Continentality of the South Florida Summertime CCN Aerosol

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ABSTRACT

Measurements of cloud condensation nuclei (CCN) were obtained in the south Florida region as part of NOAA's Florida Area Cumulus Experiment (FACE). During the summer of 1975, CCN measurements were obtained near the bases of cumulus clouds by means of an airborne static diffusion chamber operating at 0.75% supersaturation. Concentrations were highly variable across the peninsula. The change in concentration from low values over the water to very high concentrations over land surfaces was abrupt.

A continuous surface-based CCN monitoring program was carried out during the summer of 1976 with two continuous flow diffusion chambers, operating at 0.4 and 1.0% supersaturation. These confirmed the continental (high CCN) characteristics of the surface aerosol (overall mean 718 cm^{-3} at 0.4% and 1644 cm^{-3} at 1.0%). The concentration of CCN was found to vary as a function of wind speed, wind direction, and time of day. Analysis of these data suggested that the concentration of CCN was modulated by short-term localized influences superimposed on the longer term air mass characteristics. Further stratification using low-level trajectories to separate air masses of recent maritime and continental exposures resulted in a mean concentration of 543 and 1291 cm^{-3} at 0.4 and 1.0% supersaturation, respectively, for the maritime CCN data, and a mean concentration of 1149 and 2049 cm^{-3} at the respective supersaturations for the continental CCN data.

The picture that emerges is consistent with the view of local production mechanisms (probably photochemical), sometimes superimposed on larger scale advection of aged aerosol.

1. Introduction

The number density and ultimately the size distribution of droplets in the lower regions of cumulus clouds depends in the first instance on the activity spectra of cloud condensation nuclei (CCN) entering their bases (Twomey and Squires, 1959; Jiusto, 1966; Twomey and Warner, 1967; Warner, 1969; and Fitzgerald and Spyers-Duran, 1973). It has been known that the rate and efficiency of the coalescence and accretion precipitation mechanisms are dependent in large part on the drop-size spectrum evolved from the condensation process. Recent work (Hallett *et al.*, 1978) suggests that the glaciating behavior of convective clouds is linked to the manner in which the cloud drop-size distribution evolves. A characterization of the CCN activity spectrum in the air mass within which the cloud population is developing can be important, therefore, from the point of view not only of describing adequately the formation of the cloud droplet distribution but also of aiding in the prediction of the time window during which such clouds are likely to retain water in a supercooled state prior to glaciating.

Twomey (1959) provided a "classical" description of the activity spectra of CCN as a function of various air trajectories affecting southeastern Australia and showed that continentally influenced air masses contained about an order of magnitude more CCN active in the supersaturation range 0.5–1.0% than did air arriving with long trajectories over open ocean. At 1% supersaturation, for example, maritime air was found to contain CCN in concentrations of 100 cm^{-3}, while continental air contained CCN concentrations approaching 1000 cm^{-3}. Under drought conditions, CCN concentrations in continental air masses approaching 10 000 cm^{-3} active at 1% supersaturation were measured. Good agreement was found between the CCN measurements and simultaneous measurements of cloud-droplet concentrations near cloud base.

The Australian measurements showing maritime-continental order of magnitude differences in CCN concentration have been found to be, in the *mean*, representative of many regions of the world (Twomey and Wojciechowski, 1969; Hoppel, 1979; Hudson, 1980). However some cloud-base level CCN meas-

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urements made in South Florida indicated a rather pronounced variability in concentration which was attributed to northerly (continental) and southerly (maritime) boundary-layer circulation differences.[2] In the northerly flow case, cloud-base CCN concentrations (at 0.75% supersaturation) exceeding 1000 cm^{-3} were observed compared to 500 cm^{-3} in the southerly flow stratification. Most of their data (about 70% of the observations) were obtained during periods of southerly flow. These observations of so-called "modified maritime" subcloud layer CCN concentrations typically of 500 cm^{-3} formed the basis of an initialization scheme used in the EML one-dimensional cumulus model (Simpson and Wiggert, 1971).

Other CCN activity spectra obtained in the south Florida area, both offshore over the ocean and onshore over the peninsula near Miami near a supersaturation of 1% showed a spread of CCN concentration between 150 and 500 cm^{-3} over the ocean and between 300 and 1300 cm^{-3} over the land.[3] A least-squares fit of the equation

$$N = cS^k \qquad (1)$$

to the CCN activity spectra obtained by Fitzgerald showed far less variability in the data collected over the ocean. The k parameter (slope of the spectrum of a log-log plot) for both sets of data was close to 0.5, a value compatible with the median found from a number of worldwide observations in maritime conditions (Twomey and Wojciechowski, 1969).

The present studies were initiated as part of NOAA's Florida Area Cumulus Experiment (FACE) during the 1975 field season to determine the nature of the CCN content at the cloud base level within the project target area (Fig. 1). The specific objectives of the initial field season of study were 1) to determine the spatial homogeneity of the concentration of CCN within the FACE target area, 2) to verify the appropriateness of using a "modified maritime" CCN concentration as input to numerical studies of south Florida convection, and 3) to delineate changes in the CCN activity spectra as a function of air mass trajectory. Indications of rather high (continental) concentrations of CCN during occasions of distinctly maritime airflow trajectories prompted a more detailed CCN investigation as part of the FACE 76 field season. The objective of the second field season was to delineate temporal variability of the CCN activity spectrum as deduced from two supersaturation levels.

2. Methodology

As part of the FACE 75 field program, the NOAA DC-6 aircraft was equipped with a static thermal diffusion chamber[4] which was operated at a supersaturation of 0.75%. The aircraft was flown at the cloud-base level on an east to west traverse across the peninsula at latitude 26°30′N, starting from a point ~ 50 km offshore the east coast and terminating at a point ~ 50 km offshore the west coast (Fig. 1). The cross-peninsula flights were conducted at about the same time (1630–1730 GMT) on each of 13 experimental days during the month of July. CCN data points were obtained at a sampling rate of once every three minutes, corresponding to a spatial interval of ~18 km along the flight track.

As part of the FACE 76 field program, a fixed site located at Immokalee airport in the western portion of the FACE target area (see Fig. 1) was instrumented for the recording of aerosol information within the surface (6 m) layer. This airport receives almost no traffic during the summer. Two nearly identical continuous flow diffusion (CFD) chambers described by Hudson and Squires (1976) were mounted in the Desert Research Institute (DRI) field trailer. The sampling procedure was quite similar to that employed for an earlier surface CCN sampling program in Nevada and California using the same trailer and cloud chambers (Hudson and Squires, 1978). However, in this case, the two chambers drew sample air from the same level (~3 m above ground) and operated at different supersaturations. As in the earlier work, a high volume of air was drawn into the trailer through a 3 cm diameter tube from which very small volumes were drawn to each chamber. For almost all of the work described here, each chamber used a sample flow rate of 0.30 $cm^3\ s^{-1}$. Thus, the larger volume flow was used only to minimize diffusion losses between the sampling point and the cloud chamber. On several occasions during the measurement period, the two chambers were set at identical supersaturations (usually 1%) and were found to yield CCN concentrations in agreement to within 5%. The chambers were operated at 1 and 0.4% supersaturation, a range suitable to include the probable maximum supersaturation achieved in convective clouds of south Florida in the summertime.

Drop-size distributions from the cloud chambers, as described by Hudson and Squires (1973), were

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[2] Dinger, J. E., and R. E. Ruskin, 1970: On the source of cloud nuclei. *Preprints Conf. on Cloud Physics*, Fort Collins, Amer. Meteor. Soc., 155–156.

[3] Fitzgerald, J. W., 1972: A study of the initial phase of cloud droplet growth by condensation: Comparison between theory and observation. Ph.D. dissertation, The University of Chicago [Published as Tech. Note 44, Cloud Physics Laboratory, University of Chicago, June, 1972.].

[4] Allee, P., R. I. Sax and E. Delgado, 1976: Distribution and interrelationship of CCN, IN, and Aitken aerosol over selected oceanic and continental sites. *Preprints Int. Conf. Cloud Physics*, Boulder, Amer. Meteor. Soc., 2–8.

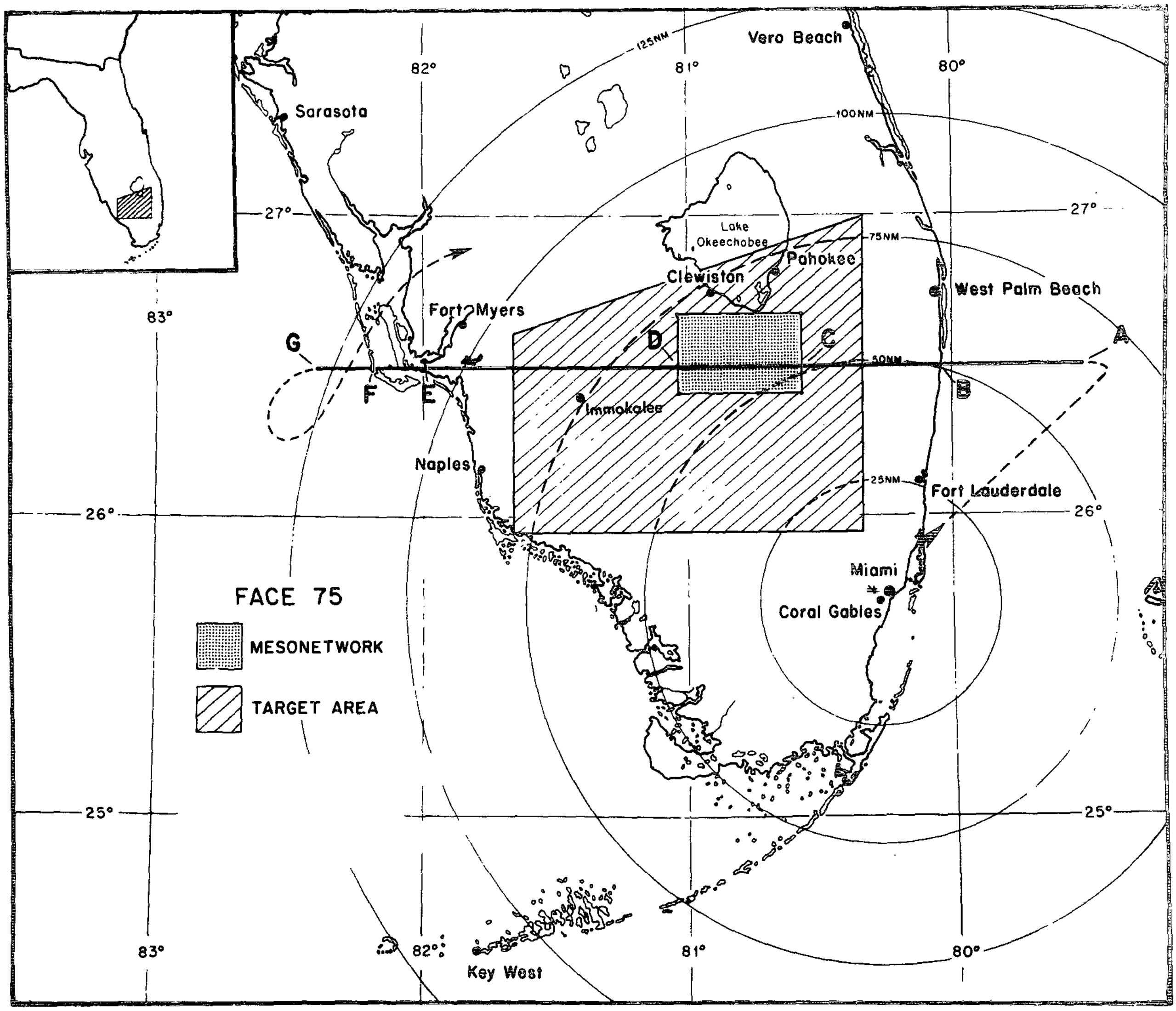

FIG. 1. FACE target area with DC-6 flight track for cloud-base CCN study (FACE 75) superimposed.

constantly monitored to ensure that all activated drops were being counted. Furthermore, frequent checks also were made to ensure that the sample had spent the proper amount of time in the supersaturated volume within the cloud chamber so that all potentially active nuclei had sufficient time to grow to measurable drop sizes without falling to the floor of the chamber. The chambers were operated in the vertical plate mode for reasons of convenience and accuracy (Hudson and Squires, 1976).

The two chambers operated continuously from 4 August–7 September. During the 3-week period 15 August–7 September, the standard meteorological variables, wind, temperature and humidity were recorded together with the CCN concentration data at a sampling rate of once every 10 s and were stored in a computer-compatible format on cassette tape.

3. FACE 75—results and interpretation

Overall results from the FACE 75 aerosol program showed highly variable concentrations of CCN (at $S = 0.75\%$) across the south Florida peninsula at the cloud-base level, with the concentrations ranging from 250 to 2500 cm^{-3}.[4] As an illustration of the variable nature of the CCN concentration data, two case studies are presented. Fig. 2 shows CCN and other aerosol and meteorological data acquired during the cross-peninsula traverse on 20 July. A similar set of data acquired the following day (21 July) is shown in Fig. 3. The dashed curve in the upper panel of each figure is a point-to-point interpolation of the individual CCN data points (labeled C). The Aitken aerosol data (top panels) as well as the air temperature meteorological data (bottom

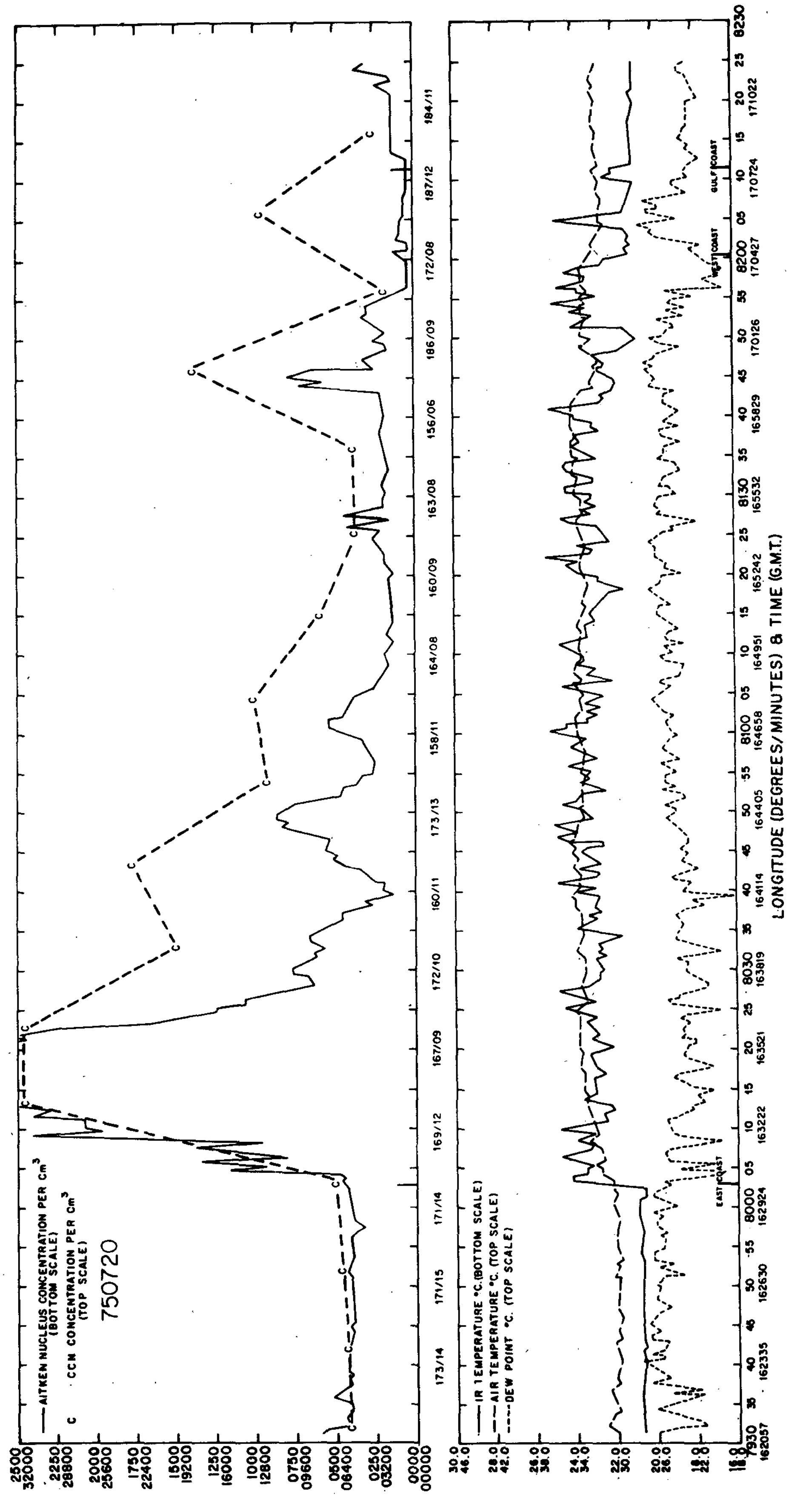

FIG. 2. Cross-peninsula profile of aerosol and meteorological data acquired at the cloud base level on 20 July 1975.

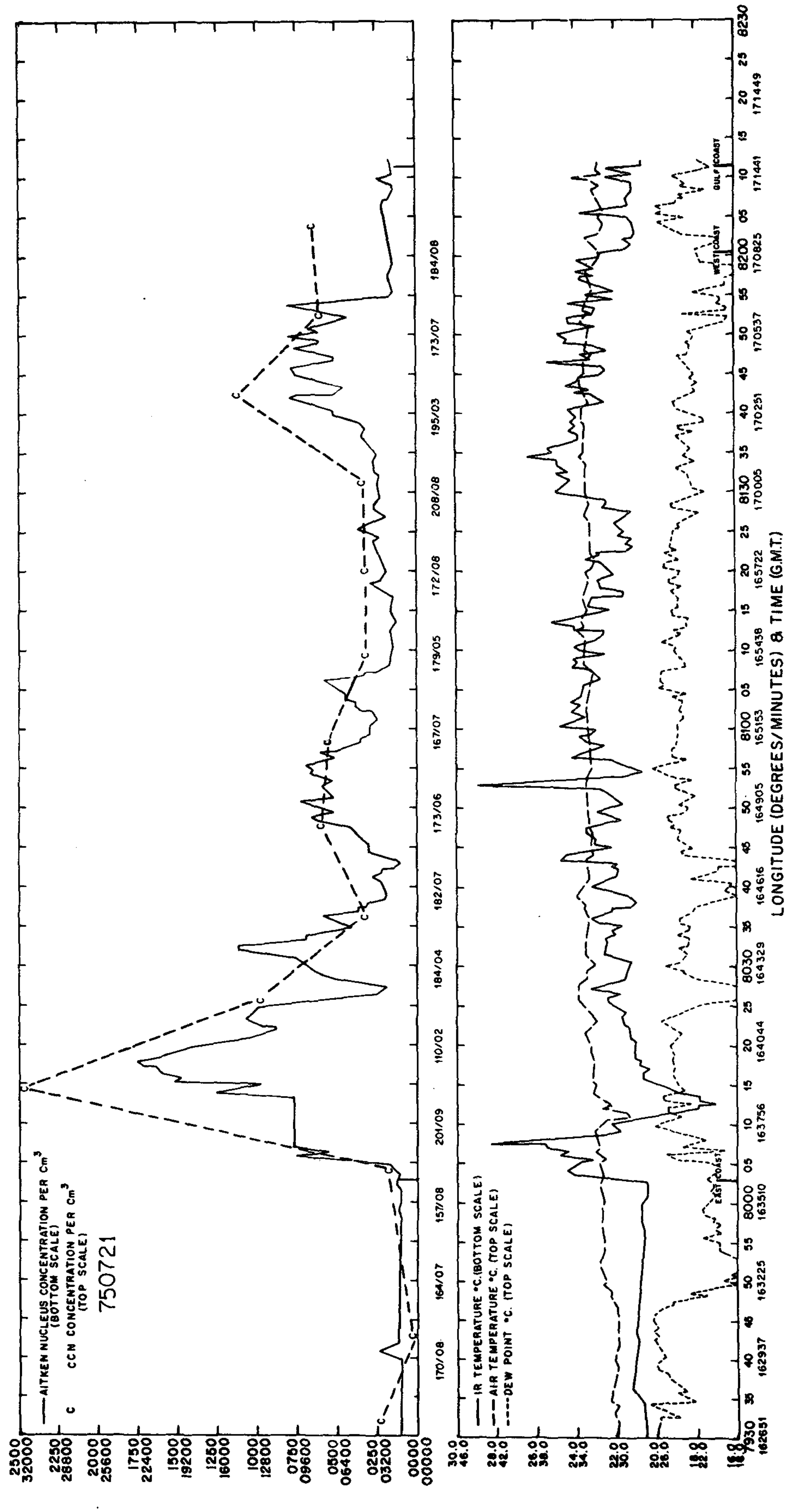

FIG. 3. As in Fig. 2 except on 21 July 1975.

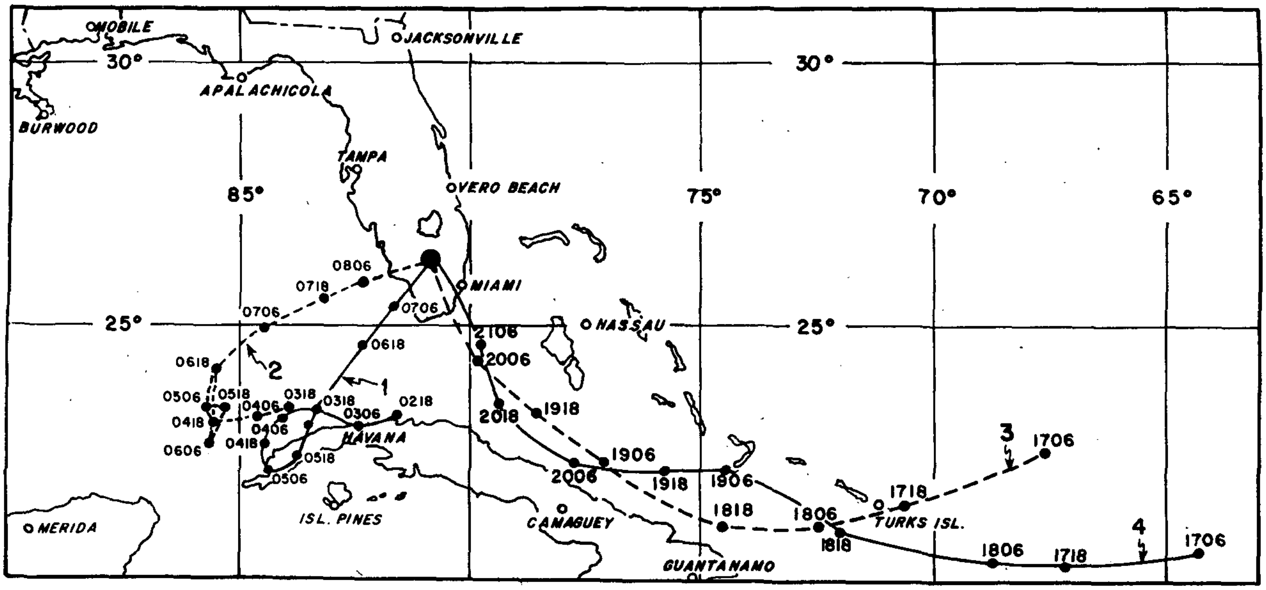

FIG. 4. Low-level air mass trajectories (5-day) terminating in the center of the FACE target area at 1800 GMT on 7, 8, 20, and 21 July 1975.

panels) are presented but will not be discussed in detail here. The flight-level (0.6 km) winds are presented in direction/speed (kt) format between the two panels in each figure.

The flight-level winds were mainly southeasterly across the peninsula on both the 20th and 21st, although they were stronger on the 20th. The CCN concentrations offshore the east coast on the 20th (Fig. 2) are consistently ~500 cm^{-3}, but increase dramatically to more than 2000 cm^{-3} just inland. The CCN concentration remains high (>1000 cm^{-3}) until the center of the peninsula and then drops to a level of ~500 cm^{-3} in the western portion of the traverse. These CCN concentrations are consistent with the concept of a continental character. Changes in the concentration of Aitken nuclei appear well correlated with changes in CCN on the east coast and again near longitude 81°45′W.

The traverse on the 21st (Fig. 3) shows far fewer CCN, with upwind offshore concentrations depressed to 200 cm^{-3} and, except for a narrow east coast peak of 2500 cm^{-3}, concentrations over most of the peninsula reduced to about 500 cm^{-3} before increasing briefly to 1000 cm^{-3} near the west coast. These CCN concentration data are consistent with the concept of a "modified maritime" character. The concentration of Aitken nuclei also is less on the 21st, and changes in the concentration of both types of aerosols appear generally well correlated with each other throughout the traverse.

Although the concentration profile of CCN across the peninsula differs in magnitude from the 20th to the 21st, the airflow trajectories for both days are essentially alike. Fig. 4 shows low-level (0–1500 m) 5-day trajectories, as computed from a block-layer transport model[5] for the air which arrived at the center of the FACE target area at 1800 GMT on both the 20th and 21st (curves labeled 3 and 4, respectively). It can be seen that the 5-day airflow is unquestionably maritime Atlantic. This can be contrasted with some trajectories earlier in the month (curves 1 and 2) which indicate a much shorter airflow from the Gulf. Documentation of the appreciably different cross-peninsula profiles of CCN concentration from one day to the next with no apparent significant change in air trajectory was one of the principal findings of the FACE 75 aerosol program and provided the impetus for a further detailed investigation of CCN daily variability during FACE 76. In general, the findings from the FACE 75 program did not support the concept of a homogeneous, modified maritime CCN aerosol entrenched over a broad area of south Florida for many days at a time. Instead, the CCN concentration at the cloud-base level was found to be highly variable in both space and time and exhibited, on occasion, characteristics similar to those expected within interior regions of continents. The peninsula itself appeared to exert overwhelming influences in rapidly modifying the CCN characteristics associated with an onshore flow of maritime air. The highest concentrations of CCN were consistently measured along the east coastal region and appeared well correlated with high con-

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[5] Heffter, J. L., and D. A. Taylor, 1975: A regional continental scale transport, diffusion and deposition model. Part I: Trajectory model. NOAA Tech. Memo ERL ARL-50, Air Resources Lab., Silver Spring, MD, 1–16.

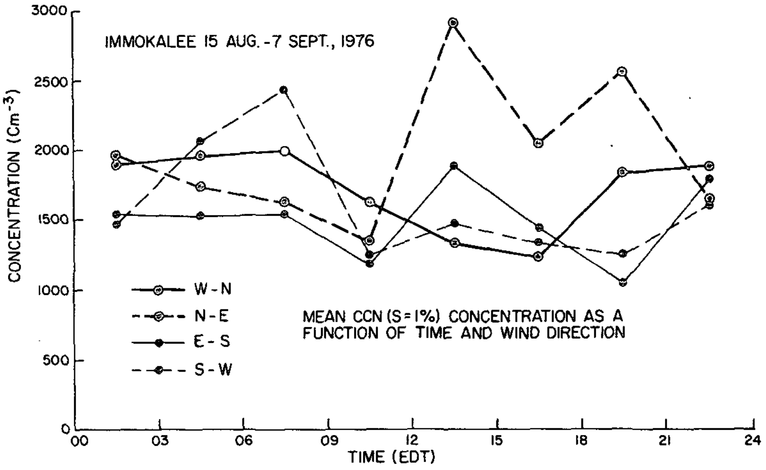

FIG. 5. Mean concentration of CCN active at 1% supersaturation as a function of time and wind direction at the surface at Immokalee, 15 August through 7 September 1976.

centrations of Aitken particles, likely of anthropogenic origin.

4. FACE 76—results and interpretation

The mean CCN concentration at $S = 1\%$ and $S = 0.4\%$, respectively, as a function of time and wind direction for the 15 August–7 September sampling period at the Immokalee surface site is shown in Figs. 5 and 6. Fig. 6 includes a mean daily profile of k [see Eq. (1)]. The data for all days were divided into three-hour time periods and four different wind directions. Each point on these graphs represents a mean of thousands of individual samples. Several features become immediately obvious from an inspection of these two figures: 1) the mean concentration of CCN active at $S = 0.4\%$ is always greater than ~500 cm^{-3} irrespective of surface wind flow, while the mean concentration of CCN active at $S = 1\%$ always exceeds 1000 cm^{-3} (and in most instances exceeds 1500 cm^{-3}) irrespective of surface wind flow; 2) the mean value of the k parameter is ~0.9 for all wind directions; 3) the greatest variability in mean CCN concentration as a function of time of day at both supersaturations occurs with winds in the quadrant north through east, while the mean k parameter shows little time of day variability for any wind direction; 4) the most extreme value of CCN concentration at both supersaturations occurs during the afternoon hours (1200–1800 LT), with the intraday variability more pronounced at $S = 1\%$ than at $S = 0.4\%$; and 5) average CCN concentrations at $S = 0.4\%$ are close to the mean in the early morning (0000–0600 LT) hours for all wind directions, and throughout the entire day for all wind directions except the north through east quadrant.

The daily fluctuations of CCN at 1% supersaturation in most cases show something of a double peak at about 0700 and 1300 EDT, with a minimum in the late morning hours. This would be consistent with an explanation that photochemical production of small particles is responsible for the CCN. The relatively high concentration at night and early in the morning may be due to the compression of the mixed layer where most of the particles are confined. The late-morning minima could then be caused by the expansion of the mixed layer which dilutes the concentration before photoproduction effectively starts to generate new particles. Since some coagulation of the newly produced particles is probably required for CCN production, the time lag between the lifting of the mixed layer and detection of newly formed CCN is accentuated.

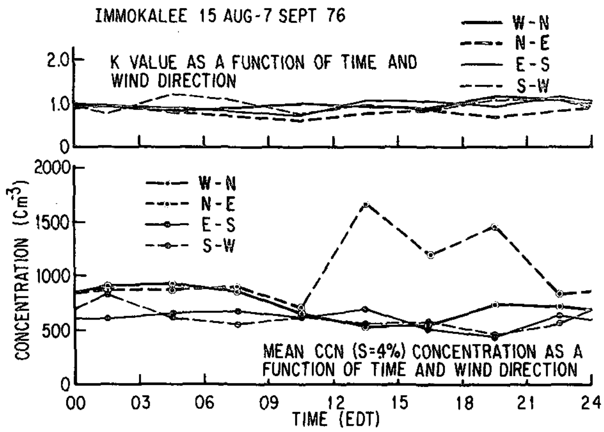

FIG. 6. Mean concentration of CCN active at 0.4% and associated mean values of k parameter as a function of time and wind direction at the surface at Immokalee, 15 August–7 September 1976.

The high afternoon concentrations in northeast winds may be due to advection of aged continental air. Advection from distant sources would be most noticeable in stronger winds typical of the afternoon. This is especially noticeable at 0.4% and is to be expected since larger particles would be most likely from distant sources where coagulation has had the most time to operate.

The greater variability in the concentration of smaller particles (active at 1% supersaturation) is to be expected since the smaller particles are probably more closely associated with direct particle production whereas the larger particles active at 0.4% supersaturation are, to a greater extent, the result of coagulation processes.

The total CCN data set for the entire sampling period has been further subdivided in Tables 1 (light winds) and 2 (strong winds), where matrices are presented as a function of wind direction (four quadrants) and time of day (6 h increments). Within each matrix the maximum, mean, and standard deviation values of CCN concentration at the two supersaturations (0.4% and 1.0%) and k parameter are presented along with the sample size (N).

Overall, the CCN concentrations are only slightly higher in light winds while the overall k is the same (0.9) with either wind-speed stratification. In the northeast quadrant, concentrations in strong winds actually exceed those in light winds by nearly a factor of 2 for both supersaturations. Moreover, k has its lowest mean value in strong northeast winds (0.6). These results reflect incursions of aged continental air which, as has already been discussed, would be more prominent in stronger winds and would also show a flatter particle spectrum (lower k) due to the effects of coagulation. For northeast winds, the concentration ratio (strong-to-light winds), in fact, is highest in the afternoon. The lowest mean value of $k(0.4)$ is seen in strong northeast winds in the evening which again is consistent with advection of aged continental air because maximum impact would be expected by that time of day.

In the morning and evening, concentrations in light winds are 30% higher for 0.4% and at least 50% higher at 1% supersaturation. The morning results point to either photochemical production (which would be more noticeable in light winds) and/or a longer retention of high particle concentrations due to the lowering of the inversion at night. Strong winds would be characteristic of an earlier

TABLE 1. FACE 76 surface aerosol data (Immokalee site) DRI CFD CCN concentrations at 0.4 and 1.0% supersaturations ($v < 3$ m s^{-1}).

	Time (EDT) 0000–0600			Time (EDT) 0600–1200			Time (EDT) 1200–1800			Time (EDT) 1800–2400			All		
Wind	0.4%	1.0%	*K*	0.4%	1.0%	*K*	0.4%	1.0%	*K*	0.4%	1.0%	*K*	0.4%	1.0%	*K*
N–E															
Max	2157	3682	2.0	1720	7080	1.6	8360	10909	2.0	6056	7837	2.0	8360	10909	2.0
Mean	872	1860	0.9	822	1519	0.6	1179	2117	0.8	1114	2121	0.8	973	1906	0.8
S.D.	460	715	0.4	320	789	0.2	1491	2042	0.4	884	1367	0.3	867	1267	0.4
N		5020			1846			2461			1994			11321	
E–S															
Max	2125	5560	2.0	1997	7101	2.0	6781	9088	2.0	2650	4733	2.0	6781	9088	2.0
Mean	629	1509	0.9	685	1527	0.8	638	1737	1.1	579	1595	1.1	633	1561	0.9
S.D.	247	749	0.4	270	833	0.3	541	1270	0.4	397	917	0.4	341	890	0.4
N		8488			6058			2664			5334			22544	
S–W															
Max	1936	4949	2.0	1808	4602	1.9	3309	6600	2.0	5946	10682	2.0	5946	10682	2.0
Mean	707	1787	1.0	756	1862	1.0	566	1366	0.9	513	1415	1.1	628	1599	1.0
S.D.	208	741	0.5	277	795	0.3	287	982	0.4	255	631	0.4	278	810	0.4
N		1810			2046			1720			2589			8165	
W–N															
Max	1816	3640	1.7	1514	4341	1.9	3069	6309	2.0	6261	10909	2.0	6261	10909	2.0
Mean	906	1944	0.9	756	1821	1.0	553	1300	0.9	725	1854	1.1	739	1746	1.0
S.D.	417	696	0.3	266	675	0.3	315	849	0.4	617	1205	0.4	466	948	0.4
N		3440			2678			2995			4280			13393	
All															
Max	2157	5560	2.0	1997	7101	2.0	8360	10909	2.0	6261	10909	2.0	8360	10909	2.0
Mean	752	1710	0.9	731	1642	0.8	734	1634	0.9	686	1714	1.1	728	1682	0.9
S.D.	368	753	0.4	282	804	0.3	864	1405	0.4	576	1067	0.4	531	991	0.4
N		18758			12628			9840			14197			55423	

TABLE 2. As in Table 1 except $v > 3$ m s^{-1}.

	Time (EDT) 0000–0600			Time (EDT) 0600–1200			Time (EDT) 1200–1800			Time (EDT) 1800–2400			All		
Wind	0.4%	1.0%	*K*	0.4%	1.0%	*K*	0.4%	1.0%	*K*	0.4%	1.0%	*K*	0.4%	1.0%	*K*
N–E															
Max	1032	3461	1.8	1520	6205	1.8	8426	10917	2.0	3597	4602	0.8	8426	10917	2.0
Mean	858	3363	1.5	993	2055	0.6	2072	3275	0.7	1366	1912	0.4	1886	2986	0.6
S.D.	106	68	0.1	237	1336	0.4	1885	2532	0.4	719	839	0.1	1718	2335	0.4
N		11			50			760			166			987	
E–S															
Max	957	3397	1.9	1714	6941	1.9	6629	9048	2.0	2720	3802	2.0	6629	9048	2.0
Mean	551	1465	0.9	517	908	0.6	558	1580	1.1	422	951	0.9	513	1265	0.9
S.D.	149	1107	0.6	196	525	0.3	405	1128	0.5	242	526	0.3	333	945	0.4
N		22			1088			2500			1298			4908	
S–W															
Max	973	1552	1.1	1362	2930	1.8	5656	10629	2.0	1192	4040	2.0	5656	10629	2.0
Mean	932	1434	0.5	522	901	0.6	567	1443	0.9	426	1184	1.0	529	1270	0.8
S.D.	58	135	0.2	219	368	0.1	446	1328	0.4	140	684	0.4	364	1090	0.4
N		2			608			1570			544			2724	
W–N															
Max		No data		1149	3050	1.9	3157	4781	2.0	2733	3712	1.8	3157	4781	2.0
Mean				568	1635	1.1	576	1236	0.9	1211	2141	1.0	605	1311	0.9
S.D.				235	657	0.5	484	828	0.4	1033	1017	0.7	524	851	0.5
N					151			1575			83			1809	
All															
Max	1032	3461	1.9	1714	6941	1.9	8426	10917	2.0	3597	4602	2.0	8426	10917	2.0
Mean	670	2060	1.0	535	994	0.6	744	1663	0.9	529	1135	0.9	663	1437	0.9
S.D.	204	1249	0.6	221	593	0.3	910	1491	0.4	456	706	0.4	755	1274	0.4
N		35			1897			6405			2091			10428	

lifting of the inversion and consequent earlier clearing of high particle concentrations.

The very high (>1300 cm^{-3}) mean concentration of CCN active at $S = 1\%$ is notable. This mean value is equaled or exceeded in all 16 light wind and in 10 of the 15 strong wind matrices. The overall mean CCN concentration for the entire unstratified data set ($N = 65\,851$) is 718 cm^{-3} at $S = 0.4\%$ and 1644 cm^{-3} at $S = 1\%$. This cannot be considered characteristic of a "classical" maritime or modified maritime air mass. Maximum values of CCN concentration exceeding 8000 cm^3 at $S = 0.4\%$ and 10 000 cm^{-3} at $S = 1\%$ are representative of continental drought conditions or polluted urban air. At $S = 1\%$ only 2% of the total data sample provided a CCN concentration of <500 cm^{-3}, while 20% of the data points had CCN values in excess of 2250 cm^{-3}. The median CCN concentrations at $S = 1\%$ was found to be in the range 1250–1500 cm^{-3}. The observed mean value of k parameter of 0.92 is much more characteristic of a continental aerosol than one which is typically encountered in maritime regions (Twomey and Wojciechowski, 1969).

Table 3 shows the daily variability of the mean CCN concentration at the two supersaturations (0.4% and 1.0%) and mean k parameter for an arbitrarily selected consecutive 10-day period (20–29 August) partitioned on the basis of four time-of-day increments. It can be seen that substantial fluctuations in CCN concentration occur, both within a given day and from day to day. The direction and strength of the predominant wind flow at the surface is also shown in Table 3 by a symbol (L, S or B) in one or more of the four corners of each matrix block. The corners represent the quadrant or quadrants from which the wind is predominantly blowing. The symbols represent either light, (≤ 3 m s^{-1}), strong (≥ 3 m s^{-1}), or both light and strong wind speeds. It can be seen that, in general, the very highest CCN counts at both supersaturations are associated with winds from the north through east quadrant (top right corner). This is apparently aged continental air.

The day-to-day fluctuations in CCN concentration are difficult to reconcile solely in terms of boundary-layer air trajectories (Fig. 7). The low-level (0–1500 m) 5-day trajectories indicate air arriving from an easterly direction with a long fetch over water on each of the last four days (26–29) and air arriving from the northwesterly or southerly direction with a significant fetch over land areas during the 6-day period 20–25 August. The trajectory pattern on 20, 21, 22 and 25 August was essentially one of stag-

TABLE 3. Daily concentrations of cloud condensation nuclei as a function of time periods.

FORMAT

$\bar{X}(0.4\%)$ $\bar{X}(1.0\%)$ $\bar{X}(K)$
S.D.(0.4%) S.D.(1.0%) N

Date: August	Time (EDT) 0000–0600	Time (EDT) 0600–1200	Time (EDT) 1200–1800	Time (EDT) 1800–2400
20	L 1386 2710 0.7 143 165 720	1033 2344 0.9 L 308 515 718	S 485 817 0.6 85 118 453	No data
21	746 1648 0.9 0 0 1	565 1076 0.7 15 206 11	L 835 1691 0.8 143 244 541	L 898 1838 0.8 105 221 715
22	L 699 1360 0.7 61 192 720	L 842 1687 0.6 L 293 1255 716	3648 5665 0.5 B 1493 1638 611	1202 1935 0.6 L 1009 1338 683
23	726 1526 0.8 L 95 123 720	No data	2398 3299 0.4 L 554 341 161	L 1656 2255 0.4 L 515 569 462
24	1822 2620 0.4 L 191 248 717	850 1345 0.5 L 283 437 650 L	682 1040 0.5 L 213 254 526	L 1019 2022 0.8 L 1051 1949 434 L
25	888 1283 0.4 L 58 177 716 L	958 1721 0.6 L 270 617 690 L	L 593 1925 1.2 L 333 1018 582 L	L 422 2092 1.7 L 129 621 405 L
26	581 1265 0.8 62 549 719 L	599 1248 0.8 172 408 717 L	353 1405 1.4 93 742 538 S	395 1828 1.6 L 62 486 676 L
27	551 1910 1.3 L 83 387 630 L	575 1023 0.6 115 187 677 L	657 1864 1.0 194 1114 373 S	331 650 0.7 119 274 692 L
28	461 820 0.6 158 346 678 L	405 731 0.6 40 163 719 B	460 825 0.6 366 782 707	872 1891 0.8 265 757 681 L
29	707 1337 0.7 72 395 720 L	748 1057 0.4 48 63 213 L	718 2016 1.0 249 1026 348 S	430 1564 1.3 168 1007 103 S

nation, with the air mass remaining in place in the Florida area during the 5-day period. The air arriving at 1800 GMT on the 23rd, 24th, 26th, 27th, 28th and 29th originated far to the east or northeast of the Florida area. Substantial differences in the mean CCN concentration at both supersaturations were computed when the data were stratified into the two periods, 20–25 August (excluding 21 August which had no data in two of the matrices) and 26–29 August. As is shown in Table 4, for both supersaturations, the mean CCN concentration during the first period (20–25 August) continental trajectory was found to be about a factor of 2 greater than that of the second period (26–29 August) maritime trajectory with an almost equal sample size of about 10 000 points in both periods. This would indicate that, although the detailed fluctuations in CCN concentration from one day to the next are difficult to associate precisely with changes in trajectory, rather important changes in the mean CCN concentration for a several-day period of time with continental trajectories to a several-day period of time with maritime trajectories are readily detectable. It can be seen from Table 4 that even during the 4-day maritime trajectory period, the mean CCN concentration exceeded 500 cm^{-3} and 1250 cm^{-3} at 0.4 and 1.0% supersaturation, respectively.

The higher k for the maritime trajectories is contrary to previous data on maritime air masses. However, it can be explained by the fact that no true

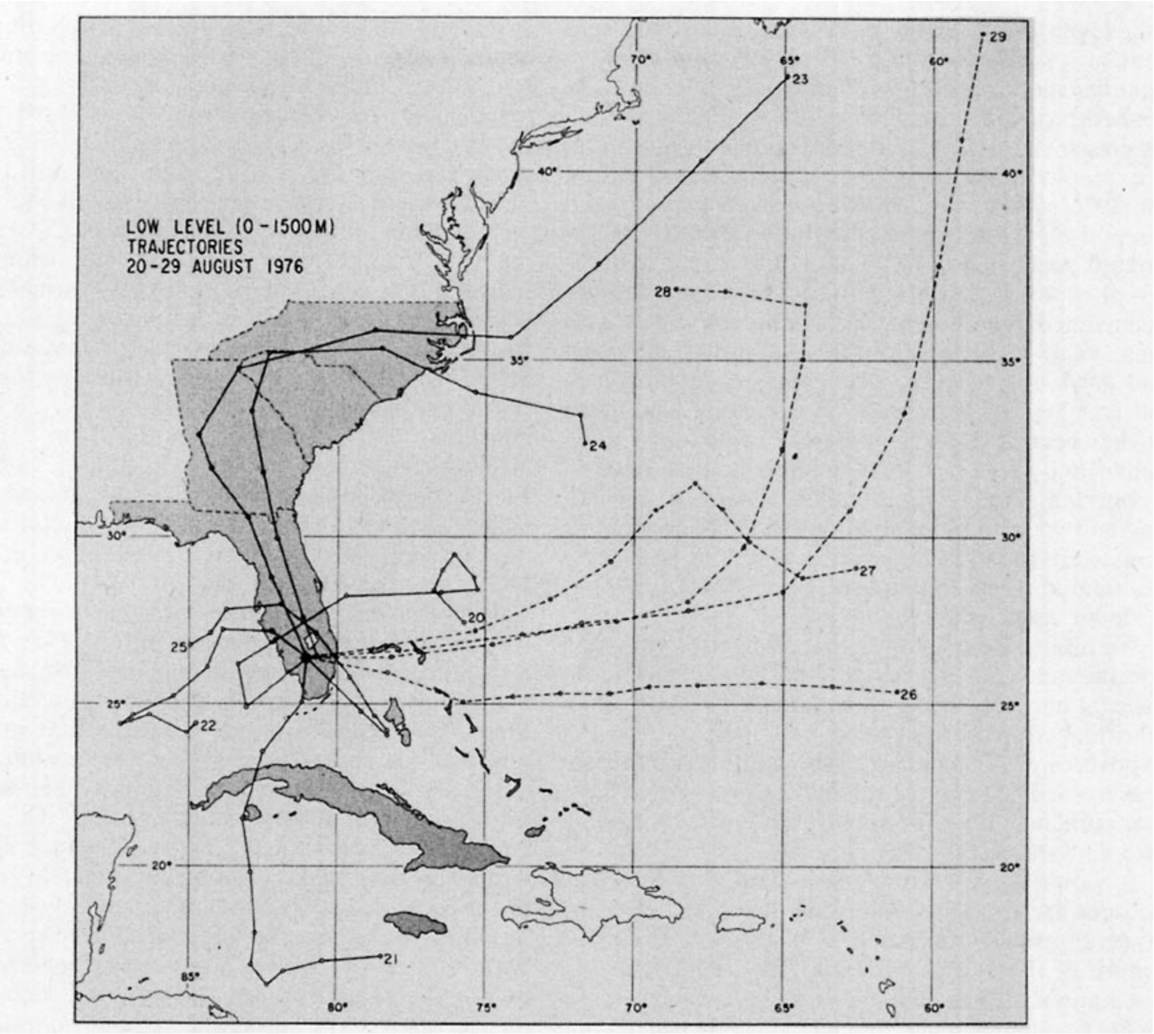

FIG. 7. Low-level air mass trajectories (5-day) terminating in the center of the FACE target area at 1800 GMT on each of 10 days during the period 20–29 August 1976.

maritime air reaches the sampling site because it is modified even in the short distance from the coast. Thus, this maritime air with recent continental modification would be expected to have a high k because the smallest particles are produced and first injected into the air while larger particles (i.e., those active at 0.4%) result from coagulation which requires some time to occur. Thus at this location "continental" air has a lower k value than the "maritime air" which is actually recently modified by land influences.

5. Summary and considerations

The indication of high but variable concentrations of CCN observed at cloud base level during FACE 75 were confirmed at the surface in Immokalee during FACE 76. The CCN concentrations at the cloud-

TABLE 4. CCN concentration as a function of continental and maritime trajectory periods.

Period (August 1977)	Sample points	CCN mean (0.4%)	CCN S.D. (0.4%)	CCN mean (1.0%)	CCN S.D. (1.0%)	k mean	k S.D.
20–25*	10727	1149	909	2049	1327	0.7	0.4
26–29	9196	543	225	1291	723	0.9	0.4

* 21 August excluded because of lack of data in the night and morning time periods.

base level were found to be consistent with the concept of a continental aerosol or, in some cases, a modified maritime aerosol. In no case could the CCN concentration at cloud base across the peninsula be classified in the traditional manner as maritime. The results from the surface data collected during the 1976 season have shown an even greater continental nature to the concentration of CCN. Continuous recording of CCN data obtained at two different supersaturations showed a high frequency of occurrence of continental CCN characteristics with mean values in excess of 600 and 1400 cm^{-3} at $S = 0.4$ and 1.0%, respectively, and values exceeding 7000 cm^{-3} at $S = 1\%$ measured on occasion. The mean of the spectral slope (k parameter) was found to be consistently near 0.9, a value more characteristic of a continental than a maritime CCN aerosol. Day-to-day and within-day fluctuations in CCN concentrations were found to be considerable, but seemingly not related solely to low-level (0–1500 m) synoptic-scale air trajectories.

We offer the explanation that air masses with long continental trajectories would be "well-aged" continental aerosols while those air masses with long maritime trajectories prior to brief continental exposures would have a "fresh" continental aerosol spectrum. The aged continental aerosol would have had sufficient time for small particles to coagulate into and onto larger particles.

It would appear from these data that localized sources are strongly influencing the character of the south Florida summertime CCN aerosol. The exact nature of the causes for such localized effects are not known at this time. We can speculate that the richly organic peat and muck fields in the sugar cane agricultural region to the east-northeast of Immokalee, and the heavily fertilized vegetable-growing areas to the northeast and northwest of Immokalee may provide a copious source of ammonia which is known to readily combine with sulfur in the atmosphere to produce ammonium sulfate, a very effective CCN. The Everglades area to the south might also be expected to be a prolific source of ammonia. This could account for the continental nature of the mean CCN concentrations with winds from all quadrants, although the winds from the northern semicircle are associated with the highest counts.

Local agricultural burning was known to be a prolific source on three or four brief occasions. However, it is difficult to see how this could be important as an ongoing source. An earlier Florida CCN study (Holle, 1971) indicated that fires were not a major overall source of CCN. The Miami urban area is certainly a CCN source as are all urban areas. Some measurements at Miami Beach in early September confirmed this fact. However, the trajectory analysis and wind direction correlations in most cases appear to rule out Miami air pollution as a major cause of the high CCN concentrations at Immokalee. Other anthropogenic sources could be responsible but earlier work by Squires (1966) showed that direct production of CCN by small urban areas should be a rather insignificant factor.

In terms of the specific objectives of the study, we conclude that the concentration of CCN within the FACE target area, active at supersaturations between 0.4 and 1.0%, is highly variable both spatially at the cloud-base level and temporally at the surface. The CCN concentration certainly cannot be characterized as homogeneous over the south Florida peninsula. Use of a generalized "modified maritime" CCN concentration of 500 cm^{-3} to characterize the aerosol for numerical studies of south Florida convection can be misleading. It is also possible that the extreme continental characteristics of the surface measurements could sometimes be higher than the concentration of CCN at cloud base. This may be reflected in the somewhat lower concentrations measured from the aircraft in 1975 although it is difficult to draw conclusions based on measurements taken by different instruments at different times. Nevertheless, the localized effects on CCN might sometimes not be as strongly felt at cloud base.

Finally, the trajectory of the air mass seems to be a useful indicator for overall background CCN concentration levels, but the activity spectra appears to also be governed by peninsular effects. A boundary-layer aerosol of oceanic origin undergoes a rapid modification as it crosses the south Florida peninsula with the result that the CCN activity spectra takes on continental and extreme continental characteristics on many days during the summer months.

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REFERENCES

Fitzgerald, J. W., and P. A. Spyers-Duran, 1973: Changes in cloud nucleus concentration and cloud droplet size distribution associated with pollution from St. Louis. *J. Appl. Meteor.*, **12,** 511–516.

Hallett, J., R. I. Sax, D. Lamb and A. S. R. Murty, 1978: Aircraft measurements of ice in Florida cumuli. *Quart. J. Roy. Meteor. Soc.*, **104,** 631–651.

Holle, R. L., 1971: The effects of cloud condensation nuclei due to fires and surface sources during South Florida droughts. *J. Appl. Meteor.*, **10**, 62–69.

Hoppel, W., 1979: Measurement of the size distribution and CCN supersaturation spectrum of submicron aerosols over the ocean. *J. Atmos. Sci.*, **36**, 2006–2015.

Hudson, J. G., 1980: Relationship between fog condensation nuclei and fog microstructure. *J. Atmos. Sci.*, **37**, 1854–1867.

——, and P. Squires, 1973: Evaluation of a recording continuous cloud nucleus counter. *J. Appl. Meteor.*, **12**, 175–183.

——, and ——, 1976: An improved continuous flow diffusion cloud chamber. *J. Appl. Meteor.*, **15**, 776–782.

——, and ——, 1978: Continental surface measurements of CCN flux. *J. Atmos. Sci.*, **35**, 1289–1295.

Jiusto, J., 1966: Maritime concentration of condensation nuclei. *J. Rech. Atmos.*, **2**, 245–250.

Simpson, J., and V. Wiggert, 1971: Florida cumulus seeding experiment: numerical model results. *Mon. Wea. Rev.*, **99**, 87–118.

Squires, P., 1966: An estimate of the anthropogenic production of cloud nuclei. *J. Rech. Atmos.*, **2**, 297–307.

Twomey, S., 1969: The nuclei of natural cloud formation II. *Geofis. Pura. Appl.*, **43**, 243–249.

——, and T. A. Wojciechowski, 1969: Observations of the geographical variation of cloud nuclei. *J. Atmos. Sci.*, **26**, 684–688.

——, and P. Squires, 1969: The influence of cloud nuclei population on the microstructure and stability of convective clouds. *Tellus*, **11**, 408–411.

——, and J. Warner, 1967: Comparison of measurements of cloud droplets and cloud nuclei. *J. Atmos. Sci.*, **24**, 702–703.

Warner, J., 1969: The microphysics of cumulus cloud. Part II: The effects on droplet size distribution of the cloud nucleus spectrum and updraft velocity. *J. Atmos. Sci.*, **26**, 1277–1282.