

PICTURE OF THE MONTH

Unusual Flow-Visualization in a South Florida Tornado

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1. Introduction

Tornadoes occur often over central and south Florida during the spring and summer months, as indicated by Golden (1971) and Tecson *et al.* (1979). Using tornado statistics derived from a data tape compiled by the University of Chicago for the years 1916–

78, Tecson *et al.* (1979) demonstrated that most of the Florida tornadoes are relatively weak (F0–F1, using the damage intensity scale as defined by Fujita, 1971, 1981). A few Florida tornadoes, particularly those in a belt across central Florida during the spring months, equal or exceed the F2–F3 intensity category. However, the frequency of such intense tor-

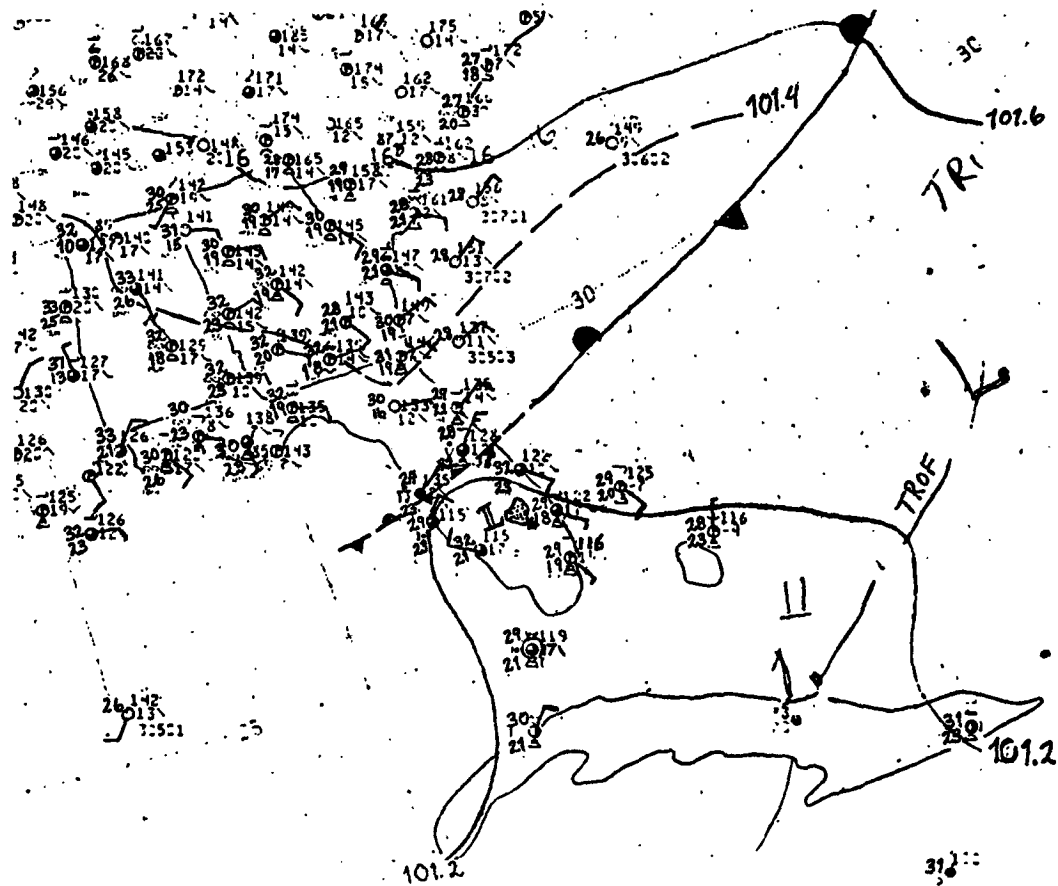


FIG. 1a. National Meteorological Center's analyzed surface synoptic chart, modified by author, with isobars and front over southeastern United States at 2100 GMT 11 September 1980. Tornado developed during preceding hour near southeast shore of Lake Okeechobee, marked by a star. Temperature/dewpoints plotted in °C.

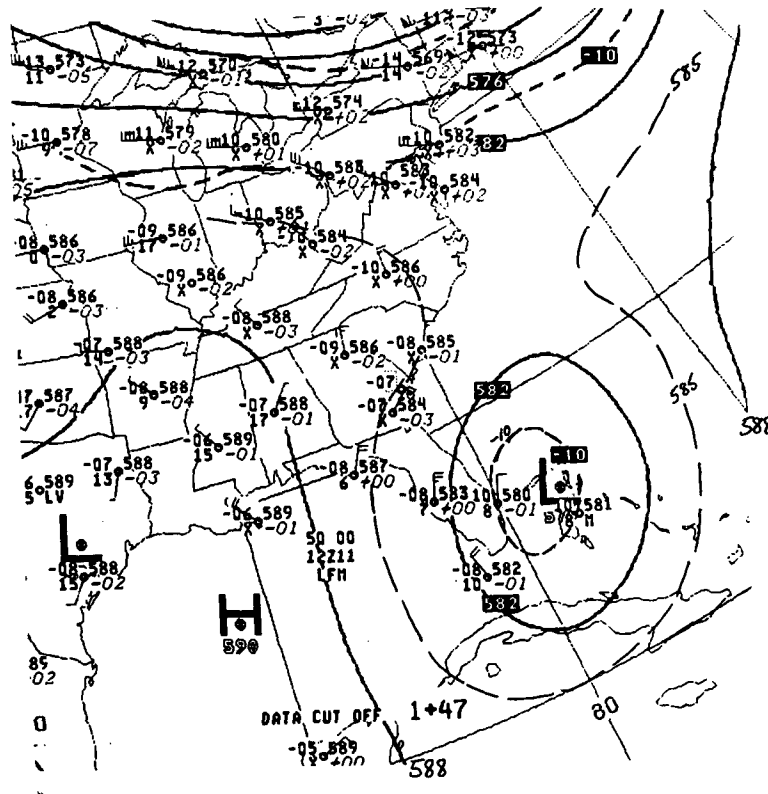


FIG. 1b. As in Fig. 1a, except 500 mb contour analysis (dcm) and isotherms (short dashes) for 1200 GMT 11 September 1980.

nadoes in Florida is usually much less than in the Midwest states. Golden (1971) documented five major tornadoes in the greater Miami area during 1968, and ascribed this anomalous number to the development of strong localized zones of convergence on the mesoscale. These convergence zones occurred along or slightly inland from the southeast Florida coast where the prevailing southwesterly tropospheric flow interacted with the sea breeze induced by the Florida peninsula.

There have also been numerous reports of funnel clouds over the Everglades west of Miami, in association with lines of cumulus congestus or cumulonimbus clouds (E. J. Zipser, 1970, private communication; Senn, 1978). R. L. Holle (1981, private communication) has noted that dozens of funnel clouds were observed during the 1971-80 summer Florida Area Cumulus Experiment (FACE) programs over the Everglades. These funnel-active cloudlines are, in turn, closely related to the well-documented double sea-breeze mechanism that dominates the Florida peninsula on the mesoscale during summer months. We present here some rather unique photographs of a tornado which occurred in the Everglades, near the southeast shore of Lake Okeechobee, on 11 September 1980.

2. Synoptic situation

The afternoon surface and morning 500 mb analyzed synoptic charts for the day of the tornado event are shown in Figs. 1a and b, respectively. We note that a diffuse surface cold front had moved into central Florida during the preceding afternoon and night, and was becoming stationary. Near the time of the tornado there was still significant cyclonic windshear across the front, and an apparent mesocyclonic circulation had developed over south Florida (Fig. 1a). A 1011 mb surface low pressure area with a weak cyclonic circulation was located in the Bahamas and was associated with an upper cut-off low at 500 mb, located just east of Palm Beach. The flow pattern at 500 mb was such that a strong short-wave trough was passing off the East Coast of the United States at higher latitudes, leaving behind a trough just off the southeast coast, with the aforementioned cut-off low just east of south Florida (Fig. 1b). This was *not* a synoptic situation where one might expect to find, based on conditions apparent from the morning data, a significant likelihood of tornadic thunderstorms later in the day over south Florida (Golden, 1971). The general pattern was similar in some respects to the benign large-scale setting found by Holle and

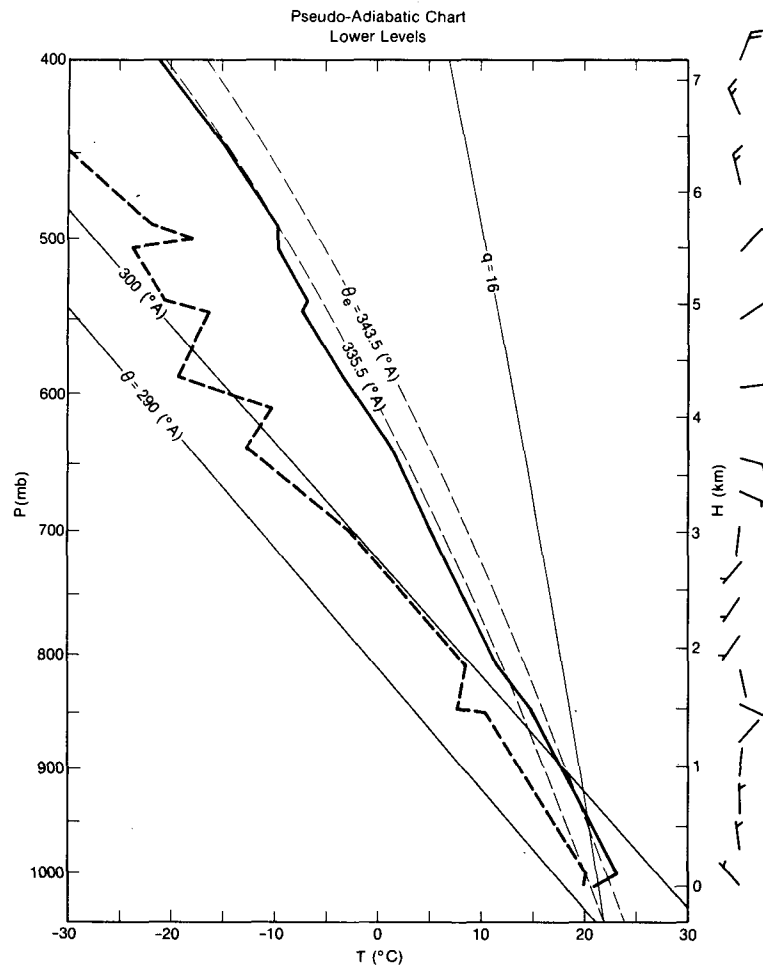


FIG. 2. Plotted sounding and wind profile (KTS) for West Palm Beach, FL, at 1200 GMT 11 September 1980 up to 400 mb.

Maier (1980) prior to a small tornado in the FACE mesonet network.

It is becoming apparent that mesoscale forcing, such as the downdraft interaction from two pre-existing cumulonimbi discussed by Holle and Maier (1980), is crucial to the tornado forecast problem over south Florida. The sounding taken at West Palm Beach on the morning of the tornado ~ 6 – 8 h before the event (Fig. 2), confirms the benign nature of the day. The atmosphere was moist, especially below ~ 700 mb, and was convectively unstable below 800 mb as well. The lifted index computed from the sounding was -4 . A sequence of five GOES satellite photographs, taken during 1800–2030 GMT on 11 September 1980 is shown in Fig. 3. Eyewitness accounts indicate that the tornado development occurred beneath a short, dark-based line of cumulus congestus clouds near the southeast shore of Lake Okeechobee between 1830 and 1930 GMT. Note especially the apparent explosive growth of cloud tops and north–south anvil development in this area in

the last two satellite pictures in the Fig. 3 sequence. Golden (1974) noted a similar distinct preference for rapid vertical cloud growth in a portion of congestus cloudiness in the Florida Keys which subsequently spawned waterspouts. The winds aloft on the Palm Beach sounding (Fig. 2) were light and variable, though generally backing with height up to 5 km, and northerly 5 – 10 m s^{-1} above 5 km.

3. Unusual tornado features

During the early afternoon of 11 September 1980, an arc of cumulus congestus clouds developed rapidly near the southeast shore of Lake Okeechobee. At approximately 1830 GMT, Mr. Herb Schall, the manager of Palm Beach County Glades Airport, one mile south of Pahokee, began taking a series of 22 photographs of a developing vortex southeast of the airport. Four of these photographs which best illustrate the tornado's approximate 10-minute lifetime are shown in Figs. 4a–d. Note in Fig. 4a that the cumulus

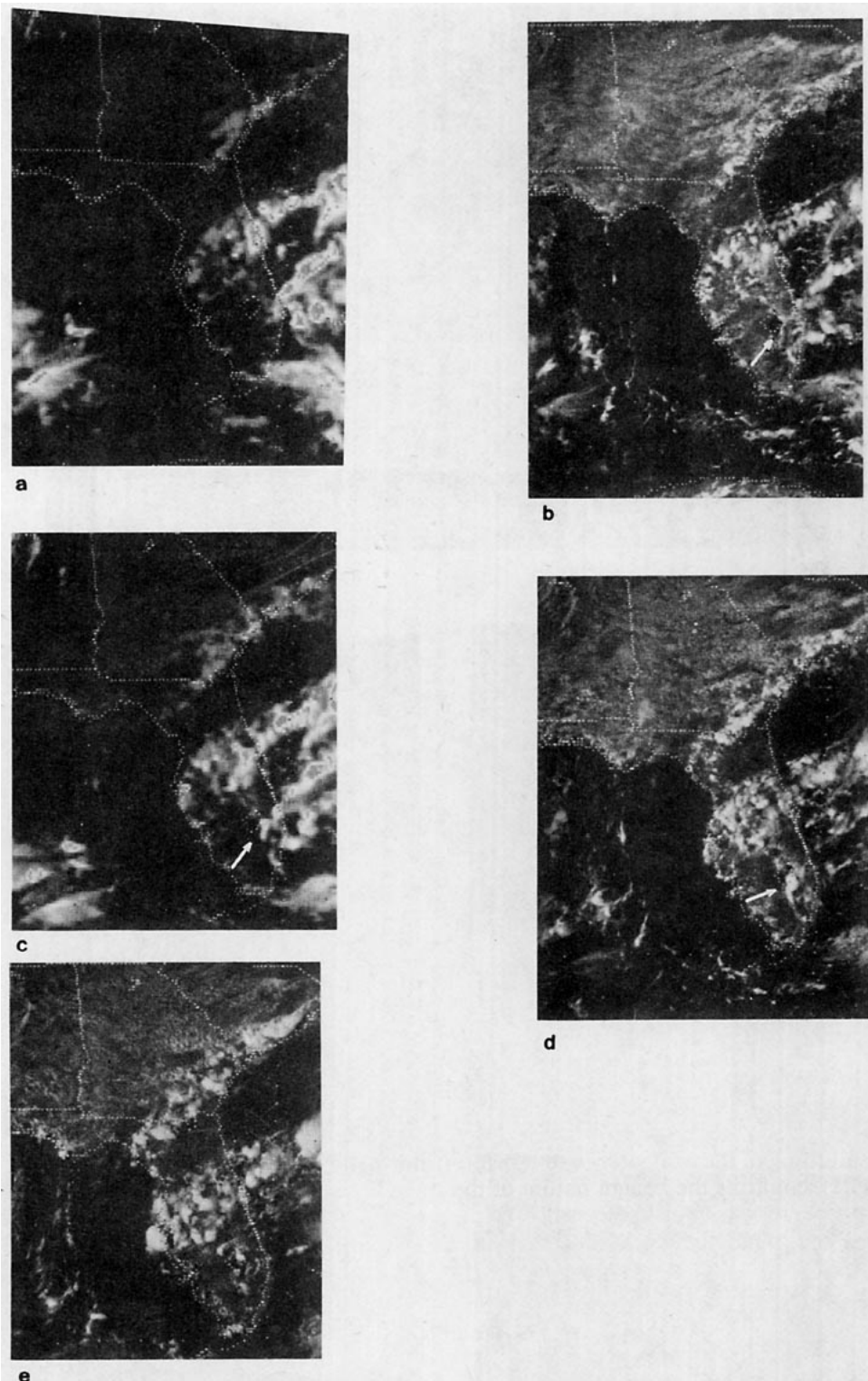


FIG. 3. Sequence of SMS Geosynchronous satellite photos, from 1800–2031 GMT 11 September 1980 over Florida: (a) enhanced IR, 1800 GMT, (b) visible, 1830 GMT, (c) enhanced IR, 1900 GMT, (d) visible, 1930 GMT, (e) visible, 2030 GMT. Note ENE–WSW oriented cloudbands over central Florida associated with diffuse front in that area. Tornado development occurred between 1830 and 1930 GMT. See text for details.

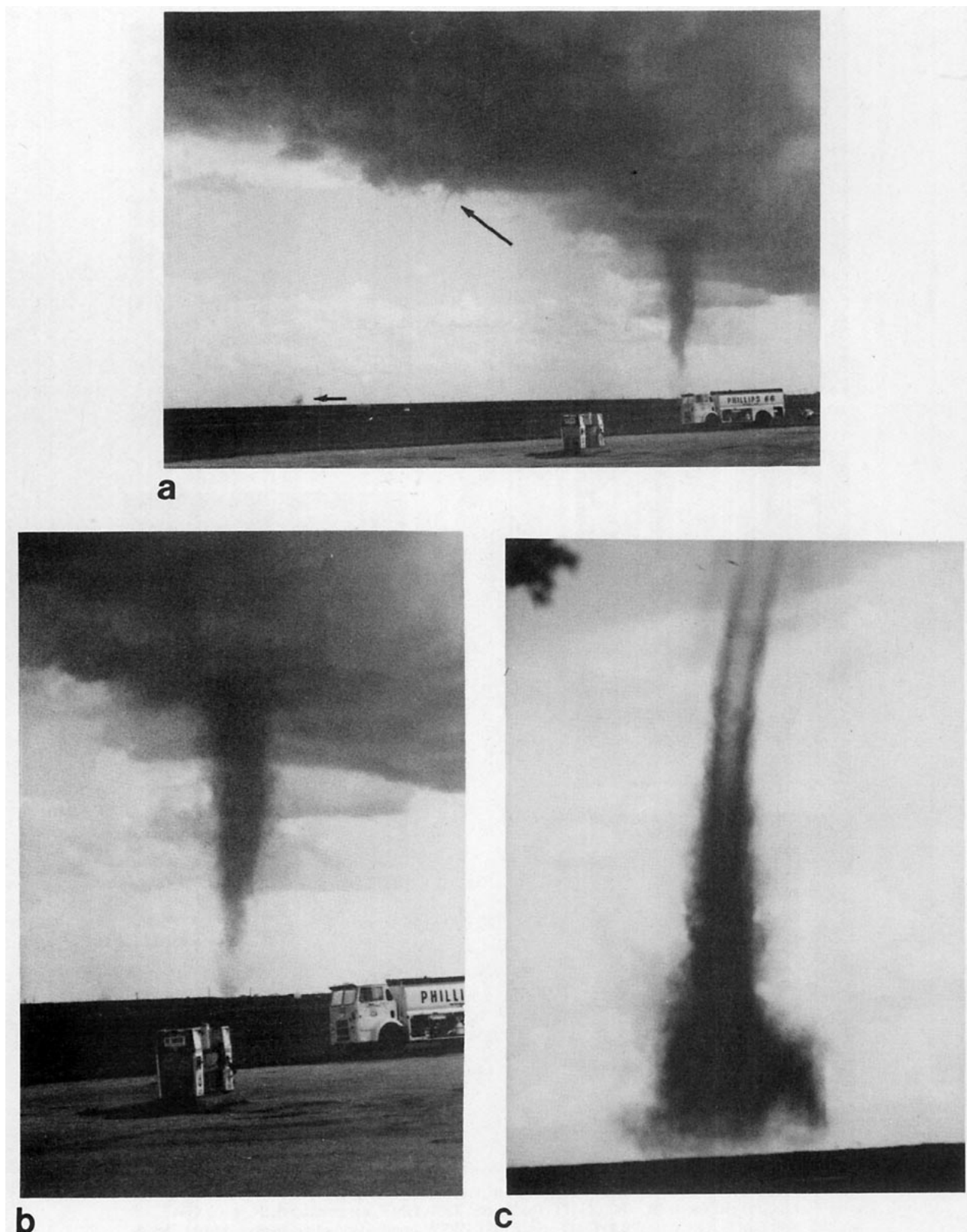


FIG. 4. Sequence of tornado photographs taken by eyewitness from Palm Beach County Glades Airport, looking east-southeast. Total elapsed time 10–15 min. See text for discussion.



FIG. 4. (Continued)

congestus cloudline appears to be oriented NW-SE, and the intensifying tornado was estimated to be ~ 2 km away. Fig. 4b, taken a few minutes after 4a, indicates that the tornado was moving slowly toward the north and had only a weak debris cloud apparent during its early stages. It is also somewhat surprising to note the flat, suppressed cumulus in the background of Figs. 4a, b. We interpret the weak vortex debris cloud in Figs. 4a, b to be due to the fact that the tornado was slowly intensifying, and was apparently initially moving over a recently-harvested sugarcane field. In Fig. 4a a second tornado is indicated (by arrows) to the left of the first—note the contorted, short funnel at cloudbase and the debris cloud below

it near the horizon. Fig. 4b shows that the larger, translucent funnel has extended nearly to the ground. Maximum funnel diameter was estimated by photogrammetry to be ~ 120 m. A faintly visible debris cloud is present near the surface in both Figs. 4a, b and rises in a turbulent envelope exterior to the funnel in Fig. 4b to considerable heights.

The latter two photographs in the series, Figs. 4c, d were taken several minutes after the first two, and show a remarkable transformation. The change in vortex structure is attributed to dynamical differences, i.e., vortex intensification, and also to the fact that the tornado had moved northward from the unharvested sugarcane fields to open muck fields where it picked up greater concentrations of solid debris particles. This latter effect accounts for the much darker debris cloud in Fig. 4c, which has spiralled cyclonically upward. It is hypothesized that the only condensation funnel visible in Fig. 4c is the hollow shell near the top of the photograph where, in fact, a double-walled funnel is apparent on the original photograph. The most spectacular photograph of the sequence, Fig. 4d, is a mosaic in the vertical. It shows that the lower debris cloud was much lighter, and the mid-section of the tornado was characterized by debris streamers rising in a pronounced cyclonic helix. The upper portion of the funnel again had a double-walled structure with undulations on both funnel walls. The flow structure inferred from this photograph greatly resembles the three-dimensional conceptual flow model for the dark-spot stage of waterspouts synthesized by Golden (1974) from vortex-entrained marine smoke flare plumes. This type of vortex flow visualization also agrees well with a series of dust-devil measurements by Sinclair (1973) in the lowest 10 m above the ground, and flow observed qualitatively by Reinking (1978) in steam devils over a hot springs pool.

In closing, it should be noted that tornadoes and waterspouts are frequently observed in this particular area of south Florida. Watson *et al.* (1981) have pointed out from data taken from the FACE mesonet, in an area just south of Lake Okeechobee, that there is a strong tendency for an area of mesoscale convergence to develop along the southeast shore of the lake where the prevailing SE flow interacts with the weak lake breeze. Values of convergence ranging upward to $\sim 10^{-3} \text{ s}^{-1}$ have been observed. It is hypothesized that this is an important factor contributing to the high incidence of convective vortices (i.e., funnel clouds) in this locale. These photographs also illustrate rapid variation of a tornado's appearance during its lifetime, depending on both the vortex dynamics and surface characteristics (for the debris cloud).

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