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ABSTRACT

A climatology of the boundary layer of the atmosphere at the Savannah River Laboratory is being compiled using acoustic methods. The atmospheric phenomena as depicted on the facsimile recorder is classified and then placed into one of ~~sixteen~~ fifteen categories. After classification, the height of the boundary layer is measured. From this information, frequency tables of boundary layer height and category are created and then analyzed for the percentage of time that each category was detected by the acoustic sounder. The sounder also accurately depicts the diurnal cycle of the boundary layer and, depending on the sensitivity of the system, shows microstructure that is normally unavailable using other methods of profiling.

The acoustic sounder provides a means for continuous, real time measurements of the time rate of change of the depth of the boundary layer. This continuous record of the boundary layer with its convective cells, gravity waves, inversions, and frontal system passages permits the synoptic and complex climatology of the local area to be compiled.

CONTENTS

A SHORT CLIMATOLOGY OF THE ATMOSPHERIC BOUNDARY LAYER USING ACOUSTIC METHODS

INTRODUCTION

The development of the acoustic sounder has extended the capabilities of the diffusion meteorologist by giving him an economical tool for monitoring in real time the height of the boundary layer of the atmosphere (mixed layer). The height of the mixed layer is important in the calculation of the concentration and transport of atmospheric pollutants (both radioactive and nonradioactive) released as either a puff or plume.

The acoustic sounder provides a means for continuous, real time measurements of the time rate of change of the depth of the mixed layer which is an important parameter in the calculation of the transport and diffusion of both radioactive and nonradioactive air pollutants. This continuous record of the mixed layer with its convective cells, gravity waves, inversions, and frontal systems permits the synoptic (analysis of climate in terms of simultaneous weather information) and complex (analysis of the climate of a single place by the relative frequencies of various weather types or groups of such types) climatoloty of the local area to be constructed.

ACOUSTIC SOUNDER

Description

The acoustic sounder used to gather the data for this study at the Savannah River Laboratory (SRL) was developed by the University of Melbourne, Melbourne, Australia. When used in the monostatic mode, this system has a height range of 6,000 ft, frequency of 1-2 kHz (variable), band width of 5 Hz, pulse length of 0.1 to 1.0 sec (variable), transducer input of 100 watts (max), and sensitivity of 0.9°C/100 ft.

The potential of the acoustic sounder for use in monitoring temperature-turbulence fluctuations and inversions has been reported in References 1-5.

Principle of Operation

The acoustic sounder is in principle similar to a SONAR in that it transmits an audible pulse of sound and receives echoes (or returns) of the sound that are reflected from inhomogeneities in the acoustic refractive index of the atmosphere. These variations in the acoustic refractive index are associated with the fluctuations of wind and temperature. Acoustic waves propagating through the atmosphere are attenuated, scattered, and refracted (Table 1).[5-9]

If the interactions of acoustic waves are expressed in terms of the sonic refractive index where one N unit is one part in 10^6, the interaction of acoustic waves can be compared with those of radio and optical waves for a given change in temperature, humidity, or velocity.[1]

The interaction of the acoustic energy with the atmosphere is strong because the atmosphere is the transmitting vehicle for the longitudinal pressure vibrations which travel with the velocity of sound. The speed of sound (C) is given by

$$C = 331\left(\frac{T}{273}\right)^{1/2}, \text{ m/sec} \qquad (1)$$

for dry air, where T is the temperature in °K.

TABLE 1

Comparison of Refractive Index Change for Acoustic, Radio, and Optical Waves for Small Changes in Atmospheric Parameters

	Change in Refractive Index, N Units[a]		
Magnitude of Parameter Change	*Acoustic*	*Radio*	*Optical*
1°K fluctuation in temperature	1700	1	1
1 m/sec variation in wind speed	3000	2×10^{-6}	2×10^{-6}
1 mbar change in water vapor pressure	140	4	0.04

a. One N unit equals one part in 10^6.

CLIMATOLOGY OF SRL

In order to identify and catalogue the various phenomena of climatological interest, the categories listed in Table 2 have been used.[10] By identifying the data in this manner, a statistical climatology may be constructed.

Table 3 shows the number of hours the sounder was operational for each month, the number of hours the records were obscured by wind and/or rain noise, the number of hours the sounder was at SRL each month, and the percentage of the total time useful mixed layer data was recovered. The data recovery rate for the total period was 41%, and the data recovery rate for the period the sounder was operational was 86%.

Mixed Layer Height

The data were tabulated by maximum height and frequency of occurrence for each height (Table 4) for each hour the sounder was in operation. Table 4 shows that the top of the mixed layer was between 1000 and 3000 ft 78% of the time for the periods sampled. Code 9999 in the height column indicates that the data were obscured by noise (wind and/or rain).

From nighttime data (Table 5), the top of the mixed layer is 3000 ft or below 85% of the time and between 2000 and 3000 ft 47% of the time.

From daytime data (Table 6), the height of the mixed layer is below 3000 ft 70% of the time and between 2000 and 3000 ft 24% of the time.

The calculated mean annual afternoon maximum mixed layer height for the SRL area is 4600 ft.[11,12] This is 1600 ft higher than 70% of the daytime signals recorded by the sounder. The sounder records should be interpreted with caution during afternoon thermal plume activity (convective cells). The sensitivity of the sounder is such that the base of the thermal plume is well defined, but the top of the plume is not very well depicted because the lapse rate of the core of the plume is essentially adiabatic.[13,14] This could cause an underestimation of the height of the mixed layer during periods of afternoon thermal plume activity.[15] Thermal plume activity (Category 13) accounts for only 14% of the total returns (Table 7).

Mixed Layer by Category

During the 2056 hr of sampling, most of the returns were from a well-mixed layer interpreted to be caused by the vertical fluxes of temperature and turbulence.[13,16,17] Category 2 was observed 51% of the time (Table 7). Category 2 is usually a well-mixed convective layer with a well-defined upper boundary (Figure 1). Category 13 consists of well-developed thermal plumes (Figure 2) and was present for 9.6% of the daytime data (Table 8). The nighttime convective activity was present 17.8% (Table 9) of the time, and the tops of the plumes were better defined than the afternoon plumes in Figure 2. In Category 14, multiple stable layers of temperature-turbulence stratification appear (Figure 3). This return may be caused by either a real meteorological phenomenon or by acoustic ghosting; that is, the signal is reflected back from a low-level inversion not only to the receiver but also to the ground and back to the inversion and then to the receiver. This reflection causes multiple returns from the same inversion in multiples of the inversion height and decreasing in intensity with height.

Figures 4 and 5 show the formation and dissipation of an inversion layer with a large separation between the inversion and the mixed layer near the ground surface (Category 6). In Category 99, data are obscured by noise (wind, rain, etc.), or the data are missing because of equipment malfunction.

Typical Diurnal Cycles

A typical diurnal pattern at the Savannah River Laboratory in March is a stable multiple layer (Category 14) forming after sundown and persisting until a little after sunrise, and an ascending layer from the surface (Category 9) until about noon. About noon, a pattern of well-developed thermal plumes forms caused by surface heating. These thermal plumes continue until sundown, and the cycle is repeated. At other times after sundown, multiple layers form, and then night time thermal plumes (convective cells) appear. These plumes appear to be much wider than the daytime plumes but this could be caused by very low winds at night, which may allow a single cell to remain over the sounder for a longer period of time.

TABLE 2

Categories of Acoustic Sounder Data

Category 99:	No data, just wind noise
Category 1:	0- to 500-ft thermospikes up to 1000 ft
Category 2:	Back-scattered layer
Category 3:	Back-scattered layer with waves
Category 4:	Very complex; many waves in the bottom layer
Category 5:	Two layers in the bottom
Category 6:	Two layers, separate one over the other, large separation from the top to the bottom layer
Category 7:	Multiple weak layers
Category 8:	Strong multiple layers
Category 9:	Ascending layer from the surface
Category 10:	Ascending layer, but not starting at the surface
Category 11:	Descending layer, but not merging with the surface
Category 12:	Descending layer merging with the surface layer
Category 13:	Thermal plumes only
Category 14:	Stable multiple layer

TABLE 3

Data Recovery Rate by Month

	Time, hr			
	Sounder Data Recorded	*Data Obscured by Wind/Rain*	*Sounder Located at SRL*[a]	*Data Recovered, %*
Sept. 73	12	4	12	67
Feb.74	168	30	168	82
Mar.74	416	72	744	46
Apr.74	100	6	720	13
May 74	236	70	600	27
Sept.74	416	6	432	95
Oct.74	336	49	744	39
Nov.74	216	29	720	26
Dec.74	156	22	192	70
Total	2056	288	4332	41

a. From May to September 1974, the sounder was located at Oak Ridge, Tennessee.

TABLE 4

Observed Frequencies of Mixed Layer Heights for Daytime and Nighttime Measurements

Height	*Frequency*	*Percent*	
500	2	0.097	
700	1	0.049	
800	1	0.049	
900	1	0.049	
1000	31	1.508	
1100	14	0.681	
1200	49	2.383	
1300	51	2.481	
1400	75	3.648	
1500	183	8.901	
1600	46	2.237	
1700	59	2.870	
1800	95	4.621	77.97%
1900	27	1.313	
2000	217	10.554	77.72%
2100	46	2.237	
2200	57	2.772	
2300	53	2.578	
2400	54	2.626	36.53%
2500	249	12.111	
2600	61	2.967	
2700	71	3.453	
2800	44	2.140	
2900	15	0.730	
3000	101	4.912	
3100	8	0.389	
3200	23	1.119	
3300	14	0.681	
3400	8	0.389	
3500	42	2.043	
3600	9	0.438	
3700	3	0.146	
3900	1	0.049	
4000	17	0.827	
4100	1	0.049	
4300	1	0.097	
4400	1	0.049	
4500	22	1.070	
9999	292	14.202	
Total	2056	100.000	

TABLE 5

Observed Frequencies of Mixed Layer Heights for Nighttime Measurements

Height	*Frequency*	*Percent*		
1000	18	1.614		
1100	12	1.076		
1200	35	3.139		
1300	42	3.767		
1400	42	3.767		
1500	104	9.327		
1600	14	1.256		
1700	24	2.152		
1800	41	3.677		
1900	4	0.359		
2000	83	7.444		84.66%
2100	22	1.973		
2200	36	3.229		
2300	30	2.691		
2400	42	3.767	47.08%	
2500	168	15.067		
2600	50	4.484		
2700	56	5.022		
2800	36	3.229		
2900	15	1.345		
3000	70	6.278		
3100	4	0.359		
3200	17	1.525		
3300	6	0.538		
3400	5	0.448		
3500	24	2.152		
3600	8	0.717		
3700	4	0.359		
3800	1	0.090		
4000	10	0.090		
4400	1	0.090		
4500	3	0.269		
9999	88	7.893		
Total	1115	100.000		

TABLE 6

Observed Frequencies of Mixed Layer Heights for Daytime Measurements

Height	*Frequency*	*Percent*	
500	2	0.213	
700	1	0.106	
800	1	0.106	
900	1	0.106	
1000	13	1.382	
1100	2	0.213	
1200	14	1.488	
1300	9	0.956	
1400	33	3.507	
1500	79	8.395	
1600	32	3.401	
1700	35	3.719	
1800	54	5.739	69.50%
1900	23	2.444	70.0%
2000	134	14.240	
2100	24	2.550	
2200	21	2.232	
2300	23	2.444	
2400	12	1.275	
2500	81	8.608	24.02%
2600	11	1.169	
2700	15	1.595	
2800	8	0.850	
3000	31	3.294	
3100	4	0.425	
3200	6	0.638	
3300	8	0.850	
3400	3	0.319	
3500	18	1.913	
3600	1	0.106	
3700	6	0.638	
3800	2	0.213	
3900	1	0.106	
4000	7	0.744	
4100	1	0.106	
4300	2	0.213	
4500	19	2.019	
9999	204	21.679	
Total	941	100.000	

TABLE 7

Observed Frequencies of Mixed Layer Categories for Daytime and Nighttime Measurements

Category	*Frequency*	*Percent*
1	10	0.487
2	1041	50.657
3	52	2.530
4	4	0.195
5	11	0.535
6	86	4.185
7	19	0.925
8	16	0.779
9	28	1.363
10	41	1.995
11	12	0.584
12	4	0.195
13	288	14.015
14	152	7.397
99	291	14.161
Total	2055[a]	100.000

a. There was 1 missing value excluded from the above totals.

TABLE 8

Observed Frequencies of Mixed Layer Categories for Daytime Measurements

Category	*Frequency*	*Percent*
2	452	48.034
3	17	1.807
4	2	0.213
5	5	0.531
6	55	5.845
7	11	1.169
8	7	0.744
9	22	2.338
10	38	4.038
11	5	0.531
12	2	0.213
13	90	9.564
14	31	3.294
99	204	21.679
Total	941	100.000

TABLE 9

Observed Frequencies of Mixed Layer Categories for Nightime Measurements

Category	*Frequency*	*Percent*
1	10	0.897
2	589	52.825
3	35	3.139
4	2	0.179
5	6	0.538
6	31	2.780
7	8	0.717
8	9	0.807
9	6	0.538
10	3	0.269
11	7	0.628
12	2	0.179
13	198	17.758
14	121	10.852
99	88	7.892
Total	1115	100.000

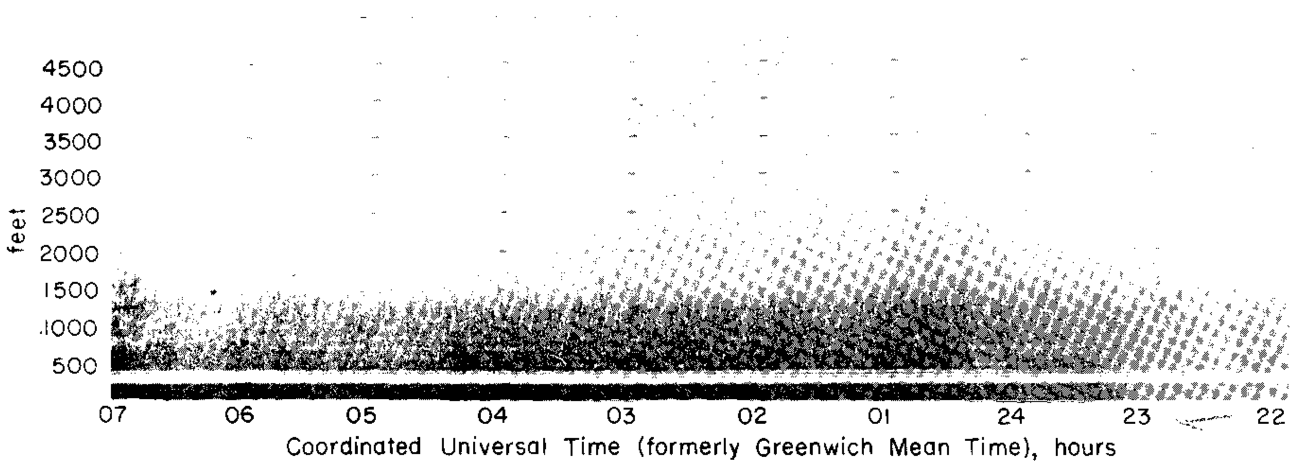

FIGURE 1. Category 2, Back-Scattered Layer

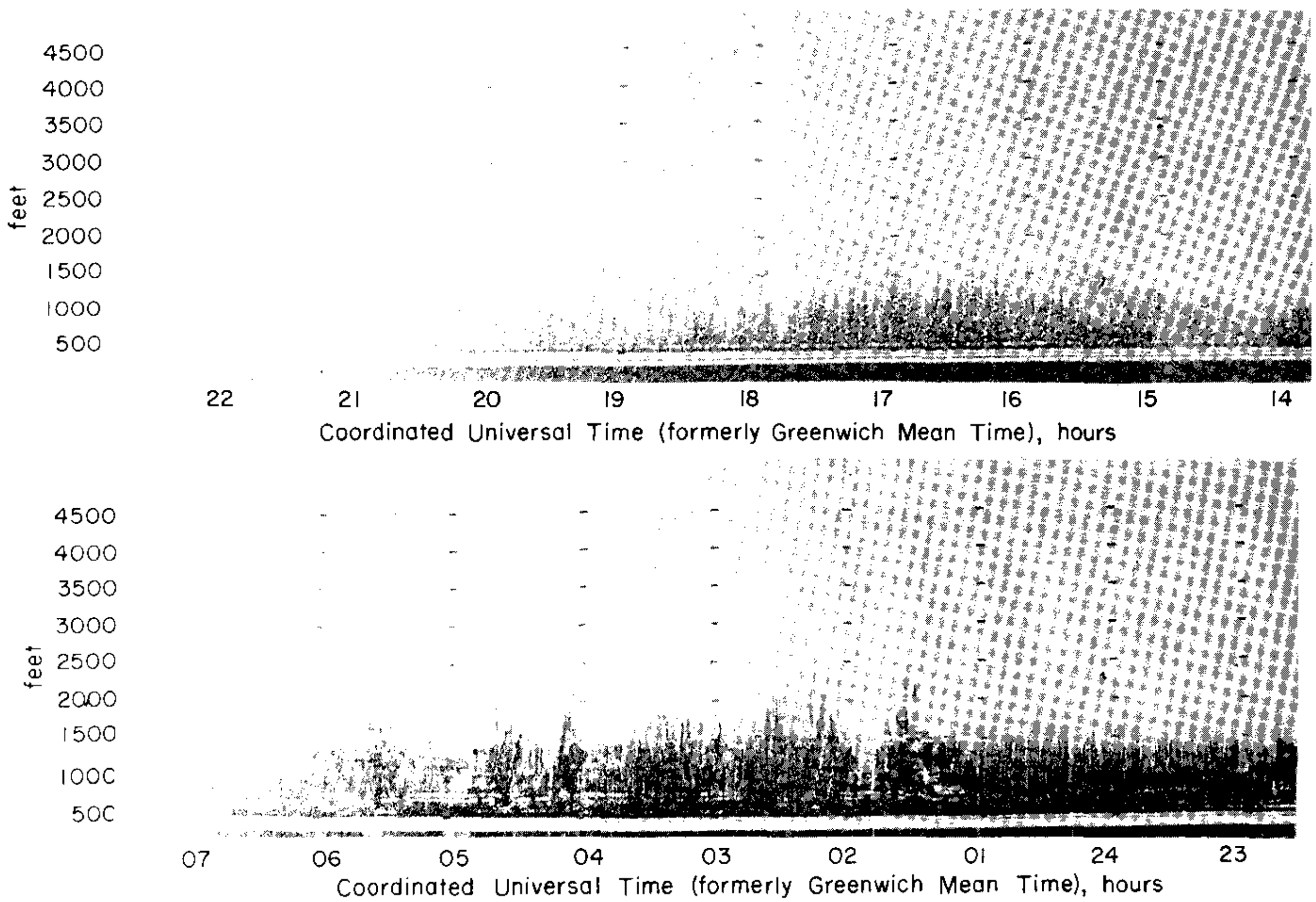

FIGURE 2. Category 13, Thermal Plumes

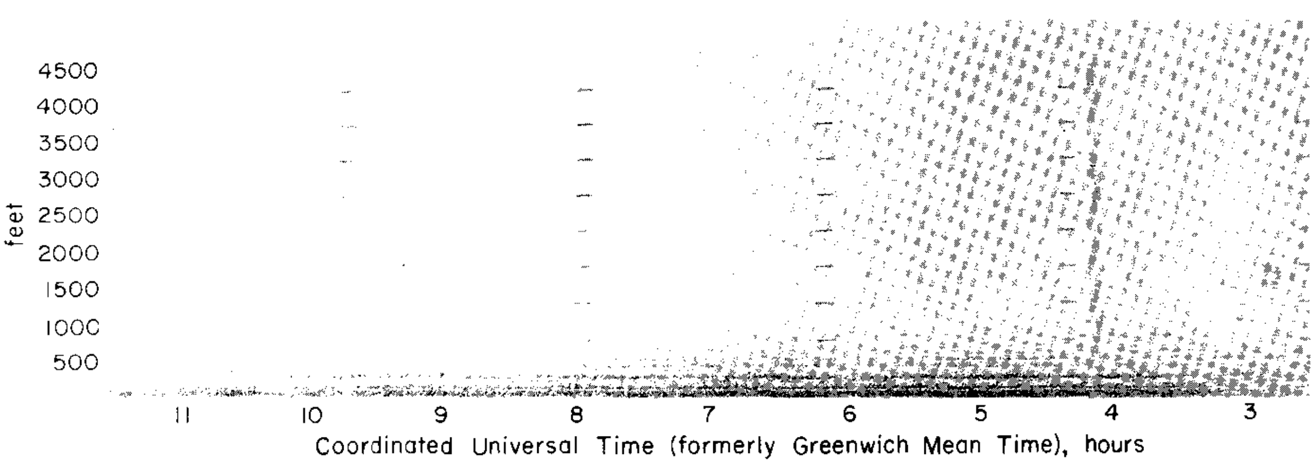

FIGURE 3. Category 14, Stable Multiple Layers Near Surface

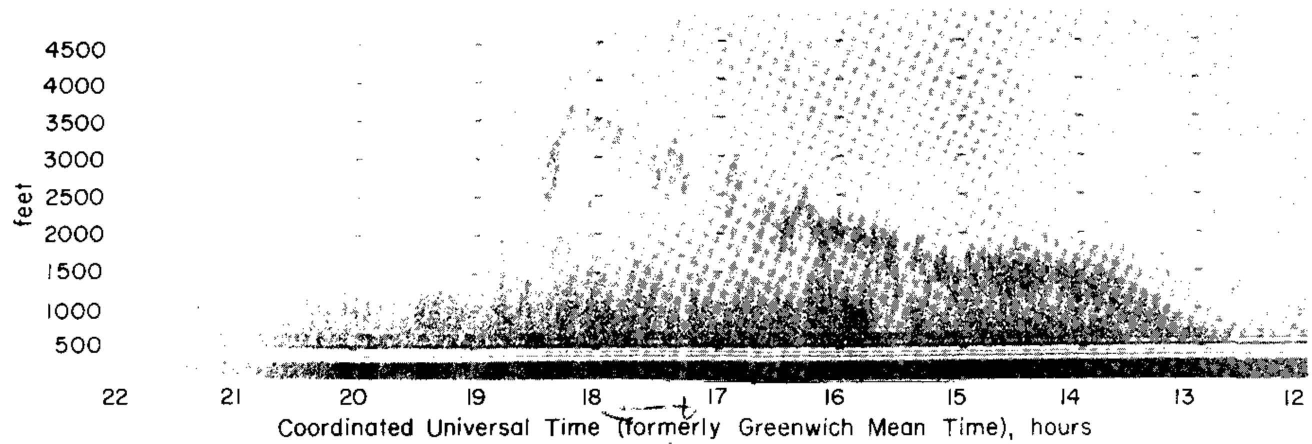

FIGURE 4. Category 9, Ascending Layer from Near the Ground Surface

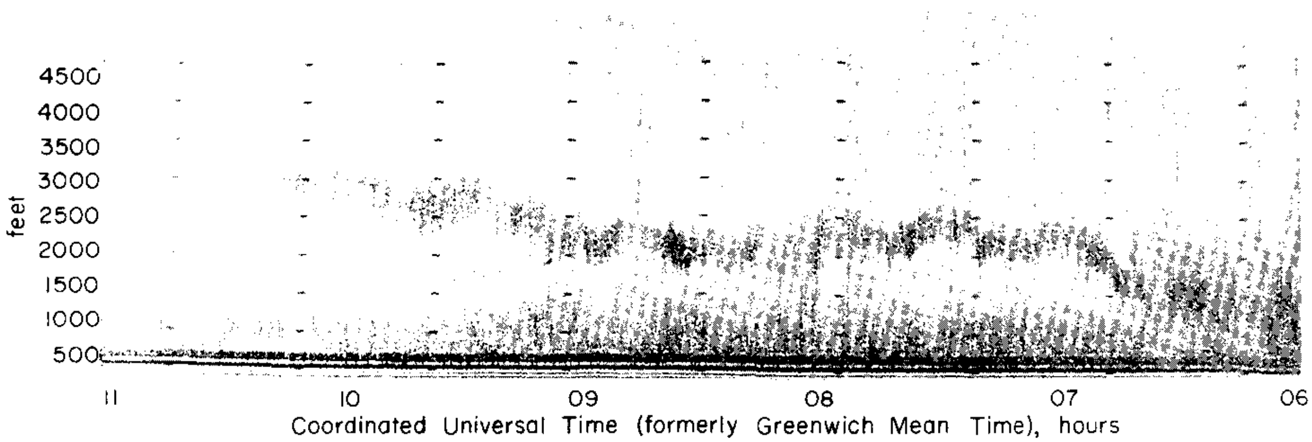

FIGURE 5. Category 10, Ascending Layer (Not Starting Near the Ground Surface). Category 10 is transformed into Category 6 with 2 layers, where the separation between the layers is large.

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