A Model of Summer Convection in South Florida[1,2]

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(Manuscript received 1 April 1971)

ABSTRACT

Hourly frequency distributions of range-corrected PPI and multi-level CAPPI radar weather echoes during July 1968 are used to model the summer convective regime in South Florida. The month of July is chosen as being a typical summer month with minimum contamination from frontal penetrations, easterly waves and the like. The resulting convection, therefore, is largely governed by the trade-wind flow and its interaction with the sea-breeze regime. The distributions reveal preferred north-south, quasi-stationary zones of convection, oriented parallel to the coast and approximately 15 n mi apart, where echoes increase in frequency and in height. The preferred zones, which shift slightly but in unison and nearly in synchronization with the development and decay of the sea breeze during the day, are thought to be induced by a combination of dynamic and thermodynamic effects.

1. Introduction

During the past 25 years, there has been a variety of studies on the general nature of precipitation, clouds and radar echoes over the South Florida peninsula. A group of papers at the beginning of the period by Byers and Rodebush (1948), Riehl (1949), Gentry (1950), Day (1953), Carson (1954), and Gentry and Moore (1954) set the stage so well as forecast guidelines that essentially nothing of operational interest was published during the next seven years. While it was recognized that certain shower patterns were typically associated with such synoptic features as fronts, easterly waves and troughs at 700 mb, there were exceptions to those rules at subtropical latitudes, and showers occurred much more frequently than the features. Consequently, the emphasis was placed mainly on studying dynamic mechanisms such as the sea breeze, convergence due to the shape of the peninsula, etc., as opposed to thermodynamic mechanisms.

Hiser and Adt (1961) brought a new dimension into the picture with RHI radar data. They found that the average height of convective echoes in South Florida was 21,000 ft, somewhat lower than one would expect with such a high tropopause. About the same time, the National Hurricane Center began a program of gridding WSR-57 radar PPI data. A series of papers resulted from that work beginning with Moore (1963). Perhaps the 1967 paper by Frank *et al.* best described the project. That series of papers represented the first attempts to produce a climatology of PPI echoes in Florida. Estoque (1962) studied the effects of the large-scale wind and temperature fields on the development of the sea breeze using a theoretical model. Certain of his results will be discussed later in this paper. Gerrish and Hiser (1965) updated monthly, seasonal and annual isohyetal patterns for the lower Florida peninsula using more than twice the number of raingage stations that were used by the U. S. Weather Bureau (1962). The resulting patterns revealed definite double sea-breeze effects and monthly trends were visible. Plank (1965) studied many features of summertime cumulus using aircraft photo-reconnaissance techniques. He stressed the importance of the advection of low-level water vapor and liquid water, and attempted to support the markedly different findings of Byers and Rodebush, and of Riehl. Gerrish (1966a) refocused attention on the moisture near the freezing level as being important for showers in this area. Later that year, Gerrish (1966b) compared frequency distributions of gridded radar data with isohyethal analyses using raingage data. It was found that the patterns agreed quite well when 26 decibels of attenuation were applied to the radar video. Sass (1967) found that 10–15 years of records were needed to arrive at a tentative "norm" for the Miami area. Holle (1968) studied echo height populations in preparation for local cloud seeding experiments using isolated maximum top reports as taken from hourly PPI echo charts.

Recently, Thomas (1970) analyzed long-term climatological records and found a "coldspot" south of Lake Okeechobee which may be related to a lower water table there. He also found five-year cycles of high rainfall along the lower East Coast. Since synoptic maps often fail to provide sufficient insight into rain

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[1] Research supported by the U. S. Army Electronics Command, Fort Monmouth, N. J., under Contract DAAB07-67-C-0224.

[2] Contribution No. 1366, Rosenstiel School of Marine and Atmospheric Science.

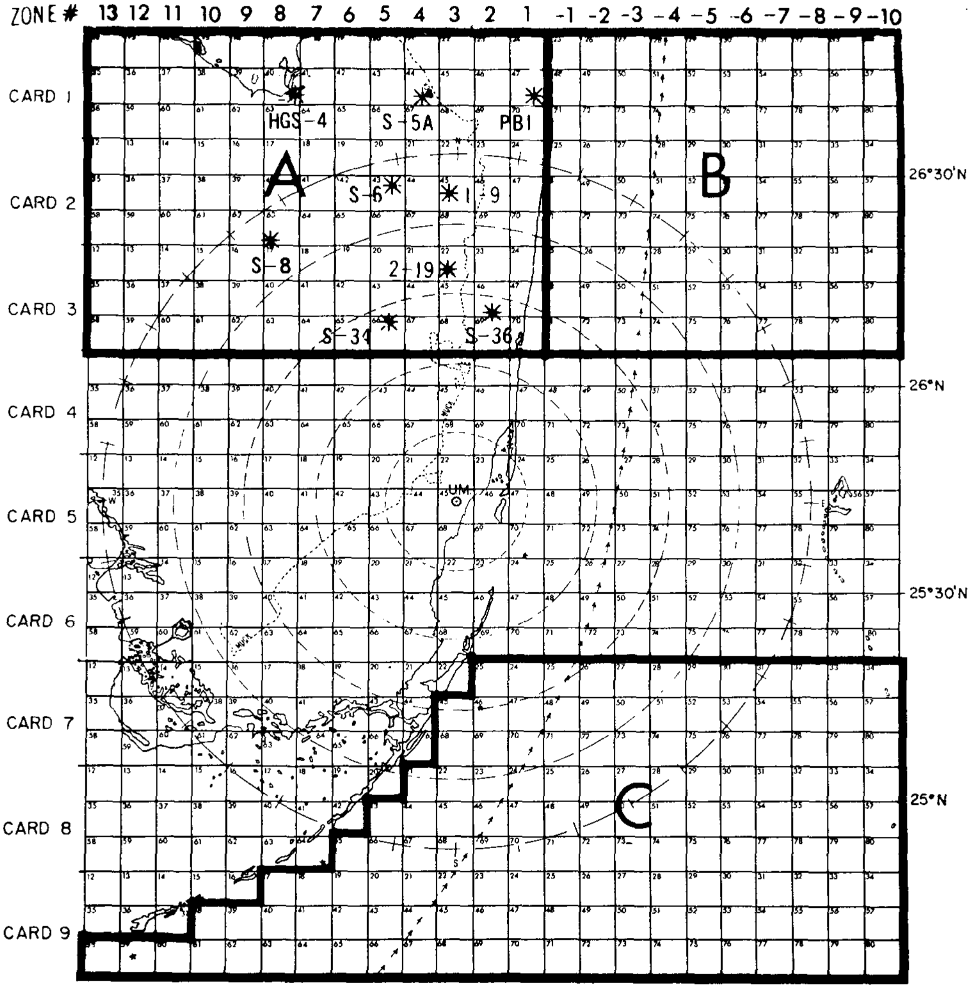

FIG. 1. Grid, 5 n mi×5 n mi, together with areas and zones used in South Florida radar study.

patterns in this area, Gerrish (1970) has studied techniques of identifying convective regimes using satellite and radar data. He identified typical patterns associated with five different convective regimes, each one with characteristically different rain patterns.

A study of gridded radar echo frequency distributions during the month of July 1968 revealed several most interesting results which potentially offer a new insight into sea-breeze effects and the general nature of relatively undisturbed summer convection in South Florida. Although the data sample is admittedly small, the results appear to be plausible and may very well serve as a much-needed model in the area until they can be either proved or disproved with a larger data sample. These results were presented earlier by Gerrish (1969) in a technical report but are revised and condensed herein for wider distribution.

2. Procedure

The location and height of range-attenuation-corrected weather echoes were tabulated on an hour-by-hour basis for the month of July 1968 using a 5×5 n mi grid (Fig. 1). This was done only for areas marked A, B and C to avoid resolution and other problems in and near the ground return (clutter). Note that the coastline runs nearly north-south between areas A and B. The PPI data were collected continuously on a 24-hr basis using the UM/10-cm radar. The height data were based on constant altitude PPI (CAPPI) displays taken on our MPS-4 height-finder radar at antenna tilts of 3, 4, 5, 6, 7.5, 9, 11 and 14 deg. This radar has a vertical beam width of 1 deg. Theoretical range-height curves developed for this area by Gerrish (1964) were used to define the spatial position of the beam at those tilts. The height data were available only for the hours 0800 to 2400 (all times Eastern Standard).

The month of July was used because it is generally a typical summer month with a minimum of contamination from frontal penetrations, easterly waves and the like. The resulting convection, therefore, is largely governed by the trade-wind flow and its interaction with the sea-breeze regime. The time variation in

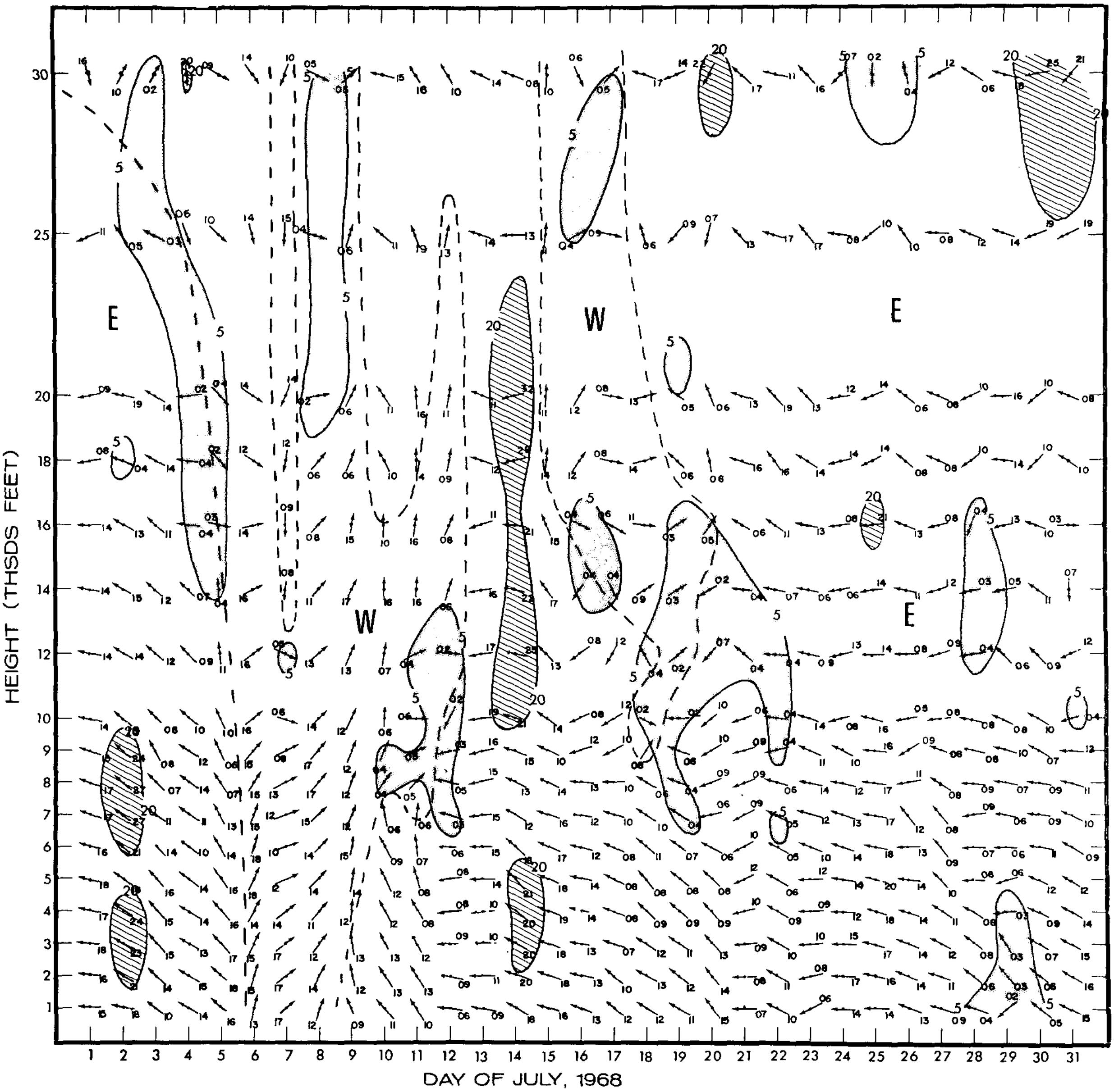

Fig. 2. Time section of 0700 EST winds aloft over Miami, Fla. Speeds are plotted in knots at tail of arrow, with values <5 kt being stippled and those >20 kt hatched. Westerlies are outlined with a dashed line.

winds aloft in Fig. 2 substantiate that such was the case in July 1968. It is clearly seen that the low-level easterlies prevailed on 27 out of 31 days at 850 mb.

3. Relative distribution of echoes by area

The relative percentages of the number of squares containing PPI echoes in the respective gridded areas are shown in Fig. 3. These are weighted with respect to area so that the differences between areas can be directly compared. The total percent in areas A+B+C equals 100 for each hour. The diurnal shift of the PPI echo frequency maxima from sea at night to land during the day is immediately obvious. While this shift is controlled primarily by radiational heating over the land, it is of interest to note that the frequency distributions over water are not constant but do show marked diurnal variations. Moreover, a higher percentage of echoes are found over the southern waters at night than slightly farther north over the same Florida Current. This is especially true during the early evening hours and near daybreak. The CAPPI data (not shown) indicate that the echoes in area C are also taller than in area B. Part of the reason for this may be related to weak disturbed areas in the trade-wind flow that

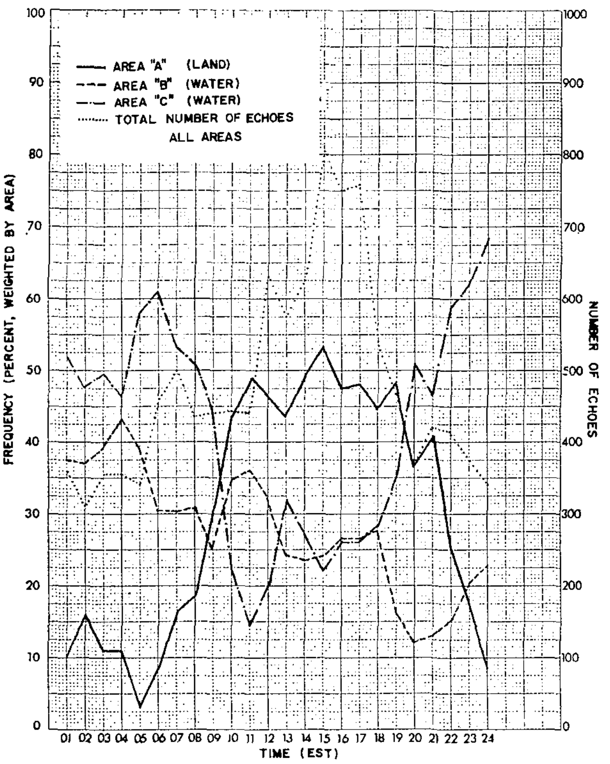

FIG. 3. Relative percentage (area weighted) of PPI echoes.

did not reach as far north as area B. Since there are converging water currents in area C, it may be that the effect of these currents on the overlying air is sufficient to produce enough convergence to excite convection there. Because of these uncertainties, the data in area C are considered to be contaminated with atypical convection and, thus, the emphasis in the remainder of this paper will be directed toward areas A and B.

4. Frequency distribution

A summary of the total number of echoes observed by zones within areas A and B is presented in Fig. 4. All hours of available data are included. The positive numbers are identifiers for the vertical columns or zones over land and the negative numbers for over water. They are numbered beginning at the coastline. Recall that each zone is 5 n mi wide by 45 n mi long. There are several features in Fig. 4 that warrant special attention. For any given zone within ±30 n mi of the coast, there are more echoes with tops >20,000 ft than those with tops 10,000–20,000 ft. Beyond 30 n mi from the coast, the situation is reversed. This can be interpreted to mean that echoes grow faster within 30 n mi of the coast. Possible confusion with blow-off from distant towers is ruled out because only convective echoes are used. The PPI curve shows several peaks. Those in zones 2, 5, 8, 10, and 13 will be discussed in more detail later. Peaks in the CAPPI data are also indicated in essentially the same zones.

Frequency distributions of echoes analyzed as a function of time and zone number in areas A and B were somewhat noisy but suggested interesting trends. To reduce some of the noise, the distributions were smoothed by time only (not by zone) by adding the frequencies of the preceding and succeeding hours to the actual frequency of each hour within a particular zone. A new total was determined for each hour in each zone. Because of the relatively small sample size of one month, general patterns were thought to be more meaningful than specific values and would most likely be reproduced in a larger sample. For simplicity, therefore, and to avoid undue emphasis being placed on values, the "running totals" were analyzed explicitly rather than first dividing all numbers by three to obtain "running mean" values. The results of this analysis are presented in Figs. 5–8.

The PPI distributions in Fig. 5 show patterns that are considered by this author to be unique. The nature of these patterns, of course, suggests a new and different model for convection during the summer in this area. First, the pattern in the region east (seaward) of zone −3 is cellular which implies that convection there is largely unorganized or random. The region west and

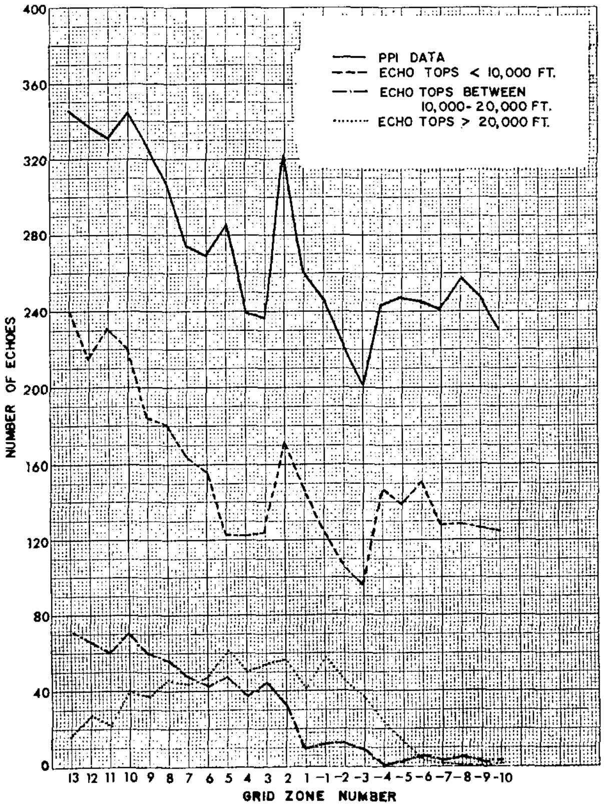

FIG. 4. Number of echoes by zone (areas A and B only).

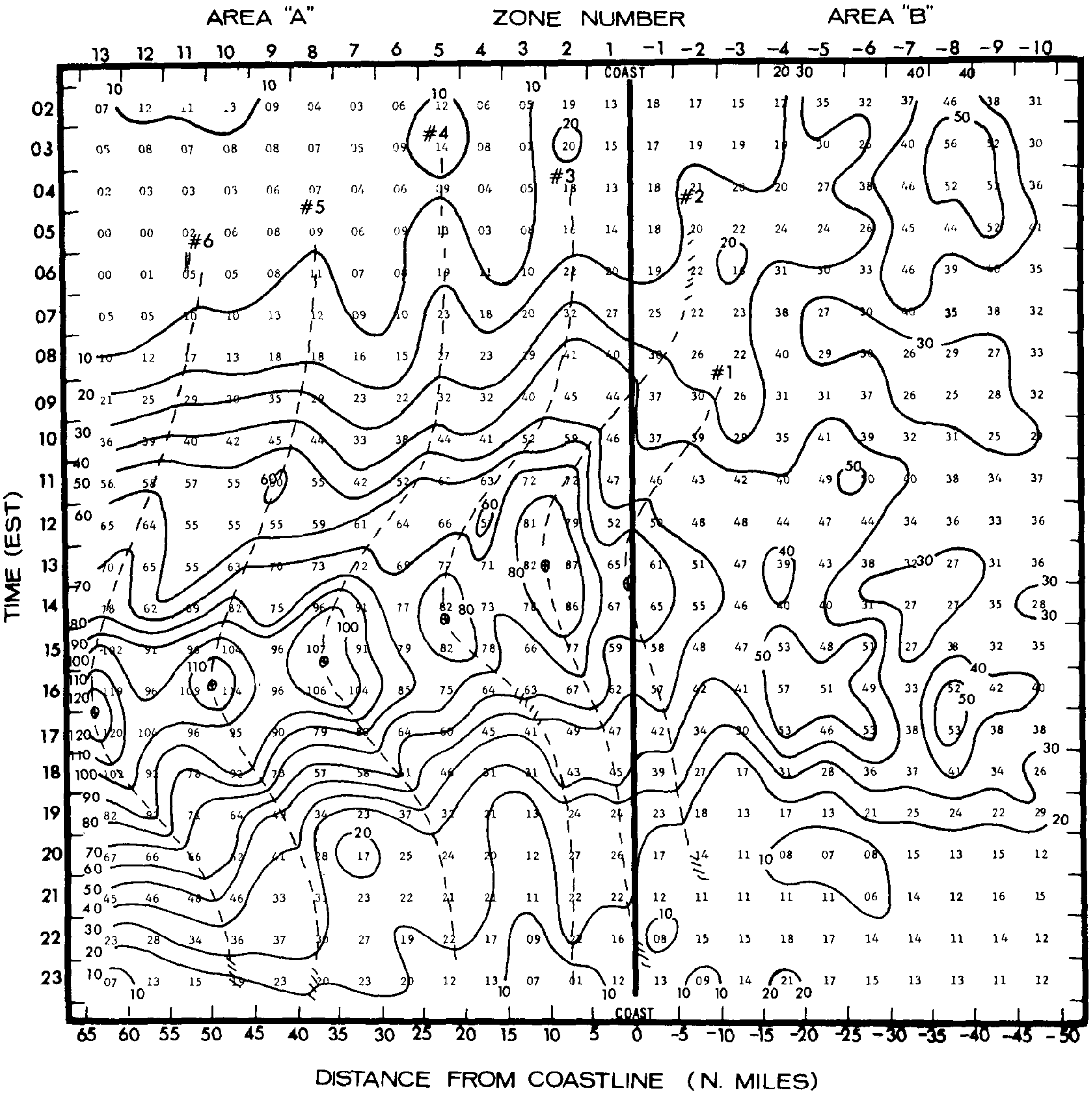

Fig. 5. Running total distribution of PPI echoes. Running means can be obtained by dividing all numbers by three.

inland displays organized patterns and trends that have reasonably good continuity over the 24-hr period. The continuity of six separate maxima are shown dashed. Those maxima begin appearing near daybreak in zones centered approximately 15 n mi apart. As dashed line number 2 moves across the coastline, those numbered 3–6 shift inland, nearly in unison, and maintain their spacing. Line number 1 exhibits similar trends. This timing together with the wind information in Fig. 2 suggests that line number 2, at least during part of its history, is associated with the sea breeze. The absolute maximum associated with each dashed line numbered 2–6 occurs approximately 1 hr later than the adjacent one closer to the coast. Could this be a result of the sea breeze passing through the preferred zones? While this cannot be answered here, it should be mentioned that the indicated velocity of 15 kt is substantially greater than the velocity of fine lines associated with sea-breeze fronts in South Florida. Those tracked by this author were on the order of 5–8 kt. We are faced with the problem, however, that sea breeze is observed farther inland than 10–15 n mi. Another difficulty involves the explanation of multi-zones or bands at the same time, 1500 or 1600 for instance, as they do occur on individual days. The continuity of the preferred zones during the late afternoon and evening hours suggests that the zones return to their initial positions, again in unison and are timed quite well with the decay of the typical sea-breeze circulation. The entire sequence of events is obviously quite dependent on this circulation; in fact, the superposition of this circulation on the trade-wind flow probably induces these zones inland from the sea-land interface and on the upper portion of Florida's "heat mountain."

Figs. 6, 7 and 8 show the resulting distributions of the CAPPI data. The PPI continuity of lines numbered 1–6 from Fig. 5 are reproduced in each of these figures to show that there is a reasonably good agreement between the PPI and CAPPI data using this analysis. Regardless of the height of the echoes, they tend to align with the preferred zones or bands.

One further test was made with the data. A figure similar to Figure 5, but not shown here, was constructed using only the data for those days when the 850-mb wind was easterly at 0700 EST. The resulting pattern and configuration was essentially the same as shown in Fig. 5 for lines 2–6. Since line number 1 was somewhat different, it should not be interpreted as a secondary sea-breeze front.

5. Conclusions and further remarks

Hourly PPI and CAPPI echo frequency distributions analyzed jointly by time and range from the coast reveal interesting patterns of summer convection in the South Florida area. The unique nature of the

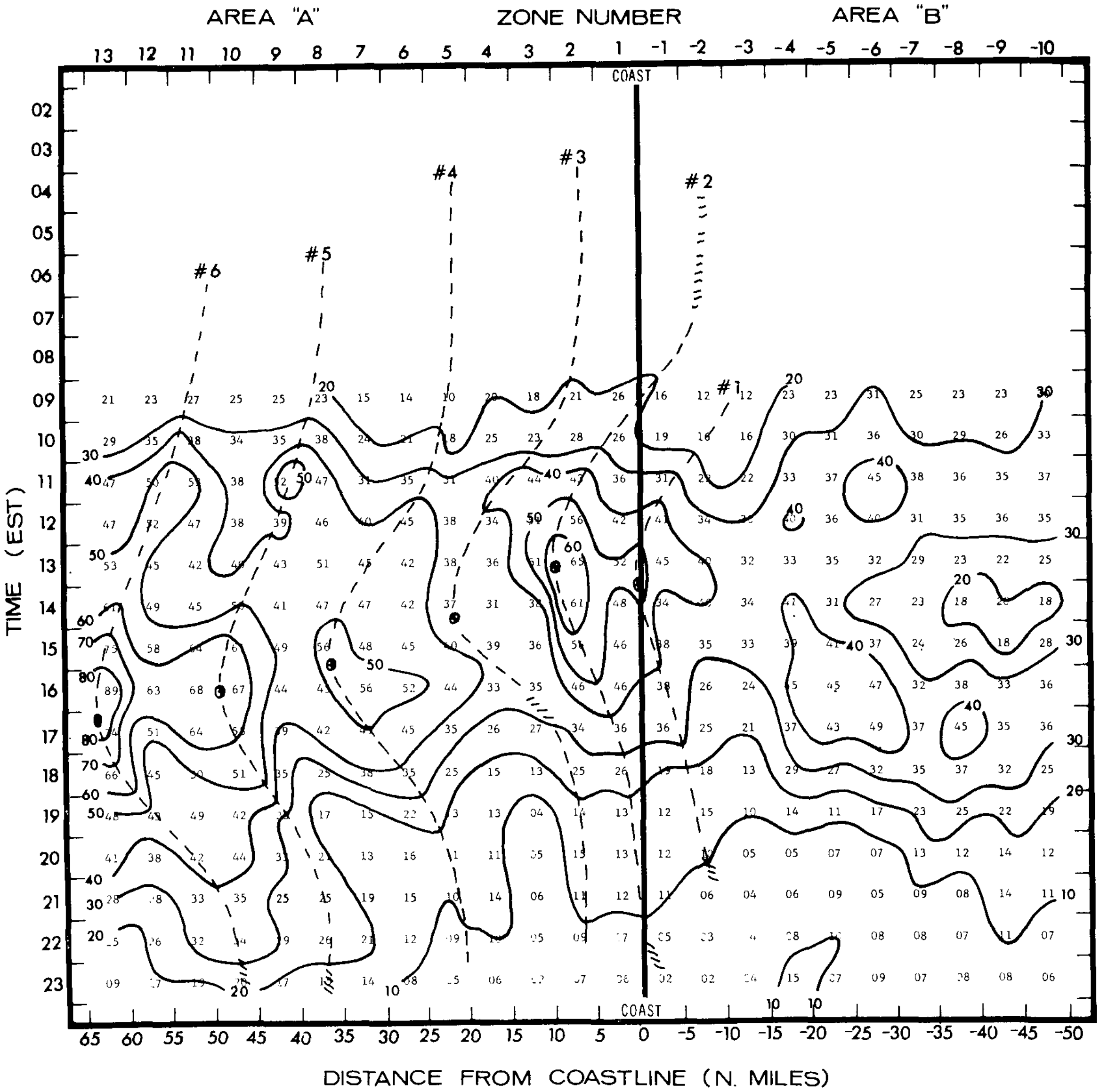

Fig. 6. Running total distribution of echoes with tops <10,000 ft in height. Running means can be obtained by dividing all numbers by three.

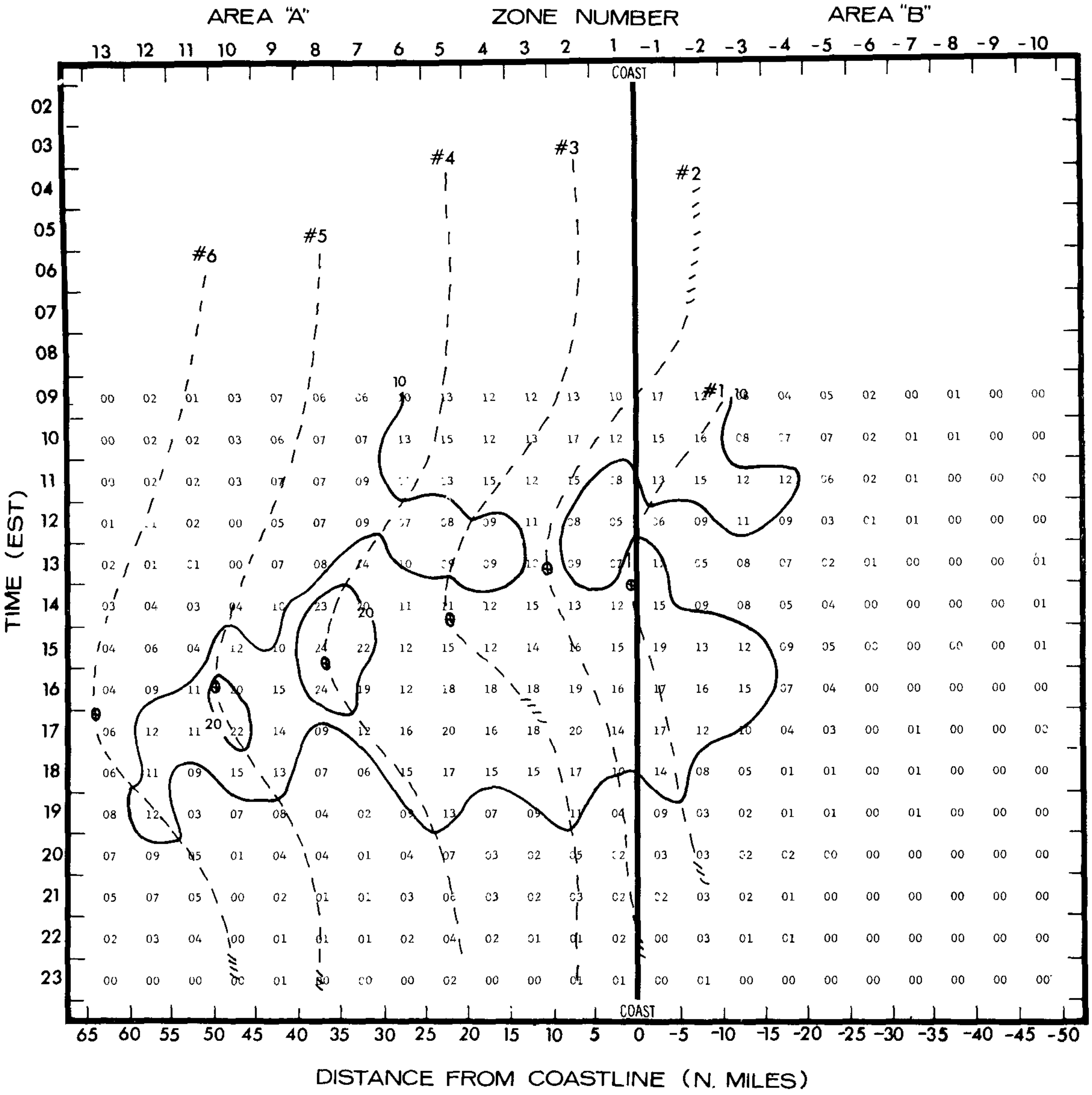

Fig. 7. Same as Fig. 6 except for tops 10,000–20,000 ft in height.

patterns suggest a new model for convective populations with trade-wind flow. It is found that convection over the Florida Current is largely random or unorganized. Near the coast and inland there are preferred north-south zones of convection spaced approximately 15 n mi apart where the echoes are not only more numerous, but are taller. These zones become apparent near daybreak and maintain the same position until the sea breeze crosses the coast. As the sea breeze moves inland, all of these equi-spaced north-south zones shift inland in unison. After reaching their maximum intensity during the afternoon, they retreat to their original positions as the sea-breeze circulation decays. These convective zones or bands resemble standing waves which are thought to be dynamically induced by the sea-breeze circulation imposed on the trade wind, and thermodynamically induced by Florida's "heat mountain."

This paper does not pretend to explain the life history of echoes in such a model. Without additional data, the discussion could be argued either way. Although there were not enough data to determine a model for the westerly regime, it is proposed that the bulges in the bands would point toward the east in response to the same mechanism along Florida's west coast. In either regime, the heaviest rain would likely be associated with interaction between convection in one of the coastal bands with the sea breeze along the leeward coast.

Estoque (1962) observed an unexpected and ap-

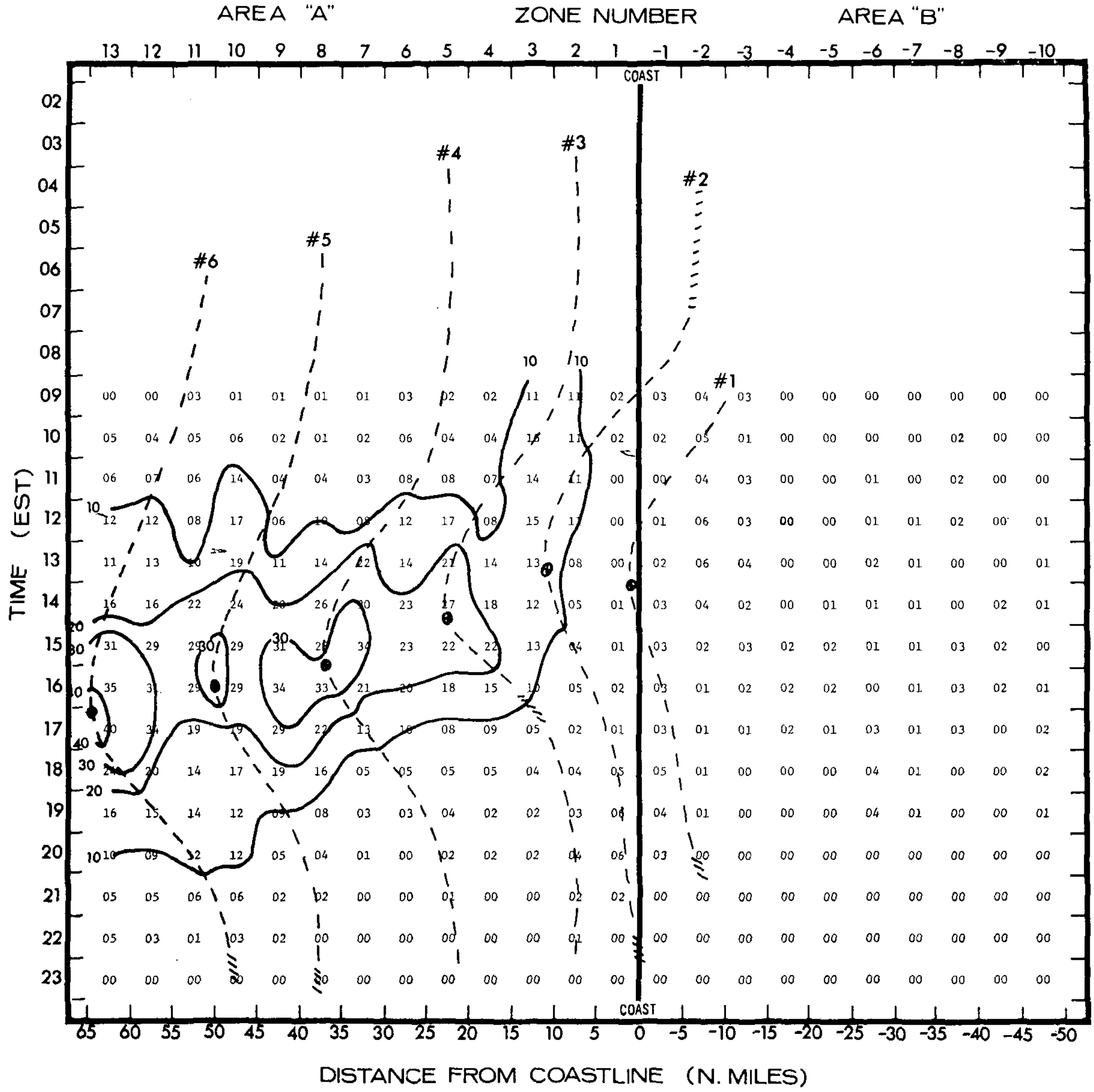

FIG. 8. Same as Fig. 6 except for tops >20,000 ft in height.

parently unexplained feature in his theoretical model that is explained by the above model. He found two separate regions of upward motions parallel to the shoreline at 1700 local time, one directly above the coast, one 9 n mi inland. Golden (1967) found that sea-breeze echoes as such do not move across the coast but rather dissipate near the coast and reform inland. The results of the current study do not necessarily conflict with that observation because it must be recognized the model discussed herein does not necessarily produce parallel rows of echoes that move like blocks of wood in a stream. Clearly, it is possible for certain parts of a zone to be devoid of echoes. The model merely outlines zones parallel to the shoreline that are most favorable for echoes to form. Moreover, echoes in those zones will also tend to become taller than in adjacent regions.

The reader must bear in mind that the data sample of one month is quite small for rigorous conclusions. However, the orderliness and plausibility of the results indicate that they may be of use until a more exhaustive study can be made. The orderliness also, to some extent, overcomes questions of computational or statistical noise in the analysis. Recall that only a simple time-smoothing technique was used and that no space smoothing was performed.

Acknowledgments. The author is grateful to the U. S. Army Electronics Command, Fort Monmouth, N. J., for supporting this work. Our entire staff deserves special thanks for their part in maintaining the radars and in collecting both PPI and CAPPI data during the period of interest. My student assistants, Bill Coertnik and Jim Rine, tabulated and processed the data.

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