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S589: Upper Air Influences

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Objectives

- Introduce the "Third dimension of the fire environment"
  - Upper air: atmosphere to the tropopause (approx.)
  - Fire and atmospheric interactions
- Understand basic storm safety
- Wind profiles and plumes
- Understand stability indexes applicable to fire

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Third Dimension of the Fire Environment

- Vertical (z-component)
  - Atmospheric phenomena
  - Fire and atmospheric interactions

- Topography

https://www.fao.org/sustainable-forest-management/toolbox/modules/mountain-forests/in-more-depth/ar/
Accessed October 22, 2021.

- Fuels

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Storm Safety and Considerations

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Storm Hazards

- **Wind**
  - **Strong storm outflow gusts may exceed 150 km/h**
  - **Outflow may lead to new storm cells**
  - **Tornados**
- **Precipitation**
  - **Large hail**
  - **Flooding: cuts off escape routes? Erosion? Slides?**
- **Heat Bursts and Pyro-Cbs (both later)**
- **Crew safety due to storms and fire spread**

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Thunderstorm comparison

	Single Cell	Multicell	Supercell	Squall Line
Environment	Weak/moderate instability	Strong instability	Strong instability, jet stream, vertical shear	Frontal passage, trough
Life cycle	< 60 min	Hours	Many hours	Hours to days
Movement	With upper winds	Erratic?	Right or left?	With airmass and into low
Precipitation	Rain, small hail	Heavy rain, hail	Heavy rain, large hail	Varied
Anvil	Single distinct	Multiple	Overshooting top	Multiple
Wind	Moderate and brief	Erratic, strong gusts	Strong gust fronts, tornado?	Frontal passage: strong winds may continue for hours
Extent	Small area	Moderate, large in MCC	Moderate	Long line affects large area

Lightning, not “lightening”!

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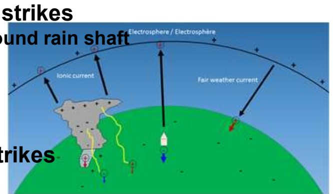
ECCC: *“When thunder roars go indoors”*

- **Watch for cloud glaciation**
- **Negative polarity strikes**
  - **Common in or around rain shaft**
  - **Lower current**



- **Positive polarity strikes**
  - **Anvil to ground**
  - **More common in winter and high elevations**
  - **Long continuing current**

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Radar Indications

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- **Radar allows speed estimates of storm cells**
- **Thunderstorms may play tricks on you though!**

Splitting thunderstorm:
http://climate.weather.gc.ca/radar/index_e.html?site=CASFW&year=2019&month=7&day=13&hour=21&minute=00&duration=2&image_type=PRECIPET_RAIN_WEATHEROFFICE

Quick Development:
http://climate.weather.gc.ca/radar/index_e.html?site=CASCV&year=2019&month=7&day=18&hour=00&minute=30&duration=2&image_type=PRECIPET_RAIN_WEATHEROFFICE

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Visible distance?

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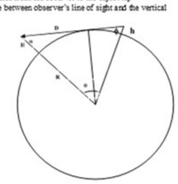
h -- Height of observer above surface **2 m**
H -- Height of distant object top above surface (for example, a cumulonimbus cloud top 15000 m above the surface
R -- Radius of the Earth, assuming Earth is a sphere **6371 km = 6371000 m**
D -- Distance from the observer to the object top
ϕ -- Angle between observer's line of sight and the vertical



Observer elevation angle ϕ: $\phi = \sin^{-1}\left(\frac{R}{R+h}\right)$ **89.9546 deg**

Angle α between the object top and observer's sight line: $\alpha = \sin^{-1}\left(\frac{R}{R+H}\right)$ **86.0722 deg**

Angle between the radii to the observer and object: $\theta = 90 - \phi + 90 - \alpha = 180 - (\phi + \alpha)$ **3.9732 deg**

Distance between the observer and the object top: $D = (R+H)(R+h)\frac{\sin\theta}{R}$ **443 km**

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Weather Warning Services

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- Keep tabs on ECCC weather watches and warnings if possible
  - ECCC's *WeatherCAN* app can provide alerts for customized regions to your mobile device

https://www.canada.ca/en/shared-services/campaigns/stories/weathercan-app.html

  - Maybe your fire weather office provides a service

The Heat Burst

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- Develops during dissipating strong thunderstorms
- Downdraft forms in dry upper levels and heats due to adiabatic compression
- Downdraft reaches ground producing strong winds, a rapid temperature increase, and RH drop
- Rare … atmospheric conditions must be 'ideal'.

Heat Burst Examples

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Springbank Airport – Friday Aug 17, 2001

Time	Temp.	RH(%)	Wind(km/h)	Weather
2100	21	41	220/08	Smoke
2200	20	47	230/16	LTG SW
2300	25	23	200/48	CB South
2316	-	-	210/60g100	RW
0000	26	20	200/14	-
0100	19	38	230/12	-

Glasgow Montana - Sept 9, 1994

Temp at 0502 : 19°C

Temp at 0517 : 34°C

What would RH do? Assume T-Td=10C (RH ~ 50%) to start

Heat burst vs collapsing plume

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- Heat burst / thunderstorm downdraft, and collapsing plume have similarities
  - Warming and drying due to adiabatic compression
  - Strong outflow winds
  - *Change in fire behaviour?*
- More about collapsing plumes later …

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Pyro-CBs

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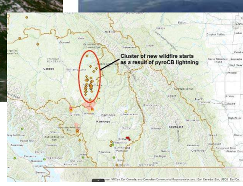
- *Cumulonimbus flammagenitus*
- Additional lightning … may produce little rain



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Atmospheric Stability Indexes

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Stability Indexes

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- Most are for shower/thunderstorm potential
  - Upper air temperature, humidity, wind
  - K, Totals, SWEAT, Showalter, Lifted, CAPE, …
  - Interest: weak or strong storms?
- Haines Indexes developed for blow-up fire potential
  - Stability and dryness (moisture) components

Stability and fire blow-up: Haines Index

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A numerical rating of stability in the lower levels of the atmosphere and the fire environment (Donald Haines, USFS, 1988).

Stability and moisture (dryness) factors

Required data: 850 hPa: Temperature and dew point
700 hPa: Temperature

- In very low country: use 950 and 850 hPa
- In high country: use 700 and 500 hPa

Haines Index Calculation

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Stability factor

T(850 MB) - T(700 MB)	Factor A
Less than 6 degrees	1
6 to 11 degrees	2
> 11 degrees	3

Dryness factor

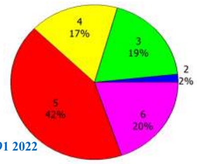
T(850 MB) - Td(850 MB)	Factor B
Less than 6 degrees	1
6 to 13 degrees	2
> 13 degrees	3

Sum the Factors

HI=A+B

<3	Very low
4	Low
5	Moderate
6	High

HI for Stony Plain, AB
May-Aug 1980-92



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Continuous Haines Index

- **Developed in Australia**
  - Original formula gives too many 6s
  - Decimal value to maximum ~ 13; no lower bound
  - Pressure levels chosen as with original HI

Stability Factor

- $C_A = 0.5(T_1 - T_2) - 2.0$

Dryness Factor

- $C_B = 0.3333(T_1 - Td_1) - 1.0$
  - if $(T_1 - Td_1) > 30.0$ then $C_B = 9.0$
  - if $(C_B > 5.0)$ then $C_B = 5.0 + 0.5*(C_B - 5.0)$

Summation (sorry, we don't have danger classes)

- $HI_C = C_A + C_B$

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Wind Profiles

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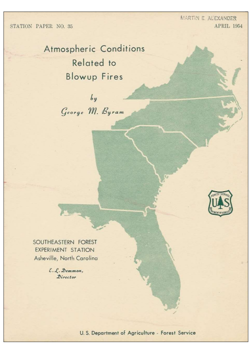
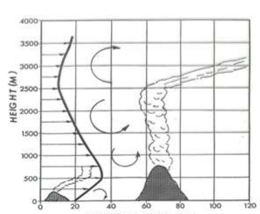
Byram's conditions for blow-up





Low level
Jet profile

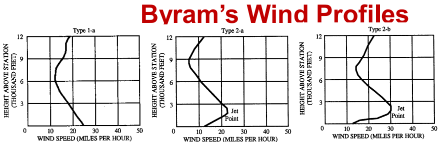
Byram's Wind Profiles

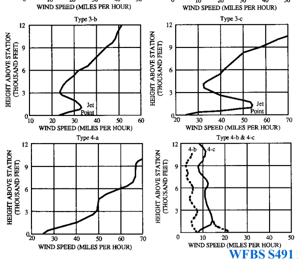
Byram's classification of wind profiles considers:

- Vertical wind speed profile
- Surface wind speed at the base of the profile (substantial)

- Lower number indicates highest risk...
- Based on fires primarily in SE states

Byram's Wind Profiles





Erhard Reinelt (1989)

10% fit Byram's classifications

3% match Byram's surface wind speed

<1% are Type 1a

Caveat: 20 years (which?) of sondes and pibals used

Caveat: Pibal wind data good?

Brotak and Reifsnyder (1977)

Edward A. Brotak and William E. Reifsnyder:
https://www.fs.usda.gov/sites/default/files/legacy_files/fire-management-today/038_02_0.pdf

- **Study details:**
  - 52 east USA fires, 1963-73, 5000+ acres
  - 33% had LLJ: |du/300m| >= 2.2 m/s
  - Prefrontal jets
  - Similar to Byram 4-a … contradictory result?

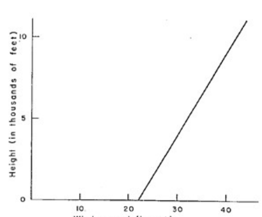


Figure 4.—Characteristic wind profile.

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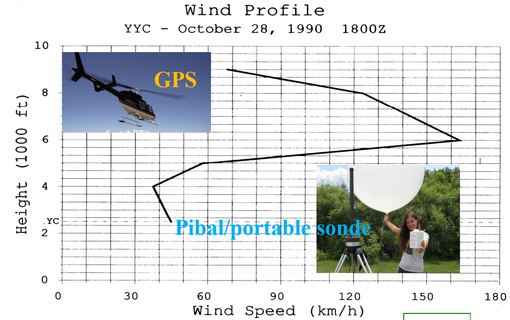
Low Level Jet Example



Which Byram's profiles may this fit? 3b, 3c

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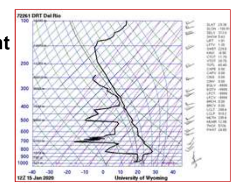
Value of vertical profiles

Temperature and humidity

- Inversion detection: breakdown leads to increased fire intensity
- Air mass stability assessment
  - Showers, fire behaviour



Wind

- Detection of strong winds aloft, including low level jet
  - May reach surface as inversion breaks, air mass mixes
  - Gusts

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Plume vs Wind-dominated fires

Vertical profiles help determine if fire will be:

Convection/plume-dominated:

- Frequently display much higher rates of spread than expected under ambient wind conditions

Wind driven:

- Dominated by the energy of the wind field
- Tend to form smoke plumes rather than 'dynamic' convection columns

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Plume-dominated fires

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- Free convection, high-intensity burning, and rapid spread rates result from:
  - Heavy, dry fuel loads
  - Unstable airmass
  - Surface winds of 30-35 km/h and light winds aloft
- Convection column may collapse or develop strong downdrafts similar to thunderstorms
- Difficult to predict fire behavior
  - Strong and erratic winds
  - Heat transfer to dry fuels

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Plume-dominated fires

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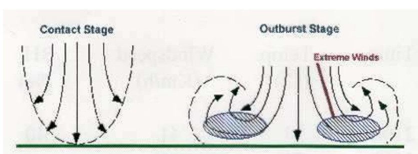
- Appearance of showers or virga signals downdrafts have begun



- Yellowstone: downdraft from column observed by Rothermel uprooted and broke trees over 5 km front.

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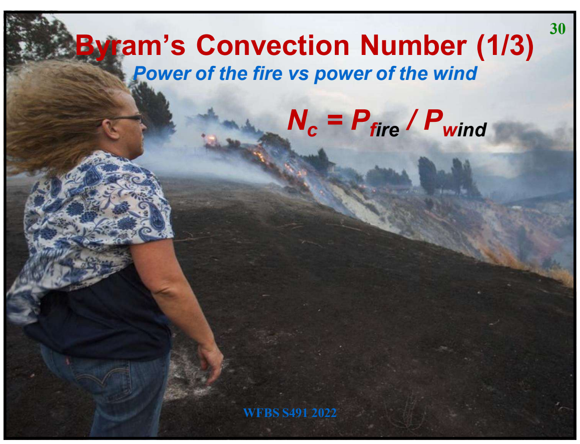

Byram's Convection Number (1/3)

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Power of the fire vs power of the wind

$$N_c = P_{fire} / P_{wind}$$

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Byram's Convection Number (2/3)

$N_c = P_f / P_w = 2gI / \rho C_p T(v-R)^3$

I	Fire intensity (kW/m)
g	Acceleration of gravity (~9.81 m/s^2)
ρ	Air density (kg/m^3) at calculation level
P	Atmospheric pressure (Pa)
R_d	Gas constant for dry air (287.0 J/kgK)
C_p	Heat capacity of dry air (~1003.5 J/kgK)
T	Air temp (ºC) at the elevation of the fire
v	Wind speed (m/s) at some height above the fire
R	Rate of spread (m/s) = ROS(m/min)/60

N_c should be calculated at the surface and at several other levels.

Byram's Convection Number (3/3)

$N_c = P_f / P_w = 2gI / \rho C_p T(v-R)^3$

Units (dimensionless):

$$\frac{\frac{m}{s^2} * \frac{kgm^2}{ms^3}}{\frac{kgm^2}{s^2 kgK} * \frac{kgK}{m^3} * \frac{m^3}{s^3}}$$

$\rho = P/R_d T$ If P is unknown, P=101,325 Pa

$N_c = 2gI / 1.2\, C_p T(v-R)^3$

Heat of combustion H and converting m/min to m/s (18000/60) = 300:

$I = Hwr = 300 \times TFC \times ROS = 300 \times (CFC + SFC) \times ROS$

$= 19.6(300(CFC+SFC)ROS) / 1.2T[(v/3.6) - (R/60.)]^3$

$ROS = a[1 - e^{-b \times ISI}]^c$ $\quad R = ROS/60$

$CFC = CFB \times CFL$ and $SFC = 5[1.0 - e^{-.0164BUI}]^{2.24}$

$$= \frac{19.6\,(300((CFB \times CFL) + 5[1.0 - e^{-.0164BUI}]^{2.24})\, a[1 - e^{-b \times ISI}]^c)}{1.2(T+273.16)[(v/3.6) - R]^3}$$

Some Reading

Ralph M. Nelson, Jr. 1993. ***Byram's Derivation of the Energy Criterion for Forest and Wildland Fires.*** Int. J. Wildland Fire 3(3): 131-138. https://www.publish.csiro.au/wf/pdf/WF9930131. Accessed February 24, 2020.

Read and answer the following questions (see Assignment in Canvas):

- **Why was Byram's approach initially criticized?**
- **How is the Froude Number related to Byram's Nc?**
- **What assumptions are made that may not have been discussed in Byram's original studies?**

Convection Number Alternatives

Other papers to look at are:

D. Morvan and N. Frangeih. 2018. *Wildland fire behaviour: Wind effect versus Byram's convective number and consequences on the regime of propagation.* International Journal of Wildland Fire 2018, 27, 636–641. https://doi.org/10.1071/WF18014. See also Corrigendum. Accessed February 24, 2020.

Byram's Convection Number

At-home Exercise

Exercise details are found in *S589-III-A-2_Exercise2022.pptx*

Fuel type:	**C3**	**FFMC:**	**93**
ISI:	**18**	**BUI:**	**55**
CFB:	**1.0**	**CFL:**	**1.15 kg/m^2**
Surface wind:	**20 km/h**		
Surface temp:	**18 ^{o}C**		

1. Calculate the value of N_c for the above conditions.
2. A helicopter sounding determines that the wind at 300 m above the fire is 35 km/h. Calculate the convection number at this level.

Summary

- **Atmospheric phenomena can influence fire; fire can influence atmosphere**
  - **Crew safety depends on weather and fire factors**
- **Downdraft from thunderstorm or collapsing plume can cause:**
  - **Erratic fire behaviour**
  - **Heat burst?**
- **Vertical atmospheric profiles help determine:**
  - **Blow-up potential**
  - **Likelihood of plume-driven fire**

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