Air Movements Above Large Bush-Fires

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INTRODUCTION

IN December 1969 the Forests Department of Western Australia arranged a series of three intense fires in an uninhabited forest area, in order to investigate some of the meteorological factors involved in the development of an uncontrolled wildfire. Members of the CSIRO Fire Research Section, with the help of Mr. R. J. Taylor of the CSIRO Division of Atmospheric Physics, collected records from a number of observation points nearby, and also carried out measurements in an aircraft which flew near and through the smoke columns produced.

During each of the three fires the fuel quantities consumed were approximately 50,000 tons, the areas burnt being about 7,500 acres in extent. All the fires were lit from the air with small incendiaries, and maximum burning rates were about 30,000 tons of fuel per hour. In the hottest fire convection went to nearly 15,000 feet, and strong inflow of air, all around the fire perimeter, was evident.

It is estimated that the total volume of air entrained in the convection column of each of the three fires was more than 100 cubic miles. In addition, it was observed that there was a large increase in con-

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vective activity as this air, which contained appreciable amounts of moisture, rose to condensation level and latent-heat was released. Indeed, the atmospheric circulation induced by the fires was somewhat similar to that of a severe thunderstorm (cf., Taylor and Williams 1967, 1968).

EVALUATION OF RESULTS

Full details of the measurements have been reported elsewhere (Taylor, Corke, King, MacArthur, Packham and Vines, 1971) but they will be briefly reviewed here. Let us consider, first of all, a relatively simple situation as found in one of the large-scale aerial prescribed burns which are now a routine matter in Western Australia.

The air in the smoke plume of one of these burns is, of course, hotter than the air outside, and Figure 1 shows a typical series of measurements, (cf., Taylor, Bethwaite, Packham and Vines, 1968). The temperatures of clear air at A, the upwind edge of the fire, and

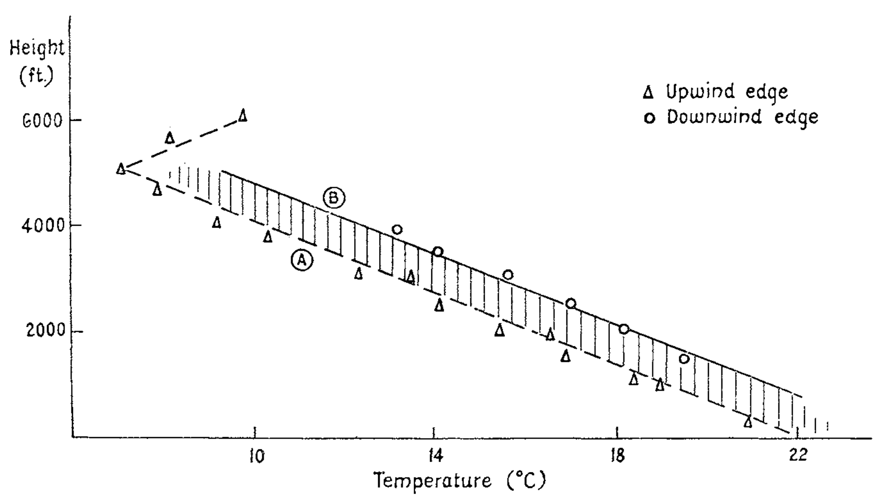

FIG. 1. Temperature measurements in the air above a typical prescribed-burn in Western Australia.

at B the downwind edge, are as indicated. The extent of the shaded area between A and B is related to the burning-rate of fuel on the ground; and, in fact, at any given time the rate at which heat in the smoke column is being blown away by the wind can be equated to the total rate of heat evolution on the forest floor. Along each centimeter width of the burning forest-block the two estimates of heat dissipation are as in Table 1, and the agreement between both methods of calculation is surprisingly good. Results are given for four separate fires.[2]

TABLE. 1. TYPICAL RESULTS FROM PRESCRIBED BURNS IN WESTERN AUSTRALIA (CF., TAYLOR, BETHWAITE, PACKHAM AND VINES, 1968.)

Fire	Heat in Smoke Plume (Cal. cm. $^{-1}$ min.$^{-1}$)	Heat from burning fuel (Cal. cm. $^{-1}$ min.$^{-1}$)
1	1.9×10^6	1.7×10^6
2	1.8 "	1.4 "
3	0.7_5 "	0.7 "
4	0.6 "	0.6_5 "

However, similar calculations for the very large fires referred to in the Introduction did not give such a simple answer. This may be seen in Figure 2, where the line AB shows the environmental temperature distribution in the atmosphere on a day when convection from one of the large fires went to a height of almost 10,000 feet—well above condensation level. The warm air rising above the fire cooled at the dry adiabatic rate (i.e., along the line EF), but beyond condensation level the cooling rate was less (along FB, the saturated adiabatic). It is evident that the air above the fire rose no further than B, the top of the convection column, because at this height it was in temperature-equilibrium with its surroundings. If we think of Figure 2 as representing the storage of heat in the atmosphere, the area enclosed by the lines AB and EFB is a measure of the total heat-input of the fire to the air above. However, when the calculation is

[2] The figures in the 2nd column of Table 1 are larger than those reported previously (Taylor et al. 1968): subsequent work suggests that these earlier values were too low.

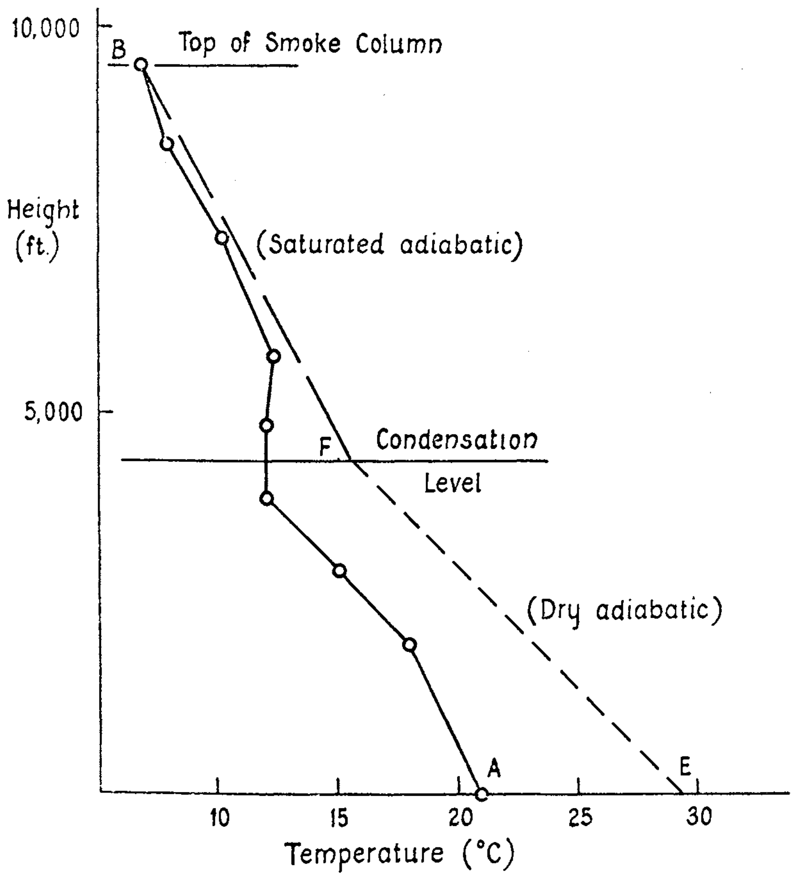

FIG. 2. Temperature structure in the atmosphere during one of the large experimental fires in Western Australia.

made, the heat estimated in this way is found to be less than that supplied by the burning fuel by a factor of almost 3; and this is because no allowance has been made for the entrainment of air.[3]

In view of this disagreement, air-entrainment was obviously very

[3] By "entrainment" is meant any dilution of the smoke column with environmental air, whether this occurs by inflow, turbulent-diffusion or by mixing of the column in the prevailing winds.

large in these intense experimental fires. Indeed, as has been mentioned already, the results suggested that the total volumes of entrained air were more than 100 cubic miles for each of the three fires. Furthermore, since this air contained appreciable quantities of moisture —in addition to the smaller amounts produced by the fires themselves—latent-heat was released when the rising air reached condensation level. This led to a large increase in convective activity: and in the hottest of the three fires the effect of the heat so evolved was almost as great as that produced by the burning fuel. In other words, had there been no condensation of moisture in the convection-column, it would have been necessary to burn an additional 40,000 tons of fuel on the ground, to produce the effects observed.

THE DARWIN FIRE

Although the experiments in Western Australia showed entrainment of air to be an important factor in determining the behaviour of convection columns, another important feature was evident during a large fire in the Northern Territory. This, too, was an experimental fire, which was purposely lit to clear the floor of a future reservoir for the city of Darwin. Fuels, covering an area of almost 10,000 acres, were mainly dense, dry grass and the trunks of felled trees. The maximum burning-rate was approximately 40,000 tons of fuel per hour—significantly higher than for the Western Australian fires.

The detailed results of the Darwin fire have been discussed in a recent paper (Taylor, Evans, King, Stephens, Packham and Vines, 1973). The overall behaviour observed was similar to that in the earlier fires, and the general level of convection was to about 10–12,000 feet: calculation shows that this is explicable on the basis of the earlier results. However, when the fire was at its peak (cf., Fig. 3) a short-lived tower climbed very rapidly to beyond 19,000 feet, and this can only be explained if the rate of ascent was so great that dilution of the plume, by mixing with surrounding air, was then substantially reduced. Such a reduction in mixing seems more than likely, for it was observed that the convection-column rose sufficiently fast to act, effectively, as a barrier to the prevailing winds.

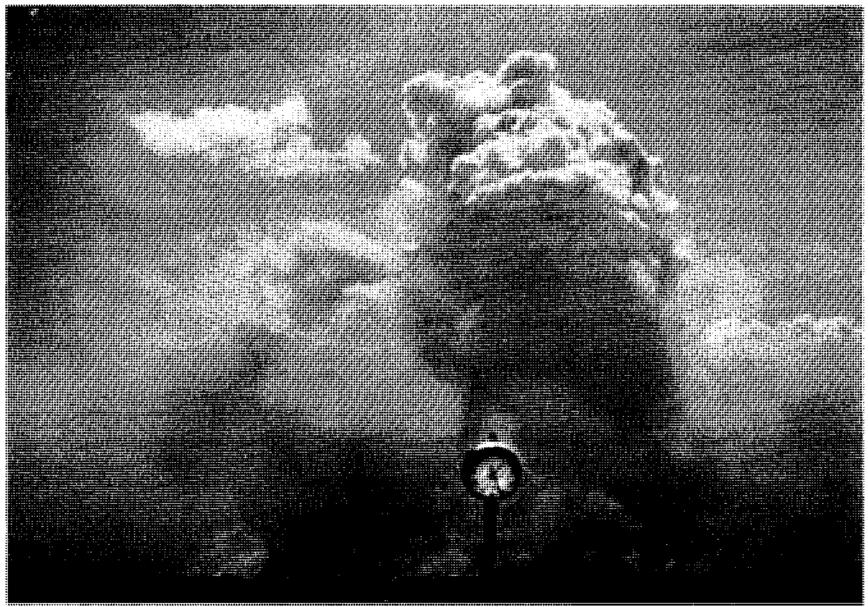

FIG. 3. The Darwin Fire close to peak-activity. This photograph was taken from a distance of about 10 miles, and shows the towering ascent (to a height of $>$ 19,000 feet) and the general level of convection at 10 — 12,000 feet.

Reexamination of the results from Western Australia showed this same effect to be apparent in the hottest fire there,—though on a smaller scale. And it is significant that, during both this fire and the Darwin fire, the atmosphere was conditionally unstable,—for convective activity would be enhanced under these conditions. It is also significant that the effect was more pronounced as fuel-burning-rates increased.

SUMMARY

The behaviour of the convection column above a large fire is thus characterized by (1) marked inflow of air at the lower levels, and (2) rapid ascent of hot air at the higher levels, whereby mixing

with the surrounding atmosphere is reduced. The height to which the plume will rise is dependent upon the burning-rates of fuels on the ground, and the stability of the air above the fire. In addition, latent-heat effects, resulting from the condensation of moisture in the ascending column, will also lead to greatly increased convective activity.

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