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WHERE ARE CIRRUS CLOUDS AND WHY ARE THEY THERE?

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This paper is a summary of the cirrus cloud climatology of Wylie and Menzel (1988) and some ancillary studies of cirrus clouds that have been made using the same data set. The Wylie and Menzel climatology is a unique data set of cloud statistics extracted from the GOES/VAS satellite. With these data we can describe the geographical distributions of clouds, there seasonal changes, some diurnal changes, and also what atmospheric conditions cause the clouds.

The GOES/VAS cloud analysis algorithm separates cloud cover on the satellite imagery into two classes; 1) those clouds that are opaque to terrestrial radiation, and 2) those that are semi-transparent to the upwelling infrared radiation. The technique identifies the semi-transparent clouds using the multi-spectral channels of the GOES VISSR Atmospheric Sounder (VAS). Some of these channels are sensitive to different levels in the atmosphere. Ideally, a low altitude cloud can not be seen by a channel sensitive only to the upper atmosphere while a high altitude cloud will be seen on all channels. The strength of the cloud signature from the cloud free background varies between the channels because each is sensitive to a different level in the troposphere. This method has also been called the "CO_2 Slicing Method" (Menzel et al., 1983) because VAS channels are capable of viewing only "slices" of the troposphere.

The differential sensitivity of the VAS channels allows the radiative transfer equation to be solved for the cloud top height independently from the emissivity of the cloud. This allows a segregation of clouds on the GOES/VAS image into opaque clouds and partially transmissive clouds which are called cirrus by Wylie and Menzel (1988). In reality, cirrus clouds are more correctly defined as ice clouds some of which are thick enough to be opaque to terrestrial radiation. A large number are sufficiently thin to upwelling terrestrial radiation. The thin clouds are very important to studies of the radiative heating of the earth because they allow solar radiation to penetrate through while partially blocking some of the upwelling infrared radiation. In this paper we use the term "cirrus" to mean only the thin and semi-transparent clouds.

Cirrus clouds are more frequent than previously estimated. They are found over the Continental United States and bordering oceans from 25 to 35 % of the time. Opaque clouds were found ~ 45% of the time and no clouds (clear skies) were found ~ 25% of the time.

Opaque cloud cover has large geographical variations while cirrus do not (see Figures 1 and 2). The "Sun Belt" where opaque clouds are infrequent and clear skies are frequently found, are obvious in the geographical summaries (Figures 1 and 2). They are found in southern Texas and Mexico during the winter and over most of the southwestern United States, Texas, New Mexico, Arizona, and California, in the summer.

Cirrus clouds, on the other hand, have very small geographical variances. They were slightly less frequent in the southwest than the rest of the United States. The only area where few cirrus were found was in the Eastern Pacific Ocean. Here a large seasonal change also can be seen because of the northward migration of the Subtropical High in the summer.

The seasonal changes over the area shown in Figures 1 and 2 are summarized in Table 1. The geographical bounds of this study are 25^o to 50^o north latitude and 60^o to 140^o west longitude. The probability of finding both opaque and cirrus clouds increases in the winter. In the summer the average probability of opaque clouds is 42% which increases to 46% in the winter. Cirrus clouds increased by a similar amount from a probability of 24% in the summer to 29% in the winter. The probability of clear skies correspondingly decreases from summer to winter, 34% to 25%.

TABLE 1: THE PROBABILITY OF CLOUDS

Season	Cirrus	Opaque	Clear sky
Summer	24%	42%	34%
Winter	29%	46%	25%

To seek answers to the question of "why are the cirrus clouds present?" the GOES/VAS cloud reports were compared to atmospheric dynamic and thermodynamic conditions which are suspected to cause clouds. To cause cirrus clouds, the upper troposphere has to be rising which can lead to saturation.. Moistening of upper layers also can lead to saturation which will cause cirrus generation. This can happen by a number of mechanisms. Cumulonimbus convection obviously is one mechanism which comes to mind because the large cirrus anvil clouds seen on top of the cumulonimbus clouds.

To determine what fraction of the cirrus clouds are related to the cumulonimbus convection, we counted the percentage of cirrus reports near radar echoes using the echoes as indicators of the presence of the cumulonimbus clouds. The radar summary from the National Weather Service was used for locating the radar echoes (Figure 3). The radar summary is a pictorial summary of all echo reports from all weather radars in the United States. Regions where echoes are reported are shaded on these summaries along with numeric information on the maximum heights of the echoes and their speeds and directions of movement.

The echo summary areas were extended to allow for cirrus blow off from the cumulonimbus. The extended boundary (solid line) was drawn from 50 to 300 km outward from the echo summary boundary. The extended boundary was placed 100 to 300 km downwind of the echo boundary. The distance was apportioned using the 300 mb wind speed allowing for advection over three hours. On the cross wind and upwind sides of the echo boundary, the extended boundary was placed ~50 km from the echo boundary to allow for lateral spreading of the cirrus anvil.

The GOES/VAS cirrus analyses at 00:00 GMT and 12:00 GMT were used in this study. The extended echo boundaries for all NWS radar summaries in the time period three hours prior to the GOES/VAS analysis were used to define the extended boundary. This study was performed in two seasons. The month of June 1986 was chosen to represent a summer season and January 1988 to represent a winter season.

The cirrus reports were separated into either being close to the radar echoes (inside the boundary) or away from any echoes (outside of the boundary). The same separation also was made for all cloud reports (cirrus and opaque) of high cloud above 500 mb. The results are given in Table 2.

In the summer approximately one-half of the cirrus and high cloud (both cirrus and opaque cloud) reports were close to or over radar echoes (52 to 57%). The other half were far away from the echoes (48 to 43%). This statistic implies that Cb convection only explains one half of the cirrus in the summer.

In the winter a different picture was found. Only 22% of the cirrus and 24% of the high cloud reports were near the radar echoes. The other 76 to 78% were separated from the echoes. The amount of area covered by radar echoes decreased in the winter while the number of cirrus and opaque cloud reports increased. Thus in winter, most of the cirrus have no relation to Cb clouds.

The cirrus not directly caused by Cb clouds must be created and maintained by other motions in the atmosphere. We are currently examining vorticity and temperature advection for their relationships to cirrus and high clouds. The polar and sub-tropical jet streams also will be examined.

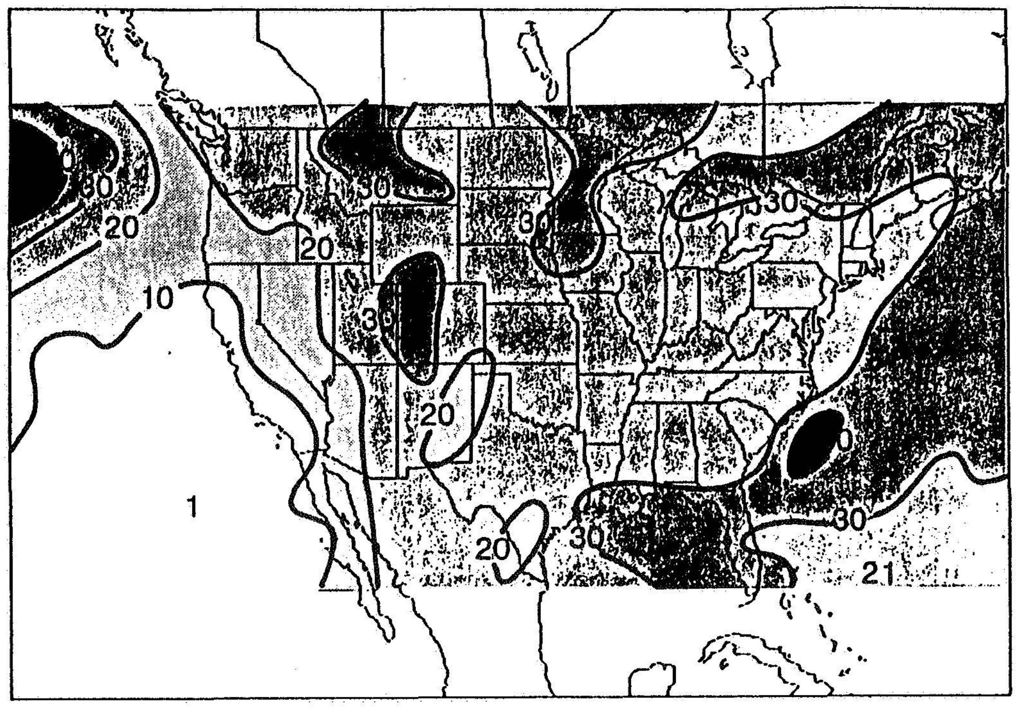
TABLE 2: THE PROBABILITY OF FINDING CLOUD OBSERVATIONS WITH RESPECT TO RADAR ECHOES.

Type of Cloud	Near or Over Echoes	Not Related to Echoes
Cirrus in summer	52%	48%
Cirrus in winter	22%	78%
All clouds <500 mb in summer	57%	43%
All clouds <500 mb in winter	24%	76%
October 86 (FIRE IFO) Cirrus	32%	68%
October 86 (FIRE IFO) All clouds	34%	66%

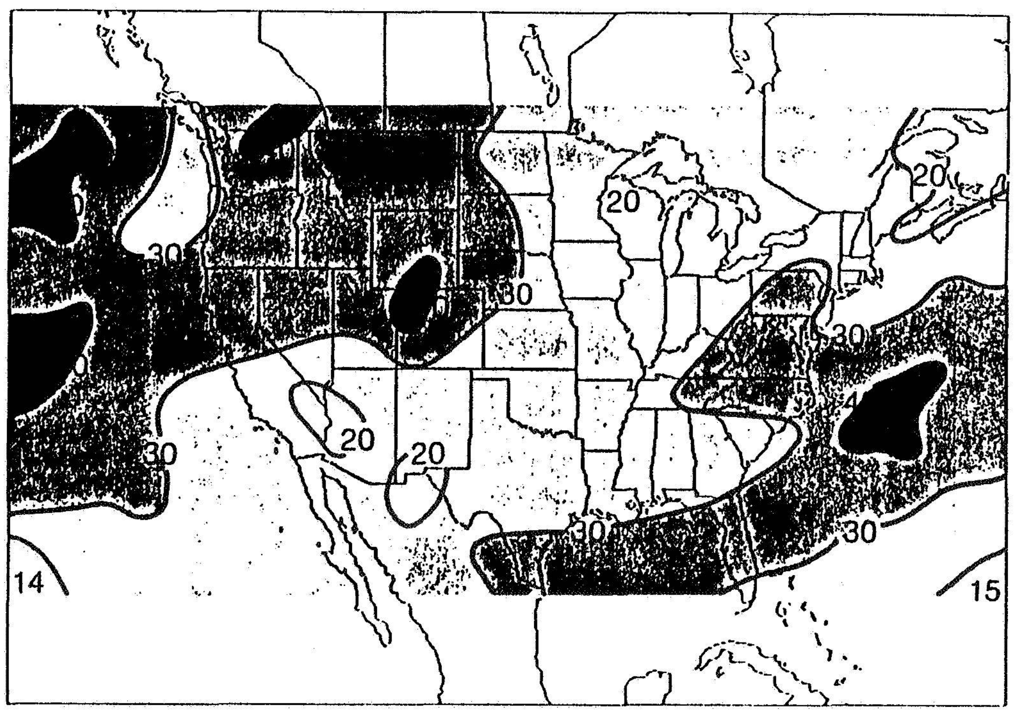
REFERENCES

Menzel, W. P.,W. L. Smith, and T. R. Stewart, 1983: Improved cloud motion wind vector and altitude assignment using VAS. J. Clim. Appl. Meteor., 22, 377-384.

Wylie, D. P., and W. P. Menzel, 1988: Cloud cover statistics from GOES/VAS, in preparation.

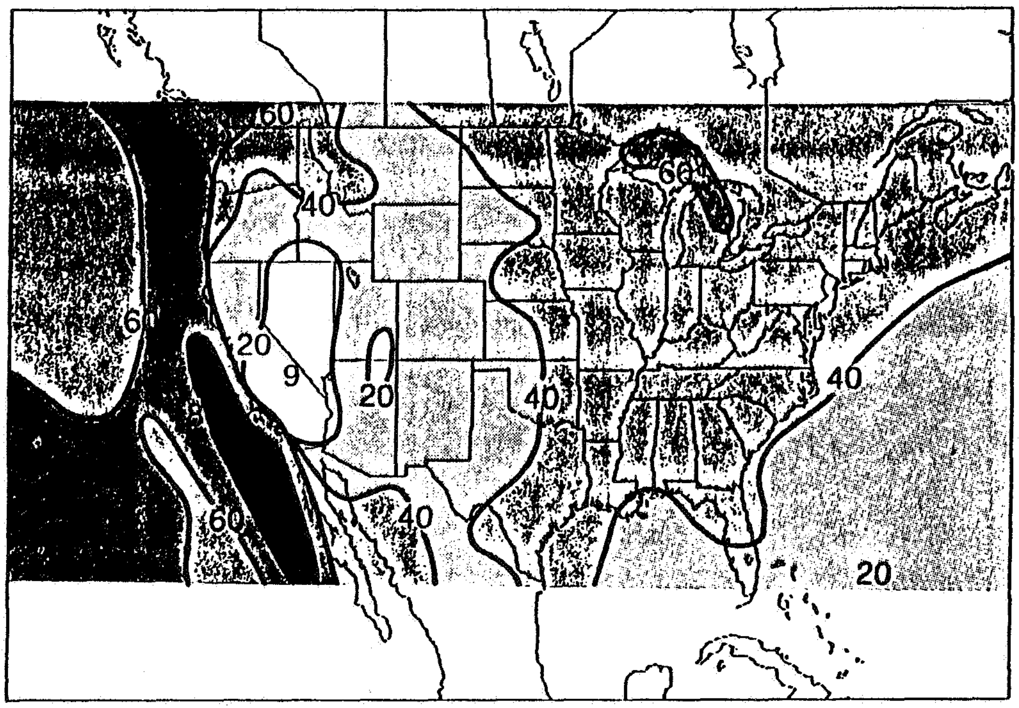


PROBABILITY OF CIRRUS IN SUMMER

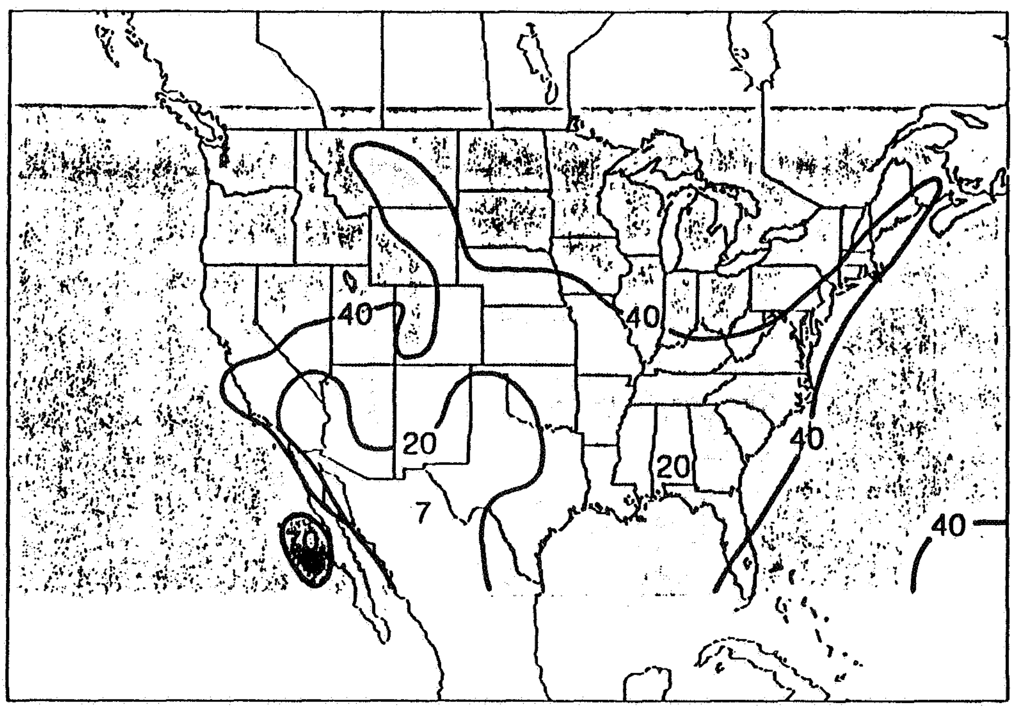


PROBABILITY OF CIRRUS IN WINTER

Figure 1: Probability of finding cirrus clouds in summer (June- August) and winter (December-February). Two winters and summers were averaged together.

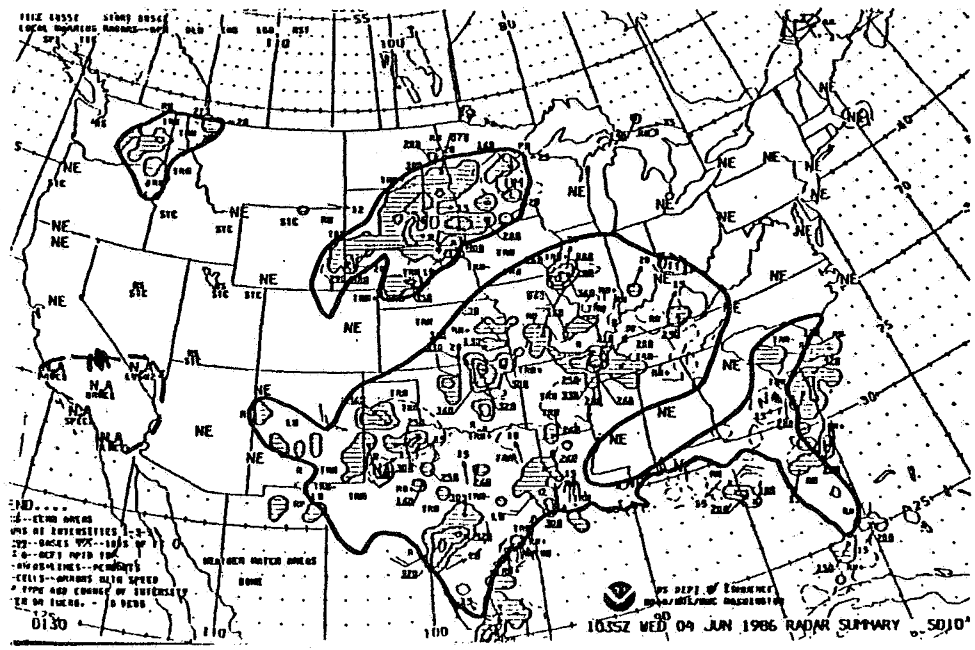


PROBABILITY OF OPAQUE CLOUD IN SUMMER

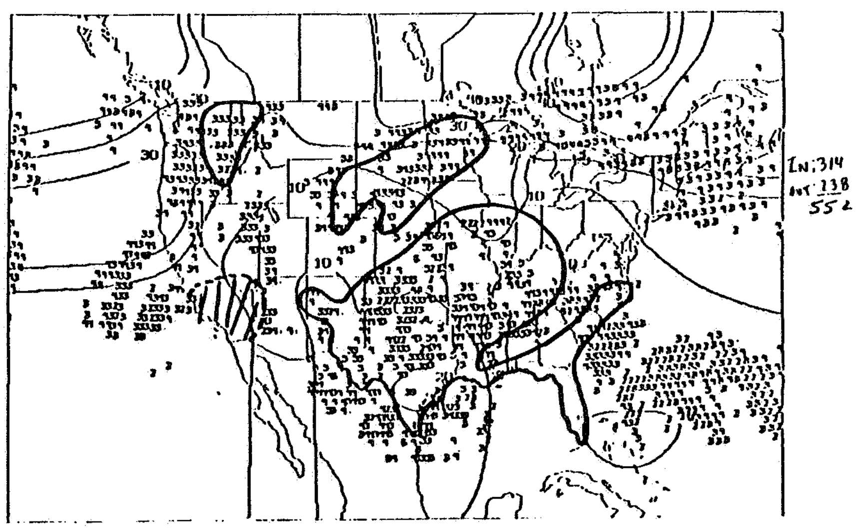


PROBABILITY OF OPAQUE CLOUD IN WINTER

Figure 2: Probability of finding Opaque clouds in summer and winter.



National Weather Service Radar Echo Summary



Cirrus Cloud Analysis

Figure 3: An example of a National Weather Service Radar Echo Summary used of defining locations of cumulonimbus clouds. The extended boundary of probable cirrus anvil is defined by the thick line.

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