Understanding fire intensity and severity

– Implications for managing wildfire and prescribed fire –

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Bushfire? What bushfire?

Two terms often used for bushfires or wildfires

Fireline '**Intensity**'

- is the rate of energy release or power ("kW" or "MW") behind any metre of fire front
- 'Byram's formula' gives its value for a steadily advancing line fire
- but what is the 'intensity' for unsteady crooked fire shapes?
- and what does it signify in practice?

Fire/Burn '**Severity**':

- is a less clear-cut concept
- it has different, possibly conflicting interpretations, such as:

'Difficulty:' hard to put out, or leading to large fire scars (as in Met Office FSI)

'Damage:' effect of the fire on vegetation or soil

- are these two meanings consistent?

- What links might be expected between **'intensity'** and **'severity'**?

Outline of presentation

- **Basic meaning of 'fireline intensity':**

  Intensity of a straight steadily-spreading line fire (looked at from two points of view) combines

  - energy released in combustion
  - degree and efficiency of burning
  - rate or speed of burning

- '*Plot-based line fire equivalent*' **intensity for irregular fires:**

  The challenge (measuring intensity meaningfully) and **motivation** (fire control, safety & habitat management)

  A geometrical approach for '*line fire equivalent*' intensity

  Example: a patterned ignition

- **Interpretation** – what does this mean?

- Next steps ...

but first, some comments on Severity

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Burn Severity (as 'fire-effect' on vegetation and/or soil) involves the degree of:

burn-off above ground

root damage and plant-kill

damage to seed-bank

loss of soil (burning of peat or humus, or by soil erosion)

Burn-off may be an objective for habitat management

— *other effects we usually wish to avoid*

Fire Severity (as 'difficult' to manage, suppress or escape):

Fire Danger Ratings and Fire Severity Indices use weather, soil and vegetation models aiming to predict this

– based on extensive data and analysis in some countries

– data for good 'calibration' is still needed in the UK

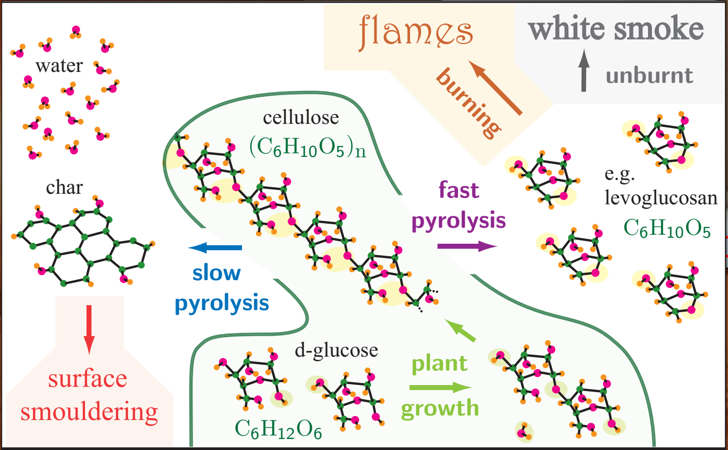
- What are the **links** between **Intensity** and these **Severities**?

  What might be expected?

basics of intensity

burning processes

- example of fast and slow pyrolysis in a sheet of paper (processed wood-pulp)



some plants contain oils and fats that vapourise at lower temperatures than cellulose and burn more energetically

basics of intensity

degree of burning

- example of a sheet of paper (again)

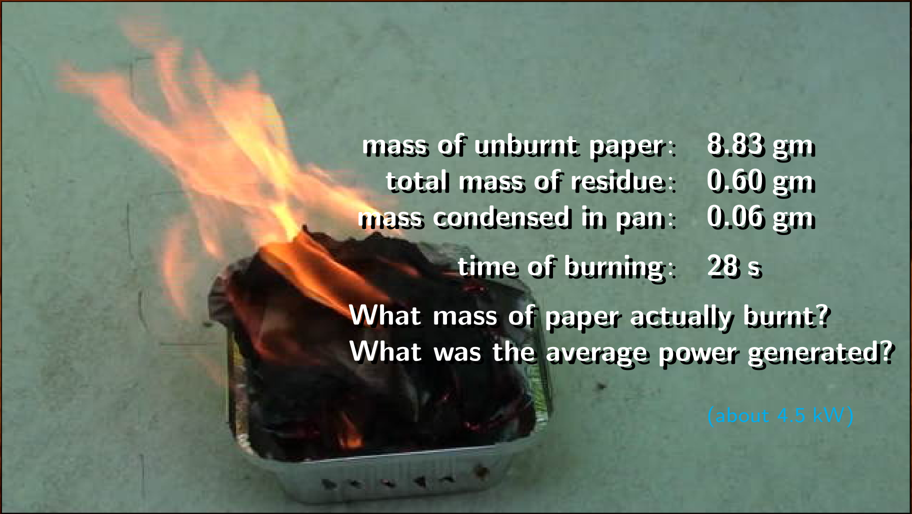
$$\text{vegetation} \longrightarrow \begin{cases} \text{flammable vapour} \longrightarrow \begin{cases} \text{flames} \\ \text{unburnt vapour} \end{cases} \\ \text{unburnt vegetation} \\ \text{char} \longrightarrow \begin{cases} \text{smouldering} \\ \text{unburnt char} \end{cases} \\ \text{ash} \end{cases}$$

- The degree of burning is less than 100% if there is any
  - **unburnt vegetation**
  - **unburnt char** (black residue)
  - **ash** (inert residue)
  - **unburnt vapour** (white smoke)
  - **incompletely burnt vapour** (black smoke)
- Unburnt Vegetation, Ash and Char can be measured
- Harder to quantify unburnt and incompletely burnt vapour

basics of intensity

degree of burning

- example of a sheet of paper (again)



mass of unburnt paper:	8.83 gm
total mass of residue:	0.60 gm
mass condensed in pan:	0.06 gm
time of burning:	28 s

What mass of paper actually burnt?
What was the average power generated?

(about 4.5 kW)

energy of combustion

A typical complete oxidation of cellulose

$$\underbrace{C_6H_{10}O_5}_{162} + \underbrace{6O_2}_{192} \longrightarrow 6CO_2 + 5H_2O \quad \text{(atomic mass units)}$$

Rule of thumb (*using oxygen calorimetry* – [e.g. Drysdale's text])

$$\begin{aligned} \textbf{energy of burning} &= 14 \ \mathrm{kJ/gm\ of}\ O_2 \ \text{consumed} \\ \text{so} \quad Q &= 14 \times \tfrac{192}{162} \ \mathrm{kJ/gm\ of}\ C_6H_{10}O_5 \ \text{consumed} \\ Q &= 16.6 \ \mathrm{kJ/gm\ of}\ C_6H_{10}O_5 \ \text{consumed} \end{aligned}$$

Roughly:

- 60 gm of cellulose burns to produce up to 1 MJ (1000 kJ) of energy

  That is: 12 A4 sheets of paper
  or 8 heaped teaspoons
  of sugar/flour

- 27 gm of carbon produces 1 MJ — *by a similar calculation*
- 52 gm of $C_6H_9O_4$ (typical of wood) produces 1 MJ

Fireline Intensity of a straight steady fire

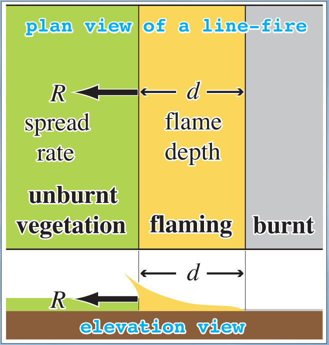
Imagine a fire moving:

at speed (**spread-rate**) R m/s

where the **fuel load** is m kg/m^2

(*reducing m if less than 100% burning*)

burning at an **energy** of Q MJ/kg



Byram's 1st formula gives the intensity as

$$I = Q\,m\,R$$

so **Intensity increases for:**

faster spread (R), higher load (m) and more complete combustion

Alternatively, if fuel burns during the **flame residence time** (t_b) then **flame depth** (d) is the distance travelled in this time (i.e. $d = R\,t_b$)

So $R = d/t_b$ and [*substituting for R*] intensity can be rewritten as

Byram's 2nd formula:

$$I = \frac{Q\,m\,d}{t_b}$$

{ [Byram, 1959] uses different symbols }

Intensity of irregular, unsteady firelines

— a plot-based approach

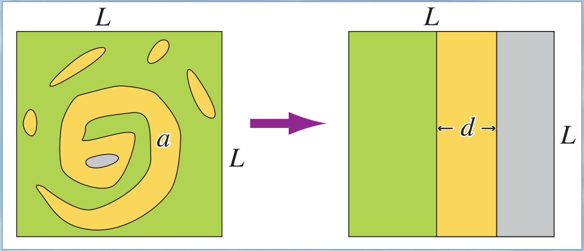
Motivation:

- wildfires are rarely straight
- spotting can create many interacting fires
- patterned ignition can create many different fireline shapes

What is the intensity of such fires?

Intensity of irregular, unsteady firelines

— a plot-based approach



Geometrical approach, for fires in a plot of area $A = L \times L\ \mathrm{m}^2$:

- imagine shifting the total flaming area (a) in the plot into the shape of a straight line fire across the plot
- measure off the resulting flame depth (d) $\{ d = L \times a / A \}$
- then the '**plot-based line-fire equivalent**' (PLFE) **intensity** is

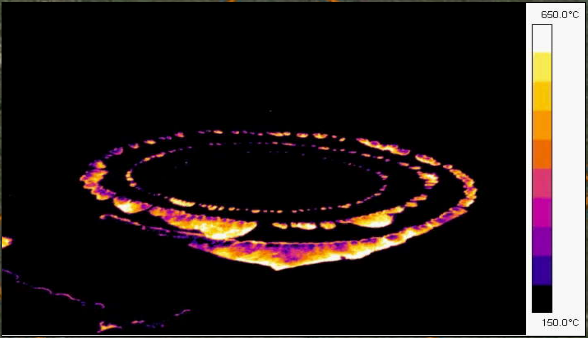
$$J = \frac{Q\,m\,d}{t_\mathrm{b}} \quad \text{or} \quad J = \frac{Q\,m\,L}{t_\mathrm{b}} \times \frac{a}{A} \quad \left\{ \begin{array}{l} \text{without the} \\ \text{geometry} \end{array} \right\}$$

Intensity increases if the flaming area (a/A) is increased

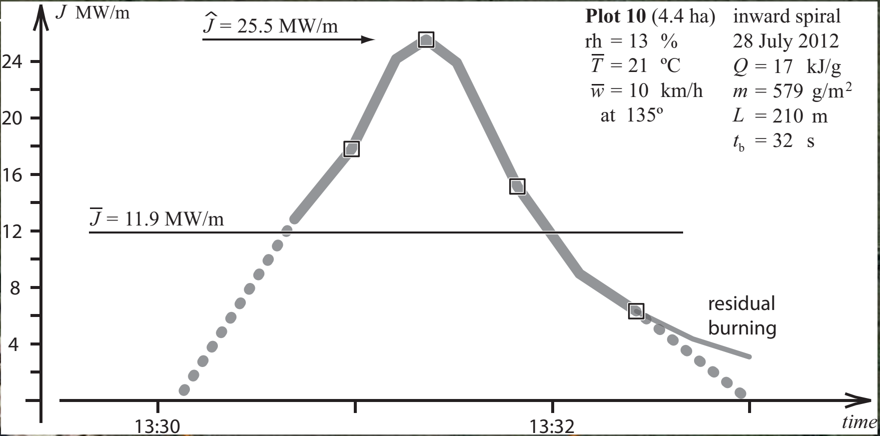
Intensity of irregular, unsteady firelines

— plot-based approach

Example: a patterned ignition



Intensity of irregular, unsteady firelines



Analysis: taking 'IR temperature' above 300°C to mean 'active flaming'

flame residence time (t_b) is found via the analysis

Intensity of irregular, unsteady firelines — interpretation & next steps

Main implications of increased **PLFE intensity** (J):

- it extends the meaning of **Byram's fireline Intensity** (I)
- equals **Byram's Intensity** ($I = J$) for a steady straight fireline
- measures increased fire activity in an area, where there may be
  - interaction between nearby flaming regions
  - strong convection processes (*fire-whirls observed*)
  - greater flame heights and thicknesses
  - increased flame emissivity (*hence radiation*)
  - enhanced 'burn severity' (. . . *to be tested*)

Next Steps (*details not given here*)

- developing the formula not to be 'plot-based'

  that is, **LFE Intensity** rather than **PLFE Intensity**

  — or a better name for it? —
- field tests are scheduled for examining effects on vegetation

(Fire or Burn) Severity *and* Intensity

Here it is assumed that

Fire Severity	means	**difficulty in suppression**
Burn Severity	means	**fire damage to vegetation and soil**
Intensity	means	**LFE Intensity**

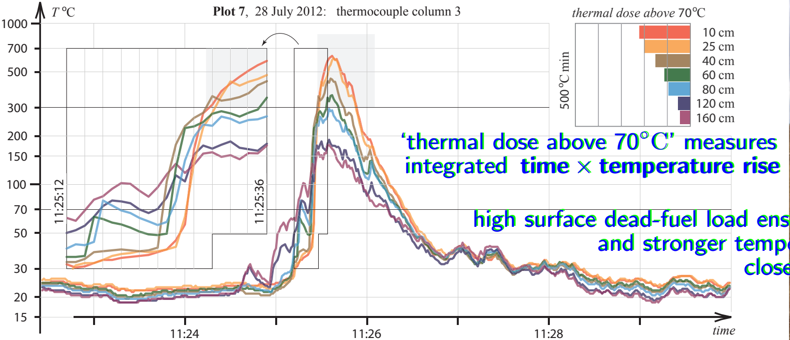
It is likely that **'fire severity'** and **'LFE intensity'** would correlate

For **'burn severity':**

- vegetal damage should relate to heat absorbed, driven by
  - exposure to higher temperature and radiation
  - size, moisture content, conductivity, etc., of the plant
  - the duration of exposure

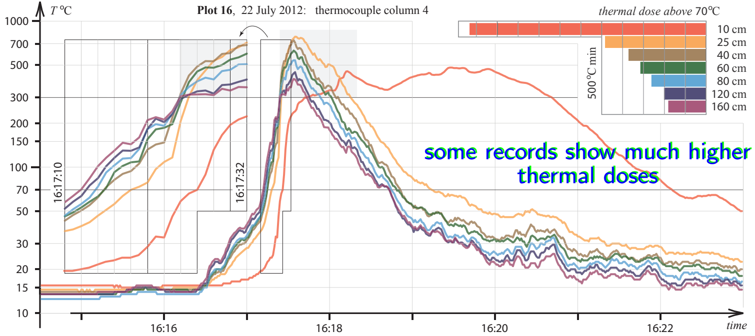
  higher intensity could increase the first of these
  but a slow fire (lower intensity) *might increase the last*
  - descriptions like '**hot**' and '**cold**' burns miss the point **!**
- vegetal soil is unlikely to suffer directly from a short intense fire (although this could ignite slow low-intensity smouldering)

Thermocouple Temperature Measurements



'thermal dose above 70° C' measures
integrated **time × temperature rise**

high surface dead-fuel load ensures longer
and stronger temperature rise
close to ground



some records show much higher
thermal doses

summary

Intensity: its calculation for steady line-fires has been extended to irregular fire patterns in plots (**PLFE Intensity**)

There are consistent ways of removing the restriction to plots (. . . *still under development* . . .)

Patterned ignition can greatly enhance intensity.

Severity: Two distinct meanings, **'Difficulty'** and **'Damage'**

Difficulty (**Fire Severity**) and Intensity should correlate

Damage (**Burn Severity**) is very multifaceted

- temperature rise & time **together** cause damage
- 'larger' vegetal components take longer to heat up
- high intensity should damage elevated fuels more

(depending on plant species, condition, structure, etc.)

Ongoing tests will help to clarify Intensity–Severity linkages

major questions

- What is a better, simpler name for **LFE Intensity** ?
- Can **this measure of intensity for irregular fires** be improved further ?
- Can we (and should we) define '**severity**' more tightly ?
- Can **patterned ignition** be used to 'design' a burn?
- Does it have a role in **habitat management** ?
  - if so, how might it be used ?

acknowledgements

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