The Radar Observation of Mature Prefrontal Squall Lines in the Midwestern United States[1]

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In very recent years, the acquisition of observations from powerful 10- and 23-cm wave length radar stations located in the midwestern United States has revealed a heretofore unsuspected micro-scale circulation pattern in prefrontal squall lines. That such a pattern exists is deduced from the precipitation echo pattern as it is displayed on plan position indicators (PPI's) of radars. Unfortunately, while the radar observation shows that highly organized micro-circulations are present in such storms, it does not tell us the nature of the air currents, namely, their speeds and directions in both the horizontal and vertical planes. At present the only possible way to get this information appears to be to fly suitably instrumented aircraft into the storms to make observations. The writer will be the first to admit that this would be a highly unpleasant and dangerous task.

The interesting features of the precipitation echo pattern are shown in fig. 1 which shows a typical situation together with a sketch to bring out in greater clarity the various elements. The illustration shows the PPI scope of a 10-cm wave length radar located in Texas. North is at the top of the picture, east to the right, etc. The heavy circles indicate range increments of 50 nautical miles from the station, the position of which is at the center of the scope. The roughly circular echo extending to about 20 miles in all directions from the center is produced by buildings and hills close to the station and may be ignored. The large white areas in the northwestern half of the display are produced by echos from hydrometeors (raindrops, hailstones, snowflakes, etc.) in a well-developed prefrontal squall line which is approaching the station from the northwest.

On the accompanying sketch, attention is invited to the features indicated by the arrows:

a) The weak "banded echo" immediately ahead of the thunderstorm belt;

b) the fine, cellular structure of storms in the main thunderstorm belt;

c) the distinct gap about 10 miles wide immediately following the thunderstorm belt;

d) the large, yet well-defined, area of fairly uniform precipitation bringing up the rear.

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Not all of the features are observed in every prefrontal squall line. For example, the banded echo may be present in one case, or the general precipitation area following the thunderstorm belt in another. However, all have been observed together in the same storm often enough to indicate they form what may be the "complete" system and will be treated here as if they actually do so.

At present, our knowledge of the significance of, and weather associated with these features is so scanty that it may be very quickly summarized:

a) The banded echo

The rather uniform banded echo which precedes the system first attracted attention to the over-all pattern. Examples in different storms are shown in fig. 2. This echo is characterized by several very interesting properties:

1. It is rarely detected at more than about 50 miles range from the radar.
2. It shows up very well on 23-cm wavelength radars.
3. It can be detected from either side of the storm (from the southwest before it reaches the station or from the northwest after it passes).
4. It is nearly always "centered" on the station, i. e., a line drawn perpendicular to its midpoint usually passes directly over the station.
5. When it approaches the station, echoes from surface targets, which are normally below the radar horizon, may often be detected in the zone between the echo and the thunderstorm belt.
6. Pressure jumps and temperature fluctuations are often observed when it passes over a weather station.

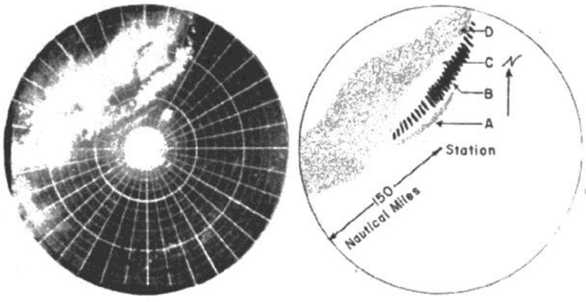

Fig. 1

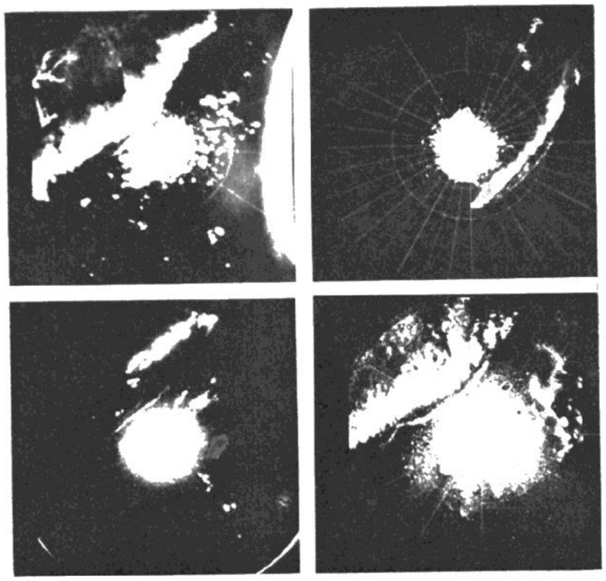

Fig. 2. Prefrontal precipitation echoes

Without going into details, from the above facts and visual observations, it has been deduced that apparently this echo is *not* produced by clouds or raindrops, but rather by dielectric discontinuities in the atmosphere. Furthermore, it is a low level phenomenon, perhaps in a layer 1000-2000 feet above the surface. While it is very suggestive of an echo which might be produced by a prefrontal roll cloud, no observations confirming such an association have been found.

b) Cellular structure in the thunderstorm belt (see fig. 1)

The same basic pattern of overlapping cells has been observed by radar in other entirely different types of line storms such as cold fronts, occluded fronts, and the spiral bands in hurricanes. Apparently a fundamental hydrodynamic principle is involved but exactly what this may be cannot be stated with certainty.

c) The precipitation-free zone

One of the most fascinating features of the system is the narrow zone behind the thunderstorm belt, where precipitation echo intensity is often so low as to be virtually undetectable. What are the circulations or atmospheric conditions which serve to remove the hydrometeors so quickly and efficiently in this region?

Precipitation in the thunderstorm belt may often be detected to several tens of thousands of feet, and even large drops should take roughly one-half hour to fall from the top of the cloud to the surface. The thunderstorm belt might easily advance a distance equal to its own thickness in that interval. One can only imagine that the raindrops are quickly evaporated in this region, or some circulation is present which keeps them out of it. Again, we simply do not know what is happening. It is believed that there is extensive cloudiness in this region which would appear to rule out the evaporation idea.

d) The light-precipitation zone in the rear of the storm

While familiar to surface observers as the region of light precipitation which often lasts for several hours after a line squall passage, the radar observation shows that this is not simply a region of residual cloudiness and rain "left over" by the storm. Something actually sustains the rain in this area, and whatever the process is, it often moves along with the thunderstorm belt and terminates abruptly as indicated by the well-defined edge on the northwesternmost side of such systems. Such would not be observed if it were formed by residual raindrops, falling out of the storm, for if this were the case, the biggest would fall out first, and the smaller ones later, and the echo would diminish more gradually in intensity to the northwest.

Electrical Activity

One other fascinating feature of these storm systems is the electrical activity which evidences itself in the form of frequent cloud-to-cloud and in-cloud lightning discharges at high

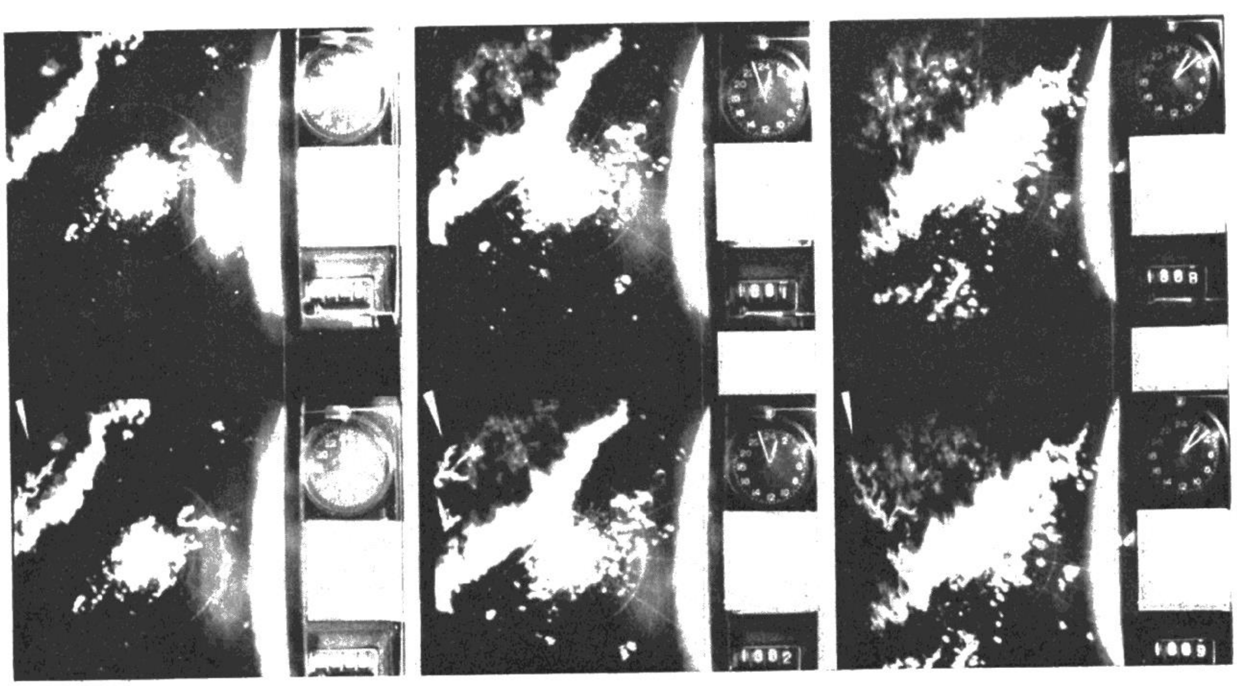

Fig. 3. Frontal thunderstorm lightning echoes

levels. The lightning discharges may also be detected by radar. Most of the echoes of this nature seem to be from strokes which flash between upper levels of the thunderstorm belt and the light precipitation zone. Fig. 3 shows a number of these which were observed during the approach of a prefrontal squall line toward a radar station in Missouri. Top and bottom pictures show adjacent frames of the film, taken about 15 seconds apart. The echoes due to the lightning discharges show in the lower pictures, and only appear on one frame of the film because of their very short duration. In the left hand picture may be seen the banded echo and the light precipitation zone behind the thunderstorm belt. The gap between the two is not very well defined; neither is the cellular structure in the thunderstorm belt. In the lower right hand picture may be seen the longest lightning echo yet observed. Part of it is embedded in the thunderstorm belt echo. Taking the two parts together, the echo is over 100 statute miles in length!

Conclusion

Systems similar to those which have been described were observed about 25 times during the 1955 tornado season in the midwestern United States. It is therefore believed that these are not chance configurations, but rather evidence of fundamental properties of prefrontal squall lines. At the present time we are most interested in the following questions:

1. What are the exact nature and cause of the banded echo? What weather conditions are associated with it?

2. What produces the cellular structure of the thunderstorm belt? What are the currents in the cells and the regions between cells?

3. What produces the precipitation-free zone immediately following the thunderstorm belt? What currents are in this region and what cloud systems are present?

4. How high do clouds go in the light rain region? What are the vertical and horizontal currents in this zone? What causes its abrupt termination? Why is it not observed in some storms?

5. What charge-separation processes are at work which result in lightning appearing to originate in the thunderstorm belt and branch toward the light-precipitation area?

Any light which can be shed on these or other features of prefrontal squall lines will be of considerable assistance in planning and conducting future studies in this field.

Résumé

Des observations à l'aide de radars très puissants, de 23 et 10 cm de longueur d'onde, ont révélé récemment l'existence, dans les lignes de rafales préfrontales du centre des Etats-Unis, de réseaux complexes, organisés, de circulation et de précipitation. Ces orages provoquent en écho au radar des réseaux qui presque toujours comportent un certain nombre des caractéristiques suivantes, et les comportent même souvent toutes: 1. une longue bande d'écho mince, à bas niveau, qui précède la ceinture d'orage principale, cette bande, bien qu'elle donne fortement l'impression de l'écho d'un rouleau de nuage pré-frontal, peut en fait être causée par de grandes discontinuités de température ou de teneur en vapeur d'eau; 2. une structure cellulaire dans la ceinture d'orage, laquelle suggère des perturbations organisées le long de l'étendue de la rafale frontale; 3. une zone où l'intensité de la précipitation est grandement réduite, zone qui suit immédiatement la ceinture d'orage principale; 4. une large zone de précipitation uniforme légère derrière la zone de précipitation légère; 5. des décharges électriques actives semblant avoir leur origine dans la ceinture d'orage, mais qui présentent des embranchements du côté de la zone de précipitation légère.

On a observé, pendant la saison des tornades en 1955, environ vingt-cinq orages présentant à quelque degré les caractères qui viennent d'être décrits. Des exemples peuvent être empruntés à nombre de ces orages pour illustrer les divers phénomènes.

Puisque l'étude de ces choses en est encore à ses stades très préliminaires, il n'y a pas grand-chose à dire pour donner l'explication causale de ces phénomènes. Il est évident que les modèles existants par lesquels on représentait les lignes de rafales préfrontales doivent être profondément revisés pour rendre compte de ces observations. Les déplacements horizontaux de petites aires de précipitation, lesquels reflètent nécessairement la vitesse du vent aux différents niveaux de la masse d'orage, montrent l'existence d'intéressantes micro-circulations, qu'on ne soupçonnait pas jusqu'ici.

Il est essentiel pour comprendre un tel orage de connaître les déplacements verticaux dans différentes portions de la turbulence. Les régions locales de forte précipitation sont-elles de façon prédominante des zones d'ascendance, ou au contraire de descendance? L'air est-il montant ou descendant dans la zone de précipitation légère derrière la ceinture d'orage? Quelles conditions météorologiques existent-il dans cette zone et dans les canaux exempts de précipitation qui séparent les cellules d'orage adjacentes? Quelle est la source de la longue et régulière bande d'écho qui se trouve devant la ceinture d'orage? Où la grêle et les tornades se forment-elles dans le système dans son ensemble? Y a-t-il dans l'orage des changements qui dépendent de l'heure du jour?

La nature fondamentale de ces questions sert à illustrer l'insuffisance de nos connaissances concernant ce type d'orage qui produit les pires tempêtes locales observées dans la nature ou leur est associé. Des vols contrôlés effectués dans ces zones d'orage représentent notre meilleure espérance, et d'ailleurs peut-être la seule, d'obtenir les observations nécessaires. Les instruments et observations météorologiques conventionnels sont impropres à cette tâche. Cela est assez démontré par le fait que ces méthodes ne nous ont pas même suggéré que de tels réseaux organisés d'orage pouvaient exister.

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