NOAA Technical Memorandum NWS ER-72

MESOSCALE FORECASTING TOPICS

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Eastern Region Headquarters
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PREFACE

There are no mesoscale experts --- only good meteorologists, intent on improving their understanding of the atmosphere, and those content to blindly follow guidance. This publication is an attempt to organize our knowledge about the mesoscale and permit it to be periodically updated. We suggest that this Technical Memo be unstapled and placed in a loose leaf binder. Past and future Technical Attachments, copies of articles, etc. would be filed with the major heading to which they pertain.

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MESOSCALE FORECASTING TOPICS

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I. INTRODUCTION

Some progress has been made over the last few years in our understanding of mesoscale phenomena and in our ability to analyze the atmosphere to detect favorable environments for the development of these phenomena. Extreme weather events, e.g., severe weather and very heavy rainfall, are small scale events that may occur with no apparent relation to synoptic scale patterns, but more frequently they are associated with some large scale dynamic forcing.

Synoptic scale weather for periods in excess of 12 hours is now handled fairly well by existing dynamical and statistical models, but current models do not perform well for the first 12 hours of the forecast period. Dynamical models are not capable of handling small mesoscale phenomena, such as convection, due to their relatively coarse grids, lack of proper initial data for small scale phenomena, and incomplete physics.

Mesoscale models are currently being developed which may be helpful to the forecaster, but their operational implementation is still in the distant future. Lack of appropriate initial data and the large computer capability needed to run them present serious problems. For the present, the forecasters most useful contribution appears to lie in improving the near term small scale forecast through the frequent monitoring of data with the aid of various mesoanalysis programs.

Although mesoscale phenomena are important at all times of the year, most of the techniques that we now have available are primarily useful in forecasting warm season convection, severe weather, and heavy rainfall. The warm season precipitation forecast is generally more difficult than the cool season, due to the difficulty in pinpointing areas that will be affected by convection. The common summertime forecast of "scattered showers" is evidence of this difficulty; the forecast would be more useful if higher probabilities could be specified over a limited area. Flash flood forecasting continues to be a serious problem due to the difficulty in specifying heavy rainfall areas. Some mesoscale techniques will be presented here, which are helpful in dealing with these problems, but of course, they are not the complete answer, and considerable research is still needed in understanding these phenomena. Meso-techniques applicable to wintertime situations will also be given where appropriate.

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II. TECHNIQUES

1. Surface Moisture Convergence

Moisture convergence usually increases one to two hours prior to the beginning of convection. It is most useful for locating areas where the first convection of the day is likely to begin. After convection has reached the mature stage, the initial moisture convergence is usually replaced by divergence and new convergence develops along outflow boundaries caused by the initial convection. After convection has begun in several areas, new convection is mostly likely to begin, where outflow boundaries intersect, since this is the area where convergence is apt to be strongest. As convection becomes more widespread, the moisture convergence pattern may become very complex and difficult to interpret.

Surface moisture convergence and its time change over a specified number of hours can be obtained from the Southern Region Mesoanalysis Programs (Bothwell, 1985). These products must be produced hourly to be of maximum value, since the lead time between increase in moisture convergence and the beginning of convection is short, usually around two hours.

This technique is useful during Spring and Summer, when convection is surface based, i.e., parcels near the ground are heated sufficiently to begin spontaneous convection. During the cool season, a stable layer is usually present near the surface, and although convection may still occur due to dynamic forcing, the ascending parcels do not originate from the surface, but from some upper level.

Cases have been observed where convection was well related to convergence at the 850mb level and had no relationship at all to surface moisture convergence. Unfortunately, upper level convergence can presently be computed only twice per day from the radiosonde observations. The lack of time and space resolution is a problem that will eventually be solved when wind profilers become available. Upper level convergence at any of the mandatory levels may be computed from the Western Region mesoanalysis programs (Spry and Anderson, 1981).

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2. Upper Level Divergence

Divergence fields in the upper troposphere can also be useful to the forecaster. These fields, although available only twice per day, change more slowly than surface convergence fields. Convection that begins under a pre-existing upper level divergence field will frequently be more intense and extend to higher levels than convection beginning under upper level convergence.

Upper level divergence can also be caused by strong convection (Maddox, 1980). A well developed meso-scale convective complex (MCC) has a strong effect on the upper level wind field, which may be noticeable even without doing the divergence computation.

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3. Jet Streaks

Jet streaks refer to the isotach pattern embedded in the jet stream. They are associated with a distinctive pattern of upper level divergence. Air parcels entering the jet must accelerate. Energy considerations require that parcels move toward lower heights on a constant pressure surface in order to accelerate. This means that divergence will occur in the right entrance region of the jet and convergence on the left. At the exit of the jet, air parcels decelerate moving toward higher heights, with divergence developing in the left exit region and convergence on the right. This pattern is illustrated in Fig. 1.

The relative position of the jet streak to a surface front, will either tend to suppress convection or stimulate it. Intersection of the exit of the jet with a surface front creates favorable conditions at and to the north of the front, as shown in Fig. 2. This process is described in more detail by Bluestein (1984). A simplified review of a part of the Bluestein paper may be found in (Stone, 1984).

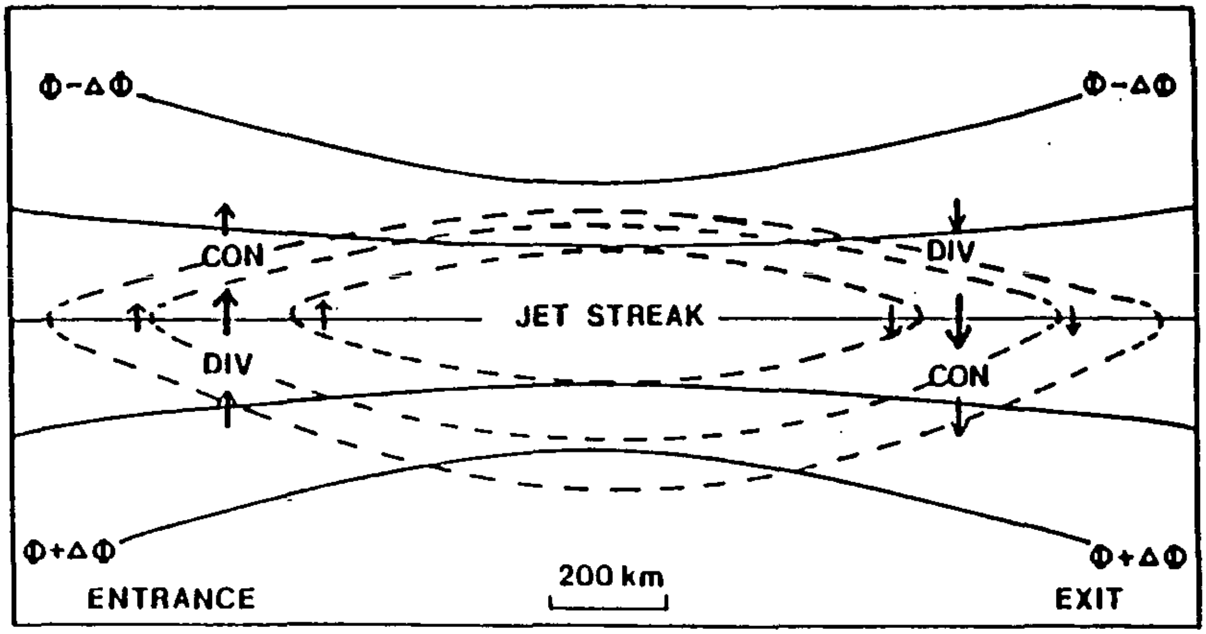

Fig. 1. Schematic representation of the ageostrophic motions (heavy arrrows) and associated convergence (CON) and divergence (DIV) patterns in the vicinity of a straight jet streak (from Bluestein, 1984).

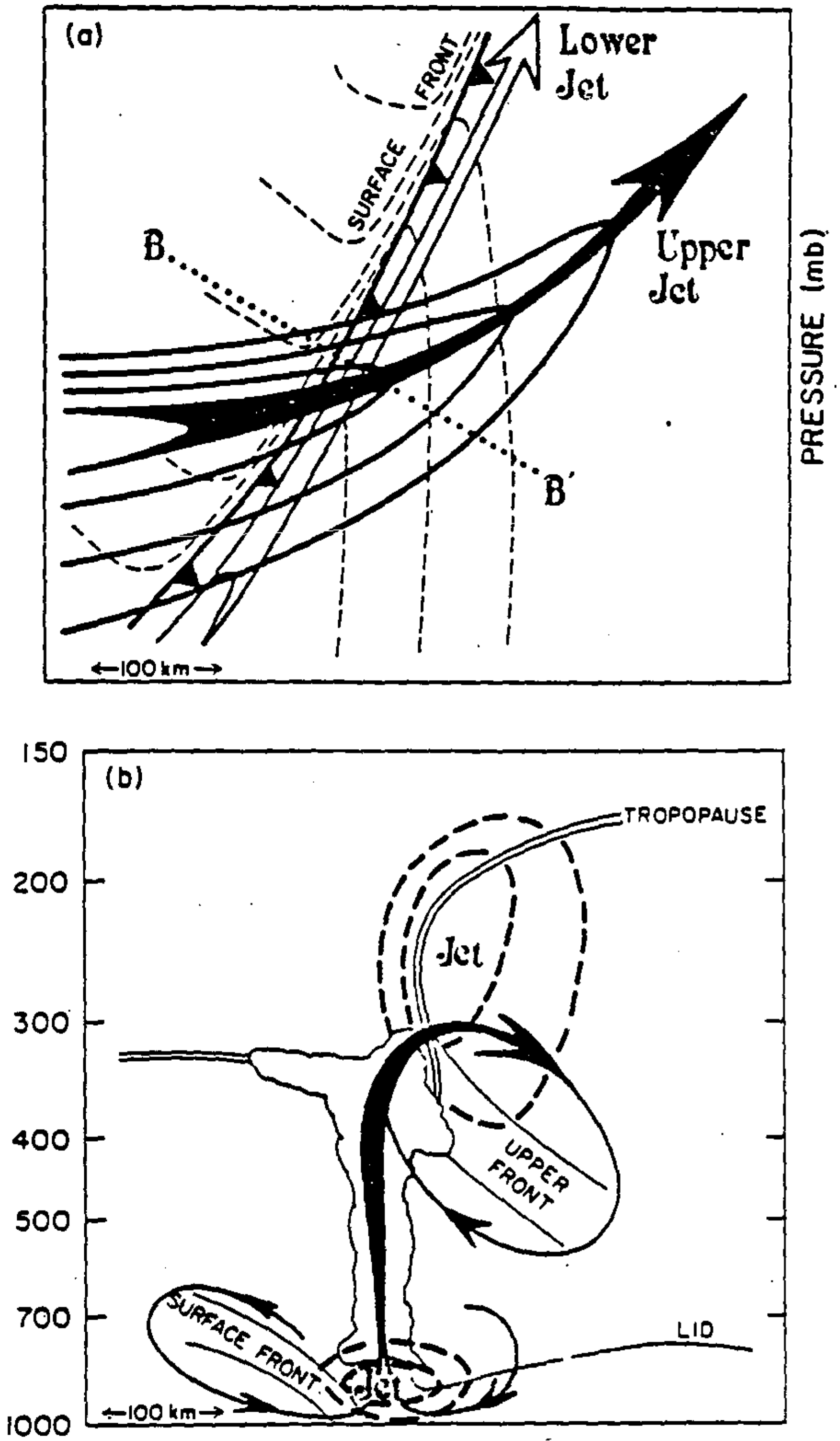

Fig. 2. Vertically coupled upper and lower tropospheric jet front systems and their associated secondary circulations. (a) Upper jet front exit situated above the surface front and low level jet. Line BB', projection for (b). (b) Cross section along line BB' of (a). (from Bluestein, 1984).

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4. Boundaries and Local Circulations

Convection tends to begin on pre-existing boundaries, such as frontal surfaces, lake or sea breeze boundaries, the edge of cloud and/or fog areas, and outflow boundaries formed by previous convection. These boundaries are almost always associated with some surface convergence and provide favorable conditions for the initiation of convection. Convective cells that have formed elsewhere frequently increase in intensity as the cell moves across a boundary.

In mountainous terrain, the first convection of the day usually begins on the leeward side of mountain ridges. This can be explained by surface heating causing upslope winds which form convergence zones mainly on the lee side of the mountains. The details of this process are given by Barker and Banta (1984).

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5. Stability

Large scale vertical motions in the atmosphere are the result of dynamical forcing, two of the most important being differential vorticity advection and thermal advection. The response of the atmosphere to the imposed forcing depends on the thermodynamic instability. The same forcing applied to an unstable air mass will produce stronger vertical motions than in a stable air mass. In the absence of any dynamical forcing small scale vertical motions associated with convection may begin spontaneously when the atmosphere becomes sufficiently unstable. In the summer this instability is usually generated by surface heating.

The energy index (EI) is a fairly good measure of stability and has been shown to have a somewhat higher correlation with developing convection than any of the standard indices such as lifted, K, or Showalter index (Stone 1985, 1986). With stagnant conditions, little or no upper level advection and no significant dynamical forcing, convection usually begins in the region of maximum EI instability; this is the situation for summertime air mass thunderstorms. When there is moderate upper level advection with little dynamical forcing, convection frequently begins in the downstream gradient of the EI field. If significant dynamic forcing is present, convection is likely to begin in the unstable area where forcing is greatest, not necessarily where maximum instability exists.

No stability index should ever replace a visual examination of the plotted sounding, at which time, subjective estimates may be made of how the sounding will change with time through the day. Differential advection of temperature and large scale vertical motions should be considered as well as potential surface heating.

Vertical distribution of positive and negative energy areas for an ascending parcel is another factor to consider. Although a large positive area may exist in the upper troposphere, a sufficiently large negative area in the lower troposphere may effectively inhibit the development of convection. On the other hand, if large positive area exists and the lower capping stability can be released at just a few points, severe weather is a good possibility.

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6. Surface Vorticity

Surface relative vorticity and surface convergence patterns are frequently similar in the summer, convergence areas associated with cyclonic vorticity and divergence areas with anticyclonic vorticity (Ulanski and Garstang, 1978). Since all stations report wind, but not all report pressure, developing mesocyclones can sometimes be detected in the vorticity field prior to the pressure field.

The vorticity field is sometimes useful in winter for detecting lee cyclogenesis, which may appear in the vorticity field prior to it appearance in the pressure field. Winter cyclones approaching the Appalachians from the west frequently do not cross the mountains in a continuous manner, but a new cyclone develops on the lee side. Early detection of lee cyclogenesis is necessary in providing a good forecast east of the Appalachians.

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7. Uses of the Hodograph

Convection may be categorized in three types: short-lived single cells, multicells, and supercells. Recent research (Weisman and Klemp, 1984) indicates that the hodograph is useful in determining the type of convection that may develop as well as the motion that the convection is likely to develop. Both of these factors are useful in forecasting severe weather and heavy precipitation (flash floods).

Convective storm type and severity depend strongly on the environmental conditions in which the storm grows. Thermodynamic instability controls the storm strength, since it controls the vertical accelerations of the air parcels. Vertical wind shear controls the type of convection that will develop.

Short-lived single cell storms develop in situations where there is little vertical wind shear. As the storm develops the downdraft spreads out equally around the original storm, cutting it off from the warm moist unstable air needed to sustain convection.

Multicell storms develop with moderate vertical wind shear. In this case the outflow produces a non-symmetric surface convergence pattern with the strongest convergence downshear from the original cell. New cells growing in this convergence zone will move in the same direction as the gust front increasing the time over which the new cells may feed on the warm unstable air ahead of the outflow.

Supercell storms evolve with stronger shear accompanied by a veering of the shear vector in the lowest 1 or 2 kilometers. This causes dynamically induced non-hydrostatic vertical pressure gradients to develop on the right flank of the storm, which accelerates surface air upwards and causes the storm to deviate to the right of the mean wind enabling it to feed on the warm moist air for a longer period of time.

Some typical hodographs for the three storm types are shown in Fig. 3. taken from Weisman and Klemp (1984). The wind shear in the lowest 6 kilometers of the atmosphere is most important for determining storm type. The most important factor in developing a right moving storm is the low level veering of the wind shear vector.

Severe weather is not confined to the supercell type storm, but a supercell is more likely to produce severe weather than a multicell storm and the worst severe weather does occur with supercell storms. A sufficient degree of thermodynamic instability is needed to produce severe weather in addition to the proper wind shear structure. The two effects may be combined in a parameter called the Bulk Richardson Number (BRN), which is the ratio of the instability (positive energy area) to the wind shear

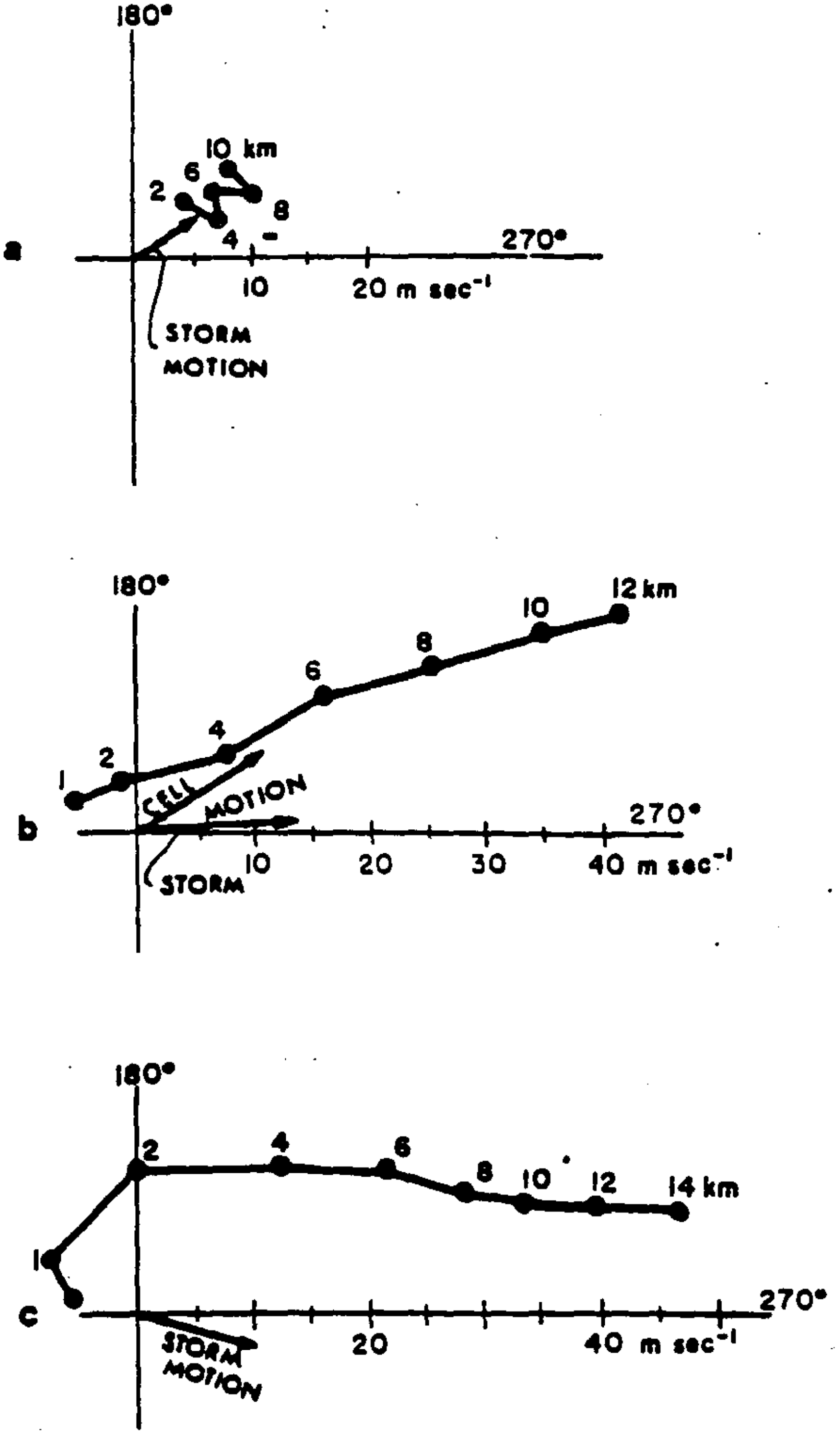

Fig. 3. Typical wind hodographs for single cell (a), multicell (b), and supercell (c) storms observed during the Alberta Hail Studies project. (from Weisman and Klemp, 1984).

factor. Fig. 4. from Weisman and Klemp (1984) shows the range of BRN over which supercell and multistorm cells are expected to develop. However, the relationship shown in Fig. 4 did not verify well in a preliminary test of convection in the eastern United States during 1986. Further studies of BRN should be completed, before its use is recommended in forecasting. Both stability and wind shear should be considered in forecasting convection, but it may be desireable to keep them seperate. Stability and plotted hodographs are available from the CONVECT applications program (Stone, 1986).

Locally heavy rains which may lead to flash flooding are frequently associated with multicell convection. The usual pattern for locally heavy rain is for a series of convective cells to generate and slowly move across the area. The most vigorous updrafts and heaviest rains are generally present in newly formed convective cells. It is possible for the centroid of a convective storm complex to show movement, while the most active part, where new cell growth is occuring to remain nearly stationary. In this case, new cell development occurs on the right rear flank of the storm complex. The hodograph, Fig. 5., typically shows an easterly component at the surface with veering of the shear vector in the lowest 1 to 2 kilometers.

A typical synoptic situation with thunderstorms forming along a warm frontal boundary is shown in Fig. 6. from Chappell (1984). Cells move northeastward in the colder air with their outflow boundary reinforcing the front and new cells form on the right rear flank of the storm complex. The net effect is a nearly stationary heavy rain area drifting eastward along the frontal boundary.

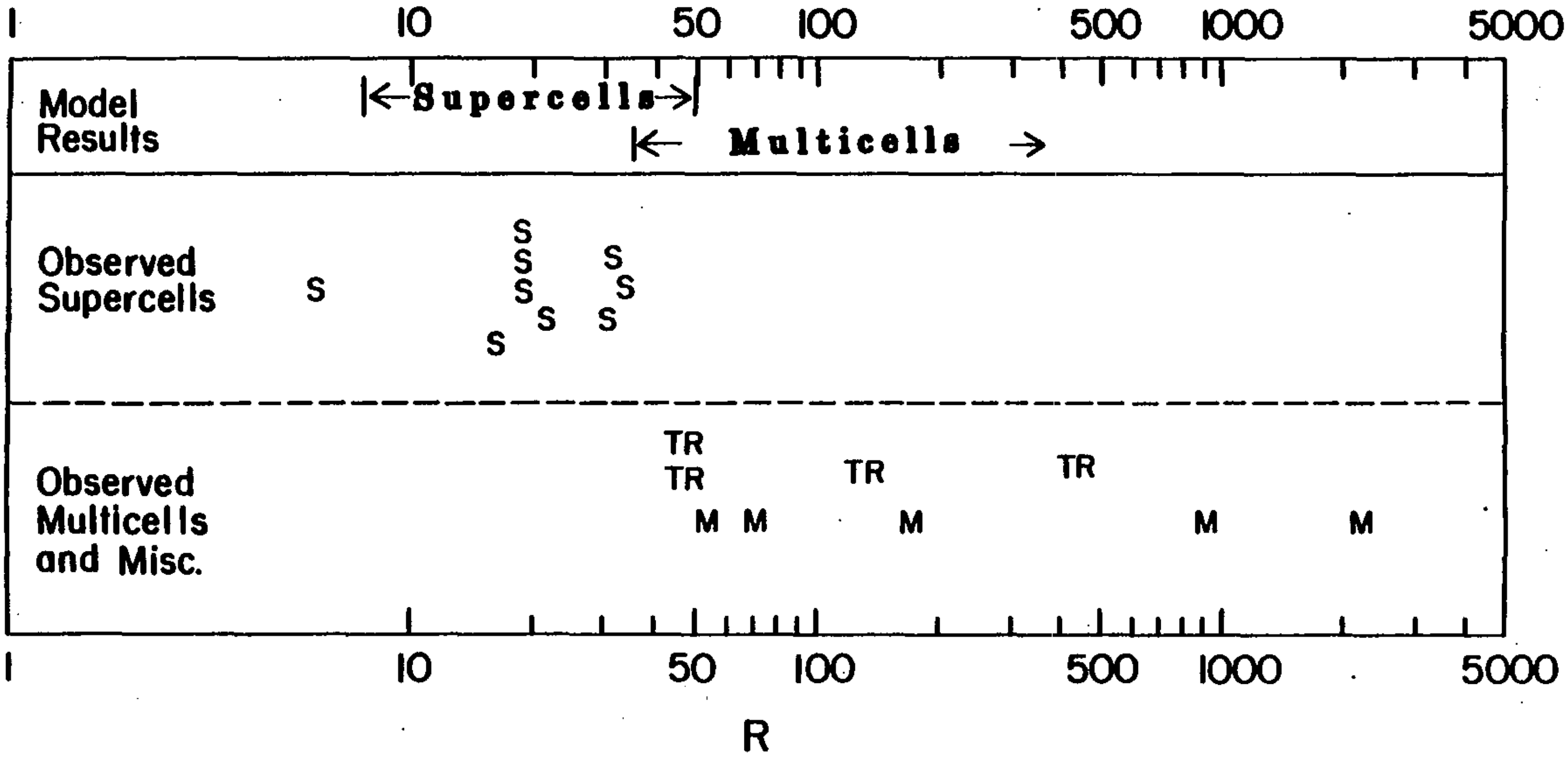

Fig. 4. Relationship of Bulk Richardson Number to various storm types. 'S' denotes supercell and 'M' multicell storms. 'TR' denotes storms in a tropical atmosphere. Observed 'S' and 'M' storms shown are from Midwest area. (adapted from Weisman and Klemp, 1984).

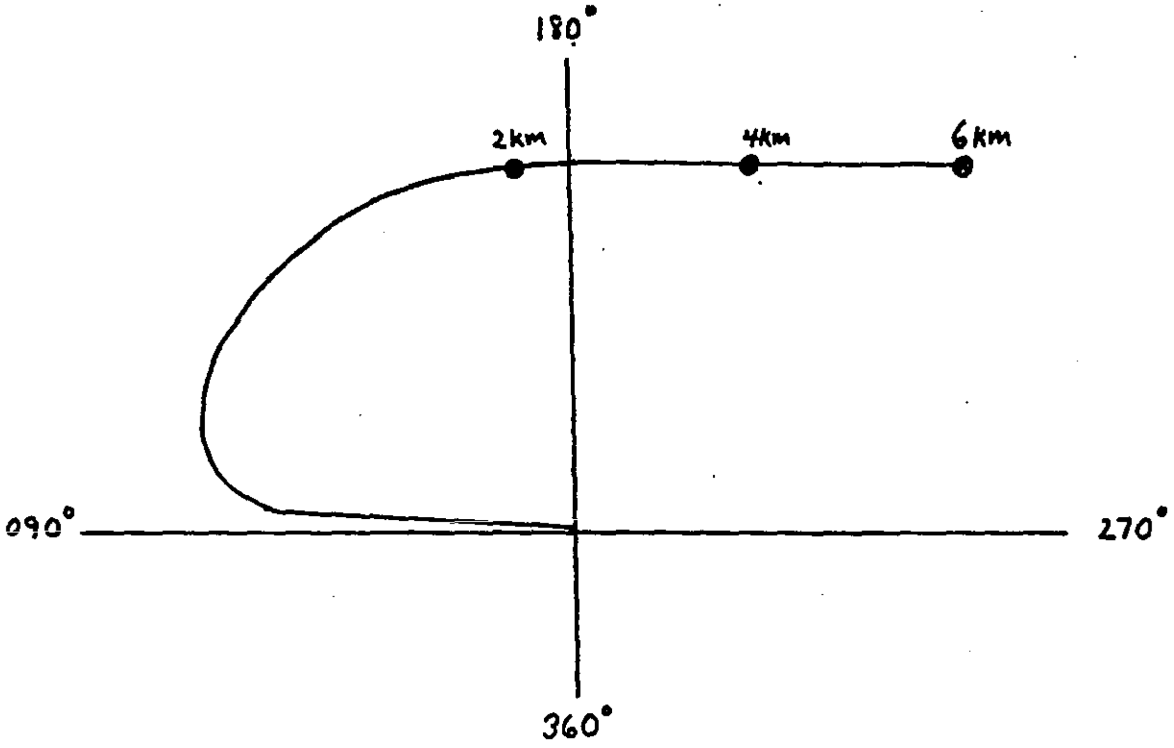

Fig. 5. Schematic representation of hodograph capable of producing stationary convection with locally heavy rainfall. New cells develop in same location on right rear flank of storm system.

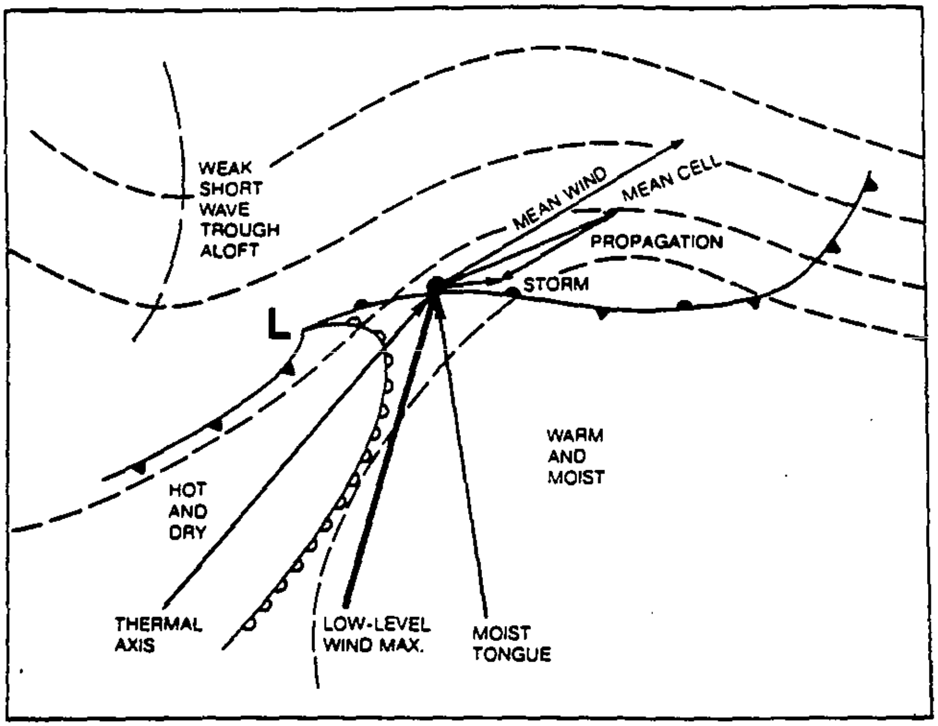

Fig. 6. Schematic diagram showing important synoptic features that can lead to the formation of a frontal type, quasi-stationary mesoscale convective system. (from Chappell, 1984).

8. Use of MDR in Estimating Rainfall

In most areas of the country an adequate rainfall reporting network does not exist for measuring locally heavy rains. Radar VIP levels reported in the MDR portion of the radar observation may be used to estimate the rainfall. Despite the inherent inaccuracies of this technique, it is frequently the only information available upon which issuance of a flash flood warning may be made.

The plotting and addition of MDR values over a period of time for one or more radars is a laborious task for the forecaster. Fortunately this task has been automated by the applications program MDR (Peroutka, 1983). When the program is run, rainfall type, convective or stratiform, must be provided, then graphics are produced that estimate precipitation over the MDR grid for 1, 3, and 6 hour time periods. In potential flash flood situations, convective precipitation is specified; experience has shown that the convective MDR rainfall estimates result in rainfall amounts approximately double that reported by the rain gage network. If desired, MDR totals over the grid may be obtained rather than precipitation estimates.

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