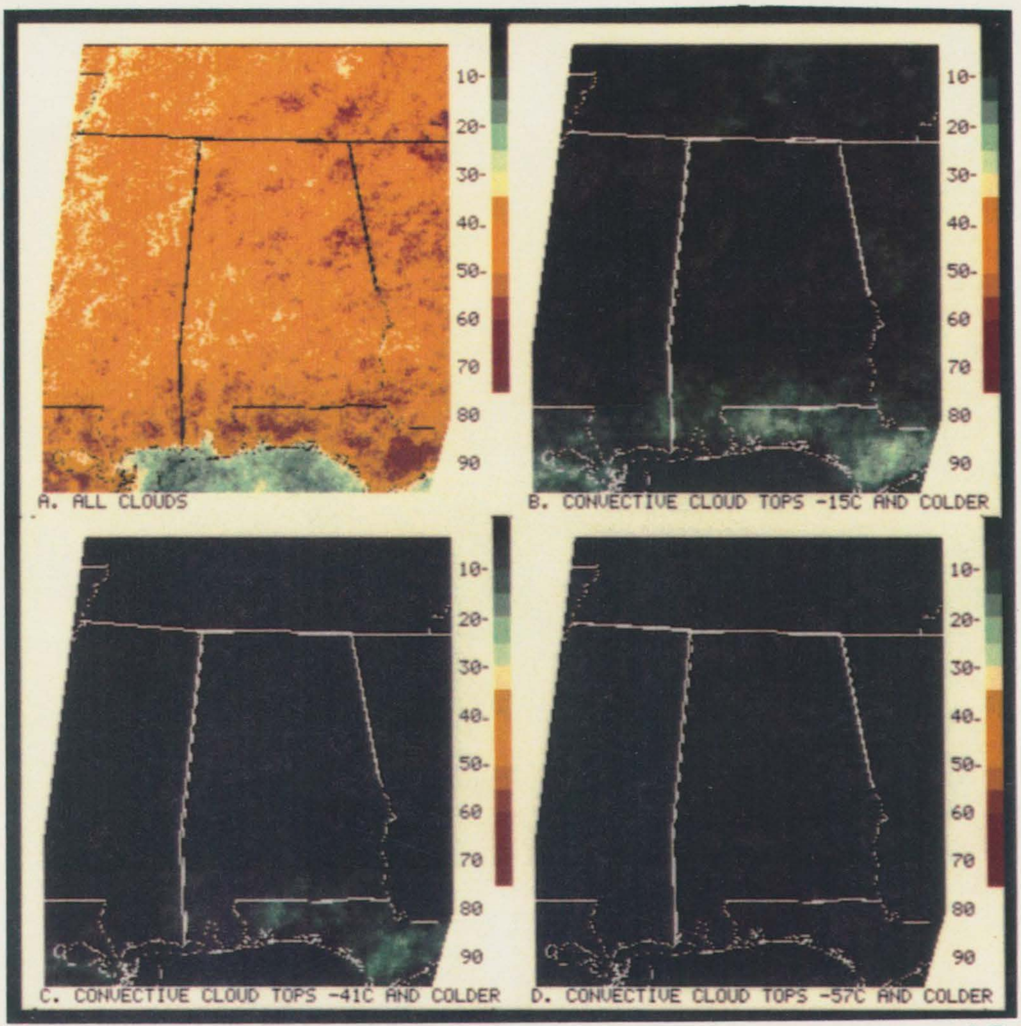

Figure 19. 1300CST Summer 1986 Frequency of Cloudiness and Frequency of Convective Cloud Tops of the Indicated Temperatures or Colder

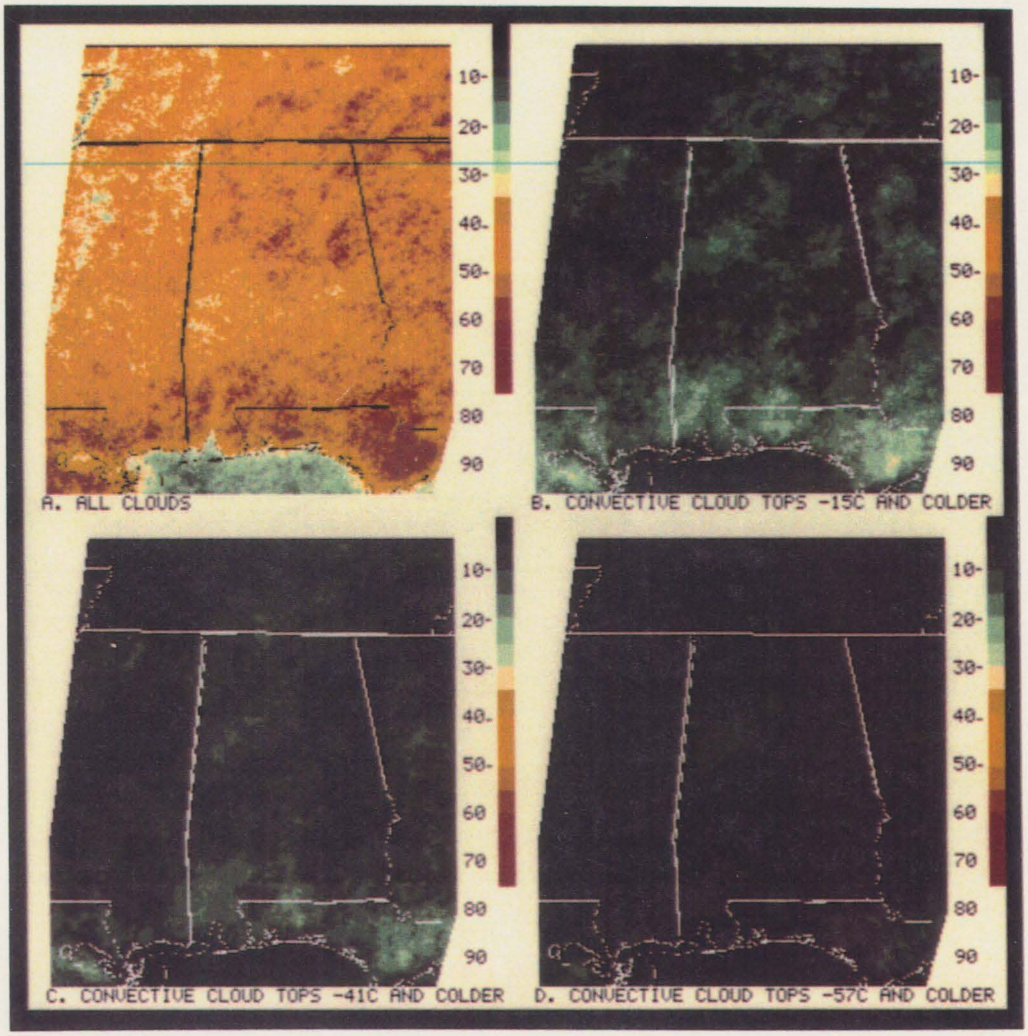

Figure 20. 1400CST Summer 1986 Frequency of Cloudiness and Frequency of Convective Cloud Tops of the Indicated Temperatures or Colder

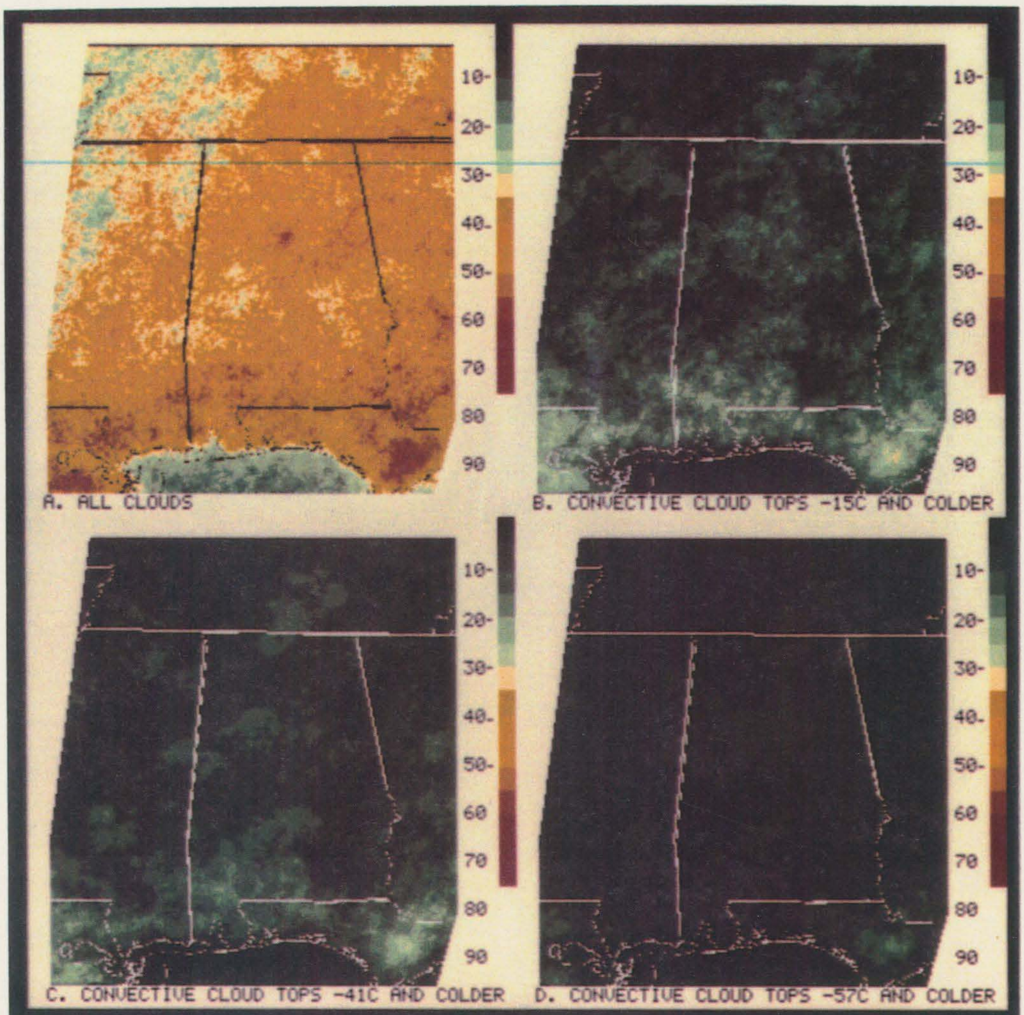

Figure 21. 1500CST Summer 1986 Frequency of Cloudiness and Frequency of Convective Cloud Tops of the Indicated Temperatures or Colder

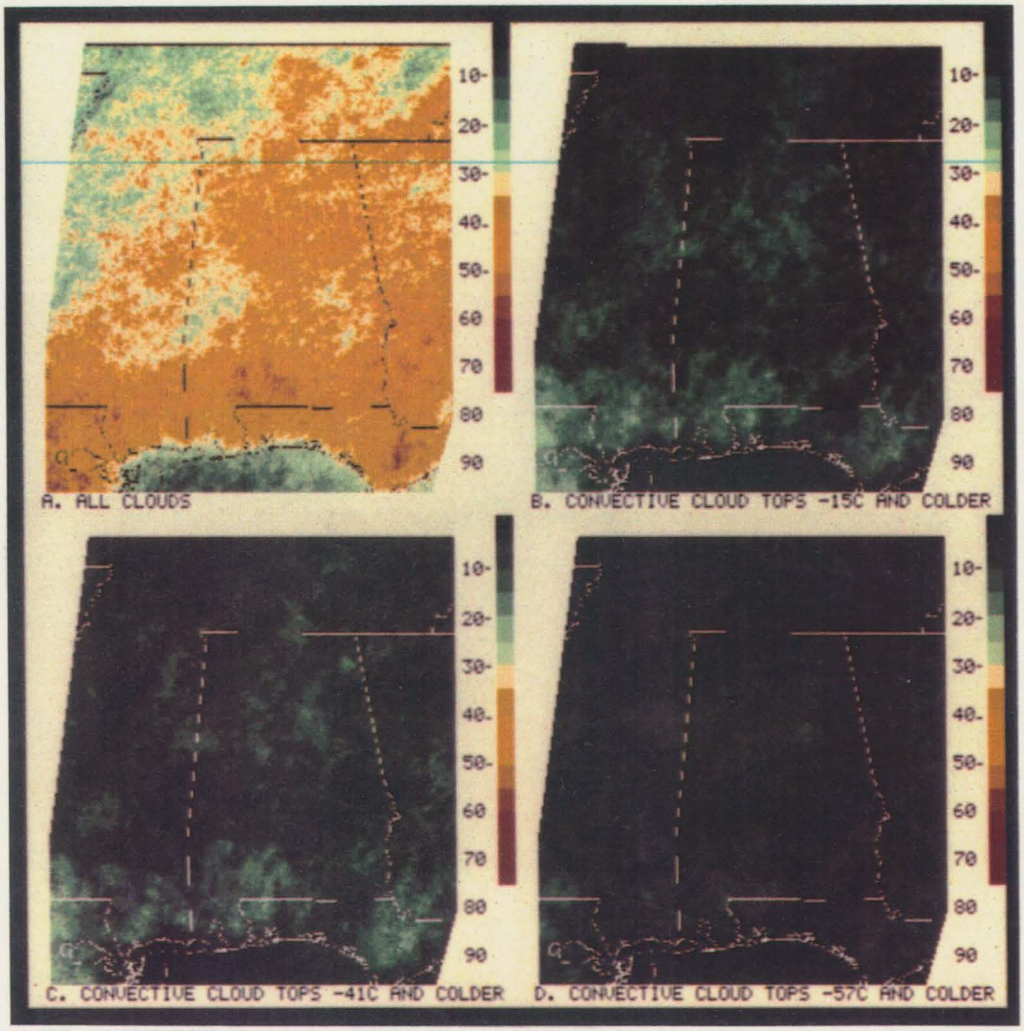

Figure 22. 1600CST Summer 1986 Frequency of Cloudiness and Frequency of Convective Cloud Tops of the Indicated Temperatures or Colder

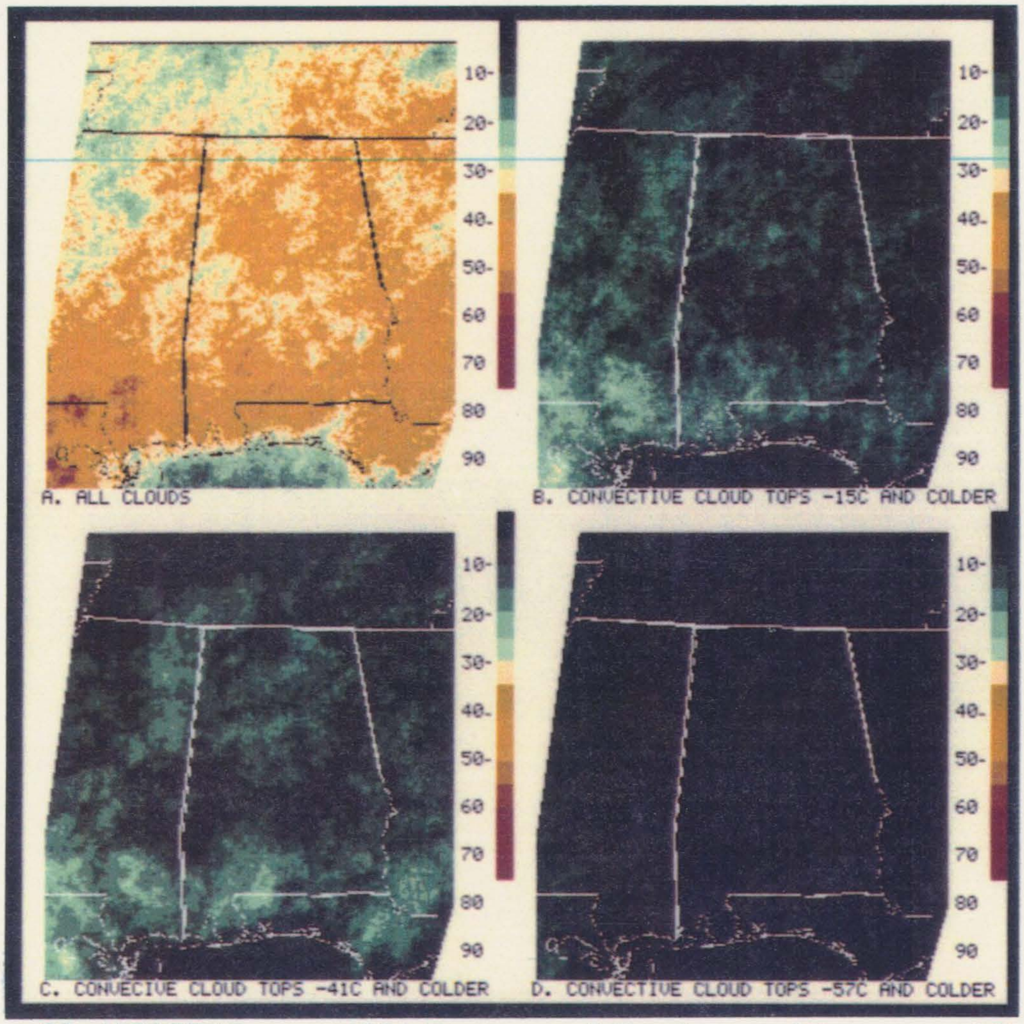

Figure 23. 1700CST Summer 1986 Frequency of Cloudiness and Frequency of Convective Cloud Tops of the Indicated Temperatures or Colder