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NEW ZEALAND METEOROLOGICAL SERVICE

TECHNICAL INFORMATION CIRCULAR NO. 131

WEATHER PARAMETERS ASSOCIATED WITH FIRE BEHAVIOUR AND CONTROL

The following paper was presented by Mr E.G. Edie at the Annual Meteorological Conference, Wellington, October 1968. It is reproduced for general information.

TIC 131

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21 April 1969.

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Introduction

Weather is of decisive importance in the ignition and spread of fire in the open, and in recognizing the vital nature of a fire weather service for the protection of forest in New Zealand, a brief review is given of some known relationships between certain weather parameters and fire behaviour.

Some effects are more obvious than others. For example, both rain and humidity strongly inhibit the spread of fire, but the effect of humidity is perhaps more subtle. Typical wild-fire fuels are so strongly hygroscopic that they can quickly absorb moisture from very dry air. Thus a change in relative humidity from 5% to 25% has a very prompt and pronounced effect in inhibiting fire, though 25% is still a very low value, and other factors may be of considerable importance.

A strong wind is as important as moisture. It speeds up the burning rate and spread by several mechanisms. It speeds the burning rate by supplying oxygen to the fire at an increased rate. It helps the heating of fuels in several ways, namely, by carrying hot gases ahead of the fire front, by increasing radiation heating of fuels ahead of the front, tilting the flame forward over the fuels, by drying out fuels, and by carrying fire-brands ahead of the fire-front, starting new fires (spotting).

Other weather elements are also important. For example, high air temperature preheats fuel, thereby speeding up ignition, and unstable lapse rates favour burning, presumably in two ways, (i) by increasing low level winds and gustiness and (ii) by increasing upward speeds over a fire, which in turn increases the induced horizontal inflow. Cloud cover, too, is often cited as an important weather parameter, but the effect is only indirect, for we know that stratiform cloud usually accompanies a stable lapse rate, and cumuliform cloud an unstable lapse rate.

The simultaneous occurrence of an unstable lapse rate and low wind favour the very dangerous phenomenon of the "blow-up" or the city fire storm. An example of the latter being the great holocaust, which took place in the city of Hamburg during World War 2, where as a result of an Allied bombing raid, tornadic effects developed with circulating winds of over 100 knots.

The "blow-up", in the forester's language is a sudden increase in fire intensity, or rate of spread. This may range from an actual explosion of hot gases to a fire merely burning out of control, and, as often as not, is accompanied by violent convection, and may have other characteristics of an atmospheric storm.

Other weather factors of a more long-term importance are the pre-fire seasonal weather conditions such as periods of drying winds, periods of favourable pre-season growth of potential fuels, and periods of snowfall. These are not dealt with here, though they are most note-worthy of mention and study.

FIRE POLICY OF THE NEW ZEALAND FOREST SERVICE

The policy virtually follows from the premise that fire is the greatest single menace to forests and protection vegetation in New Zealand, for within a few hours, fire can undo the work of many years in building up a soil and vegetation balance.

The fire risk in New Zealand cannot be measured by comparing the generally adequate and well-distributed rainfall experienced in most districts with conditions in countries where droughts are frequent and severe, and the summers normally hotter and drier. New Zealand is a mountainous country and the characteristic high wind and strong sunshine will dry out the forest vegetation on exposed situations, even in the heavy rainfall areas, in a remarkably short time.

Although widespread dangerous fire-conditions occur only infrequently, there are few seasons during which there are no dry spells or partial droughts in some part or other of the country, and very high fire hazards develop. The peculiar feature of many New Zealand forest species in being very exacting in their requirements for regeneration to take place, is of special importance. Forest fires in most countries mean the loss of a crop, but in New Zealand, a severely burnt forest usually means a destroyed forest. Even the beech species, which will regenerate freely under favourable conditions, can do so after a severe fire, only under circumstances, which are often quite fortuitous in character. Virgin mixed temperate forests, admittedly, do not burn readily under normal seasons, but the greater proportion of the remaining forests of this type, have been logged for commercial species, and as cut-over forests, they are very inflammable, and when burnt, become waste lands.

The consequences of the relatively small fires which occur all over the country every normal season are as serious in the long run as the spectacularly large fire common in some countries. The losses are cumulative, because most of our forest species lack the powers to recuperate from fire damage.

The provision of a fire hazard prediction and warning service is an essential function of the fire protection organisation. Here in this country, there is a wide network of "fire weather" and radio stations. The fire-hazard situation in any part of the country is known at Head Office of the Forest Service in Wellington each day during the fire season, (October to April,) within an hour of the weather observations being taken at the station. This enables appropriate action, such as advice to fire authorities and broadcast of warnings, to be taken.

WEATHER FACTORS INFLUENCING THE INCIDENCE OF FIRE AND FIRE BEHAVIOUR

The list of factors which affects fire behaviour is large, and would make it appear that the problem of forecasting fire behaviour in the field would be extremely difficult. Fortunately, this is not the case, and it is possible to forecast the behaviour of low intensity fires with a reasonable degree of accuracy.

The following is a list of the <u>main</u> factors affecting fire behaviour:

(1) Fuel moisture

(2) Wind velocity

(3) Fuel quantity

(4) Fuel size and arrangement

(5) Slope of terrain

(6) Atmospheric instability

A full discussion of these factors is not given here though some further reference to the meteorological parameters is made below. Three factors which must be considered to determine whether a fire will go out, smoulder or burn with increasing intensity are:

(1) The quantity of heat required to raise the temperature of the fuel to the ignition point.

It has been stated that for dead vegetation that makes up the bulk of forest fuels, ignition does not normally take place until the temperature of the fuel is raised to the neighbourhood of 280°C. Complete combustion of dry wood yields approximately 4,500 calories per gram, and even when free surface water and bonded moisture in the fuel is taken into account, there is found to be more than sufficient heat to maintain combustion.

(2) The efficiency with which heat of combustion is transferred to adjacent fuels.

This is a problem on emissivity and radiation, which is beyond the scope of this survey.

(3) The rate at which oxygen is available for combustion.

This factor involves the effect of wind and the influence of water vapour from the fuels on flame.

A relation between fire behaviour and relative humidity is given in Table 1.

TABLE 1

Relation between fire behaviour and relative humidity

Relative Humidity	Fire Behaviour
Over 60%	Fires will not spread
50 - 60%	Fires spread slowly in favourable materials
40 - 50%	Fires begin to pick up
30 - 40%	Fires gain headway and may spread rapidly
Below 30%	Fires may go beyond control
Below 25%	Crown fires develop

From the Table, one is able to see that around 40% relative humidity or approximately 15°C dewpoint depression, we have a critical condition, and to answer the question as to what time lag one can expect between a change in relative humidity and a corresponding change in fuel moisture content it has been stated that for finely divided fuels, the equilibrium lag is of the order of two hours.

However, to interpret relative humidity fully in terms of inflammability, it is necessary to know the kind of fuel, its present moisture content, its exposure, the ambient temperature, the rate of evaporation, and the wind velocity.

Turning now to air temperature - an obvious parameter because of its influence on the capacity of the air to hold moisture. For example, air at 16° C(60°F) and 50% R.H. when heated to 33°C (90° F) reduces the R.H. to 19% - a dangerously low level. However, a rather poor correlation has been found to exist between temperature and the occurrence of fires, although investigators admit that fires are seldom associated with air temperatures below 10°C(50°F). Fuel temperatures bear some relation to air temperature, but insolation is much more important, and again we have the indirect effect of air temperature on fire behaviour, through thermal turbulence. Convective activity is usually at a maximum on hot days, thus favouring fire development by facilitating the removal of combustion products.

Mention was made earlier of the effect of wind on fire behaviour, but there is another important aspect to be borne in mind. Fire moving under the influence of wind does not maintain a uniform front in the form of a long straight line or rounded curve, but rather as a number of sharp arrow-shaped heads in which the fire intensity is a maximum, and a major fire would have several such heads. It is seen, then, that wind direction becomes an important factor. From the point of view of fire control, and the protection of fire-fighters and equipment, wind direction is always uppermost in the minds of fire-controllers determining fire-fighting strategy.

The meteorologist providing a fire warning service must therefore always be alert to the probability of wind change. Some causes of this which come immediately to mind, are frontal wind shifts, seabreeze developments, thunderstorm downdraughts, up-slope and down-slope winds, mountain and valley winds.

STABILITY

It is common knowledge that fires tend to undergo a pronounced change in behaviour towards evening. The damping down effect is usually explained in terms of higher relative humidity, which accompanies the cooling in the lower layers. However, Byram and Nelson (1951) considered that "it is possible that an increase in stability of the air may have as great or greater influence on fire behaviour than a combination of increased fuel moisture and decreased fuel temperature. Conversely, a decrease in atmospheric stability might be expected to have an opposite effect on fire behaviour. In point of fact, the exact role of stability is not clear".

Some case studies have indicated that an unstable atmosphere with its accompanying thermal turbulence was associated with severe fires. However, other studies, have shown that severe fires were also occurring at night, when the air was stable. In addition, many fires do not build up to a high fire intensity during the afternoon hours, when instability is presumably greatest.

It appears then that the most significant effects of the atmospheric stability conditions on fire behaviour appear to be indirect, in that they operate through the wind profile.

TYPES OF FOREST FIRE

Fires fall into two broad classes:-

(1) those whose behaviour can be predicted with reasonable accuracy taking account of terrain and weather factors, and

(2) those whose behaviour is erratic and anomalous.

The majority of forest fires are of type (1) with a low intensity seldom exceeding 1000 BTU per sec per foot of fire front, while in contrast, fires of type (2) are of high intensity and are usually large and very destructive, the terms "blow-up" and "conflagration" being commonly applied to them. The intensity of "blow-up" fires can reach 20,000 to 30,000 BTU per sec per foot of fire front.

Associated with this contrast in energy output, there is a similar contrast in the geometry of the two types of fire. The former is essentially 2-dimensional, the depth of the convective activity over the fire being restricted and of the order of some tens of feet. The "blow-up" fire, however, is 3-dimensional in nature, the vertical structure extending to many thousands of feet. Occasionally a large "blow-up" fire may reach an energy output comparable with that of a thunderstorm.

Byram has studied in some detail the relation between wind structure and fire behaviour. His treatment of forest fire behaviour entails the study of the rate of energy flow in the wind field over the fire, in comparison with the rate at which heat is converted into kinetic energy in the convective column, and introduces two energy-criterion equations which determine the conditions under which a fire will be

(a) a forced-convection system dominated by the energy of the wind,

or (b) a free-convective system dominated by its own energy.

Reference to his studies on this subject can be found in the bibliography cited in the Manual of Meteorology. Brief mention is made below of Byram's work showing the importance of the wind speed/height profile in connection with the behaviour of large fires.

Fig. 1 shows examples of ten types of wind profile he studied. It will be noted that a feature of almost all of the profiles is the low level jet-subsidiary maximum in the wind speed occurring below about 5000 ft. Byram states that "the most consistent feature of the wind field associated with extreme behaviour is the low-level jet. The depth of the layer can range from 1000 ft. to 8000 ft. or more. Extreme fire behaviour is associated with low-level jets at a height of 1500 ft. or less above the fire."

Type (1a) is associated with probably the most dangerous type of fire that can exist from the standpoint of personal safety and erratic and unpredictable behaviour. Fortunately, it is one of the less frequent types, but if fuel is dry and plentiful, large whirlwinds (possibly up to 500 ft. or more in diameter) may form in the head of a fire and even travel out ahead of the fire on to fresh fuels.

A towering convective column is almost certain to form as the fire becomes larger. This can happen in a matter of minutes if the fire burns into heavy fuel.

Type (1b) is associated with fires whose behaviour is similar to those associated with (1a). They are not as serious. When the lower air layers cool and stabilise in the late afternoon, the surface wind drops and this type develops into the "safe" Type (4a).

Type (2a) may occur with the next most dangerous types of fire to those associated with Type (1a). It may develop either during the day or night, but is more likely to occur at night or early afternoon. It is more serious in rough or rolling country, where a considerable part of the forested terrain may have an elevation approximating that of the jet-point, which usually moves upward as the lower air cools and stabilises. During the early part of the night, therefore, the terrain between 1000 ft. and 2500 ft. above the general land level will be somewhere in the neighbourhood of the jet-point. In addition, the wind speed at the jet-point increases, when the cooling of the lower air layers diminishes the frictional drag at the earth's surface and the surface wind drops.

This is a somewhat different picture from that which we normally have of wind structure, and on nights when such a profile exists, it seems that the conditions are favourable for the so-called "blow-up" to occur. It is usual to think of the strong steady winds as blowing at the higher levels and gradually diminishing with height into the lower level areas. Just the reverse seems often to be true.

On the worst nights, the higher mountains may have little wind, and the strongest winds will be down in the low country. Also, the gain in wind speed at 1000 to 2500 ft. level seems to build up from below, not above.

Type (2b) resembles (2a) except that the wind speeds are higher. Not much is known about the fire behaviour in this circumstance, except that it undoubtedly is dominated by the wind, whose rate of flow of kinetic energy is most often greater than the rate at which heat is converted to kinetic energy in the convective column above the fire. But if and when this is not so, the stage is set for the explosive convective fire of fire whirlwinds.

Types (3a, 3b, 3c) have similar speed profiles, but the behaviour of fires in each circumstance is quite different. Strong winds at high levels exist, but there is a layer of 2000 ft. or so of lesser winds above the jet-point. It depends on the strength of convective activity as to whether the column can project through the jet-point layer and reach the faster higher level winds and produce spotting. Little is known about type (3c).

Type (4a) is the most common type of all. Fires can be intense and fast-spreading but are not considered dangerous to experienced fire crews. Rapid increase in wind should keep active columns from forming.

Type (4b, 4c) give probably "safe" conditions, as long as wind speed at the jet-point remains below about 15 m.p.h. One important exception is the case of fire burning up-slope roughly in the same direction as that of the wind. The effect of slope is equivalent to adding several miles per hour of wind in the lower layers, and so this type (4b) or (4c) may convert into the type (2a) associated with dangerous conditions. This is why a fire can range up-slope, build a tremendous convection column in so doing, and then quickly die down again (unless perhaps it spots over to the bottom of the next slope).

Types(4b) and (4c) can also develop into Type (1a), through an increase in wind speed in the lower atmosphere during the afternoon, or possible into Type (2a) in the late afternoon or early evening, when the surface winds drop with cooling and a corresponding increase in wind occurs at 100 to 250 ft. above the general ground level.

FIRE WEATHER PREDICTION

For fire control purposes, forecasts are of two types, (i) large area forecasts - (areas of the order of 100 miles square) of wind, precipitation and temperature, and where possible the diurnal rise and fall of temperature and of relative humidity, and (ii) forecasts of these and other elements for areas of the order 2-10 miles square.

The New Zealand Weather Broadcasts cover the large scale forecasts, and on the small scale, the Head Office of the Forest Service is provided with forecasts for local forest areas during burning-off operations. These latter require an intimate knowledge of the topography and local meteorology of the areas involved, and in mountainous areas especially, small scale weather may differ very significantly from the large scale. Humidity may differ by factors of 2 or 3, temperature by 20 or 30°F., and wind direction by 180° depending on elevation and location with respect to topography. The causes of such variations relate to the barrier effects of hills and mountains on the airflow and to such effects as heating and cooling of slopes and valleys.

In general, small scale weather is much less understood than large scale and some research and systematic observation should be directed to this field if meteorologists are to make an effective contribution to the management of the forest resources in New Zealand.

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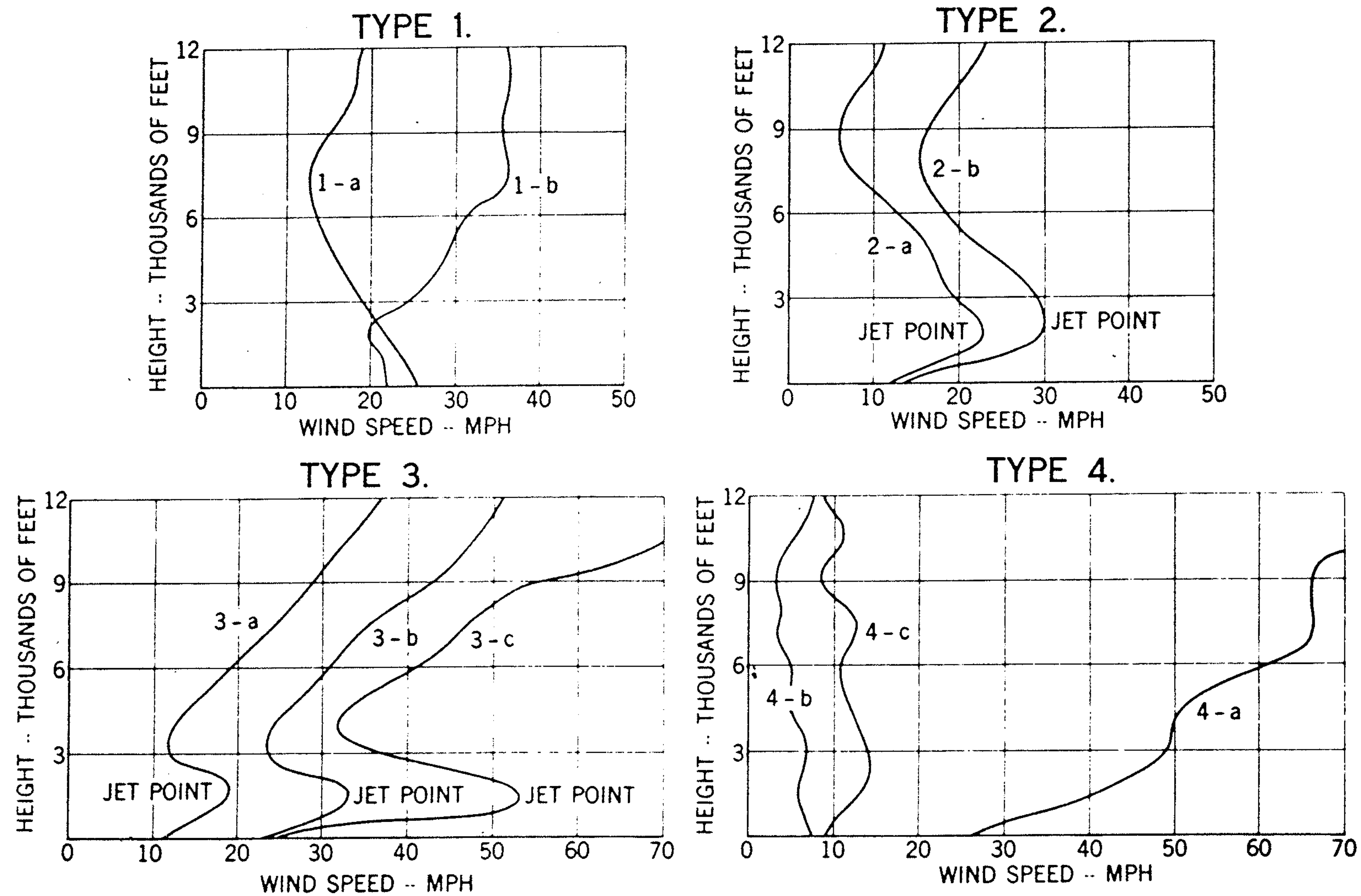

FIG .1 Byram's wind speed profile types.