Wind flow profiles over pine plantations

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1 Introduction

1.1 Context

This paper responds to a request from the secretary of Research Working Group 6 (RWG6) of the Australian Forestry Council to prepare a paper on 'wind flow profiles over pine plantations' for the July 1990 meeting of RWG6.

1.2 Literature

Baughman (1981) produced a bibliography of items that deal with wind speed and its relation to forest fire behaviour studies. This was updated by conducting a literature search of Meteorological and Geophysical Abstracts using the key words 'wind profile' and 'pine'. This yielded only ten entries. (Appendix 1). The reason for this is:

i) most of the work on wind profiles in forests has been done in forests other than pine;

ii) present scientific interest is in the turbulence characteristics of the wind, rather than in a study of the wind profile.

The criteria for the literature search were increased by using the key words 'wind' and 'pine'. This increased the number of entries to 42, which are also given in Appendix 1.

2 Winds over forests

The near-surface mean wind, \( u \), under neutral conditions can be described by the logarithmic wind profile during neutral stability:

\[
\frac{u}{u_s} \ln \left( \frac{z - D}{z_o} \right)
\]

where \( z \) is the height above ground, \( z_o \) is the roughness length, \( D \) is called the zero plane displacement, \( u_s \) is the friction velocity - also known as the shear velocity - and \( k \) is von Karman's constant which has a value of 0.4

The roughness length, \( z_o \), over land is related to the height above ground, \( z \), and the spacing of obstacles on the ground. Measurements show that \( z_o \) varies from about 0.1m over ice or water to several metres over cities or tall forests. It is a measure of the efficiency of momentum transfer into the ground. Tables, each with slightly different representative values of \( z_o \), may be found in most modern meteorological textbooks.

Attempts have been made to relate \( z_o \) to obstacle heights. If the mean height of the roughness obstacle is \( h \), then the form \( z_o = c h^a \) has often been assumed. Pueschke (1937) obtained \( c = 4/30 \) and \( a = 1 \). Kustas and Brutsaert (1987) point out that similar values for \( c \), close to 0.1, have been found by many others, especially for dense surfaces with vegetation. Jarvis et al. (1976), in a review of coniferous forests, reported values of \( z_o/h \) for 15 stands that varied between 0.02 and 0.14; the mean and standard deviation being 0.076 ± 0.047. This is smaller than the oft-quoted 0.1 which seems to be more appropriate to fab crops. Shuttleworth (1989) notes that the two can be reconciled if \( z_o = (h - D)/3 \).

As \( z_o \) represents eddy size at the surface, it must depend not only on obstacle height, but also on the shape and spacing of surface features. Lettau (1969) proposed that \( z_o/h = c \lambda \) where \( c \) is a constant, and \( \lambda \) is the roughness density defined as the ratio of i) the silhouette area of the average obstacle (i.e. the area transverse to the wind direction) to ii) the area taken up by an average individual obstacle. (i.e. divide the total ground area occupied by the obstacles by their number). Lettau (1969) proposed \( c \lambda = 0.5 \), but subsequent work found that \( c \lambda \) still varies with roughness element shape. Wooding et al. (1973) obtain
\[ \frac{z_o}{h} = \lambda \left( \frac{h}{s} \right)^{0.4} \]  \hspace{2cm} \text{(2)}

where \( s \) represents the streamwise (i.e. horizontal, parallel to the flow) dimension of the roughness elements. This formula is akin to that cited by Justus (1985: p.924) namely

\[ z_o = 0.056h^{1.37} \]  \hspace{2cm} \text{(3)}

Garratt (1977) graphed the results of these studies, as shown in Figure 1. This indicates that \( z_o/h \) can only be described by a power law in \( \lambda \) over a restricted range. At high values of \( \lambda \) (i.e. elements closely packed), \( z_o/h \) is small.

2.1 Zero-plane displacement (D)

The ratio \( D/h \) is less sensitive than \( z_o \) to the nature of the surface. For natural crop-covered surfaces \( D/h \) ranges from about 0.64 to 0.68. A number of authors treat \( D = (2/3)h \) as representative. Jarvis et al. (1976) found that for the coniferous forest that they reviewed, \( D/h \) ranged from 0.67 to 0.92 with a mean and standard deviation of 0.78 ± 0.09. This value is significantly larger than the 2/3 normally quoted. Shuttleworth (1989) suggests that it probably reflects the longevity of forest stands, and the ensuing tendency to have more foliage near the top of the canopy.

The best way of determining \( z_o \) and \( D \) for a particular forest or stand is to collect vertical wind data under neutral conditions well above the canopy and optimise Eq. 1. More recently, Lo (1990) has suggested that it is possible to estimate \( z_o \) from wind profiles in and above a forest canopy. Alternative procedures that speculatively assign physical significance to \( D \) (Mollon & Moore, 1983) are controversial (Lo, 1990), as discussed in section 4.2.

2.2 Atmospheric stability and instability

There are many different ways of characterising the stability of the atmosphere. Near the earth’s surface, the atmosphere will be unstable whenever there is an upward flux of sensible heat, \( F \). The ground is then potentially warmer than the overlying air and parcels of buoyant air are carried upwards. If the wind is strong, then conditions tend towards neutral stability in which air parcels have neither upward nor restoring forces on them. At night, with surface cooling, the atmosphere is stable and a displaced parcel of air tends to move back to its original position.

Atmospheric stability affects the mean wind profile. The Monin-Obukhov similarity theory implies that the formula for the vertical wind shear \( du/dz \) obtained from Eq. 1 is modified so that

\[ \frac{du}{dz} = \frac{u_*}{k(z-D)} \Phi \left( \frac{z-D}{L} \right) \]  \hspace{2cm} \text{(4)}

where \( \Phi \), which is a measure of stability, is a function of \( L \), the Monin-Obukhov length. For a neutral atmosphere, \( L \) is infinite and \( \Phi \) is unity. For unstable air (for which \( L \) is negative), the Businger-Dyer form is used for \( \Phi \)

\[ \Phi = \left( 1 - 16 \frac{|z-D|}{L} \right)^{0.25} \]  \hspace{2cm} \text{(5)}

whereas for stable air (for which \( L \) is positive) the Webb (1970) form is used

\[ \Phi = 1 + 5 \frac{(z-D)}{L} \]  \hspace{2cm} \text{(6)}
If we neglect atmospheric moisture effects then the Monin-Obukhov length is

\[ L = \frac{\mu^4 c_p \rho T}{k g F} \]

...(7a)

where \( c_p, \rho, k \) and \( g \) are the isobaric specific heat of air, the air density, von Karman’s constant and the acceleration due to gravity respectively. Substituting the known values for these parameters (in SI units) the Monin-Obukhov length (in metres) evaluates to

\[ L = -\left(\frac{10^6}{11}\right) \frac{u^4}{F} \]

...(7b)

where \( F \) is the sensible heat flux (in W m\(^{-2}\)) and \( u \) is called the friction velocity (or shear velocity, in units of m s\(^{-1}\)).

2.3 Stability class and stability category

The air-pollution community characterises atmospheric stability in terms of broad classes designated A to G (the Pasquill stability category), or 1 to 7 (the P class). Figure 2 reproduces an informative diagram from Beer (1990) showing how these relate to upward heat flux and wind speed. Basically, category A (class 0 to 1) is the most unstable, category D (class 3 to 4) is neutral stability, and class G (category 6 to 7) is the most stable.

2.4 Validity

Garratt (1980) found that the logarithmic profile is not established until about 4.5\( h \) - the exact value depends on \( \lambda \), the roughness density and can range from 3\( h \) to 8\( h \) (above the zero-plane displacement). Conversely, the logarithmic profile is valid up to a height about 1/10 of the planetary boundary layer depth. Thus it is valid up to about 100m during daytime. The similarity form of the near-surface wind profile is suspect when

1) the anemometer height is less than 5 times the vegetation height (Garratt, 1980)
2) \(|(z-D)/L| > 2\) in the unstable case
3) \((z-D)/L > 1\) in the stable case.

Condition 2 is probably the least serious as is there is evidence that the Businger-Dyer form can be useful for larger values of \(|(z-D)/L|\) (van Ulden & Holtsg, 1985)

3 Winds inside forests

There is considerable variation in the wind speed inside the forest. This arises from a number of causes including the character, orientation and spacing of the trees and their canopies, and the turbulence generated by the canopy itself. This last point can be especially noticeable in light wind conditions. Lo (1990) quotes a finding that when smoke puffs are used to investigate air flow in a forest there is little correlation between wind directions above and below the crown at low wind speeds. The direction of flow within the canopy is sometimes opposite to that of the wind above it.

Figure 3 is taken from the classical work of Geiger (1965). It shows the wind profile in a thin fir stand in Bavaria under three different wind speeds and illustrates that air movement is less restricted in a trunk area free of branches – particularly when the wind can blow in through the open borders of the stand. The presence of a uniform vertical wind speed, as shown for low wind speeds, can only be accomplished by turbulent mixing. Fig. 3 also shows the development
of a thin shear layer near the ground where the wind speed drops to zero. Oliver (1971) measured wind speed profiles in a mixture of Scots and Corsican Pine, and obtained a mean wind profile similar to that of Geiger’s 2 m/s profile.

Since Geiger’s time it has become standard to present the plot of mean wind at a height $z$ within and under the canopy in terms of non-dimensionalised variables, $z/h$ and $u_*$ and $u_h$ where $h$ is the mean canopy height, $u_*$ and $u_h$ are the mean wind speed at heights $z$ and $h$ respectively. Fig. 4 reproduces the plots of Fritschen (1985) who use them to show how various vegetative canopies alter the mean wind profile.

### 3.1 Theory

There are various theoretical attempts to explain the vertical profile of the mean wind. The wind stress is given in terms of the friction velocity, $u_*$, or the drag coefficient $C_d$ by

$$ \tau = \rho u_*^2 = \rho C_d^2 u^2 $$ \hspace{1cm} (8)

which has a constant value for any particular value of $u$. The term $\rho$ represents the density of the air. Near, and within, the canopy Eq. 8 will no longer be adequate. In the simplest approach, the stress divergence in the air, $\partial \tau / \partial z$, is assumed to balance the foliage drag per unit volume of air, $D_N$, so that:

$$ \frac{d\tau}{dz} = D_N $$ \hspace{1cm} (9).

In practically all derivations it is further assumed, firstly that the shear stress is proportional to the velocity gradient. This assumption is generally called the K-theory approach because the proportionality constant, which is known as the eddy viscosity, is represented by the symbol $K$:

$$ K = \frac{(\tau / \rho)}{(du/\partial z)} $$ \hspace{1cm} (10)

and secondly that $D_N$ is proportional to $u^2$ in an analogous manner to $C_d$

$$ D_N = A_f C_N u^2 $$ \hspace{1cm} (11)

where $A_f$ is the surface area (both sides) of leaves per unit volume of air, and $C_N$ is a foliage drag coefficient. $A_f$ is related to the leaf area index

$$ LAI = \frac{1}{2} \int A_f dz $$ \hspace{1cm} (12).

The leaf area index is the area (one side) of foliage per unit area of ground surface and is a parameter used in radiation studies.

For a given $A_f$ and $z$ in a given type of vegetation $C_N$ is probably a function of Reynolds number. The matter is complicated in actual canopies, however, due to the distribution of angles of attack of the leaves, the variety in their shapes and their mutual interference which depend on the foliage density $A_f(z)$. Thom (1971) concluded that $C_N$ is proportional to $u^{1/2}$ for an artificial crop consisting of cylinders and for beans, though Segner et al. (1976) found $C_{ef}$ to be a constant for a model canopy of slender rods.

### 3.2 Profiles

If it is assumed that the product $A_f C_N$ is a constant, that
\[ K = I \int \frac{du}{dz} \]  
\[ \text{...(13)} \]

and that the mixing length, \( l \), is also a constant, then one obtains the exponential profile, introduced independently by Inoue (1963) and Cionco (1965)

\[ u = u(h_0) \exp \left[ -a \left( 1 - \frac{z}{h_0} \right) \right] \]  
\[ \text{...(14)} \]

where \( u(h_0) \) is the mean velocity at \( z = h_0 \), and \( a \) is an extinction parameter. Brutsaert (1982; p. 101) gives a different derivation which does not invoke a mixing length hypothesis.

Different assumptions about the nature of \( K \) lead to slightly different profiles. Cowan (1968) obtained a hyperbolic sine profile. If both \( K \) and \( A_f C_{df} \) are taken as constants (Landsberg & James, 1971; Thom, 1971) then one obtains

\[ u = u(h_0) \left[ 1 + a' \left( 1 - \frac{z}{h_0} \right)^2 \right] \]  
\[ \text{...(15)} \]

where \( a' \) is another parameter.

It is not easy to identify which, if any, of these assumptions are valid. Nevertheless, all three give a mean velocity which is decaying with depth and the differences among them, when fitted to data, are usually well within the scatter observed in field experiments. In fact, Albini & Baughman (1979) assume a constant wind speed below the canopy and claim good agreement between their theory and observations.

Jarvis et al. (1976; p. 196-198) in discussing these results point out that Eq. 15 implies that the bulk fluxes of air from the upper parts of the canopy must be large. Shuttleworth (1989) expresses the same idea in a different way when he states that the vertical mean wind speed profile is inconsistent with a monotonic loss of momentum through the canopy, and is indirect evidence of countergradient flow.

### 3.3 Bursts and Sweeps

The occurrence of a rapid air flow, or 'blow-through', below the crowns is evident in the results of Geiger (1965). It was originally ascribed to penetration from the edge of the stand, or from large breaks in the canopy. But the finding that blow-through occurs also in near-ideal conditions of fetch, as at Thetford (Oliver, 1971) led Jarvis et al. (1976) to conclude that it is a general phenomenon arising from horizontal pressure gradients which are sustained by persistent up-and-down draughts at varying points in the stand.

Both wind tunnel observations (Cantwell, 1981) and field observations (Raupach, 1988) indicate that immediately above a surface - such as the wall of a wind tunnel, or the canopy of a forest - longitudinal 'streaks' of low velocity flow are formed (as a consequence of instability arising from the strong shear between the wind above the surface, and that at the surface). These streaks are the potential source of turbulence, which is suddenly released and ejected into the outer layers of the flow in a process that is initiated by inrushes of high momentum fluid from above (called 'sweeps'). These downward-moving, intense, gusts are the dominant turbulent events. They have a horizontal length scale of the order of \( h \), the canopy height and are intermittent in occurrence. The return flow is composed of lower momentum 'bursts' that remove the momentum from the canopy.
The implication in these findings, namely that K-theory in forest canopies is inappropriate, means that the meteorological community needs to actively work on methods with which to model (and hence predict) the details of the wind-field in a forest. The simple forms described in section 3.2 can be used to give approximate answers, but only direct measurement will enable the fire-fighter to know the details of what he is likely to expect in terms of a forest wind-field. One thing does seem clear - no matter how dense the canopy, the region below it will be subject to intermittent strong sweeps of air.

4 Winds at forest edges

Even though there may be a secondary wind maximum underneath the canopy, the magnitude of this wind will be much less than that above the canopy. Yet outside a forest, say over a large grass fetch, we know that the wind at a corresponding height will be stronger than that inside a forest.

There are at least two issues of relevance. Firstly, if anemometer measurements are taken in the open, how can they be used to infer the wind speed inside the forest. Secondly, how far do edge effects penetrate into the forest.

4.1 Inferring forest winds from outside measurements

The problem of inferring within-canopy forest winds from outside measurements will frequently arise in forest-fire management and control because guidelines for the establishment of meteorological stations are such that forested areas fail to meet them. It should first be pointed out that there is no theoretically satisfactory simple way in which to handle this problem - even in the ideal case of an abrupt transition from a uniform grassland with a long fetch to a homogeneous forest of trees of uniform height.

The most promising advance is that of Li et al. (1990) who solve the averaged momentum equations and parameterise $K$ in a way which they claim describes the sweep-burst mechanism described above. They check their model against the pine-forest observations of Raynor (1971) and the agreement is impressive (Figure 5). In part, this may arise from the fact that Raynor (1971) failed to measure at least one critical parameter required by the model, namely the vertical distribution of the leaf surface area density, and Li et al. (1971) were thus free to specify it.

4.2 Edge effects

What fetch is needed for a new steady-state wind profile to be established following a change in surface roughness? There are numerous wind tunnel and atmospheric studies on the problem which are reviewed by Garratt (1990). Basically, an internal boundary layer (IBL) forms which grows downstream. Above the IBL the flow field is that of the upstream conditions except for a displacement $\delta$ (upward in the case of grass to forest). A number of authors have equated $\delta$ with the zero-plane displacement, but Lo (1990) shows that this is incorrect. There appears to be no simple rule allowing one to estimate $\delta$.

There is an inner equilibrium layer inside the IBL which has a height that is about one-tenth of the IBL height. Far downstream of the leading edge, in neutral conditions, the inner equilibrium layer is characterized by a logarithmic profile appropriate to the new roughness. If we denote the height of the inner equilibrium layer by $H$, then Garratt (1990: Eq. 22) predicts that at a downstream distance $x$ it is given by

$$\zeta \ln \zeta - \zeta + 1 = x/(2z_o)$$

...(16)

where $z_o$ is the roughness length of the downstream roughness element and

$$\zeta = 10H/z_o$$

...(17)
This assumes that $H$ is one-tenth of the IBL height. If we further assume that $z_a$ is one-tenth of $h$, the canopy height, then it is possible to determine the minimum fetch, $X$, required for a satisfactory wind speed reading in the new downstream roughness. To obtain $X$ use the result that a logarithmic profile is only established at $H = 5h$. Substitution then reveals that the requisite fetch is $X = 520h$.

In relation to airflow to and from forests, the situation is similar to that described in section 4.1 in that Li et al. (1990) seem to provide the only realistic model, and one needs to examine data such as that of Raynor (1971) to provide rules of thumb. These results, as shown in Fig. 5, indicate that edge effects penetrate a maximum distance of four times the canopy height. It is unclear how this distance depends on the spacing between trees (sometimes referred to as the porosity), except for the common-sense notions that the distance should be zero if the trees form a solid barrier, and should be infinite if the trees are vanishingly sparse.

### 4.3 Windbreaks

Results on windbreak studies in the field and laboratory are reviewed by Plate (1971: p.161) and more recently by Taylor (1988). It is disappointing to see how little new work has been done in the intervening 17 years, and the situation is even more depressing when one realises that much of the work summarised by Plate (1971) is from Geiger (1965). One could wrongly imagine that everything one needs to know on such an important topic is already known. What is known is that:

* Potentially beneficial reductions in wind speed can occur for short distances (2$h$ to 4$h$) upstream of the windbreak and over much longer distances in the lee (20$h$ to 40$h$); where $h$ is the canopy height
* Windspeed reductions immediately downwind of the windbreak are greatest with a solid or closed windbreak, but the greatest overall shelter is obtained with windbreaks of about 50% porosity, as shown in Fig. 6.

### 4.4 Firebreaks

Raupach (1988) points out that turbulent events (i.e. bursts and sweeps) within the canopy are coherent on length scales of the order of $h$, the canopy height. This observation, combined with the results of Raynor (1971), implies that firebreaks whose width exceed the canopy height will experience increased wind speeds - and at two canopy heights the canopy wind will be transferred down to the firebreak.

### 5 Practical implications

Fritschen (1985) notes some of the problems involved in the measurement of wind in the forest. He cites some of the `rules of thumb', mainly based on wind-tunnel studies, which apply to measurement of wind above a horizontal surface. These include:

* The lowest anemometer should be situated at least 5 times above the average roughness of the surface or the structure of the canopy surface
* The maximum height of the anemometers should not exceed 1/50 of the upwind fetch.
* The minimum distance of 8 times the downwind obstacle height should be added to the fetch obtained from instrument height considerations
* The minimum distance upwind from a roughness change should be at least 6 times the change in roughness.
Fritschen (1985) then proceeded to show that most forest experimental sites violate these rules. In fact, the manner in which Fritschen (1985) applied these rules does not appear correct, and it is worth examining each one in detail to see how it was derived, what it means, and what are its limitations. Fig. 7 illustrates the application of these rules.

5.1 The lowest anemometer should be situated at least 5 times above the average roughness of the surface or the structure of the canopy surface.

Garratt (1978, 1980) showed that below this height it is unlikely that a logarithmic profile will be established, even under neutral conditions.

5.2 The maximum height of the anemometers should not exceed 1/50 of the upwind fetch.

This is an attempt to set a fetch criterion based on some early wind tunnel work. The way it is expressed is probably correct, but the opposite is not necessarily true in that anemometer heights below 1/50 of the fetch may still be too large. Consider Fig. 7 which is annotated on the basis of the results of Eqs. 16 and 17. A fetch of more than 500 $h$ is needed to obtain valid anemometer readings at a height of $5h$. Though it is therefore true that the anemometer height should not exceed 1/50 of the upwind fetch, heights exceeding 1/100 of the upwind fetch will be outside the inner equilibrium layer.

5.3 The minimum distance of 8 times the downwind obstacle height should be added to the fetch obtained from instrument height considerations.

This recommendation is intended to allow for edge effects and effectively says that in a porous boundary, wind effects penetrate up to $8h$, and the fetch should be measured only beyond this distance. The numerical value will depend on the porosity of the forest. The results of Raynor (1971) shown in Fig. 5 indicate that $4h$ would have been adequate for his forest.

5.4 The minimum distance upwind from a roughness change should be at least 6 times the change in roughness.

This recommendation allows for the fact that airflow streamlines are affected before they meet a change in roughness. The distance of upstream disturbance is less than the distance of penetration into the forest, but both will depend on the porosity of the forest. The results of Fig. 5 indicate that a value of about $2h$ would have been sufficient in that particular case.

5.5 Applicability of the rules

It should by now be clear that the above rules have been developed so that the instrument will provide a reliable estimate of the near-surface wind field which is synoptically relevant. They are designed to produce a wind field estimate that can be extrapolated upwards, not one that can be extrapolated downwards. They are not designed to provide information on the wind-field close to, or within, the canopy.

6 Discussion

The above exposition is limited to the case of a uniform canopy on level ground under conditions of neutral atmospheric stability. The forest, or pine-plantation has been assumed to be two-dimensional - extending off to infinity in the direction transverse to the wind. None of these assumptions will hold in real pine-plantations and the violation of each assumption will introduce new complexities into the wind speed profiles.
The most difficult future problem appears to be that of canopies in hilly terrain. The reason for this is that the nature of the airflow over barren hills is still an area of active research. Until more is known about this conceptually simpler problem, we are unlikely to be able to deal scientifically with the more complex situation of canopies on hilly terrain, though the operational forester will rely on climatology supplemented by common-sense to guide his operations. Thus guidelines to minimize windfall following cuttings in mature and overmature stands (Alexander, 1964) caution against locating cutting boundaries where they will be exposed to accelerated winds funnelling through saddles in ridges to the south and west of the area, especially if the ridges are at higher elevation. Though these directions refer to United States conditions they sound useful in the southern parts of Australia where southwesterlies predominate.

7 Conclusions

To conduct research on wind fields in pine plantations requires:

- Instrumented towers that extend to at least 10m above the top of the canopy.
- Wind measuring instruments that can sample all three components of the wind.
- Instruments capable of measuring and recording the turbulent fluctuations.
- Sufficient spatial coverage to be able to deduce the two-dimensional nature of the wind field.

It is not surprising that there are few organisations equipped to conduct serious research on winds in canopies, and that one finds the same data sets [e.g. that of Raynor (1971)] being used by theoreticians to validate their models. The model of Li et al. (1990) holds great promise in this regard and offers plantation managers the possibility of being able to predict mean winds within their plantations. Implementing it within Australia, calibrating it and validating it against some local data would be an enormously useful research project.

Nevertheless, the recent understanding of the potential importance of bursts and sweeps highlights how little is known of the statistics of their occurrence, their spatial distribution, and their interaction with clearings in the forest. Sweeps show up as sharp jumps in temperature (Bergström & Högström, 1989) so that it may be possible to answer particular questions about them using relatively simple equipment. Such questions include:

- Are there preferential locations for the occurrence of sweeps? If so, do clearings act as such preferential locations?
- Can one develop a statistical climatology for the amount of time bursts and sweeps take place?
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9 Figures

1 Variation of $z_0/h$ as a function of $\lambda$ - the roughness density. (Gurratt, 1977)

2 Relationship between stability category, sensible heat flux and 10 cm wind speed for a 10 cm roughness length. The solar radiation scales at the top are roughly in accord with warm ocean and with arid zone conditions (Beer, 1990: p. 36).

3 Wind profiles in a stand of pine for three ranges of wind speed (Geiger, 1965: p. 312)

4 Comparison of normalised wind profiles of various vegetative canopies where $Z$ is the height above ground, $H$ is the height of the canopy and $U$ is the wind speed. (Fritschen, 1983). The profiles are 1 - dense cotton, 2 - Douglas fir forest, 3 - dense conifer with understory, 4 - moderately dense conifer with no understory, 5 - dense hardwood jungle with understory, 6 - isolated conifer stand.

5 Comparison of the results of the model of Li et al. (1990) with the results of Raynor (1971) on the wind speed within and outside a pine forest.

6 The effects of a windbreak, given as a percentage of wind speed reduction, for different porosities (Plate, 1971: p. 167)

7 Schematic diagram (not to scale) showing the internal boundary and equilibrium layers and their relationship to various ‘rules-of-thumb’ for the siting of anemometers.
Fig. 1. Variation of $z_o/h$ with roughness element density $\lambda$ based on results of Kutzbach (1961), Lettau (1969) and Wooding et al. (1973). The shaded area indicates uncertainty in $z_o/h$ for a given $\lambda$ when the mean curve is applied to natural surfaces. The observed atmospheric range in $z_o/h$ (see Table 2) is shown, and data from Table 1 are also plotted as horizontal bars separating $\lambda_1$ and $\lambda_2$ values. The lettering code is as follows (see Table 1): a, trees (M1); b, trees (M2); c, wheat (early in season); d, wheat (late in season); e, pine forest; f, vineyard (flow parallel to rows); g, vineyard (flow normal to rows).
Fig 2
Fig. 3. Wind profiles in a stand of pine for three ranges of wind speed.
Figure 4. Comparison of normalized wind profiles of various vegetative canopies where Z is the height above the ground, H is the height of the top of the canopy and U is wind speed. Line 1 is dense cotton (Fritschen, 1966); 2 is Douglas fir forest (Fritschen et al., 1970); 3 is dense conifer with understory (Gisborne, 1941); 4 is moderately dense conifer stand with no understory (Fons, 1940); 5 is dense hardwood jungle with understory (Latimer, 1950); and 6 is isolated conifer stand (Reifsnyder, 1955).
5. **Typical isopleths of wind speed in mps (meters per second) for winds with a long fetch through the forest (north wind) and winds into the forest edge (south wind).** The squiggly line encircles the forest (average height, 10.5 m).

Fig. 5. The computed isopleths of the wind field.
Fig. 6  Sheltering at different porosities, according to Nägell (1941).
Results of computerised literature search on wind, wind profiles and forests

1/3/4
30110299 ID NO.- MBA30110299
Turbulence measurements above a pine forest.
Thompson, N.
Refs. DLC

1/3/5
29060328 ID NO.- MBA29060328
Some measurements of the adiabatic wind profile over a tall and irregular forest.
Bergen, James D.

1/3/6
28100359 ID NO.- MBA28100359
Some measurements of the adiabatic wind profile over a tall and irregular forest.
Bergen, James D.
Rocky Mountain Forest and Range Experiment Station, USDA ForestServ., Ft. Collins, CO

1/3/7
27090284 ID NO.- MBA27090284
Wind profile estimates for a hardwood forest.
Singh, B.
McGill Univ., Montreal

1/3/8
24010115 ID NO.- MBA24010115
Kohlendioxidstrom und -bilanz in einem fichtenwald. Carbon dioxide flux and CO2 SUS 2 balance in a pine forest.
Von Faller, Heinrich

1/3/9
23060361 ID NO.- MBA23060361
Vertical profiles of windspeed in a pine stand.
Bergen, James D.
U. S. Rocky Mt. Forest & Range Experiment Station, Ft. Collins, Colo.

1/3/10
20033202 ID NO.- MBA20033202
Estimations of surface roughnesses and displacement heights above a growing pine forest from wind profile measurements over a period of ten years.
Jaeger, Lutz
Dept. of Met., Freiburg Univ., W. Germany
A DIALOG® SEARCH
FROM THE
METEOR/GEOSTRAPHIC ABS DATABASE

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METEOROLOGICAL AND GEOSTRAPHICAL ABSTRACTS provides current citations in English for the most important meteorological and geostrophic research published in worldwide literature sources. Over 200 sources, including technical journals, monographs, proceedings, reviews, and annual publications are scanned for relevant literature. Subject coverage includes meteorology, seismology, physical oceanography, hydrosphere/hydrosphere, environmental sciences, and climatology. Abstracts are included for records from 1972-1973 and 1976 to the present.

SAMPLE RECORD

The positions of the key fields are shown in the following sample record.

JA 27070809 10 NO.- MDA27070809
TI Influences des facteurs météorologiques sur la variabilité de la ménopause chez l'homme. (Influence of meteorological factors upon the changes in magnesium levels in man.)
AU Darlu, P.
CS Équipe de Biostatistiques Humaines du C.N.R.S., Paris, France
CP CITY OF PUBLNL
AB The magnesium level of the blood plasma and erythrocytes was studied in 24 human subjects for a one-year period. The data show that the magnesium levels are higher during the summer than during the winter, whereas the erythrocyte magnesium concentration seems to be linked to the outside temperature, the plasma magnesium concentration seems to be sensitive to relative humidity and to sudden weather changes.
DE DESCRIPTION: Weather effects on human Biochemistry
COPYRIGHT BY THE AMERICAN METEOROLOGICAL SOCIETY, 1975.

Key to Data Fields

AB Abstract
AU Author
CF Country of Publication
CS Corporate Source
DE Descriptor
DT Document Type
JA Journal Announcement
LA Language
LJ Title

Data present in record depends on output format requested and type of record.
**DIALOG File 28: METE/O GASTRO ABSTRACTS - 70-80/APR**

37000048 10 NO. - MA33210275

**Studics on the windbreak nets, Pt. 9. Vertical and horizontal velocities influenced by the kinds of windbreak nets in a sandy field.**


**Country of Publication:** Japan

**Abstract:** Various windbreak nets and their characteristics were studied in a sandy field. The horizontal and vertical velocities were measured at different distances and heights. The results showed that the windbreak net with two layers of netting had the highest windbreak effect.

37000104 10 NO. - MA33210344

**Experimental and theoretical investigation of the dry denosition of particles to snow, pine trees, and artificial collectors.**


**Country of Publication:** Japan

**Abstract:** The study involved the experimental and theoretical investigation of the dry denosition of particles to snow, pine trees, and artificial collectors. The results showed that the denosition rate was influenced by various factors such as wind speed and particle size.

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Mechanisms of trace element deposition from the free atmosphere to surfaces in remote High Sierra cedars, E.B. Proctor, S. Davidson, and C. Mathur, U.S. Geological Survey, Reston, VA.

The energetic effects of a forest on intercepted water, which involves the reciprocal dependence between evapotranspiration and interception, were investigated in a young pine stand. In addition to interception loss, the measurements included dry and wet deposition, and rainfall and radiation above the canopy, and soil temperature, litter mass, and sensitive root fluxes, which were calculated by Svendsen's method. The ratio BE/BEH was calculated for the data collected in the least square method: BEH (potential temperature, and the specific humidity and water vapor pressure at 2 m) and BE (potential temperature, and the specific humidity and water vapor pressure at 1 m). The results indicate that the interception loss and the input of BEH are not affected by the rows of trees, reaching a minimum in the center (above and below the center) and a maximum in the periphery. The result was consistent with the variation of the latent heat of evaporation, which was influenced by the shortfall in energy use in the form of sensible heat.

DESCRIPTORS: Precipitation interception by forests; Energy balance of forests.

22000610 ID NO.: M2A2000482

Mechanisms of trace element deposition from the free atmosphere to surfaces in remote High Sierra cedars, E.B. Proctor, S. Davidson, and C. Mathur, U.S. Geological Survey, Reston, VA.

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DESCRIPTORS: Precipitation interception by forests; Energy balance of forests.
**3030030**  
**ID No.** - MA3030030  
**Title:** Solar luminosity and the sun spot cycle.  
**Author:** Blick, R. H.  
**Country of Publication: UK**  
**Abstract:** The intermittency and short duration of a sharply tuned, 22-year period in a climate parameter is indicated to be caused by an  
**SOLAR LUMINOUSITY AND THE SUN SPOT CYCLE**  
D R. H. Blick  
J OURNAL OF AGRICULTURAL METEOROLOGY  
L O N D O N 2 O ( 1 ) ( 1 9 7 1 ) 2 4 - 2 7  
J ULY 5 , 1 9 7 8  
R E F S .  F I G S .  D A S , D L C  
C O U N T R Y O F P U B L I C A T I O N : U K  
A B S T R A C T  
The intermittency and short duration of a sharply tuned, 22-year period in a climate parameter is indicated to be caused by a variation in the solar luminosity. Hence, the correlation is due to a 22-year period of the Sun's luminosity.  
**30300114**  
**ID No.** - MA30300114  
**Title:** Model for predicting synoptic weather types based on model output statistics.  
**Author:** Swart, W.  
**Country of Publication: US**  
**Abstract:** The model for predicting synoptic weather types based on model output statistics was developed by the National Meteorological Center. The model uses statistical analysis of historical weather data to predict future weather conditions.  
**30300073**  
**ID No.** - MA30300073  
**Title:** Fire weather conferences.  
**Author:** National Interagency Fire Center  
**Country of Publication: US**  
**Abstract:** The fire weather conferences are annual events that bring together experts in the field of fire meteorology to discuss and share knowledge about fire weather conditions and management strategies.  
**30300010**  
**ID No.** - MA30300010  
**Title:** Fire damage increased by the windbreak.  
**Author:** Yeung, Y.  
**Country of Publication: US**  
**Abstract:** Fire damage is increased by the presence of windbreaks, which can cause severe wind gusts and increase the risk of fire.  
**30300032**  
**ID No.** - MA30300032  
**Title:** Local climatological observations in the Atsuki Peninsula, Kobe Prefecture.  
**Author:** Nakamura, K.  
**Country of Publication: Japan**  
**Abstract:** Local climatological observations in the Atsuki Peninsula, Kobe Prefecture were conducted to understand the local climate and its impact on agriculture.  
**30300042**  
**ID No.** - MA30300042  
**Title:** Dry season measurements at a pine forest.  
**Author:** Kaya, M.  
**Country of Publication: Japan**  
**Abstract:** Dry season measurements at a pine forest were conducted to understand the local climate and its impact on agriculture.  
**30300034**  
**ID No.** - MA30300034  
**Title:** Wind stress is reduced by the windbreak.  
**Author:** Yeung, Y.  
**Country of Publication: US**  
**Abstract:** Wind stress is reduced by the presence of windbreaks, which can cause severe wind gusts and increase the risk of fire.  
**30300012**  
**ID No.** - MA30300012  
**Title:** Solar luminosity and the sun spot cycle.  
**Author:** Blick, R. H.  
**Country of Publication: UK**  
**Abstract:** The intermittency and short duration of a sharply tuned, 22-year period in a climate parameter is indicated to be caused by an  
**3030030**  
**ID No.** - MA3030030  
**Title:** Solar luminosity and the sun spot cycle.  
**Author:** Blick, R. H.  
**Country of Publication: UK**  
**Abstract:** The intermittency and short duration of a sharply tuned, 22-year period in a climate parameter is indicated to be caused by a variation in the solar luminosity. Hence, the correlation is due to a 22-year period of the Sun's luminosity.  
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**Author:** National Interagency Fire Center  
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**ID No.** - MA30300012  
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**Author:** Blick, R. H.  
**Country of Publication: UK**  
**Abstract:** The intermittency and short duration of a sharply tuned, 22-year period in a climate parameter is indicated to be caused by a variation in the solar luminosity. Hence, the correlation is due to a 22-year period of the Sun's luminosity.
date, when the forest canopy was externally dry and transpiration of the only water loss gave a Bowen ratio of 0.99. Soil temperatures were generally lower than leaf temperatures, with a distinct trend showing that there was a significant component of the energy budget. When the canopy was wet, internal transpiration was more important than leaf transpiration, and the Bowen ratio was generally less than 0.3 and often negative. Methods: Several methods were used: emission spectrometry for evaporation when the net radiation was low or negative.

DESCRIPTORS: Forest biomass; Forest climate; Forest vegetation; Energy balance of forests; Heat flux over forests; South Australia, Australia.

270503058
ID: NH. N/A-270503058
Particulate dispersion free sources within a forest.

Manor, Stuart L.; Hayes, Janis V.; Ogden, Eugene C.; Brownlee, Near the site of a natural forest fire, the data were collected using a portable infrared smoke detector and a smoke concentration monitor. The concentration patterns were analyzed using simple statistical methods. Results: The data showed a clear relationship between smoke concentration and smoke dispersion. The results indicate that smoke dispersion is affected by factors such as wind speed, temperature, and humidity. In addition, the data suggest that smoke dispersion is influenced by the topography of the area.

DESCRIPTORS: Forest smoke; Smoke dispersion; Forest fire; Smoke concentration.

270503059
ID: NH. N/A-270503059
Evaporation from land areas.

Glock, Klaus.

DESCRIPTORS: Water vapor; Water content; Soil moisture; Evaporation.
Instruments measure the energy available for evaporation; and a subsequent development, the EPER, provides a continuous automatic recording of evaporation. Direct measurements of surface evaporation in agricultural crops have been developed to calculate evaporation rates from standard meteorological observations of temperature and humidity. In two-dimensional evaporation studies, progress has been made in refining modifications of the global model to fit field observations in dry land, limited size reservoirs, and other related research and investigation. Some recent developments in this area include: the development of a promising local evaporation theory for use with the energy balance equation; additional energy transfer models; and the use of more sophisticated models for complex terrain. The results of these studies are being incorporated into the land surface component of the land surface model (LAMS) developed at the Australian National University. The use of energy balance theory has been extended to include the effect of vegetation cover and the presence of the water table. The major types of evaporation standard are: (a) ground cover; (b) cloud cover; (c) ocean; and (d) crop canopies. Evaporation and water balance studies for different plant types are applicable to both agricultural and natural plant communities. The results of these studies are likely to be useful in the development of future models for predicting evaporation from different types of vegetation.

**DESCRIPTIONS:**

Evaporation from land surfaces: Evaporation from plants: Australia

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24050239

**ID NO.:** WMA24050239

**Title:** Wind speeds within the trunk space of a pine forest

**Authors:** A. O. Unger, Div. of Atmos. Phys., CSIRO, Victoria, Australia and J. F. Collins, Div. of Atmos. Phys., CSIRO, Victoria, Australia

**Source:** Canadian Meteorological Society, Brussels, Eng., Quarterly Journal, 104(427):197-202, June 1979

**Country of Publication:** UK

**Document Type:** A

**DESCRIPTIONS:**

Wind speeds in the trunk space of a pine forest

**UDC NO.:** 551.94; 551.018; 025.48; 025.48

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24050238

**ID NO.:** WMA24050238

**Title:** Atmospheric turbulence and its influence as influenced by a small cloud in a larch and pine forest


**Country of Publication:** US

**Document Type:** A

**DESCRIPTIONS:**

Forest influences on snow accumulation; Forest influences on snow accumulation; Forest influences on snow accumulation; Forest influences on snow accumulation

**UDC NO.:** 551.677; 551.561; 551.57; 551.67; 2556.124

---

24050232

**ID NO.:** WMA24050232

**Title:** Energy budgets in pine forest

**Authors:** W. D. Smith, Inst. of Hydrol., Wellingford, Eng., Dept. of Met., Univ. of Edinburgh


**Country of Publication:** UK

**Document Type:** A

**DESCRIPTIONS:**

Energy budgets in pine forest

**UDC NO.:** 551.511; 551.566.8

---

24050215

**ID NO.:** WMA24050215

**Title:** Light: temperature in a forest canopy

**Authors:** A. O. Unger, Inst. of Hydrol., Wellingford, Eng., Dept. of Met., Univ. of Edinburgh


**Country of Publication:** UK

**Document Type:** A

**DESCRIPTIONS:**

Energy budgets in pine forest

**UDC NO.:** 551.511; 551.566.8

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24050214

**ID NO.:** WMA24050214

**Title:** Geomorphology and multiple glaciation in the area of Banff, Alberta


**Country of Publication:** CA

**Document Type:** A

**DESCRIPTIONS:**

Geomorphology and multiple glaciation in the area of Banff, Alberta

**UDC NO.:** 551.94; 551.018; 025.48; 025.48

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24050213

**ID NO.:** WMA24050213

**Title:** Geomorphology and multiple glaciation in the area of Banff, Alberta


**Country of Publication:** CA

**Document Type:** A

**DESCRIPTIONS:**

Geomorphology and multiple glaciation in the area of Banff, Alberta

**UDC NO.:** 551.94; 551.018; 025.48; 025.48

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24050212

**ID NO.:** WMA24050212

**Title:** Measured and measured roughness parameters for a pine forest

**Authors:** Leonard, R. J.; Federer, C. A.; Northeastern Forest Experiment Station, U.S. Forest Serv., Trenton, next page

**Country of Publication:** US

**Document Type:** A

**DESCRIPTIONS:**

Measured and measured roughness parameters for a pine forest

**UDC NO.:** 551.95; 551.566.8

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24050209

**ID NO.:** WMA24050209

**Title:** Mean wind-direction shear through a forest canopy

**Authors:** Smith, P. B.; Carson, D. J.; Oliver, H. W.

**Country of Publication:** NL

**Document Type:** A

**DESCRIPTIONS:**

Mean wind-direction shear through a forest canopy

**UDC NO.:** 551.95; 551.566.8

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24050208

**ID NO.:** WMA24050208

**Title:** Local climate as a factor forcing hindrances of tree growth in Japan

**Authors:** Yutaka, M.; Hiroshima, H., Inst. of Geology, Tohoku, Dept. of Geography, Geographical Notes, No. 8, 1970, 95 p.

**Country of Publication:** JA

**Document Type:** A

**DESCRIPTIONS:**

Local climate as a factor forcing hindrances of tree growth in Japan

**UDC NO.:** 551.95; 551.566.8

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24050207

**ID NO.:** WMA24050207

**Title:** Local climate as a factor forcing hindrances of tree growth in Japan

**Authors:** Yutaka, M.; Hiroshima, H., Inst. of Geology, Tohoku, Dept. of Geography, Geographical Notes, No. 8, 1970, 95 p.

**Country of Publication:** JA

**Document Type:** A

**DESCRIPTIONS:**

Local climate as a factor forcing hindrances of tree growth in Japan

**UDC NO.:** 551.95; 551.566.8

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24050206

**ID NO.:** WMA24050206

**Title:** Local climate as a factor forcing hindrances of tree growth in Japan

**Authors:** Yutaka, M.; Hiroshima, H., Inst. of Geology, Tohoku, Dept. of Geography, Geographical Notes, No. 8, 1970, 95 p.

**Country of Publication:** JA

**Document Type:** A

**DESCRIPTIONS:**

Local climate as a factor forcing hindrances of tree growth in Japan

**UDC NO.:** 551.95; 551.566.8

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24050205

**ID NO.:** WMA24050205

**Title:** Local climate as a factor forcing hindrances of tree growth in Japan

**Authors:** Yutaka, M.; Hiroshima, H., Inst. of Geology, Tohoku, Dept. of Geography, Geographical Notes, No. 8, 1970, 95 p.

**Country of Publication:** JA

**Document Type:** A

**DESCRIPTIONS:**

Local climate as a factor forcing hindrances of tree growth in Japan

**UDC NO.:** 551.95; 551.566.8

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24050204

**ID NO.:** WMA24050204

**Title:** Local climate as a factor forcing hindrances of tree growth in Japan

**Authors:** Yutaka, M.; Hiroshima, H., Inst. of Geology, Tohoku, Dept. of Geography, Geographical Notes, No. 8, 1970, 95 p.

**Country of Publication:** JA

**Document Type:** A

**DESCRIPTIONS:**

Local climate as a factor forcing hindrances of tree growth in Japan

**UDC NO.:** 551.95; 551.566.8

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24050203

**ID NO.:** WMA24050203

**Title:** Local climate as a factor forcing hindrances of tree growth in Japan

**Authors:** Yutaka, M.; Hiroshima, H., Inst. of Geology, Tohoku, Dept. of Geography, Geographical Notes, No. 8, 1970, 95 p.

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**Document Type:** A

**DESCRIPTIONS:**

Local climate as a factor forcing hindrances of tree growth in Japan

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**Country of Publication:** JA

**Document Type:** A

**DESCRIPTIONS:**

Local climate as a factor forcing hindrances of tree growth in Japan

**UDC NO.:** 551.95; 551.566.8
Investigated the local conditions of hindrance to tree growth in the Taoro-Carpe region, Aokigahara, and found that the trees were only 10 to 20 cm high on the north side of the forest, while on the south side they were 2 to 3 meters high. The trees on the north side were also shorter and had fewer branches.

On the north side of the forest, the trees were shorter and had fewer branches.

The site was studied by measuring the depth of the soil, the amount of water available to the trees, and the amount of sunlight reaching the forest floor.

The results showed that the trees on the north side had less water available to them and received less sunlight, which limited their growth.

These findings have important implications for forest management and conservation efforts in the region, as they highlight the importance of site-specific conditions in determining the success of forest planting and regeneration efforts.

In conclusion, the study highlights the importance of site-specific conditions in determining the success of forest planting and regeneration efforts in the region, as they highlight the importance of site-specific conditions in determining the success of forest planting and regeneration efforts.

**References:**


Humidity deficit and the wind velocity. Monthly precipitation totals were determined on the basis of the absorbed radiation. 

DESCRIPTIONS: Sublimation of snow: Water vapor diffusion through snow cover. Yukitsuki, Astotic R.S.F.S.R.,

Subject to shelter effects, total evaporation was not very sensitive to the choice of diffusivity. Thus, the lower boundary condition was given by the lower boundary condition. 

DESCRIPTIONS: Forest microclimate: Evaporation from forests.