NOAA Technical Memorandum NWS SR-140

TORNADIC SUPERCELL OVER DADE AND BROWARD COUNTIES (FLORIDA) ON JANUARY 15, 1991

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1. INTRODUCTION

On the afternoon of Tuesday, January 15, 1991, a supercell thunderstorm developed over southern Dade County and moved north-northeastward across populous urban areas of northeastern Dade and southern Broward counties. The associated mesocyclone produced four confirmed tornadoes, injuring five persons and causing several million dollars in damage. Another thunderstorm, following a parallel track several miles west of the tornadic supercell, contained a weaker mesocyclone which spawned no tornadoes. This report does not attempt a detailed quantitative investigation into the mesoscale dynamics responsible for the tornadoes. Instead, observations and descriptions of the event are presented, along with largely qualitative investigation into those mechanisms likely to have contributed to this rare supercell event for southern Florida. In addition, forecast implications are discussed, and the concept of helicity is presented as a useful forecast tool for such events.

2. STORM CHRONOLOGY AND OBSERVATIONS

2.1 Tornadic mesocyclone (eastern storm)

The tornadic supercell's wall cloud was initially observed by on-duty WSFO and NHC employees at 2010 UTC to the northwest, over the city of West Miami. Well-defined cyclonic circulation was evident in the wall cloud, with helically ascending scud tags underneath. A narrow condensation funnel, laminar in appearance, formed rapidly at about 2015 UTC in the eastern part of the mesocyclone. Debris then appeared near the ground, signalling tornado touchdown. Power lines arced, and a bright blue flash lit the debris cloud as a power transformer blew out. The tornado hit an elementary school, injuring a teacher and causing damage rated F0 according to the Fujita damage scale (Fujita, 1971). A brief tornado touchdown minutes later caused F0 tree damage about two miles SSW of Miami International Airport.

The mesocyclone passed directly over the airport (Figs. 1, 2) before spawning a third tornado over Hialeah. The airport observer reported a continuous tornado during the period (Fig. 3); however, subsequent damage analysis has revealed three distinct Dade County touchdowns (Fig. 2). The Hialeah tornado (F1 damage) followed a 3.5 mile long path between 2036 and 2045 UTC, overturning cars, causing three minor injuries, and barely missing a major pari-mutuel race track.

The parent mesocyclone continued into Broward County, where it produced its fourth, final, and most intense tornado. This tornado touched down in Miramar at 2054 UTC, about 1.5 miles S of North Perry Airport. An off-duty NWS employee witnessed the event and subsequently photographed some of the damage (Figs. 4a-4d). After causing some minor home and tree damage and overturning a truck, the tornado struck North Perry Airport. Twenty-two aircraft were destroyed, but hangar damage was limited to roofs, doors, and non-load-supporting walls. The South Campus of Broward County Community College was hit next, with one minor injury. Modular classrooms were heavily damaged, and a prefabricated metal gymnasium was flattened. This tornado (strong F1 damage) lifted about 2105 UTC, terminating a 2.5 mile path. The mesocyclone became wrapped in rain and dissipated shortly after 2110 UTC, after lasting for over an hour.

2.2 Non-tornadic mesocyclone (western storm)

A separate and visually distinct cell was observed west of the tornadic supercell on radar (Sec. 2.3) and by the author. The storm and its attendant mesocyclone were smaller and weaker than its eastern counterpart, and produced no confirmable tornadoes. The mesocyclone was first observed as a weakly rotating lowering, with a wrapping gust front extending northeastward from the wall cloud in a semicircle around the southern periphery of a small (two-mile diameter) precipitation core. When initially observed about 2015 UTC, the wall cloud was located over the uninhabited Everglades of west-central Dade County.

The author intercepted the mesocyclone as it crossed Krome Avenue (Fig. 2) in rural northern Dade County. Well-defined cloud-base rotation was seen as the wall cloud passed overhead; on the surface, characteristic wind veering of about 180 degrees and a one-minute sustained windspeed of 50 kts was estimated. The mesocyclone proceeded harmlessly northeastward into southern Broward County and dissipated at approximately 2100 UTC.

2.3 Radar observations

Radar echoes traceable to the tornadic supercell were first indicated over extreme southern Dade County during the 1830 UTC Miami (MIA) radar observation. A single DVIP-3 echo was shown near the northern shore of Florida Bay, about 15 miles south-southwest of Florida City. This cell was located in the southern fringes of a large area of rain, with scattered embedded clusters of strong (DVIP-4 to DVIP-5) thunderstorms, which covered most of the southern 1/4 of the peninsula.

Two distinct strong (DVIP-4) echoes were evident along the southern edge of the large rain area by 1930 UTC. Although these became embedded within ground clutter as they continued north northeastward into populated areas, they were intermittently distinguished as separate DVIP-4 to DVIP-5 echoes until 2332 UTC, by which time the storms began weakening over northeastern Broward County. The echoes followed parallel paths, approximately 7-10 miles apart, throughout this period.

Neither echo ever exhibited the classical hook signature, due to loss of horizontal echo resolution in the ground clutter and small size (less than one mile diameter) of their mesocyclones. The eastern storm, which spawned the tornadoes, was sufficiently close to the radar site (Fig. 2) to make reasonably precise precipitation top measurement impossible; however, a peak top of 55,000 ft was estimated in the 2101 UTC special observation, compiled at the time of the North Perry tornado (Fig. 5).

3. SYNOPTIC CONDITIONS

3.1 Upper air analyses

The 500 mb pattern over the United States was dominated by a broad, full-latitude longwave trough centered roughly along 100 degrees west longitude. This feature was amplified in its base by a sharply defined, slightly negative-tilted shortwave trough. The NMC 500 mb analysis for 1200 UTC, 15 Jan (Fig. 6), depicted this shortwave trough over Oklahoma and eastern Texas, in phase with another shortwave trough over the northern plains states. Resultant difluent flow extended from Missouri southeastward to South Carolina and Georgia, then weakly across Florida. The subsequent 0000 UTC 500 mb analysis (Fig. 7) showed that the shortwave trough had begun to shift east-northeastward, extending from the middle Missouri valley to the northwestern Gulf of Mexico. The depicted winds and pressure field analysis did not hint at the existence of a shortwave trough or vorticity maximum (vort max) over the southeastern Gulf of Mexico.

3.2 Surface Analysis

The 1200 UTC analysis for 15 Jan (Fig. 8) was prepared by the Tropical Satellite Analysis and Forecasting (TSAF) unit of NHC. The warm front was drawn from a 1003 mb low over the Arklatex region across the northern Gulf of Mexico to the southern tip of Florida. Although surface observations in the area showed general homogeneity of the airmass across southern Florida, the Keys, and northern Cuba, satellite imagery indicated a somewhat more southerly frontal position over the Straits of Florida. The apparent airmass continuity on the surface in this area was largely eliminated by differential diabatic heating on either side of the front as the day progressed, shown on the 0000 UTC map for 16 Jan (Fig. 9). This front became the leading edge of return flow, after its passage as a cold front during the previous two days, and continued east-northeastward as a cold front into a deep North Atlantic low (not shown).

By 0000 UTC on 16 Jan (Fig. 9), a warm front was depicted along 26 degrees north latitude (26N) through the Bahamas and southern Florida, curving northwestward across the northeastern Gulf of Mexico and southwestern Mississippi to a 1004 mb low over Arkansas. However, based on the relatively low temperature and backed wind reported from the buoy in the eastern Gulf, as well as satellite imagery, the warm front may have actually been slightly farther south than shown, continuing westward along 26N to near 82W/83W before curving northward toward Mississippi. High relative humidities, backed surface winds, and scattered precipitation continued along and within 150-200 miles north of the front over Florida.

3.3 Satellite interpretation

Imagery from the U.S. geostationary weather satellite (GOES-7) was useful in clarifying, to a limited extent, the rather muddled mix of clues provided by the NMC charts for diagnosis of the upper air support for this event. Although higher-resolution pictures in the visible wavelengths, for the immediate Florida vicinity, were archived at NHC, they were unavailable at this writing. Instead, full-disk and partial-disk imagery was used to infer some of the most important features.

The most well-depicted contributive factor appeared to be a middle/upper level cyclonic circulation, or vort max, over the eastern Gulf of Mexico (Figs. 10a-10h). This feature was readily apparent in the infrared and moisture channel patterns after about 1400 UTC. A less definitive middle/upper level disturbance was inferred over the same area as early as 0600 UTC (Fig. 10a), based on the isolated cluster of convection offshore from northwestern Cuba. The vortmax moved only slowly northeastward as the day progressed, embedded within a broader middle/upper level difluent zone ahead of the pronounced cyclone over the south-central U.S. In addition, a sharp contrast was seen between moist areas -- as indicated by white convection or light gray water vapor -- and relatively dry (black) areas on the moisture channel imagery (i.e., Fig. 10h), in the vicinity of the vort max. This indicated a strong associated UVV/subsidence couplet, and thus a vigorous circulation in both the vertical and the horizontal.

The low-level baroclinic zone was denoted on infrared images by the contrast between cloudy and relatively cloud-free areas in the low levels, from the eastern Florida coastal waters eastward to another middle/upper level disturbance over the Atlantic. This zone was enshrouded within the cloudy area associated with the vort max over southern Florida and the eastern Gulf; however, frontal location there was inferred to be near the southern periphery of the multilevel convective clouds.

4. SOUNDING ANALYSIS

Plotted 1200 UTC soundings from the two upper-air stations in the region, West Palm Beach (PBI) and Key West (EYW), provided a representative view of the morning airmass over southern Florida (Figs. 11 and 12). The subsequent 0000 UTC PBI sounding was not practically useful; for it was launched into convective residue. The 1200 UTC EYW sounding, closer to the warm front, had a shallower low-level backed-wind layer than PBI, with 60 degrees directional shear in the lowest 300 mb. In the same layer at PBI, net directional shear was approximately 80 degrees; however, a slight backing existed in the 750-650 mb layer, possibly attributable to a nearby transient shortwave trough not resolved by the models. Speed shear was limited in the low levels of both soundings, being only about 5 kts net through the lowest 300 mb.

Thermodynamically, a somewhat greater boundary-layer dewpoint depression and a shallow (but pronounced) 800-850 mb dry slot at

PBI differentiated these soundings. The 1200 UTC surface-based lifted indices (LI) of -1 to -3 degrees C were the rule, with EYW having a somewhat larger positive energy area. EYW, however, was not capped, signalling an early start to convection; this agreed with satellite indications of morning convection nearby over the western Straits of Florida. The 50-mb deep, 2-3 degrees C low-level inversion at PBI acted to retard convection until a more favorable combination of diabatic heating, frontal convergence, and middle/upper level dynamics occurred later in the day.

Though apparently favorable for later convection, the 1200 UTC PBI sounding did not by itself show a large positive area and suitable low-level shear profile such as those commonly associated with tornadic supercells. If the sounding were modified using estimated or actual afternoon conditions at several levels, however, a much more ominous scene unfolds. For simplicity, the PBI sounding was manually modified for immediate pre-storm conditions in only four significant ways:

1) Observed pre-storm surface temperature and dewpoint at MIA were used.
2) 1200 UTC lower-middle level dry slot was expanded, based on proximity and strength of the vort max as shown on afternoon satellite imagery.
3) 1200 UTC inversion was strengthened, in order to depict an atmosphere just prior to free convection; this was reasonable based on expected adiabatic lower-middle level warming in the dry slot.
4) 500 mb temperature was cooled several degrees due to approach of the vort max, with the environmental lapse rate smoothed correspondingly elsewhere between 600 mb and the tropopause.

Although these changes were general and somewhat arbitrary, they were qualitatively sensible with respect to the situation. The modified sounding was then used to estimate certain convective parameters (Fig. 13). Under this scenario, explosive convection could be expected. Of particular interest were the large positive area and high maximum convective top (based on rough equal-area energy negation above the equilibrium level). The maximum top estimated in this manner closely approximated the 55,000 ft top reported by the radar operator. Also, the new surface-based LI was in the -10 deg C range, indicating extreme convective instability. Still, some mechanism for improving low-level shear was needed.

5. MESOSCALE DISCUSSION

The vort max obviously played a crucial role in firing deep convection along the warm front over the eastern Gulf and southern Florida; but this key feature was very poorly handled by the NMC charts previously mentioned. Although the warm front acted as an isentropic "overrunning" mechanism for light rain across much of the area east of the vort max and within several hundred miles north of the front, this activity was suppressed in the area of subsidence west of the vort max over the eastern gulf. In addition, the most intense convection developed in a zone of middle-upper level difluence east of the vort max. This difluence implied divergence, which was the "focusing mechanism" acting on the warm front to increase low-level convergence in the area of convection; this served not only to help initiate the deep convection, but also to sustain it.

Analysis of the modified PBI sounding (Sec. 4) provided important clues to the vigor of the storms; however, a more favorable low-level speed and directional shear pattern would better account for the presence of mesocyclones in these storms. How would such an environment come about, and why was the eastern (tornadic) storm's mesocyclone appreciably stronger? Before addressing these issues, some brief background review may be necessary.

Helicity is the scalar product of storm-relative vorticity and velocity -- qualitatively speaking, a measure of the tendency of an updraft to rotate (a form of helical fluid motion). Helicity is roughly represented by the area under a storm-relative hodograph below 4 km, or about the lowest 350-400 mb. The larger this area is, the greater the helicity, and the likelier the possibility of mesocyclone formation, assuming of course that deep convection is favorable thermodynamically. Helicity, and the related concept of streamwise vorticity, have been shown to be dominant factors in mesocyclone formation and supercell sustenance. Excellent comprehensive discussions of these concepts, with case examples, are available in Davies-Jones (1984), Lilly (1986), and Brandes et. al. (1988).

For this case, the radar-observed cell motion vector (Fig. 5) was placed on the morning PBI hodograph (Fig. 14) to better illustrate the storm-relative reference frame. With respect to the vector's endpoint, morning helicity was small, even becoming negative in places. In order to make mesocyclone formation and maintenance more likely, as denoted by hodograph-implied helicity, surface winds must have been backed relative to low-level winds above the surface; and some increase in speed with height in low-middle levels should have occurred. Foremost, the midlevel speed weakness and backing, a clear detriment to helicity, must have been re-arranged. A more favorable overall speed shear was most likely supplied by a combination of boundary-layer frictional suppression and higher low-middle level speeds, in a pressure gradient which increased with the approach and intensification of the vort max.

Favorable low-level directional shear was probably caused and sustained by some combination of three factors: the warm front, sea breeze effects, and ultimately the mesolow itself. With the proximity of the warm front, surface winds were already east-southeasterly to southeasterly in the pre-storm environment. Due to solenoidal circulations arranged by differential diabatic heating of the mainland and adjoining waters, a light seabreeze was possible. Resultant flow off Biscayne Bay would have had a predominant easterly component, due to the largely meridional orientation of the coastline. Such a seabreeze, if it existed, could have helped intensify the eastern storm through helicity augmentation, convergence, and extra moisture supply. The western storm could have been "robbed" by its eastern neighbor of much of this localized low-level assistance, thereby rendering it unable to produce tornadoes in an otherwise similar environment. Once the eastern mesocyclone formed, its circulation should have backed the low-level winds in the immediate vicinity. Aforementioned local contributors continued without interference from other cells; and the mesolow sustained itself in this manner until wrapping precipitation stabilized its environment and choked off its inflow over Broward County.

6. SOUTHERN FLORIDA TORNADO CLIMATOLOGY

Tornadoes are uncommon events in this region; those spawned by identifiable supercells are quite rare. From cumulative maps by Fujita (1987), overall tornado occurrences are fewer in southern Florida (south of an imaginary east-west line through Lake Okeechobee) than in any other comparably sized area of the state. The majority of confirmed tornadoes over this area occur within 10 miles of the Atlantic coast; however, the immeasurable factor of population-density reporting bias likely contributes to this. Most of these tornadoes occur in summer months of August and September and produce F0 damage; these would largely not be of supercell origin due to the climatological absence of required upper-air support in the prevailing late-summer tropical regime. In fact, during the period 1916-1985, no January tornadoes were confirmed south of Fort Lauderdale! Several notable tornado events in southern Florida may be attributed to supercell activity. Among these were 7 February 1986 (Revitte, 1986), 13 April 1984 (Hebert, 1984), 19 February 1968 (Golden, 1971), and 5 April 1925 (Grazulis, 1990).

7. FORECASTING AND OPERATIONAL IMPLICATIONS

7.1 January 15 forecasts

Although the same-day forecasts issued by WSFO MIA did not specifically mention any likelihood of severe weather over southern Florida, a high probability of showers and thunderstorms was emphasized (Fig. 15). Notably, rain chance was increased from 60% to 80% between the 500 a.m. and 1100 a.m. public forecasts. The 400 a.m. state forecast discussion accurately foretold the northward migration of the warm front over southern Florida; but at that time, the later strength and influence of the vortmax was not hinted, either in satellite imagery or by model guidance. Accordingly, no significant severe weather likelihood was apparent at that early hour, except for the 18 to 24 hour forecast period over northern portions of the state due to the expected presence of both low LIs and a nocturnal low-level jet.

7.2 Forecast problems for similar future events

The lack of tornadoes in general in southern Florida, and the absolute rarity of tornado-producing supercells in this region, has made such forecasting uncommon due to unfamiliarity and/or inexperience. The convective emphasis has been placed on probability of precipitation (POPs), which is justifiable in an area so dependent on tourism and recreation. On the great majority of potential thunderstorm days, this approach is sufficient. When dynamic conditions threaten to stimulate the atmosphere in the direction of sustained and/or severe convection, however, the forecaster must contemplate the worst-case scenario, and analyze all relevant data -- especially soundings and hodographs -- with that in mind.

Operationally, time limitations may prevent the forecaster from compiling a storm motion vector for qualitative storm-relative helicity estimation, as done in Sec. 5. A user-friendly personal computer (PC) program by Hart and Korotky, the Skew T/ Hodograph Analysis and Research Program (SHARP), has been disseminated to many NWS offices. This program allows a forecaster to modify actual soundings, then calculates dozens of parameters, including helicity. Until SHARP is distributed to all NWS offices, and forecasters become familiar with its use and underlying concepts, a rough helicity estimation off the morning hodograph is still the main way to judge mesocyclone/tornado potential for nowcasting purposes. Although the forecaster should think in a storm-relative framework, "quick-glance" helicity estimation directly from the 1200 UTC hodograph would be more useful than nothing under intense deadline and warning constraints.

7.3 Conclusions

During any potentially convective situation over southern Florida in which low-level winds could possibly veer and increase with height, at least a remote chance of mesocyclone formation must be considered, especially if upperair dynamic support is apparent or probable. Although any tornadoes that do form would likely be weak and short-lived, as per southern Florida tornado climatology, supercell events such as 15 Jan 91 obviously can and do happen here. Moreover, because even the weakest of tornadoes can kill, public safety demands the highest possible level of forecaster expertise in anticipating potential mesocyclone formation. Thorough familiarity with severe weather forecasting on the part of individual meteorologists is the first step, followed by application of this knowledge to tools such as AFOS and/or McIDAS (at MIA) -- and in the near future, SHARP, other PC programs, profiler data, NEXRAD, and AWIPS.

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Lilly, D.K., 1986: The structure, energetics, and propagation of rotating convective storms. Part II: Helicity and storm stabilization. J. Atmos. Sci., 43, 126-140.

Revitte, F.J., 1986: Heavy rain and tornado formation over South Miami on Feb. 7, 1986. NWS Significant Weather Event report, WSFO Miami, 20 pp.

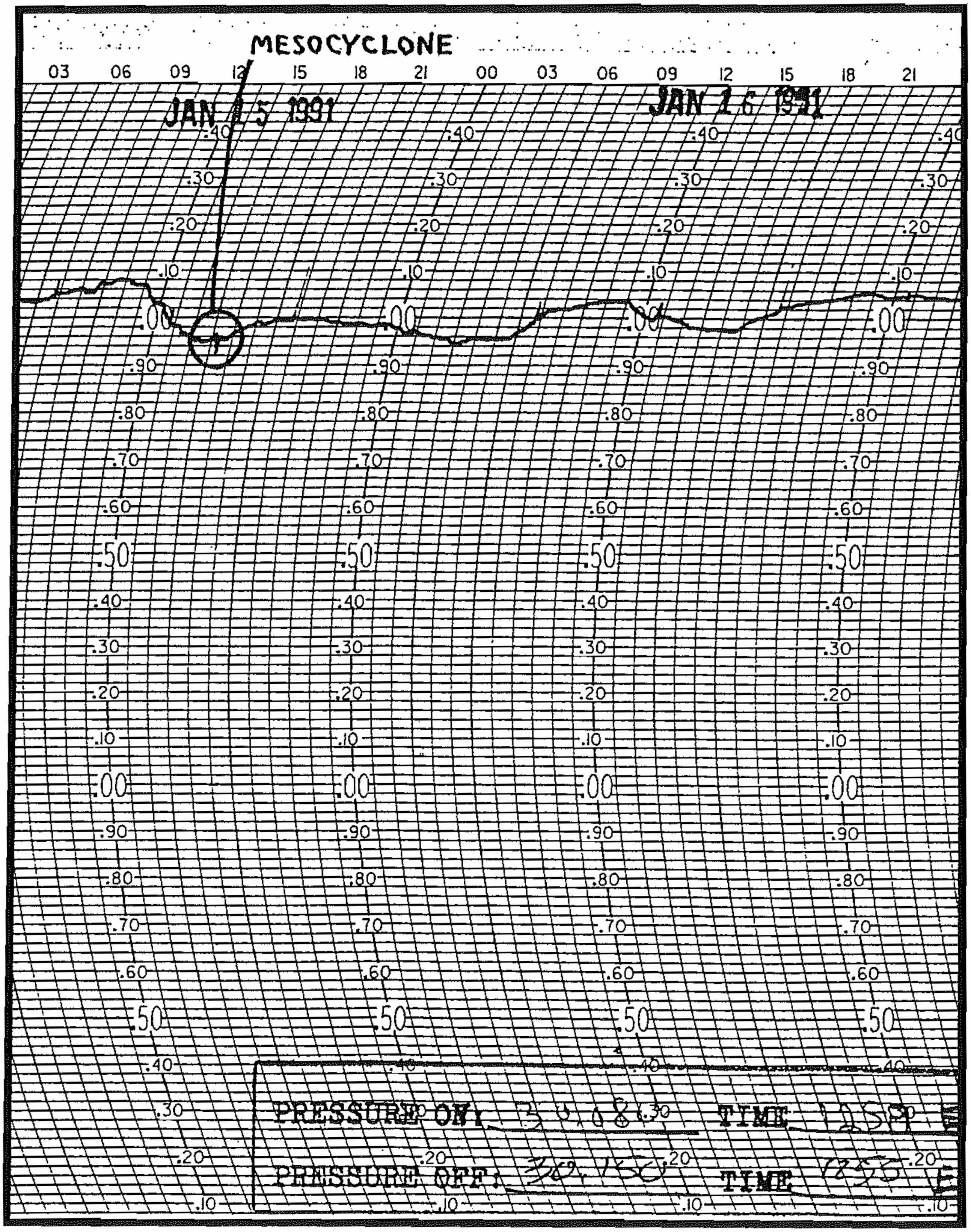

Figure 1. Miami International Airport (MIA) barogram, mesocyclone passage highlighted. (Upward spikes are time marks.)

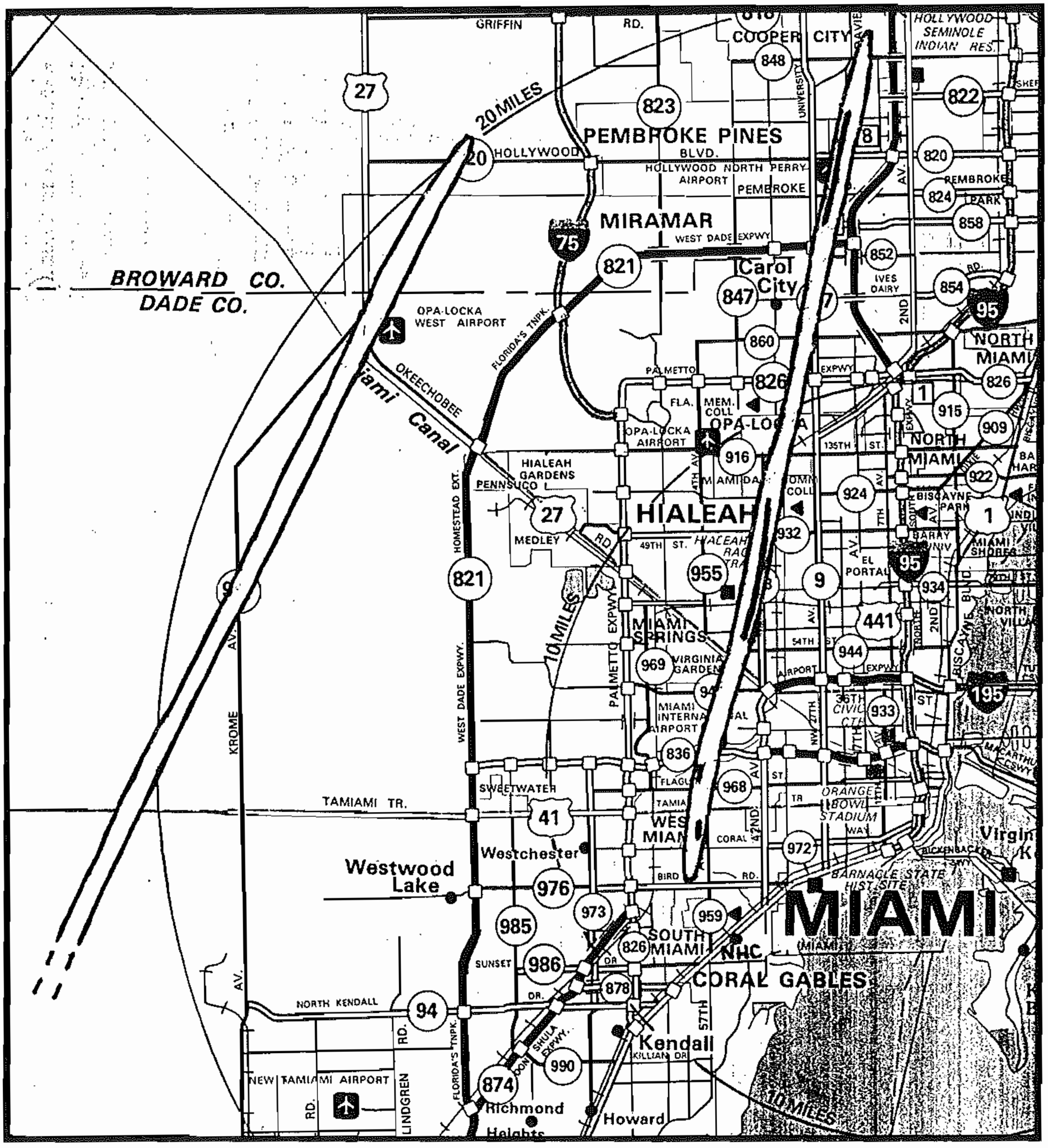

Figure 2. Mesocyclone tracks and tornado paths (inner lines, eastern mesocyclone) for 15 January 1991.

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MIA SA 195Ø 18 SCT M5Ø BKN 85 OVC 7 146/76/7Ø/1415G22/996/TCU S-SW SCT V BKN

MIA SP 1953 18 SCT M5Ø BKN 85 OVC 7T 1516G22/997/TB52 S MOVG NE OCNL LTGCG CB RWU S-SW
MOVG NE

MIA SP 2ØØ3 M13 BKN 5Ø BKN 85 OVC 2TRW+ 1517/997/T S MOVG NE OCNL LTGICCG

MIA SP 2Ø1Ø M11 BKN 23 OVC 1/2TRW+ 1812G22/998/RØ9LVR18V6Ø T ALQDS MOVG NE OCNL LTGIC

MIA USP 2Ø15 TORNADO B15 1 S MOVG N

MIA USP 2Ø26 TORNADO 1/2 NE MOVG N

MIA USP 2Ø36 TORNADO E36 MOVD N

MIA SP 2Ø4Ø 15 SCT M65 BKN 95 OVC 7T 1811/997/T N MOVG NE OCNL LTGICCG

MIA RS 2Ø5Ø 15 SCT M65 BKN 95 OVC 7 15Ø/73/7Ø1712/997/TE48 MOVD NE CB RWU N MOVG NE RB
1956E37 PCPN Ø54 TORNADO B15E36 MOVD N/5Ø854 197/
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Figure 3. Surface observations at MIA during the period from 1950 UTC through 2050 UTC, 15 January 1991.

Figure 4a. Downed trees and a moved parking barricade in a neighborhood playground in Miramar, FL.

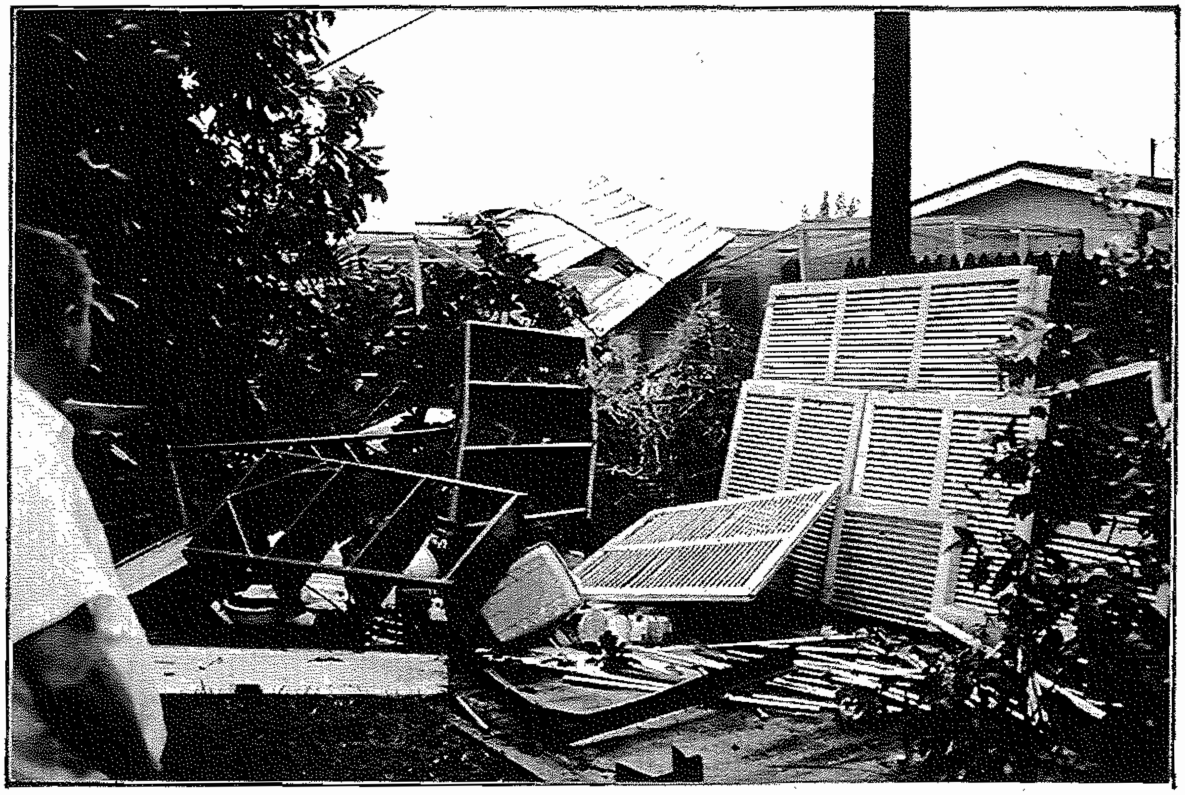

Figure 4b. Remnants and contents of a destroyed backyard shed in Miramar. The shed roof is on the pool enclosure of the home in the background.

Figure 4c. Tree and fence damage in Miramar.

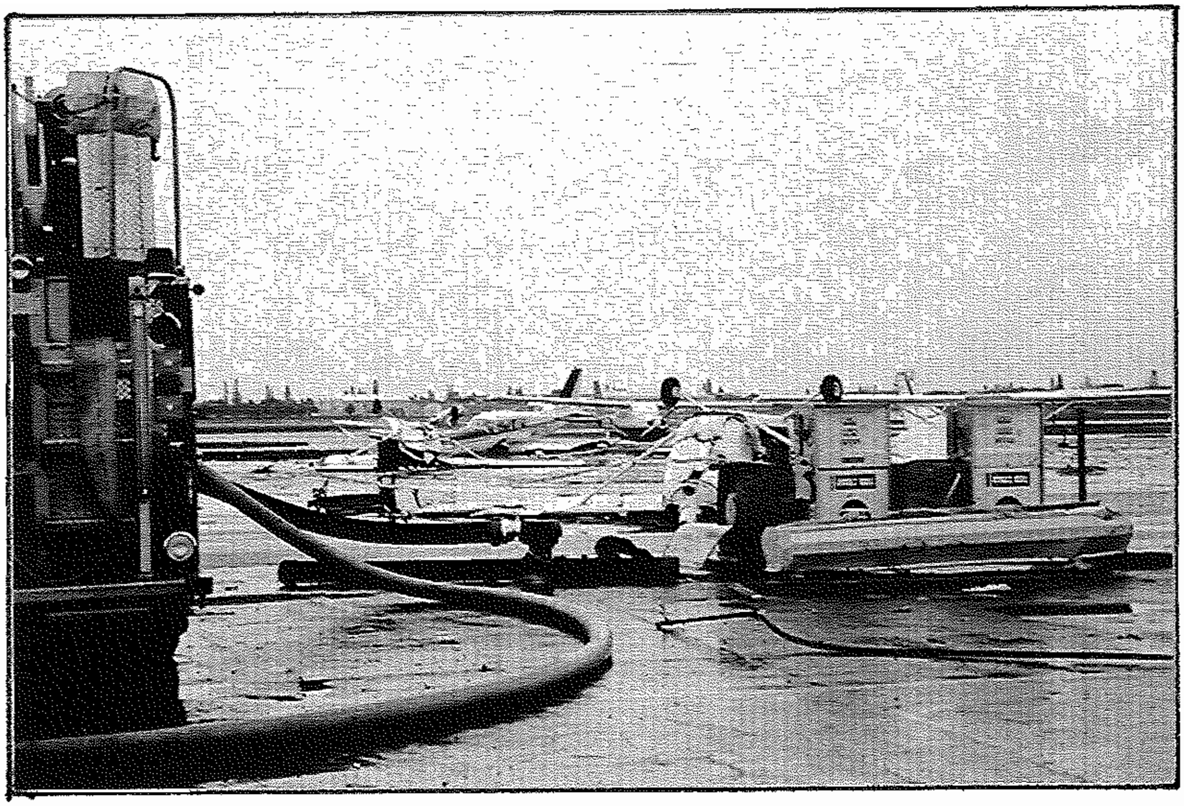

Figure 4d. Damaged and overturned aircraft at North Perry Airport. All photos courtesy Martin Nelson, NHC, via WSFO MIA.

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MIA 2030 COR SPL CELL TRWX/NC 322/10 D7 C2322 MT 450 TORNADO
THIS CELL AREA 2TRW++2R-/NC 35/125 260/165 165W C2322 MT 390
AT 319/13
^GK2222 HJ2222 II222242 JI222422 KG2222343 LG22234522
MG22244452 NG2224322 OG22222 PJ2=

MIA 2101 SPL CELL TRWX/NC 357/18 D7 C2322 MT 550 TORNADO RPTD
THIS CELL
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Figure 5. MIA special radar obs, taken from the NHC site in Fig. 2, for 2030 and 2101 UTC, 15 January 1991.

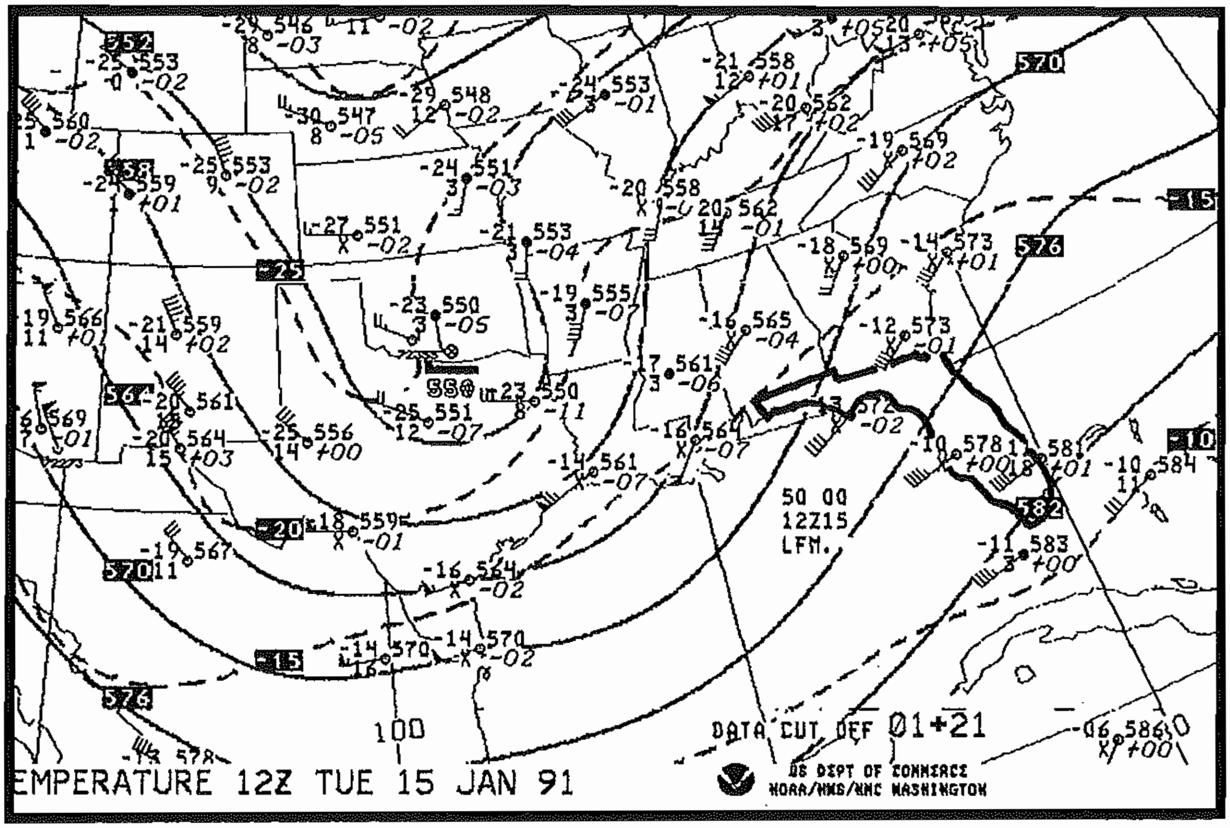


Figure 6. 500 mb analysis for 1200 UTC, 15 January 1991 (LFM version, Florida highlighted).

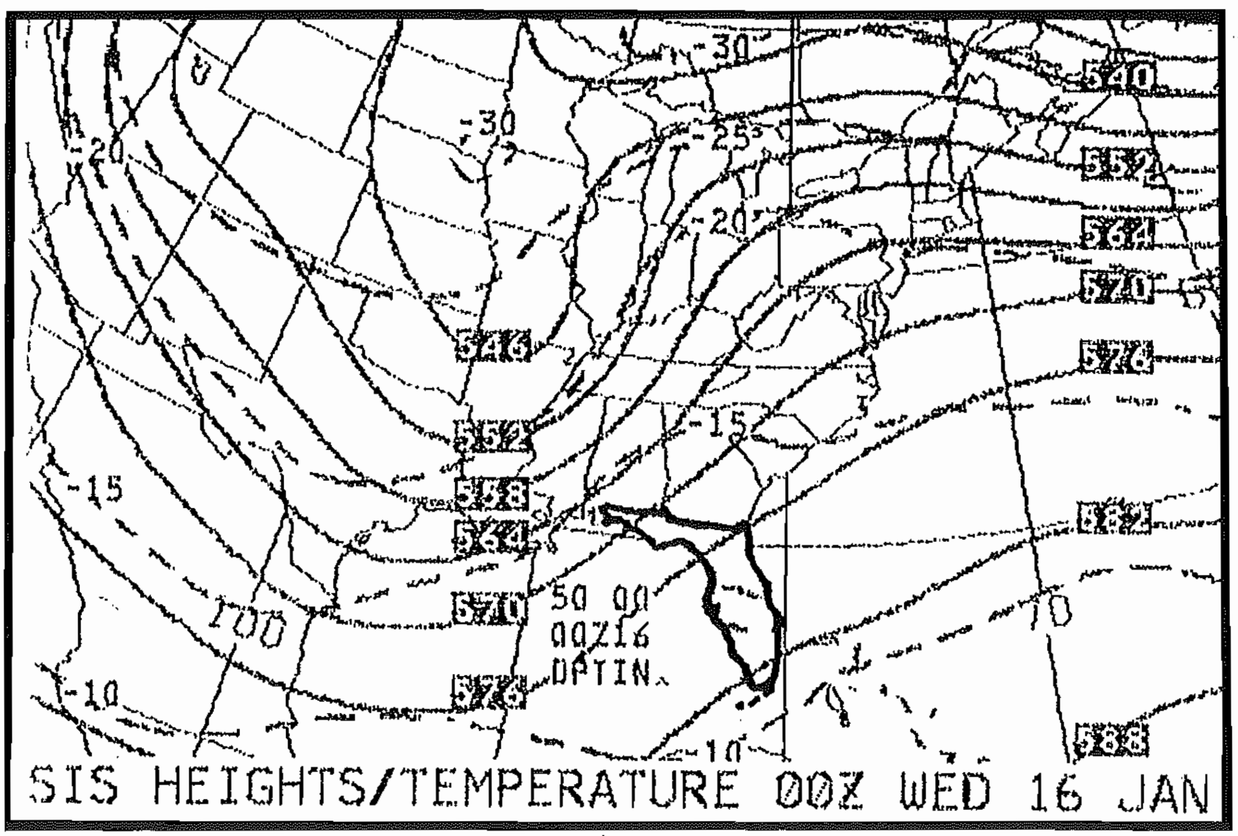


Figure 7. 500 mb analysis for 0000 UTC, 16 January 1991 (hemispheric map, Florida highlighted).

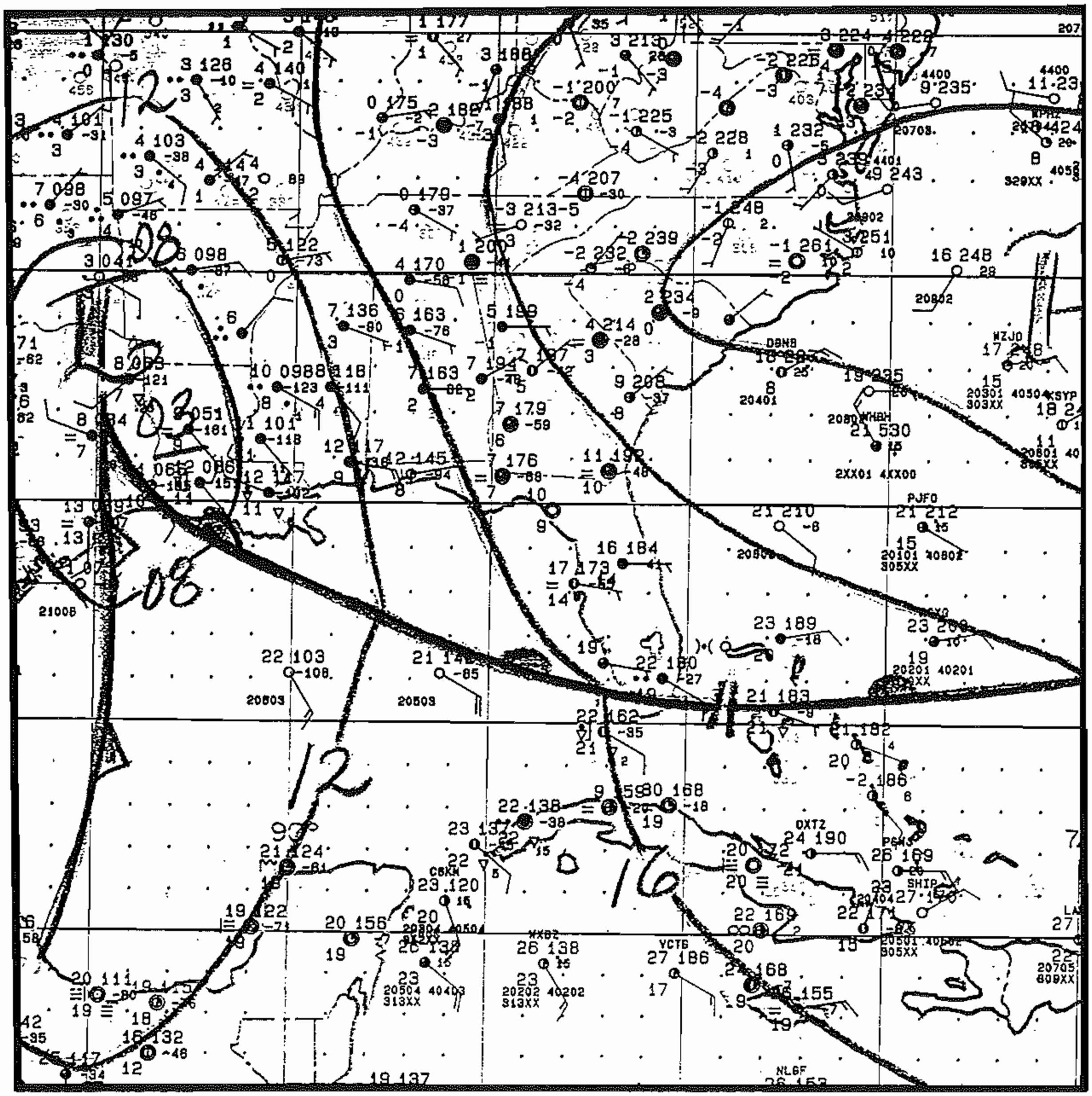


Figure 8. Surface analysis for 1200 UTC, 15 January 1991 prepared by Tropical Satellite Analysis and Forecast (TSAF) unit, NHC.

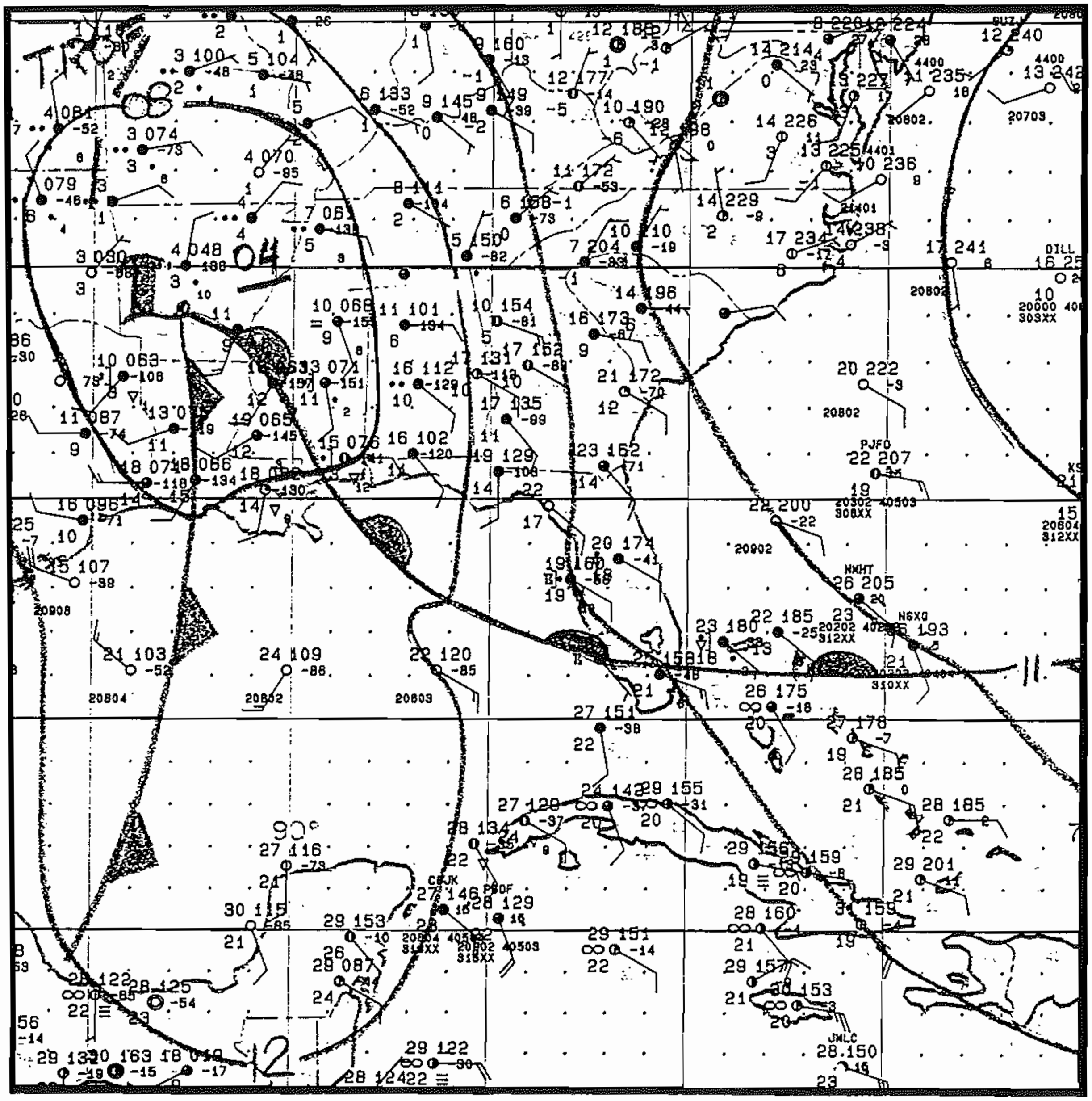


Figure 9. Surface analysis for 0000 UTC, 16 January 1991, prepared by NHC-TSAF.

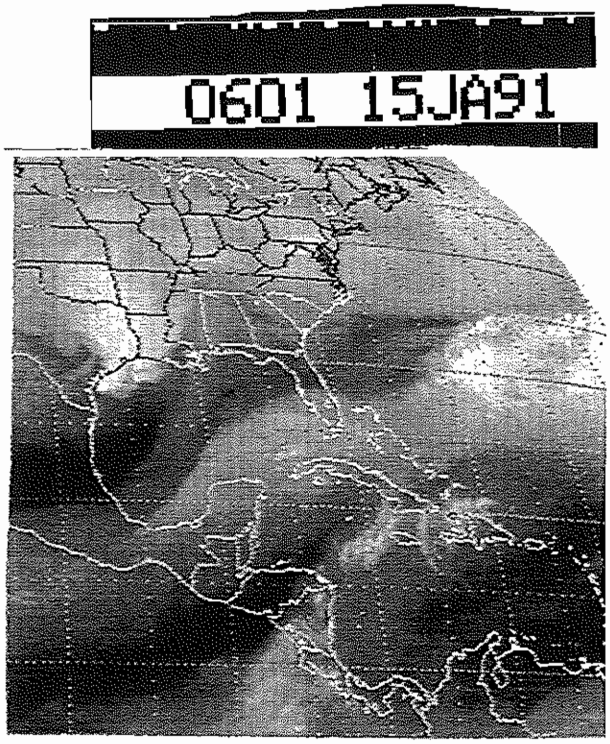


Figure 10a. 0601 UTC (15 January 1991) moisture channel picture. Note the middle/upper level moisture swath over the southeastern Gulf of Mexico and convection breaking out offshore from northwestern Cuba.

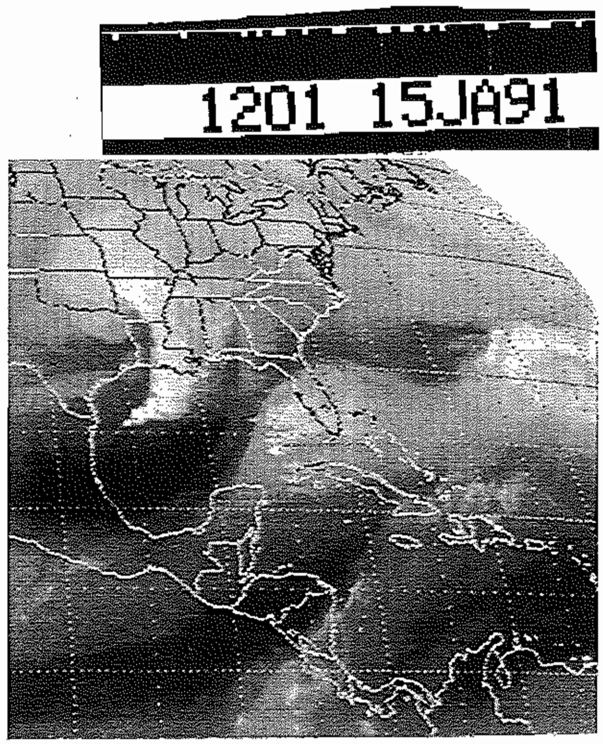


Figure 10b. 1201 UTC (15 January 1991) moisture channel picture. Convection over the southeastern gulf increased, and flow was backed along the western edge of water vapor gray, indicating intensification of the middle/upper level disturbance.

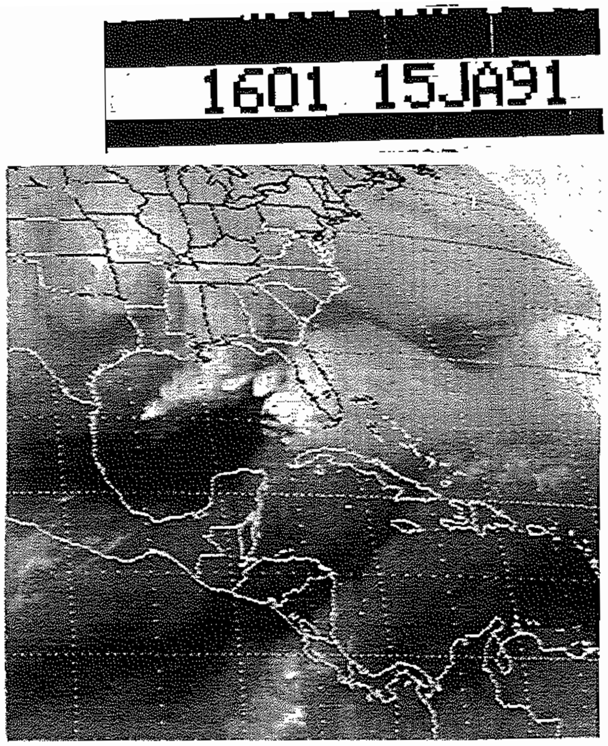


Figure 10c. 1601 UTC (15 January 1991) moisture channel picture. Convective coverage is greatest near the evolving vort max and along a northern Gulf baroclinic zone.

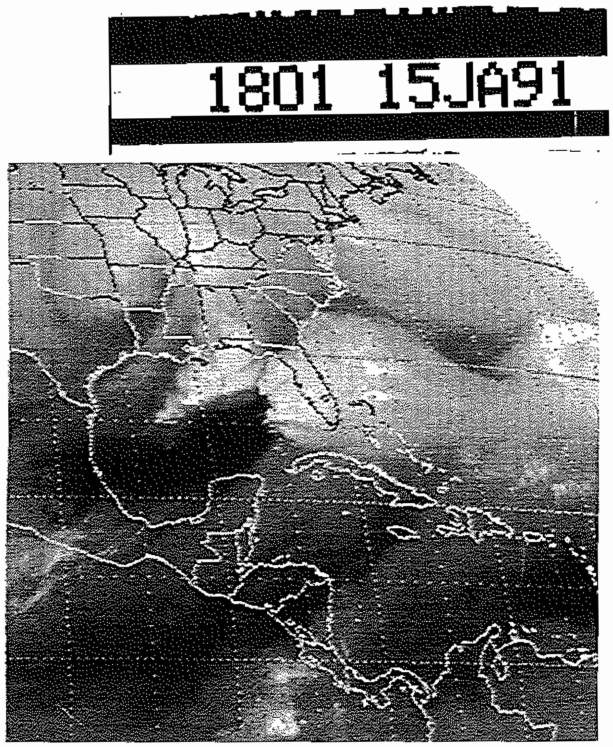


Figure 10d. 1801 UTC (15 January 1991) moisture channel picture. Cyclonic curl was evident about 100 nmi WSW EYW, indicating dry slot formation associated with the vort max.

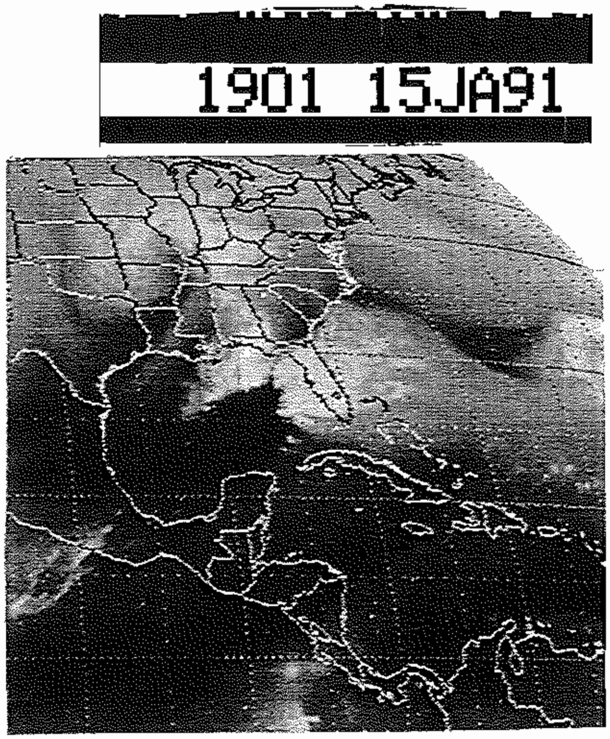


Figure 10e. 1901 UTC (15 January 1991) moisture channel picture. Strongest convection, including the future tornadic supercell, was developing along the southern edge of the cloud mass -- along the warm front and under difluent flow ahead of the vort max.

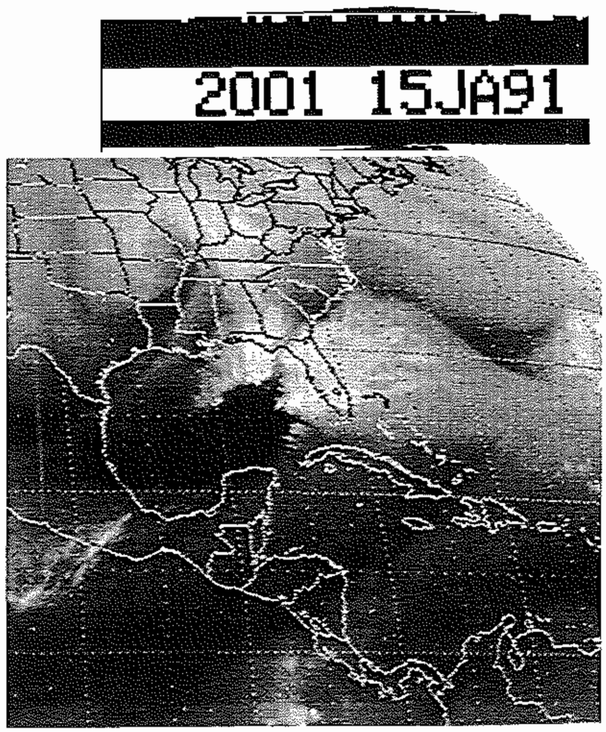


Figure 10f. 2001 UTC (15 January 1991) moisture channel picture. The vort max was moving slowly north-northeast, with southern Florida convection becoming severe.

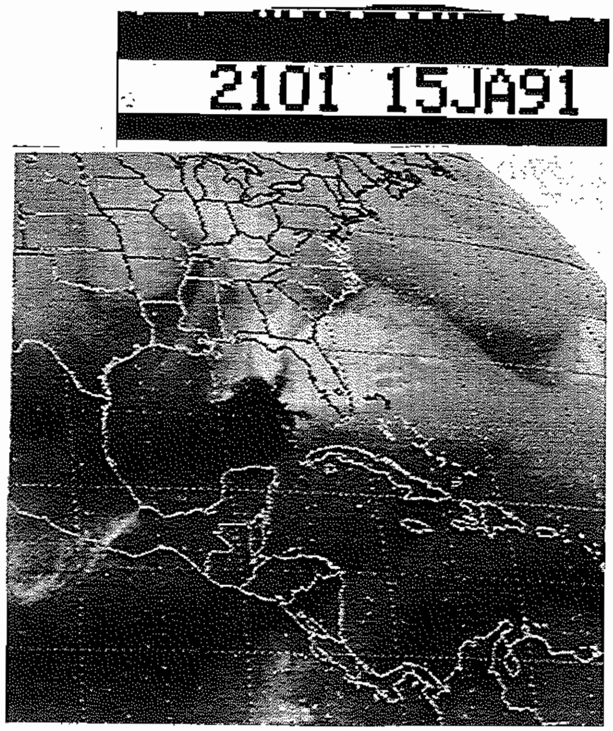


Figure 10g. 2101 UTC (15 January 1991) moisture channel picture. North Perry tornado was on the ground at this time.

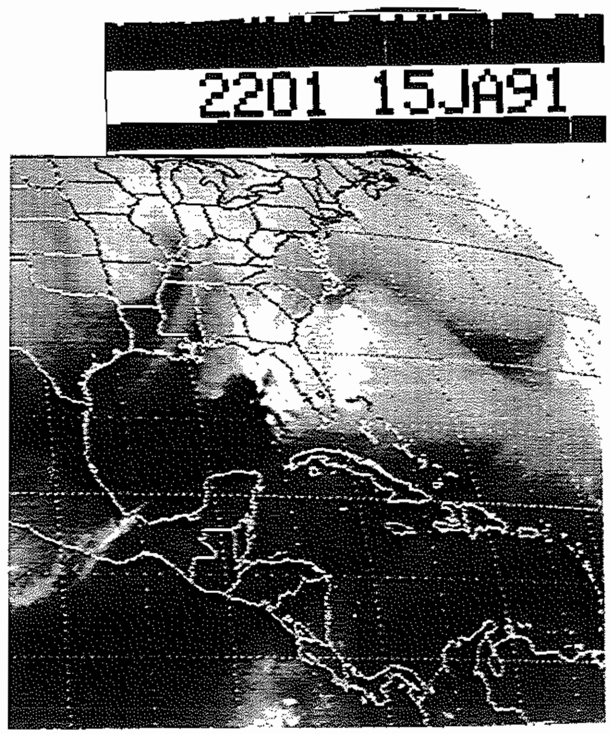


Figure 10h. 2201 UTC (15 January 1991) moisture channel picture. Severe convection was moving offshore from southeastern Palm Beach County; convection would continue during much of the night due to the eastern Gulf system.

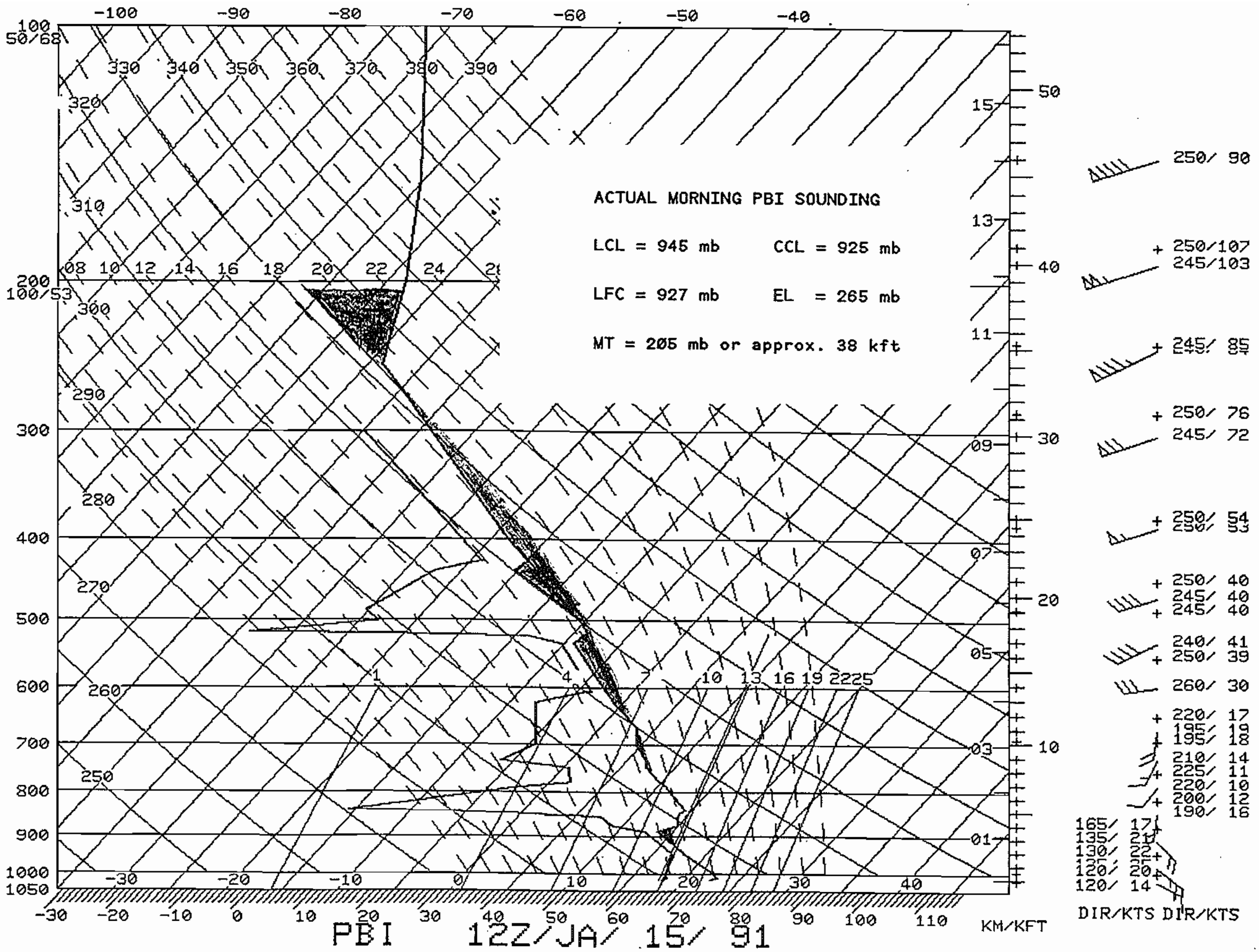


Figure 11. 1200 UTC West Palm Beach sounding, 15 January 1991, with estimated convective indices/parameters.

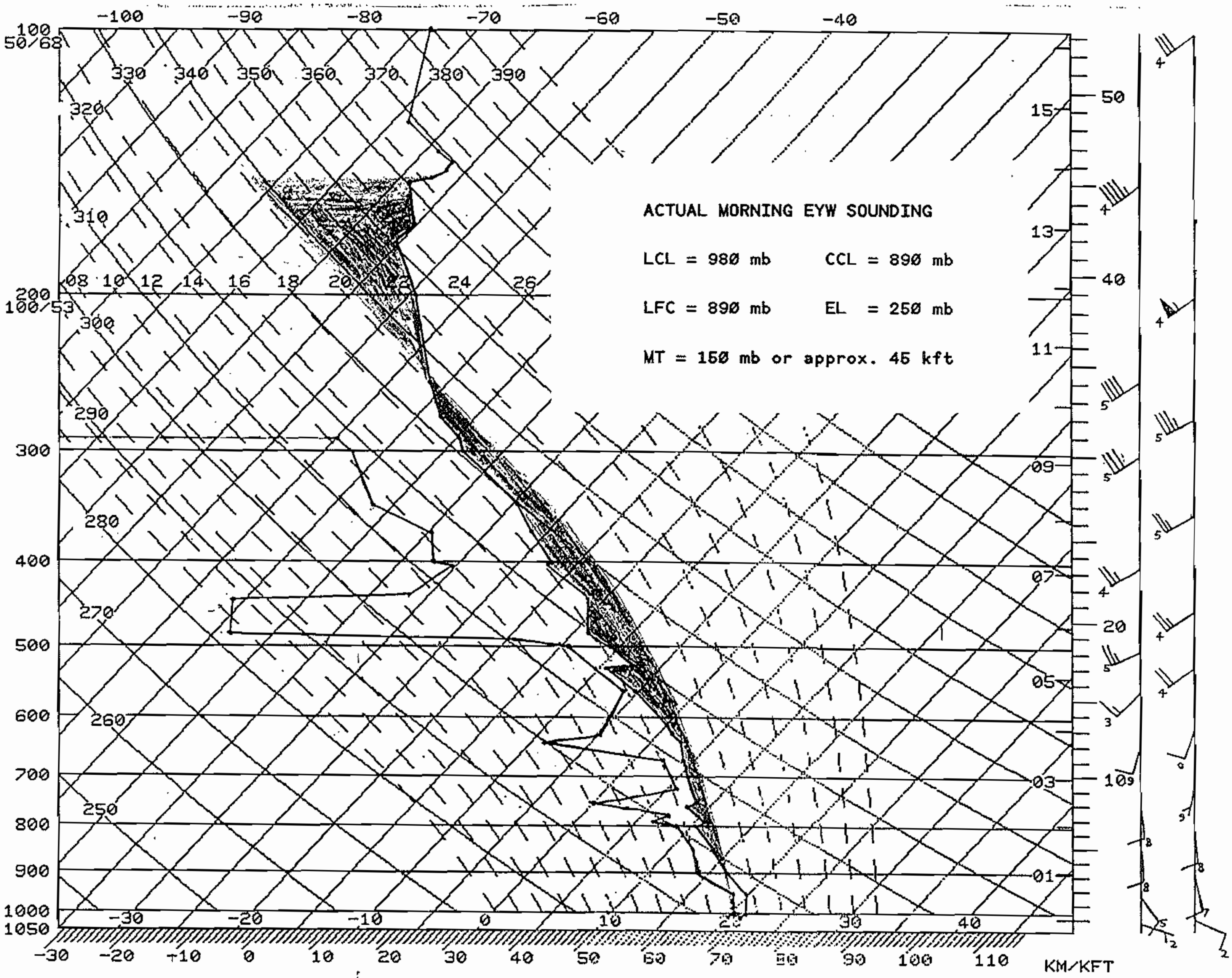


Figure 12. 1200 UTC Key West (EYW) sounding (hand plotted from raw data), with estimated convective indices/ parameters.

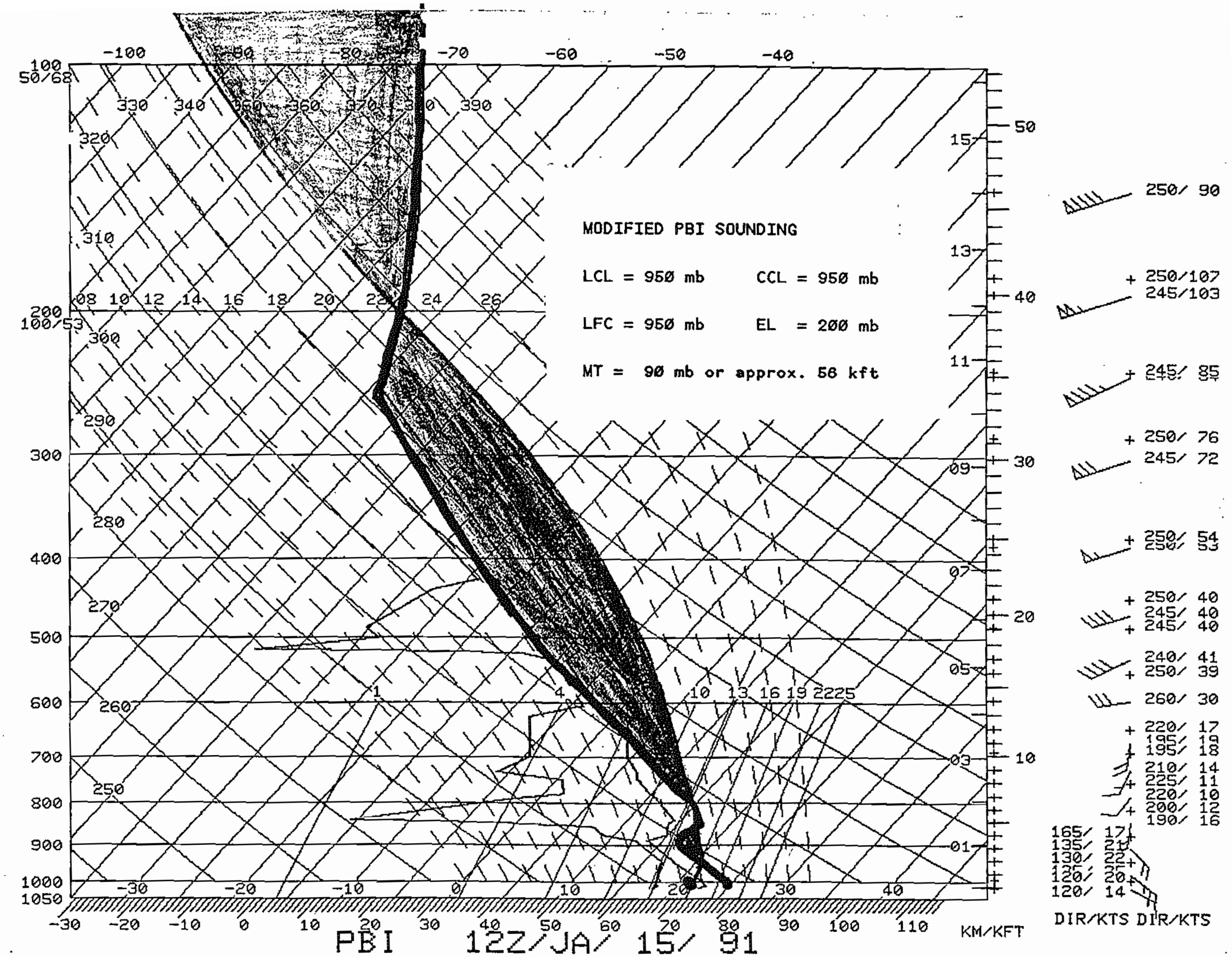


Figure 13. 1200 UTC West Palm Beach sounding, modified for actual afternoon surface conditions and probable storm environment aloft, with estimated convective indices/ parameters.

PBI 12Z 15 JAN 91

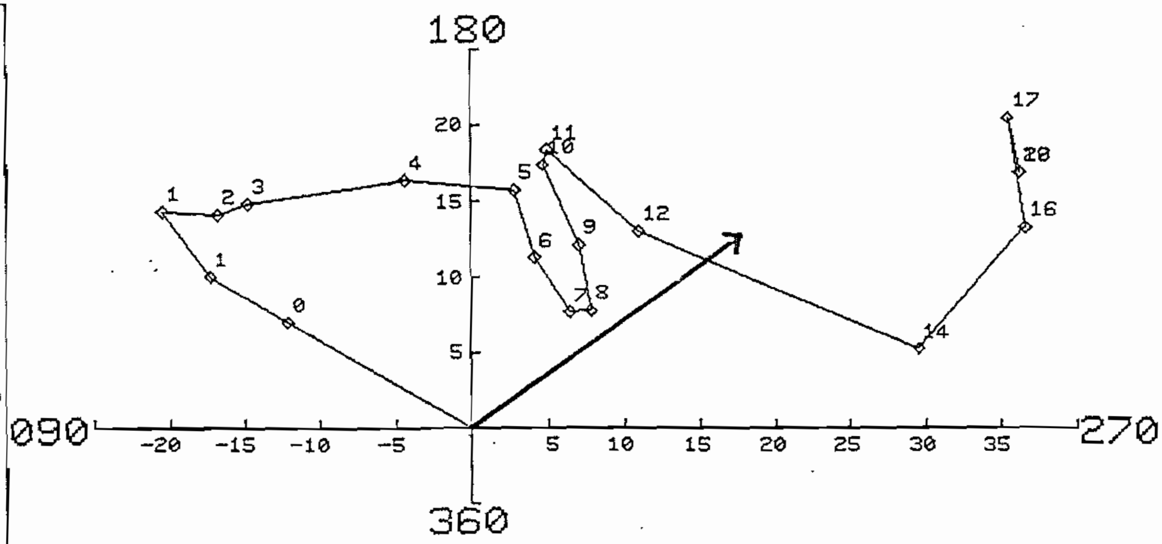
UNITS : KNOTS, LVLS : THSD FT (MSL)

```
B R N =      4
B+    =     41 (M/SEC)**2 X 10
B-    =     -4 (M/SEC)**2 X 10
SHR   =     93 (M/SEC)**2
WMAX  =     27  M/SEC
EL    =    265 MB,    340  HND FT
MPL   =    405 HND FT
VSS   =     13 (M/SEC)**2
SS15  =    116 10-4 SEC-1
```

```
PARCEL FROM PMAX
ENTRAINMENT = 60 PERCENT
P0     =   1017 MB
PMAX   =   1011 MB
LCL    =    945 MB
LFC    =    927 MB

EI     =     -9 J/KG X 10
EI+    =      4 (+ PART)
EI-    =    -13 (- PART)

ENERGY CHANGE IN LAYERS
P1      P2
1011    927       -1 J/KG X 10
 927    882        1
 882    619       -9
 619    527        2
 527    469       -3
 469    429        2
 429    100     -454
```




```
LI    =     -1
KI    =     18
SWI   =      8

CCL   =    925 MB
C TMP =     24 C,      75 F
WAVG  =    125 G/KG X 10-1
```

SFC ELV (FT) = 20   L = 19

Figure 14. Radar-observed storm motion vector superimposed on 1200 UTC West Palm Beach hodograph; convective indices given are for ground-relative morning conditions.

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STATE FORECAST DISCUSSION
NATIONAL WEATHER SERVICE MIAMI FL
400 AM EST TUE JAN 15 1991

FNT ACRS FL STRAITS SHUD MOV N TDA AS MAJOR LO PRES AREA DVLPS OVR
LWR MS VLY DURG NEXT 24 HRS. LOOKS LIKE ALL OF STATE WL EXPERIENCE
SHWRS AND TSTMS THRU WED. HIEST POPS WL SHIFT TO N AND CNTRL FL
TNGT AND WED AS WARM FNT MOVS THRU THOSE SECTIONS OF STATE AND
AHEAD OF ADVANCING CDFNT. THREAT OF SVR WX AND HVY RAINS WILL EXIST
ACRS N FL TNGT AND WED AS LI DROPS TO LESS THAN -4 AND STG LO LVL
JET PUMPS ABUNDANT GULF MSTR INTO THE AREA. WINDS WL BE INCRSG TDA
AND SCEC ALL SECTIONS OF CSTL. HOWEVER...THIS WILL HAVE TO BE UPPED
TO SCA TNGT AS WNDS AND SEAS CONT TO INCRS..

FL...NONE


STATE FORECAST DISCUSSION
NATIONAL WEATHER SERVICE MIAMI FL
400 PM EST TUE JAN 15 1991

NGM HAS BEEN THE BEST WITH THE WM FNT AND RDG AND WL CONT TO FLW
ITS CD FNTL PSNS ON THIS MRNGS 12Z RUN. ALTO IT DID NOT HAVE THE
VORT MAX TIMING OVR THE SRN PEN THIS MRNG AT LEAST IT HAD IT.
RMNTS OF WM FNT MOVG NWD OVR PEN TNGT AND THEN CD FNT WL MOV DOWN
THE PEN ON WED BCMG STNRY IN THE STRAITS THU. MOS TEMPS A LTL LO
TNGT IN THE NRN ZNS BECAUSE OF CLD CVR OTRW MOS POPS AND TEMPS
BASICALLY OK.

FL...SCA SAV TO AQQ THRU WED.
```

Figure 15. State forecast discussions (SFD) issued by WSFO MIA during 15 Jan 1991.