Analysis of Low-Level Atmospheric Refraction over Miami during July 1970[1]

KALIPADA CHATTERJEE[2]
India Meteorological Department, New Delhi
AND HAROLD P. GERRISH
Rosenstiel School of Marine and Atmospheric Science, University of Miami, Fla.

9 February 1971

1. Introduction

The earthward bending of radar energy is a function of the vertical gradient of the radio refractive index. The radio refractive index N is given by

$$N = 77.6PT^{-1} + 3.73 \times 10^5 eT^{-2}, \qquad (1)$$

where P is pressure, T temperature, and the vapor pressure e is given by

$$\ln e = 21.64 - 5418T_d^{-1}, \qquad (2)$$

an integrated form of the Clausius-Clapeyron equation, where T_d is the dew point temperature. In practice it

---

[1] Contribution No. 1365, Rosenstiel School of Marine and Atmospheric Science, University of Miami.

[2] WMO Fellow assigned to the Radar Meteorological Laboratory, University of Miami, during the period 27 September to 13 November 1970.

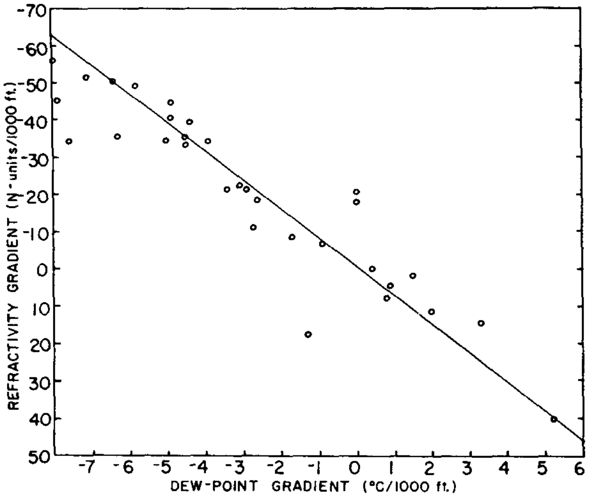

Fig. 1. Refractivity vs dew point gradients, surface–1000 mb, 0000 GMT July 1970.

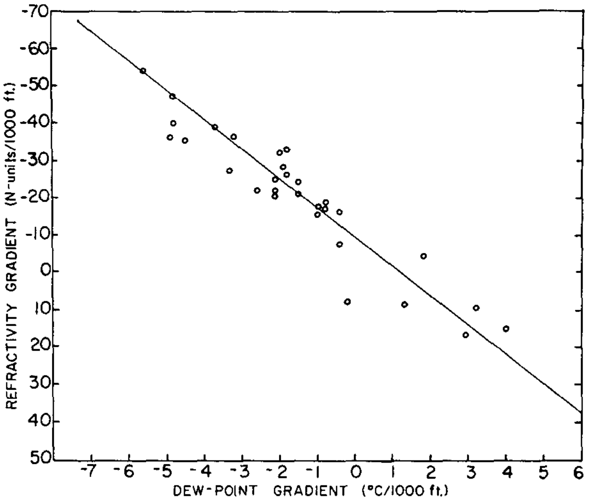

Fig. 3. Refractivity vs dew point gradients, surface–1000 mb, 1200 GMT July 1970.

is much easier to solve these equations using nomograms such as the Project Arowa Refractive Index Nomogram.

Since changes in the vertical pressure profiles are normally small, abnormal bending is a function of the temperature and dew point profiles. Mathematically, it is readily seen that an increase in temperature or decrease in dew point temperature, or both, will cause a decrease in N with height. When the N gradient is more negative than minus 24 N units (1000 ft)$^{-1}$, superrefraction occurs. Atlas (1960) and Gerrish (1967b) have shown that such conditions are primarily a function of the moisture lapse. While this is true, there is still some question as to whether or not intense superrefractive conditions generally occur with temperature inversions even though the moisture lapse may have been primarily responsible for the refractive conditions. Thus, this study, in part, seeks to shed more light on this question, at least for a representative summer month.

Such things as "fine lines" and anomalous propagation (A.P.) on radar are a result of superrefractive conditions. Gerrish (1967a) has discussed these features as viewed in the South Florida area in the absence of range attenuation correction which suppresses lighter signals. Now that this correction is applied routinely on radars in this area, it is of interest to restudy these features to determine the nature of those patterns that remain. Thus, another purpose of this work is to study radio refractive conditions and the resulting radar displays in the South Florida area during the month of July 1970.

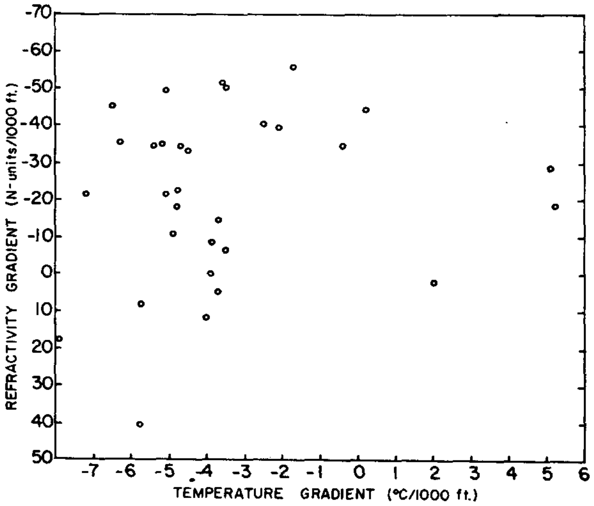

Fig. 2. Refractivity vs temperature gradients, surface–1000 mb, 0000 GMT July 1970.

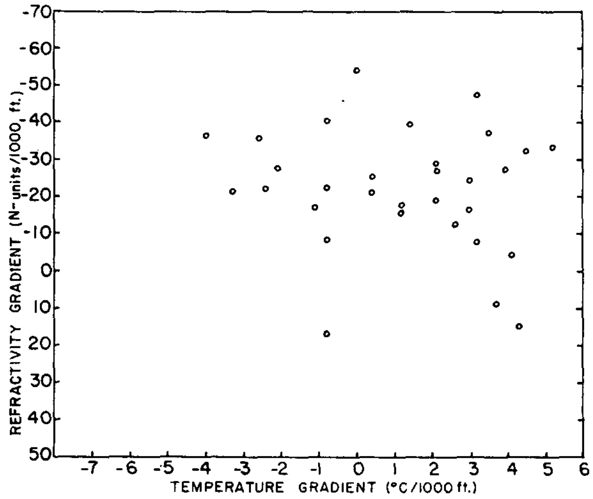

Fig. 4. Refractivity vs temperature gradients, surface–1000 mb, 1200 GMT July 1970.

2. Analysis of Miami raob soundings

Pressure, temperature, dew point and height values were tabulated for mandatory and significant levels up to 850 mb, using the 0000 and 1200 (all times GMT unless otherwise indicated) Miami raob soundings during the month of July 1970. July is considered to be a representative summer or rainy season month in South Florida. The radio refractive index was then computed at each of these levels using the Project Arowa nomogram. The refractive gradients between successive levels in N units (1000 ft)$^{-1}$ were determined and both the temperature and dew point lapses were noted.

The N, T and T_d gradients between the surface and 1000 mb for both 0000 and 1200 are shown in Figs. 1–4. Fig. 1 shows a linear relationship between the N and T_d gradients at 0000, whereas, in Fig. 2 there is no relationship (random distribution of points) between the N and T gradients. The same held true at 1200 as shown in Figs. 3 and 4. This clearly indicates that at least for a representative summer month, superrefraction immediately above the ground occurs primarily as a function of the moisture lapse which confirms the earlier observations of Atlas and Gerrish. The superrefraction was attended by anomalous propagation. Note that intense superrefractive conditions in the early morning hours were accompanied by temperature inversions about two-thirds of the time but there was no relationship between the strength of the inversions and the intensity of the superrefraction.

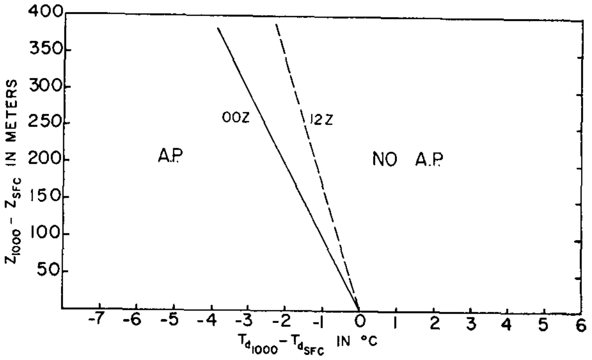

FIG. 5. Anomalous propagation template.

It is seen in Figs. 1 and 3 that superrefraction occurred when the T_d gradient was more negative than -3.1C (1000 ft)$^{-1}$ at 0000 (1900 EST) and -1.8C (1000 ft)$^{-1}$ at 1200 (0700 EST). This fact was utilized to draw the A.P. template shown in Fig. 5. By knowing the thickness and the difference in dew point temperature between the two levels, it is readily possible to determine whether or not A.P. is likely to occur by noting which side of the appropriate line (0000 or 1200) the point falls. This eliminates time consuming computations of N and of N gradients.

A summary of the locations of the superrefractive layers aloft, those regions where the N gradient is more negative than minus 24 N units (1000 ft)$^{-1}$, is shown in Fig. 6. Along the bottom of the diagram is a listing of the daily convective regimes.

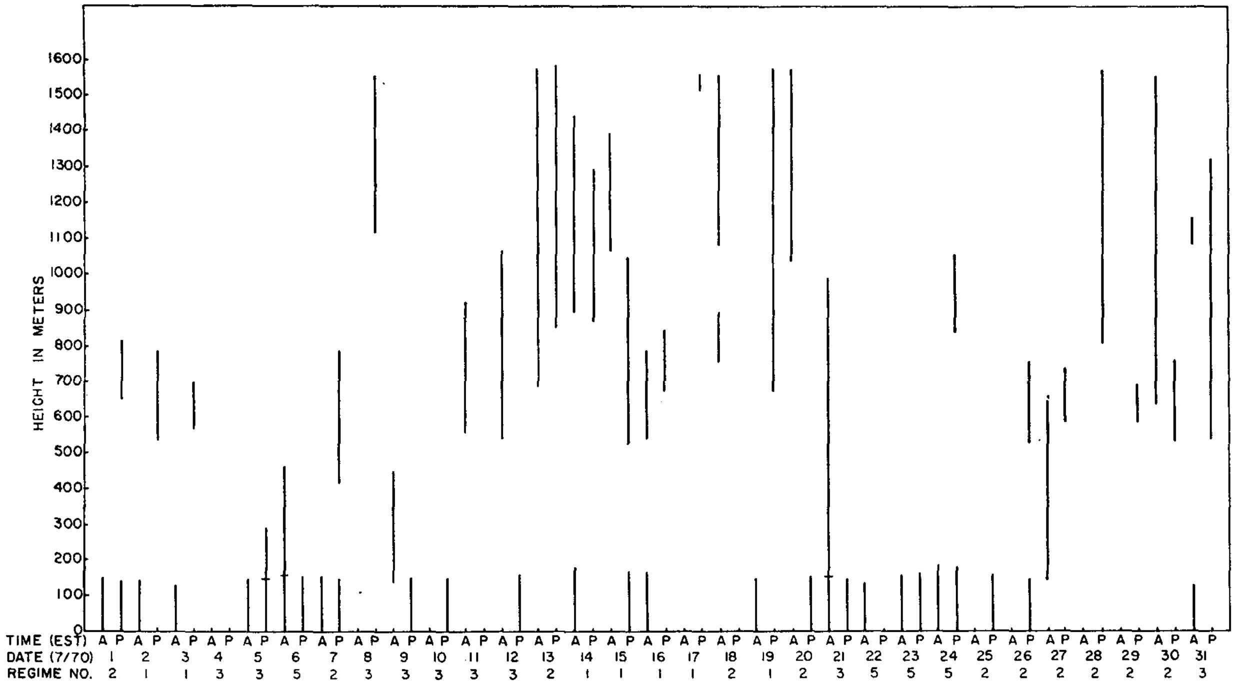

FIG. 6. Location of superrefractive layers over Miami, surface–850 mb, July 1970 (A=0700 EST, P=1900 EST, regime numbers refer to convective regime).

LaSeur (1966) found that five convective modes adequately described the rainfall regimes on the Island of Barbados. Those modes were determined on the basis of the number of stations receiving daily rainfall. This technique was used by Gerrish (1970a,b) to stratify and study satellite cloud patterns and the temporal variations in echo coverage in the vicinity of South Florida during the summer of 1968. In this present study, daily rainfall data during July 1970 were tabulated for 20 well-spaced stations throughout South Florida and the following frequencies of stations receiving rainfall were used to define the convective activity regime:

Regime no.	Percent of stations receiving rainfall	Number of stations receiving rainfall	Number of days regime observed
1	0– 15	0– 3	7
2	16– 45	4– 9	11
3	46– 70	10–14	9
4	71– 85	15–17	0
5	86–100	18–20	4

Each day shown in Fig. 6 was labeled on that basis. Note that the higher the regime number, the greater the areal coverage of rainfall and thus the greater the degree of the disturbance. Here, and as shown earlier by Gerrish (1970a,b), it is seen that regimes 2 and 3 are those most frequently observed in South Florida.

A summary of Fig. 6 is presented in Table 1. This table shows slightly more superrefractive layers at 1900 than at 0700 EST. Normally, more layers are to be expected in the early morning hours. Also, superrefractive conditions are to be expected more during regimes 1, 2, and to some extent 3. This was borne out in the table, but there was also a substantial number of ground based layers during regime 5. This may have been partly due to moisture gradients produced by widespread precipitation. When considering the actual number of regime 1 days, it is seen that *all* of those had layers aloft in the evening and most of them had ground based layers in the morning. Most of the regime 5 days had ground based layers in the morning and on most evenings, with a tendency for no layers aloft because of the convection. It is interesting to note that, in general, superrefractive layers tended to occur at the ground or aloft but not at the ground and aloft simultaneously. Perhaps the most important feature in this table is the pronounced tendency for layers to occur during the early evening hours. This observation obviously indicates the importance of the sea-breeze regime on the production of layers at this time.

3. Analysis of radarscope displays

Miami (MIAC) WSR-57 and UM/10-cm time-lapse radar film during July 1970 were examined frame by frame for fine lines and anomalous propagation. Time of occurrence, range, azimuth and other descriptions were noted. These displays were then studied with regard to preferred location, motion and refractive structure of the lower troposphere.

Anomalous propagation was evident on 28 out of 31 nights with a preferred location along an azimuth northwest from the station. The preferred range was 50–80 n mi beginning near sunset. Anomalous propagation was also pronounced north of the station along the east coast and west from the station. On occasion the area southwest from the station was preferred. It is quite clear that selective rather than uniform A.P. occurs in South Florida, supporting the findings of Gerrish (1970b).

Fine lines were rather frequently observed from convective echoes with a preferred location over land areas west of the station out to a radius of ~50 n mi. They were not observed over the water surrounding the Florida peninsula. All of the fine lines occurred between the hours of 1130 and 1830 EST or during the afternoon. Most of the fine lines associated with the sea-

Table 1. Superrefractive layers under different convective activity regimes over Miami during July 1970.

Type of refractive index profile	0700 EST Activity regime						1900 EST Activity regime					
	1	2	3	4	5	Total	1	2	3	4	5	Total
Number of ground based layers	5	2	3	0	4	14	1	5	5	0	3	14
Number of situations with layers aloft	3	5	5	0	1	14	7	8	3	0	1	19
Number of situations with layers both at the ground and aloft	2	0	2	0	1	5	1	3	1	0	1	6
Number of situations with layers at the ground but none aloft	3	2	1	0	3	9	0	2	4	0	2	8
Number of situations with layers aloft but not at the ground	1	5	3	0	0	9	6	5	2	0	0	13

Table 2. Motion [direction/speed (kt)] of several fine lines in South Florida.

Case no.	Motion of fine line*	Winds aloft over Miami 700 mb	850 mb	1000 mb	Surface
1	a) SE/9 b) WSW/8	270/01	230/04	145/06	220/06
2	a) NW/8 b) SW/15	220/23	195/11	235/14	260/03
3	a) NW/11	235/11	240/10	180/04	140/03
4	a) SE/13	175/10	180/06	220/02	240/02
5	a) NW/8 b) WNW/7	065/19	085/16	100/10	090/08
6	a) NW/8 b) WNW/5	050/04	140/16	135/10	130/05
7	a) SE/21	150/08	150/15	120/08	120/04

* Direction from which line is moving. The letters "a" and "b" refer to different fine lines.

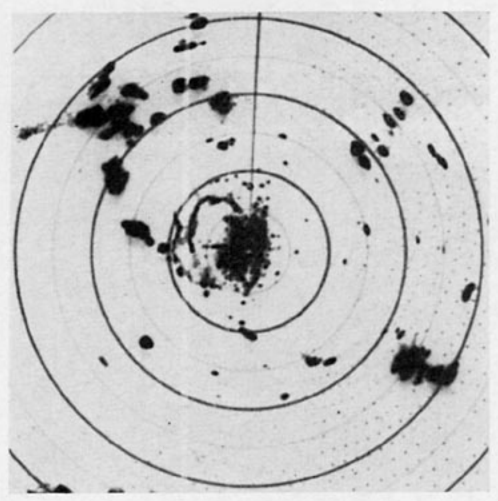

FIG. 7. Fine lines on MIAC radar, 1514 EST 3 July 1970. Heavy range circles are shown at 50 n mi intervals.

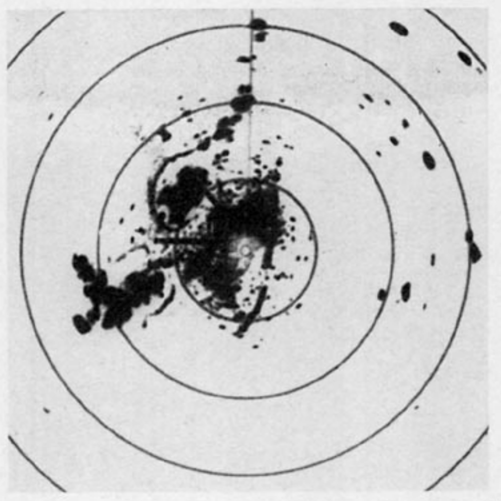

FIG. 8. Fine lines on MIAC radar 1314 EST 28 July 1970. Range circles are at 20 n mi intervals.

breeze front were suppressed by the sensitivity time control and only a few remained visible on the film beyond the ground pattern which obscures all echoes.

There were many nice displays of fine lines during the month of July 1970. Two of them are shown in Figs. 7 and 8. Because most of the fine lines had curved configurations, only general directions of motion can be given. Seven of the most intense fine line situations were selected for motion computations. The results are shown in Table 2.

The 700-mb winds are shown as indicators of the convective echo motion. The 850-mb winds are considered to be representative of the low-level flow above the Ekman layer. Fine lines are considered to occur from elevations on the order of 1000–1500 ft above the ground (Senn and Gerrish, 1964). Thus, the 1000-mb winds are tabulated as being near this level. Surface winds are also added to the table. It is seen that generally there is no preferred direction of motion of the fine lines with respect to the convective echo motion, or the winds in the lower troposphere.

There didn't seem to be any preferred refractive structure in the lower troposphere on those days that fine lines formed. The seven pronounced cases occurred on days with different combinations of superrefractive layers at the ground and aloft. Moreover, they formed in every type of convective regime observed during the month. There was a tendency for anomalous propagation to occur earlier in the evening on those days when fine lines were observed during the afternoon but there were exceptions. A larger sample would be required to shed more light on this.

4. Conclusions

This brief study has revealed several interesting findings concerning low-level atmospheric refraction in South Florida. It is observed that ground-based superrefractive layers and the resulting A.P. in a representative summer month are produced primarily by the moisture lapse and are essentially independent of temperature inversions. This finding prompted the construction of an Anomalous Propagation Template which permits quick determinations as to whether the atmospheric structure is conducive for A.P. formation. Analyses of all superrefractive layers below 850 mb indicate that slightly more layers occur in the evening than in the morning. Generally, they tend to occur at the ground or aloft but not simultaneously. Obviously, moisture brought inland by the sea-breeze regime plays an important role in the production of low-level superrefractive layers during the summer evenings in South Florida.

Anomalous propagation is found most often northwest of Miami at a range of 50–80 n mi. It also occurs frequently along the east coast, and in the Everglades west and southwest of Miami. Fine lines are observed mostly over the Everglades out to a range of 50 n mi. They occur rather frequently during the afternoon in association with convection. There is a definite tendency for them not to occur over the water surrounding the peninsula. The fine lines move at speeds of approximately 8 kt, reaching as high as 21 kt in one case. There is no preferred direction for the movement, nor do they occur with any preferred atmospheric refractive structure. They are observed during every convective regime.

Acknowledgments. The authors are grateful to Mr. Gene Woods of WBAS Miami for copies of the Miami raob data, to Mr. Alvin Samet of the National Hurricane Center, Miami, for the loan of radar film, and to Mr. Larry Greives for drafting the figures. Mrs. Sandra Weber typed the manuscript. The senior author is especially appreciative to the Director General of Observations, India Meterological Department; to the World Meteorological Organization; and to the Radar Meteorological Laboratory, University of Miami, for providing this research opportunity.

REFERENCES

Atlas, D., 1960: Radar detection of the sea breeze. *J. Meteor.*, 17, 244–258.

Gerrish, H. P., 1967a: Mesoscale studies of instability patterns and winds in the tropics. Rept. No. 14, Radar Meteor. Lab., RSMAS, University of Miami, 72 pp. (DDC AD 659-786).

——, 1967b: An objective climatology of the trade-wind inversion and rapidly drying layers aloft over Miami using super-refractive diagnostic techniques. *Proc. 5th Tech. Conf. on Hurricanes and Tropical Meteorology*, Caracas, Venezuela, Amer. Meteor. Soc., also Contribution No. 850, RSMAS, University of Miami, 15 pp.

——, 1970a: Mesoscale studies of instability patterns and winds in the tropics. Rept. No. 20, Radar Meteor. Lab., RSMAS, University of Miami, 39 pp.

——, 1970b: Temporal variations in echo coverage as a function of tropical convective regime in South Florida. *Preprints of Papers, 14th Radar Meteor. Conf.*, Tucson, Ariz., Amer. Meteor. Soc., 425–428.

LaSeur, N. E., 1966: On the distribution of rainfall probability over Barbados. *Proc. 1966 Army Conf. on Tropical Meteorology*, Miami Beach, Fla., Army Electronics Command, 36–41.

Senn, H. V., and H. P. Gerrish, 1964: Three-dimensional analysis of a precipitation-free, sea-breeze front by radar, Tiros, visual and mesosynoptic data. *Proc. 1964 World Conf. Radio Meteor.*, Boulder, Colo., Amer. Meteor. Soc., 36–41.