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Turbulence Structure in Clear and Cloudy Regions of the 7 July 1987 Electra Mission

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I. Introduction

The 7 July mission of the 1987 FIRE marine stratocumulus intensive field observations has been chosen by several researchers for analysis because a well-defined transition from stratocumulus to clear conditions was sampled by the aircraft on this day. It is hoped that by studying this case we can learn something about the processes responsible for the maintenance and breakup of stratocumulus layers, a primary objective of FIRE.

The preliminary analysis reported on here is based on data from the Electra flight of this day. The properties of turbulence elements, i.e. updrafts and downdrafts, are examined to gain information on the nature of the turbulent exchanges through the boundary layer and across the inversion. Since such exchanges in large measure determine the stability and structure of cloud layers, a study of draft properties should be informative. These results will also be useful in the development of boundary layer models that are based on draft circulations (e.g. Randall, 1988; Hanson, 1988).

II. Methodology

The technique that we use is conditional sampling based on an indicator function. The indicator function is set to +1 or -1 when the vertical velocity exceeds predetermined positive or negative thresholds. Other variables are sampled based on this indicator function and conditional averages computed. Prior to computing the indicator function all variables are linearly detrended and a high pass filter is applied to remove fluctuations greater than about 8 km in length. As done is previous studies (e.g. Khalsa and Greenhut, 1985) the thresholds are based on the one-sided vertical velocity variances about zero. Also, no change of state that lasts less than 0.2 sec is allowed.

III. Conditions on 7 July 1987

Four turbulence measuring legs were flown on 7 July 1987 (Fig. 1). The first 50m leg was flown towards the west, followed by a 370m leg just below cloud base and a 580m leg just below cloud top. A leg at 50m was repeated approximately 2 1/2 hours after the first, but shifted to the east because of the movement of the cloud boundary.

The cloud boundary that was the focus of this mission was aligned approximately with the mean wind, making the cross-wind turbulence legs normal to it. The cloud boundary in the measurement region was found to move to the east at approximately 3 ms^{-1}. Each flight leg was divided into cloudy, transition and clear segments. The cloudy region to the east was generally solid stratocumulus, transition had approximately 50% cloud cover and "clear" had only widely scattered small cumulus.

The wind speed at 50m was from 330° and varied from 15 ms^{-1} in the east to 10 ms^{-1} in the west. Sea surface temperature was lower in the east by about 1°C. Momentum flux and sensible and latent heat fluxes at 50m were smaller in the cloudy region. The smaller stress in the east despite greater wind speed implies a smaller transfer coefficient, in accord with the greater stability

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implied by cooler surface temperatures. The sensible and latent heat fluxes in all three regions were much smaller during the second 50m leg.

Another difference between the first and second 50m legs was in skewness which was a factor of two smaller during the second leg in both clear and cloudy regions. At 370m the second, third and fourth moments are all larger in the cloudy region compared to the clear region, probably a result of circulations originating in the cloud layer. In the cloudy region near cloud top the skewness is negative and the kurtosis is 3.6 compared to a positive variance and a kurtosis of 9.5 in the clear region. Negative skewness probably arises from strong sinking motions. The large kurtosis in the clear region is due to the fact that the latter part of the highest leg in the clear region actually penetrated the inversion towards the end of the run (the inversion sloped downward towards the west) resulting a high degree of intermittency in the time series.

IV. Conditional Sampling Results

Conditional sampling results from the four aircraft flight legs in the clear, transition and cloudy regions are shown in Fig. 2. Lines show the vertical variation of conditional averages for updrafts, downdrafts and the environment (i.e. everything that is not updraft or downdraft). The second 50m leg was slightly lower in altitude than the first.

The conditionally sampled vertical velocity (Fig. 2a) for updrafts and downdrafts ranges in magnitude from 0.5 to 1 ms^{-1} except for the 580m level in the clear region. Updrafts leave the surface layer with positive buoyancy but soon begin to decelerate as they entrain environmental air and do work against a slightly stable stratification.

The cloudy region has the smallest 50m magnitudes of w', a consequence of the cooler surface temperatures and therefore weaker buoyant forcing. In contrast, this region has the largest magnitudes of w' at 370m and magnitudes near cloud top exceed those of the clear region by approximately a factor of two, with downdrafts having larger magnitudes than updrafts. This suggests that circulations in the upper half of the boundary layer are being driven by local processes and not surface forcing.

In the transition region the magnitudes of w' at 50m are similar to those in the clear region but w' does not decrease away from the surface. The magnitudes at cloud top are the largest of the three regions. It may be that the vertical motions in this region were driven by both surface and cloud layer processes.

Updraft temperature perturbations (Fig. 2b) are positive at 50m in the clear region and switch to negative above. Downdrafts have negative T' at 50m and slightly positive T' at 370m. A negative value of T' near the inversion in the clear region is somewhat unusual in that downdrafts are expected to contain warm air entrained from above the inversion. However, if entrainment is weak, the downdrafts that are measured will be dominated by cool updrafts that have turned over at the inversion. Further discussion of draft overturning is contained in the next section.

In the cloudy region updraft T' is near zero at all levels except near the inversion where it attains the largest value of any class in all 3 regions. Downdraft T' at this level has the largest negative value of any region. These magnitudes are approximately 50% of the standard deviation in T at this level. The signs of the perturbations indicate that the circulations in the cloud layer are thermally direct and are being driven by processes near the cloud top.

The transition region displays a mixture of properties found in the clear and cloudy regions. For example, updrafts in the first 50m leg have positive T' and a negative T' at 370m, as in the clear region but a negative T' again near the cloud top, as in the cloudy region.

Conditionally sampled absolute humidity perturbations are shown in Fig. 2c. All updrafts are moist and all downdrafts are dry, as expected. Downdraft ρ_v' is nearly constant with height in the cloudy and transition regions whereas it decreases with height in the clear region. As with the T' perturbation for downdrafts near the inversion in the clear region, this is contrary to what would be expected if downdrafts were mainly air entrained from above the inversion. The large ρ_v' perturbations for updrafts in the transition region are also puzzling. To explain these results we have to look in more detail at the nature of the drafts near the inversion.

V. Draft Characteristics Near the Inversion

A greater understanding of the nature of turbulent elements can be gained by further classifying updrafts and downdrafts by their mean temperature and moisture perturbations. In this way we can distinguish, for example, between downdrafts that originate as entrained inversion air and downdrafts that originate as overturning updrafts. In the first case the drafts will be dry and in the second moist. In Tables 1, 2, and 3 the following conditional sampling results from the 580m leg are given: number of events expressed as percentage of total events in each state (up, down or environment); mean draft length; horizontal wind perturbation in the direction of the mean wind; and virtual temperature perturbation. Only the dominant classes which together account for 80-90% of the drafts in each region are given.

In the clear region the significant classes are warm/dry and cool/moist. Entrained air will be warm and dry and will have a positive u' perturbation due to a positive shear across the inversion. Warm/dry events make up 49% of all downdrafts at this height in this region. The most common updraft class is cool/moist. These drafts carry a u' deficit. Both of these classes, warm/dry and cool/moist exist as both updrafts and downdrafts, indicating that drafts can overturn and still remain distinct. Note also that in the clear region the size of the overturned drafts is greater that the originating draft. The u' perturbation is not always preserved which may be a result of vertical momentum being converted to horizontal momentum in the process of overturning. The small mean q' for downdrafts (Fig. 2c) probably results from the compensating effects of dry entrained downdrafts and moist overturned updrafts in the average.

In the cloudy region cool/dry is by far the dominant downdraft class, accounting for nearly three-fourths of all downdrafts. This air has a positive momentum perturbation, indicating it has come from above the inversion, and is negatively buoyant. This entrained air is probably cooled by evaporation of cloud liquid water making the parcel negatively buoyant. Radiative cooling may also play a role. These downdrafts descend to below cloud base, as suggested by the substantial magnitudes of conditionally averaged vertical velocity at 370m. A fraction of the cool/dry downdrafts turn over and are sampled as cool/dry updrafts. These retain, in the mean, the positive u' and negative T_v' perturbations they had as downdrafts.

The dominant updraft class is warm/moist, which has negative u' and positive buoyancy perturbations. The downward flux of mass in sinking parcels produces compensating upward motion, but the conditionally averaged w' for warm/moist updrafts is nearly a factor of two greater than the threshold value used to define the updrafts making it unlikely that this is mere "compensating" motion. Moisture-driven updrafts from lower in the boundary layer may attain a positive temperature perturbation upon reaching the cloud layer as latent heat is released. Overturned warm/moist events are also seen as downdrafts. The portion of the time series not classified as updraft or downdraft, the environment, has equal numbers of the dominant updraft and downdraft classes.

Both clear and cloudy conditions are sampled in the transition region so some of each type of thermodynamic class is represented. Cool/dry is the most common downdraft class, characteristic of the cloudy region. The average negative buoyancy is half that for the cloudy region. Cool/moist events are also present but the sizable positive u' perturbation suggest that they are not overturned surface-based updrafts. The large negative u' for warm/moist events suggests that these have come from below, as conjectured for the cloud region. Even in the environment state warm/moist events have a u' that is an order of magnitude greater than for the other classes. The warm/moist environment class is also distinguished by small mean size which more characteristic of draft states.

Warm/dry downdrafts are also present in the transition region, indicating entrained air that has not mixed with cloud layer air. Warm/dry air makes up over one third of the environment with event sizes over twice as large as for the other classes. This air probably occurs in the region between clouds.

VI. Conclusions and Future Work

A conditional sampling analysis has shown that the properties of updrafts and downdrafts reflect the nature of the forcing of convective motions in the clear and cloudy boundary layers of the 7 July 1987 flight. In the clear region, draft statistics are characteristic of a boundary layer in which convective motions are forced from the surface and entrainment is driven by impinging surface-based updrafts (and perhaps also horizontal wind shear). In the cloudy region, the strongest convective motions are driven by cloud layer processes, apparently evaporative cooling of entrained parcels. If this were strong enough it would lead to cloud breakup. In the transition region there is a combination of clear and cloudy layer processes. Cool/dry downdrafts, which we believe to be the "agents" of cloud-top entrainment instability (CTEI), are more prevalent and more negatively buoyant in the cloud layer than in the transition layer. Thus it is difficult to use CTEI to explain why the transition region was less cloudy that the region to the east. Apparently the cloud layer is maintained through the resupply of moisture from lower in the boundary layer evidenced by the greater number and larger vertical velocity of cool/moist updrafts at cloud base in the cloudy region compared to the transition region.

Further work needs to be done before we have a full understanding of the processes producing the cloud conditions observed on this day. We plan to include cloud liquid water, particle size and ozone in the conditional sampling analysis. A conserved parameter analysis of draft properties will be performed and results compared with the analysis of Betts and Boers (1989) who looked at mean conditions in each region. We will also examine draft statistics for evidence of differences in conditions above the inversion that may have been a factor in determining whether or not a cloud layer could be maintained.

V. References

Betts, A.K. and R. Boers, 1989: A cloudiness transition in a marine boundary layer. *Proceedings of the FIRE Science Meeting,* Monterey, CA, July 1989.

Hanson, H.P., 1988: Plume mechanics and stratocumulus convection. *Proceedings of the FIRE Science Team Workshop,* Vail, CO, July 1988.

Khalsa, S. J. S., and G. K. Greenhut, 1985: Conditional sampling of updrafts and downdrafts in the marine atmospheric boundary layer. *J. Atmos. Sci.*, **42**, 2550-2562.

Randall, D.A., 1988: Fractional cloudiness in shallow cumulus layers. *Proceedings of the FIRE Science Team Workshop,* Vail, CO, July 1988.

Acknowledgments

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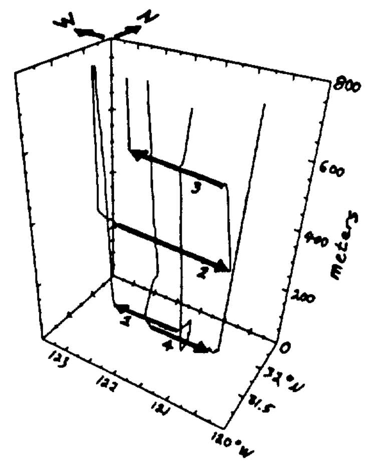

Figure 1. Turbulence flight legs of the NCAR Electra on 7 July 1987.

Table 1

Significant Classes - CLEAR - 580m

	%	(m)	u'	T_v'
DOWN				
warm/dry	49	68	0.18	0.06
cool/moist	38	100	0.00	-0.08
ENVR				
warm/dry	42	214	0.05	0.06
cool/moist	50	178	-0.06	-0.05
UP				
warm/dry	30	96	0.03	0.06
cool/moist	51	63	-0.18	-0.08

Table 2

Significant Classes - CLOUDY

	%	(m)	u'	T_v'
DOWN				
cool/dry	74	78	0.12	-0.06
warm/moist	20	45	-0.24	0.04
ENVR				
cool/dry	46	121	0.10	-0.05
warm/moist	46	124	-0.10	0.05
UP				
cool/dry	22	67	0.26	-0.05
warm/moist	65	79	-0.18	0.07

Table 3

Classes - TRANSITION

	%	(m)	u'	T_v'
DOWN				
cool/dry	38	72	0.10	-0.03
cool/moist	26	57	0.18	-0.07
warm/dry	25	76	0.00	0.06
warm/moist	11	39	-0.23	0.09
ENVR				
cool/dry	23	167	0.03	-0.02
cool/moist	34	172	0.04	-0.04
warm/dry	23	412	0.02	0.02
warm/moist	20	68	-0.30	0.06
UP				
cool/dry	24	49	0.49	-0.04
cool/moist	34	54	0.04	-0.07
warm/dry	6	26	-0.05	0.06
warm/moist	36	79	-0.46	0.11

Tables. Conditional sampling statistics for thermodynamically classified events in the clear (Table 1), cloudy (Table 2), and transition (Table 3) regions. Data is from the 580m leg. The variables given are: *number of events expressed as a percentage of the total number of events in each state (updraft, downdraft, environment), the mean event length in meters, and the along-wind velocity perturbation in m/s, and the perturbation virtual temperature in °C.*

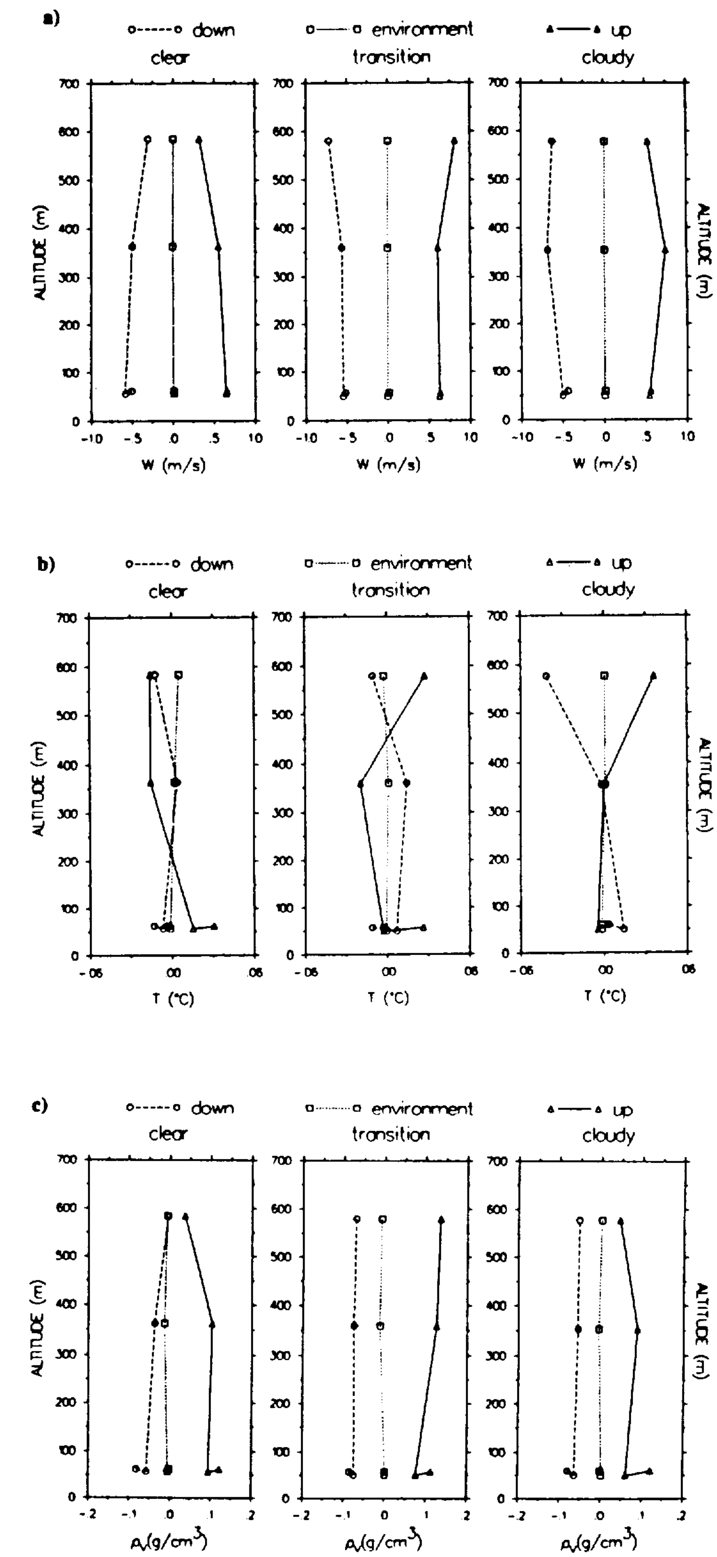

Figure 2. Vertical variation of conditionally sampled a) vertical velocity, b) temperature and c) absolute humidity from the four turbulence flight legs shown in Figure 1. Statistics were computed separately for the clear, transition and cloudy segments of each leg.