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Canadian Fire Weather Index System (FWI system)

CANADIAN FOREST SERVICE

FIRE RESEARCH

Why build the FWI System?

FWI 9

FWI 15

FWI 17

FWI 24

FWI 34

Adapted from Alexander & de Groot (1988)

Before the FWI

- In 1928 fire research effectively began in Canada
  - Day-to-Day fire susceptibility began to be tracked everywhere

- By 1957 there were 4 major danger rating systems and many regional modifications to these

- The conceptual basis of these lead to the FWI system

Scope

"It was decided early on, however, that the main goal was a new danger index based solely on weather that could be used to give uniform results throughout Canada. The question of how fire behavior varies with fuel types was judged to be a separate problem, to be tackled in other ways."

- C. E. Van Wagner (1987)

- Not a fire behavior model
- It tracks moisture changes in different layers of forest floor alongside changes in weather
- It combines fuel moisture with current weather conditions to give relative estimates of potential fire behavior

Fuel Moisture Codes

Fine Fuel Moisture Code (FFMC)

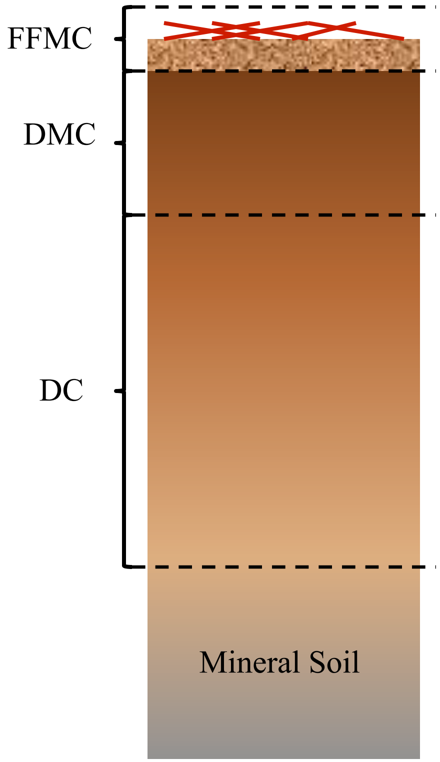
- Litter layer, and other cured fine fuels
- 0 – 1.2 cm depth in the forest floor (0.25 kg/m^2)
- Plays a significant role in ignition probability and spread

Duff Moisture Code (DMC)

- Loosely compacted, fermenting (decomposing) organic matter
- 1.2 – 7 cm depth in the forest floor (5 kg/m^2)
- Contributes to lightning receptivity and over all fire intensity

Drought Code (DC)

- Deep layer of compact humus (decomposed) organic matter
- 7+ cm depth in the forest floor (25 kg/m^2)
- Contributes to depth of burn, intensity, and suppression difficulty



Fuel Moisture Codes

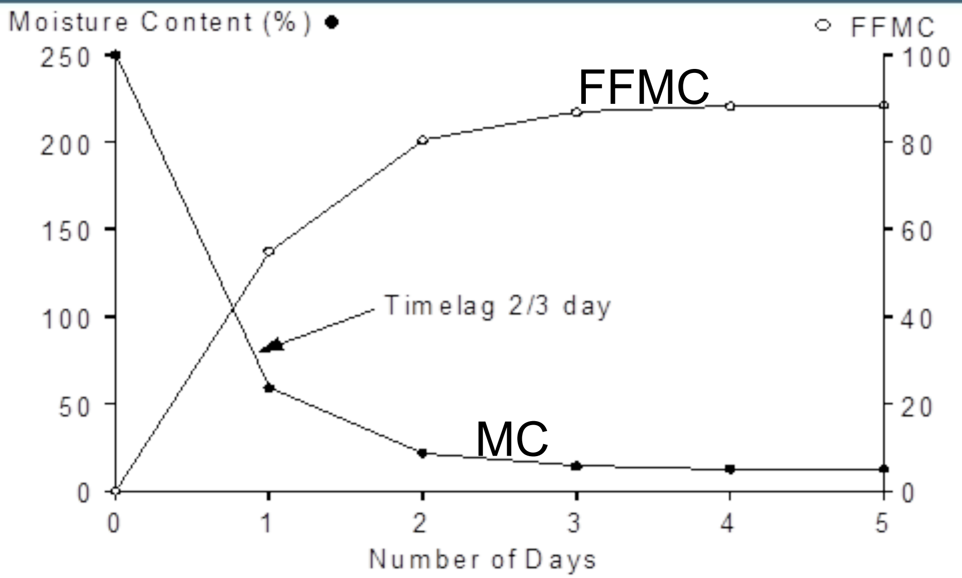
- Differences in the codes can be understood in-terms of their water capacity and drying speed
- Drying occurs exponentially
    - Instantaneous drying rate is proportional to the current free moisture content
- Drying speed can be understood by the slope of these curves, but more commonly by the "Timelag constants" (the time it takes for one of these layers to lose 2/3 of its moisture)

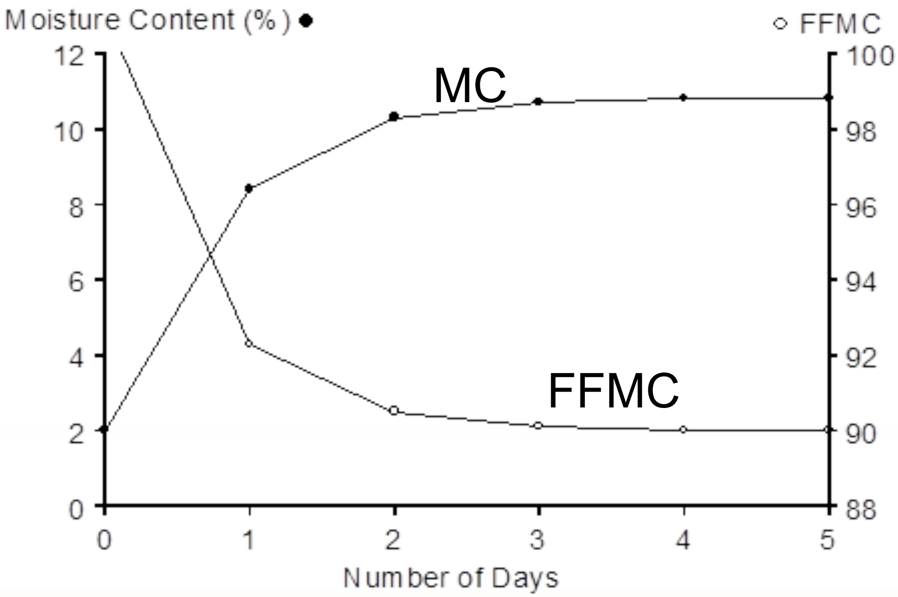
Table 1. Properties of the three fuel moisture codes

Code	Timelag days	Water capacity mm	Required parameters[1]	Nominal fuel depth cm	Nominal fuel load kg/m^2
FFMC	2/3	0.6	T, H, W, r	1.2	0.25
DMC	12	15	T, H, r, mo	7	5
DC	52	100	T, r, mo	18	25

[1]T — temperature, H — humidity; W — wind, r — rain, mo — month.

MC = 101 - FFMC


Moisture Content (%) ●
○ FFMC
250
200
150
100
50
0
100
80
60
40
20
0
FFMC
Timelag 2/3 day
MC
0
1
2
3
4
5
Number of Days


Moisture Content (%) ●
○ FFMC
12
10
8
6
4
2
0
100
98
96
94
92
90
88
MC
FFMC
0
1
2
3
4
5
Number of Days

Fire Behavior Indices

Initial Spread Index (ISI)

- Combines FFMC and wind speed
- Varies greatly based on current wind conditions
- Represents ROS as a relative term (i.e. ISI = 17 > ISI = 10 => higher ROS)

Build-Up Index (BUI)

- Combines DMC and DC, with increased weight placed on the DMC
- Does not vary throughout the day
- Represents total fuel available for consumption

Fire Weather Index (FWI)

- Combines the ISI and BUI, with increased weight on the ISI
- Is more stable than the ISI, but varies with it throughout the day
- Represents potential fire intensity

Fire Behavior Indices

(ISI) and (BUI) => (FWI)

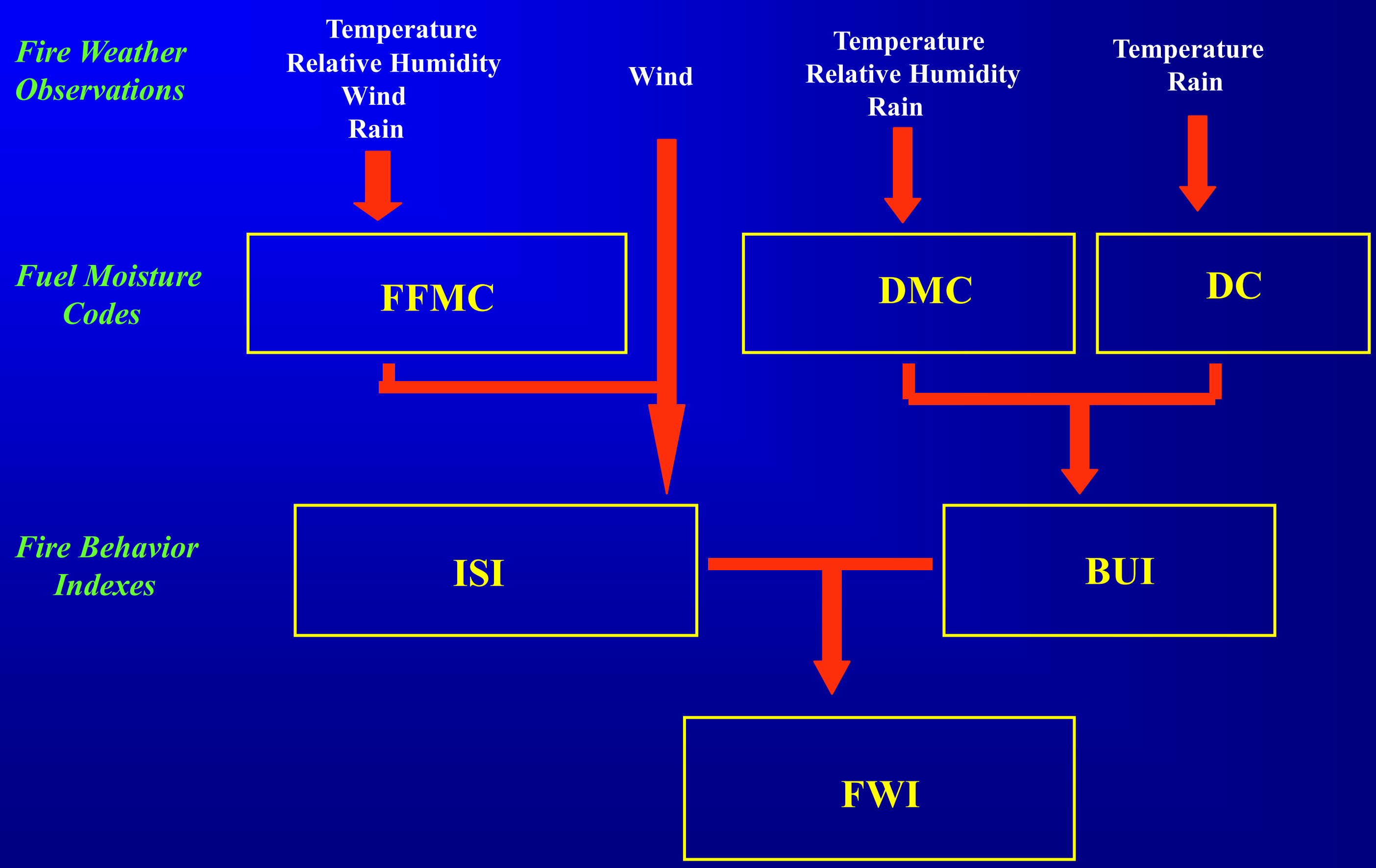
Where:
- ISI = potential ROS
- BUI = potential fuel consumption
- FWI = potential fire intensity

I = hwr

Byram's Intensity

Where:
- r = spread rate (m/sec)
- w = fuel consumption (kg/m^2)
- h = low heat of combustion (kJ/kg)
- I = fire intensity (kW/m)

Canadian Forest Fire Weather Index System



Data Collection

"Standard Fire Weather"

A standard fire weather station should be in a 100 m diameter clearing, not adjacent to water body

Daily weather observations collected at 12:00 local standard time (LST) of:

- Ambient temperature (°C)
- Relative Humidity (RH) (%)
- Mean wind speed, at 10 m above surface (km/h)
- Rainfall, 24 hr total (mm)

FFMC

The FFMC is the only code that can be directly converted to fuel moisture

The internal calculations of the code are performed on moisture – not the FFMC

INPUTS:

- Temp (°C)
- RH (%)
- WS (km/h)
- Precip (mm)

INITIAL CONDITION:

- Previous FFMC

OUTPUT RANGE:

0 - 101

$$FFMC = \frac{59.5\,(250 - m)}{147.2 + m}$$

$$m = \frac{147.2(101 - FFMC)}{59.5 + FFMC}$$

FFMC

Drying:

$$k_0 = 0.424\left(1 - \left(\frac{RH}{100}\right)^{1.7}\right) + 0.0694\sqrt{Wind\ Speed}\left(1 - \left(\frac{RH}{100}\right)^{8}\right)$$

Wetting:

$$k_0 = 0.424\left(1 - \left(\frac{100 - RH}{100}\right)^{1.7}\right) + 0.0694\sqrt{Wind\ Speed}\left(1 - \left(\frac{100 - RH}{100}\right)^{8}\right)$$

Now you get k, which is change in (log(m/day)):

$$k = k_0(0.581\, e^{0.0365\, T})$$

FFMC

$$E_d = 0.942\, RH^{0.679} + 11\, e^{\frac{RH-100}{10}} + 0.18\,(21.1 - T)(1 - e^{-0.115\,RH})$$

$$E_w = 0.618\, RH^{0.753} + 10\, e^{\frac{RH-100}{10}} + 0.18\,(21.1 - T)(1 - e^{-0.115\,RH})$$

$$m = E_d + (m_0 - E_d) \times 10^{-k_d}$$

$$m = E_w - (E_w - m_0) \times 10^{-k_w}$$

FFMC - rainfall

$$\frac{\Delta m}{r_f} = 42.5\, e^{\left(\frac{-100}{251-m_0}\right)} \left(1 - e^{\left(\frac{-6.93}{r_f}\right)}\right)$$

Δm = increase in m due to rainfall

r_f is the forest canopy corrected rain: $r_f = r_0 - 0.5$

IF $m_0 > 150$ then a correction is added to the above:

$$0.0015\,(m_0 - 150)^2\, r_f^{\,0.5}$$

DMC

Duff ≈ F-layer (also H)

DMC = duff up to 7 cm

DMC

The internal calculations of the code are performed on moisture

INPUTS:

-Temp (°C)
- RH (%)
~~- WS (km/h)~~
- Precip (mm)

INITIAL CONDITION:

- Previous DMC

MOISTURE RANGE:

MAX = 300 %
EQ = 20 %

Duff is not exposed to wind

DMC

Rainfall phase, only if: $r_0 > 1.5$ mm

$$r_e = 0.92\, r_o - 1.27$$

r_0 = wx rainfall
r_e = effective rainfall

$$M_r = M_o + 1000\, r_e/(48.77 + br_e)$$

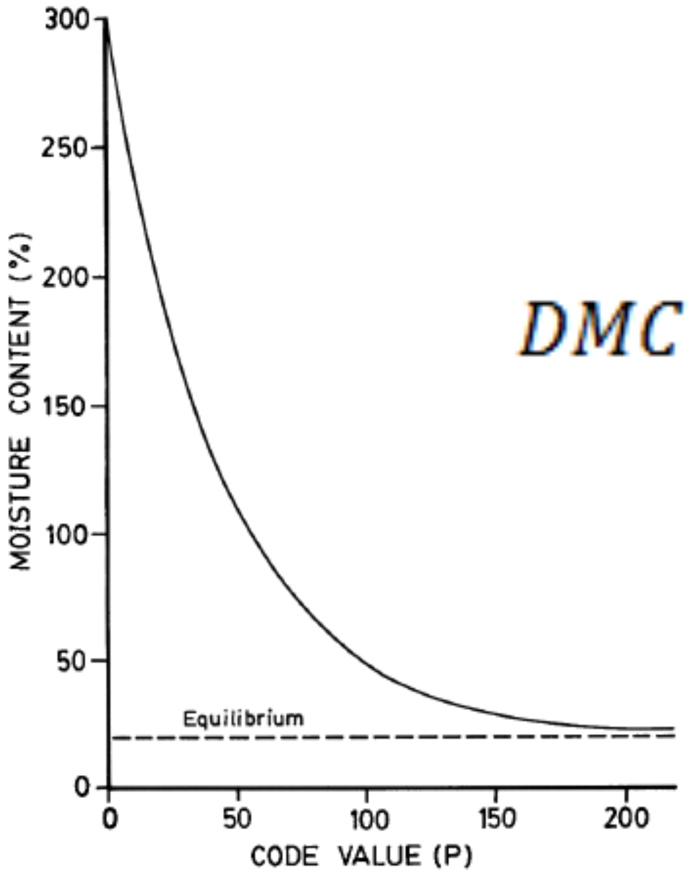
P_0 = previous DMC

$$b = 100/(0.5 + 0.3\, P_o) \quad , P_o \le 33$$

$$b = 14 - 1.3 \ln P_o \quad , 33 < P_o \le 65$$

$$b = 6.2 \ln P_o - 17.2 \quad , P_o > 65$$

DMC



$$DMC = 244.72 - 43.43\ ln(m - 20)$$

Figure 5. Graph of scale linking DMC to duff moisture content.

DC

- Represents the DEEP organic layer (min 7 cm, typically 18 cm)
- Also correlates well with coarse woody debris
- 54 day time lag
- primary long-term memory in the system

DC

Provides a warning about deep fuels

DC

The internal calculations of the code are performed on moisture

INPUTS:	**INITIAL CONDITION:**	**MOISTURE RANGE:**
-Temp (°C) ~~- RH (%)~~ ~~- WS (km/h)~~ **- Precip (mm)**	- Previous DC	MAX = 400 %

Deep / coarse layer only responds to temp and significant precip

DC

$$D = 400 \ln (800/Q)$$

Where:
-D = current DC
-Q = m equivalent

Rainfall Phase (if $r_0 > 2.8$ mm):

$$r_d = 0.83\, r_0 - 1.27$$

$$Q_r = Q_0 + 3.937\, r_d$$

DC

Drying Phase

$$V = 0.36\,(T + 2.8) + L_f$$

V = potential evapotranspiration
T = noon temp
L_f = day length adjustment by month

$$D = D_o \text{ (or } D_r) + 0.5\,V$$

D_0 = initial DC
D_r = DC after rain calculation

DC

OVERWINTERING


GREENPEACE

DC

OVERWINTERING

The DC time lag is long enough that you cannot assume snow melt will saturate the DC

$$Q_s - a\,Q_f + b\,(3.94\,r_w)$$

Q_s = final fall moisture equivalent
r_w = is winter precip in mm
Q_s = starting spring moisture equivalent
a and b are constants

- Topic of great concern
- Depends very much on the nature of the melt (e.g. Ontario 2012)
- Most managers dont trust spring DCs until a heavy rain resets them

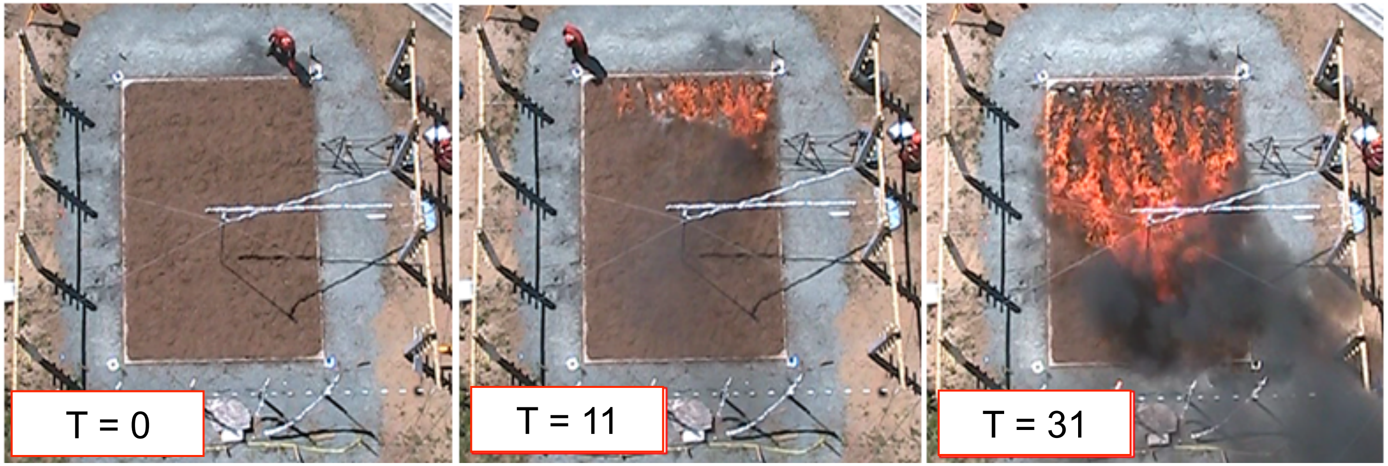
ISI

- The wind function of the fire behavior based indexes
- Describes the potential rate at which a fire will spread
- Depends solely on wind and the fine fuel moisture code

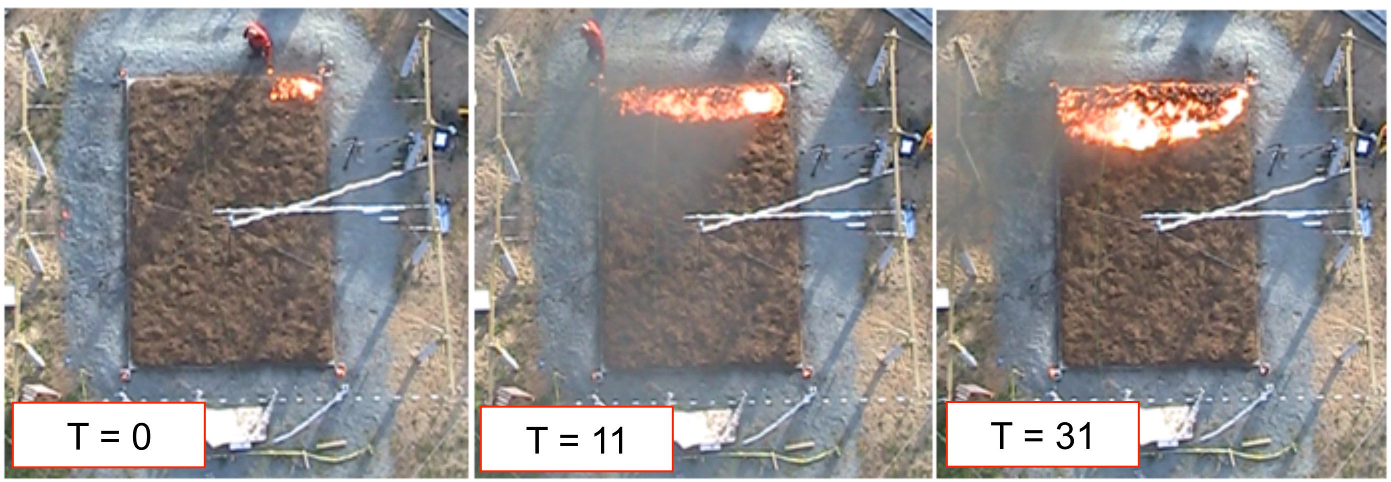
INPUTS:

-WS (km/h)
-FFM

FFMC = 93.7, WS = 8 km/h → ISI = 10.8



FI = 3854 kW/m



FI = 676 kW/m

FFMC = 91.8, WS = 2.6 km/h → ISI = 6.2

ISI

Wind Function $f(W) = e^{0.05039\,W}$

FFM Function $f(F) = (91.9\,e^{-0.1386\,m})\left(1 + \frac{m^{5.31}}{4.93 \times 10^{7}}\right)$

$$ISI = 0.208\,f(W)f(F)$$

BUI

- Represents the available fuel for combustion
- Combines the DMC and DC in a harmonic mean
- If the DMC ~0 then no value of DC can raise the BUI

INPUTS:

-DMC
-DC

- Due to the trend of increasing DC over the summer there is a slight seasonal BUI trend

$$BUI = \frac{0.8\,(DMC)\,(DC)}{(DMC + 0.4DC)}$$

FWI

INPUTS:

-ISI
-BUI

- Represents potential fire intensity
- Combines the ISI and BUI as theoretical FI scale
- Provides a general scale for potential fire intensity
- **Is not used anywhere in the CFFBPS, and often not in response either**

FWI

BUI < 80

$$f(D) = 0.626 BUI^{0.809} + 2$$

BUI > 80

$$f(D) = \frac{1000}{25 + 108.64\, e^{-0.023\, BUI}}$$

$$\ln(FWI) = 2.72\left(0.434\, ln(0.1\, ISI\, f(D))\right)^{0.647}$$

* IF (0.1 ISI f(D)) < 1 then FWI = (0.1 ISI f(D))

Applications

Weather Forecast Report (Official)
Report Produced: 2012/07/04 11:32
All times on this report are Eastern Time
Total Number Of Records: 39

Report Selection Criteria
Time: 13:00 Start Date: 2012/07/05 End Date:
Fire Area: CHA

Forecast for 2012/07/05 saved on 2012/07/03 at 14:38 by corbettma
Resp. Sector: E04

Station	Type	WS	RS	Date	Temp	RH	Dir	Speed	Rain	FFMC	DMC	DC	ISI	BUI	FWI
BNR	P	E04	E04	2012/07/05	27.9	45	230	9.0	.0	86.6	56	274	4.1	74	14
CHA	P	E06	E04	2012/07/05	28.9	43	280	6.0	.0	89.0	35	266	5.1	52	14
CHB	P	E09	E04	2012/07/05	26.3	52	250	14.0	.0	88.8	40	187	7.3	52	18
DAL	P	E06	E04	2012/07/05	27.8	52	260	12.0	.0	87.3	38	276	5.4	56	15
FLL	P	E06	E04	2012/07/05	30.4	36	290	8.0	.0	90.7	29	271	7.1	46	17
FOL	P	E06	E04	2012/07/05	27.9	40	220	6.0	.0	84.3	15	224	2.6	26	5
MEA	P	E09	E04	2012/07/05	30.8	36	260	11.0	.0	91.3	37	225	9.0	52	21
PAN	P	E08	E04	2012/07/05	20.9	75	300	2.0	.0	78.1	16	120	1.0	24	1
QRK	P	E09	E04	2012/07/05	27.1	51	250	17.0	.0	90.0	43	205	10.1	56	24
RAM	P	E06	E04	2012/07/05	30.1	34	210	2.0	.2	89.9	42	327	4.6	63	14
RAN	P	E09	E04	2012/07/05	28.1	44	270	14.0	.0	89.6	35	206	8.2	50	19
SAU	P	E09	E04	2012/07/05	25.6	56	200	6.0	.0	87.3	35	161	3.9	45	10
TLN	P	E09	E04	2012/07/05	24.5	60	230	9.0	.0	87.2	34	107	4.5	38	10

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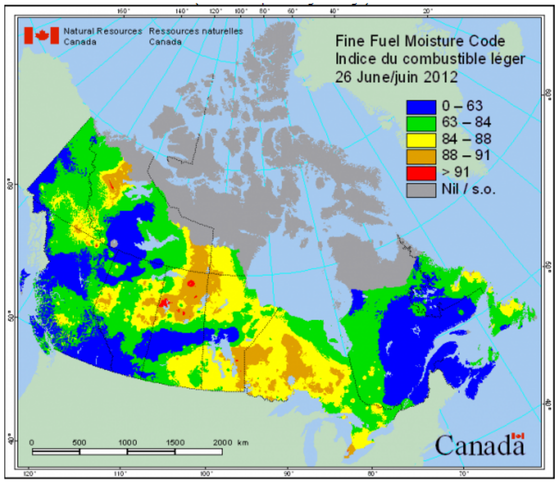
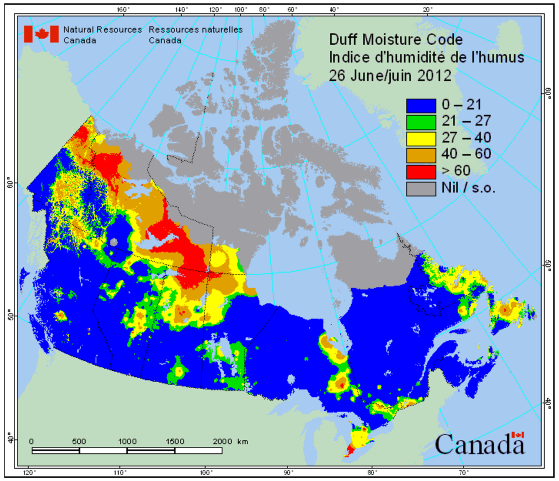
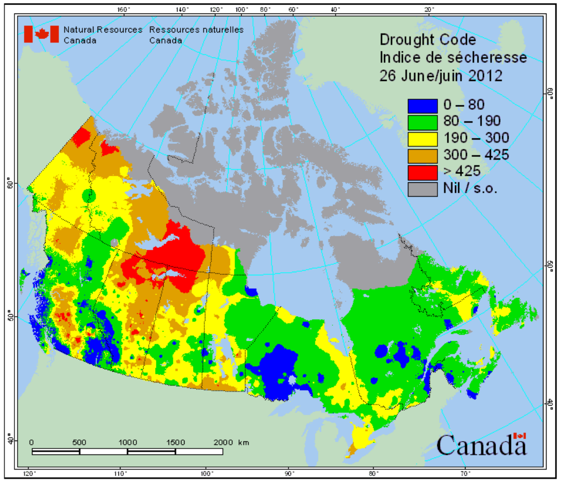
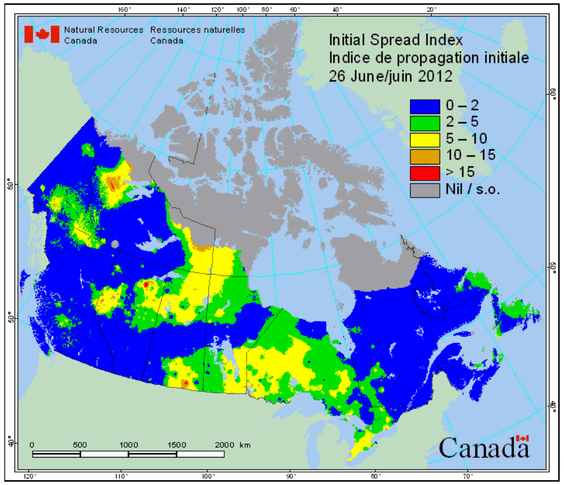
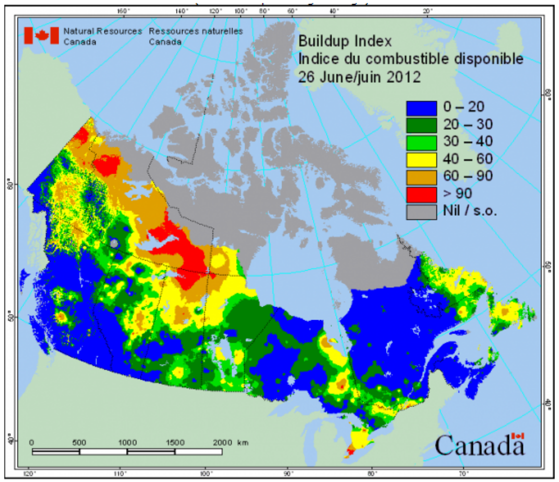
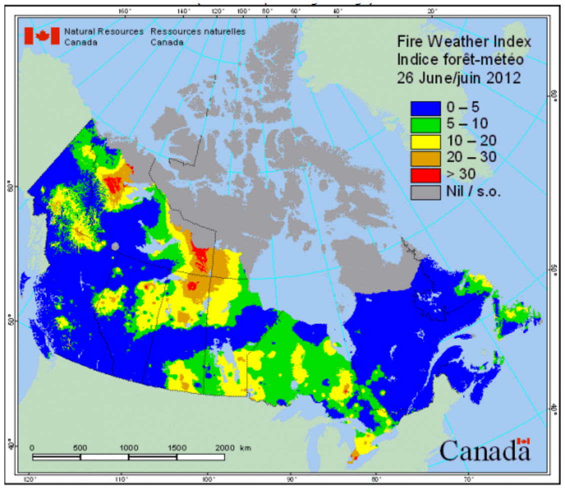






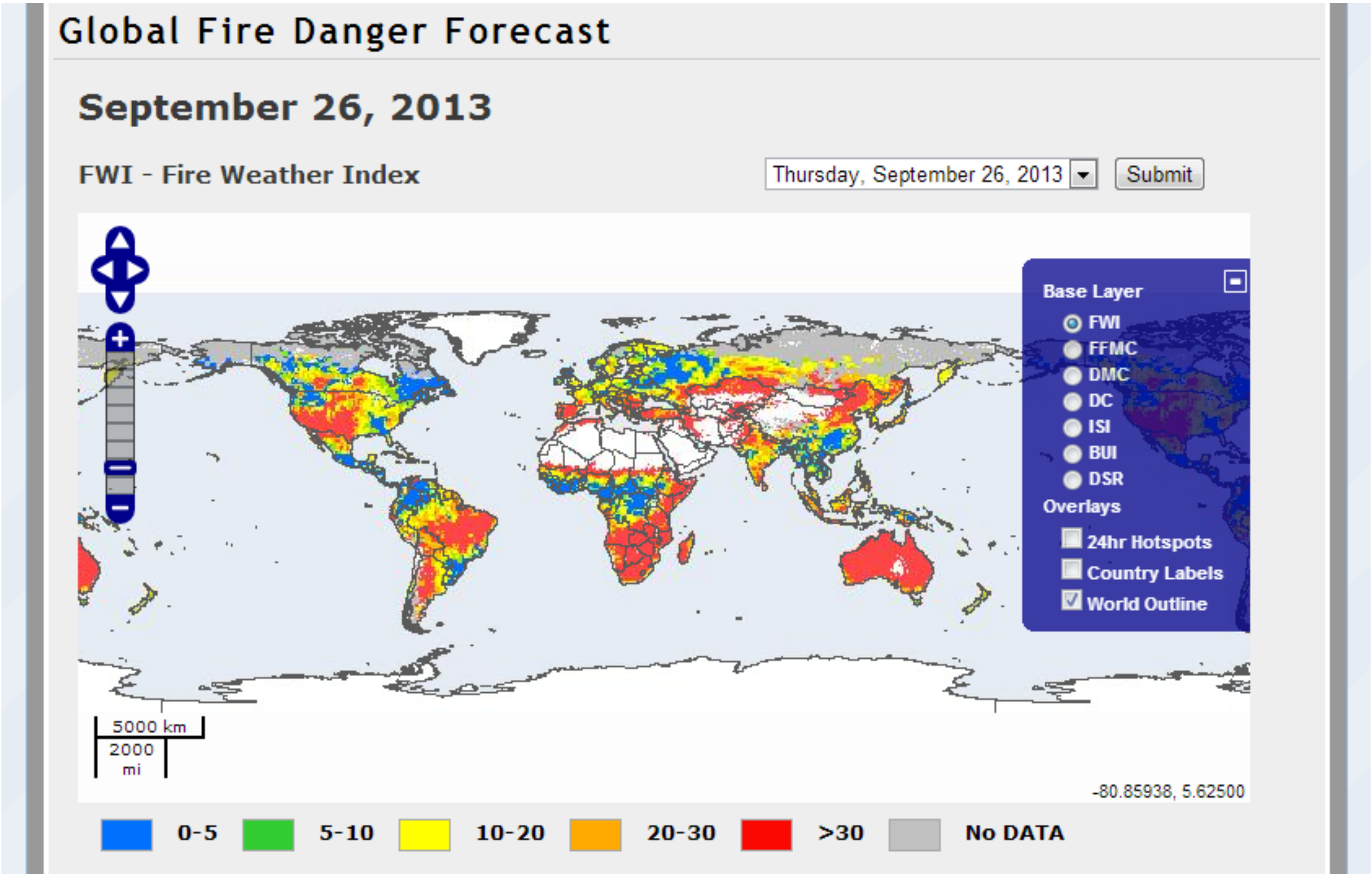






Canada

Calibration



Exportation

It works pretty much everywhere.

Carvalho, A, Flannigan, MD, Logan, K, Miranda, AI, Borrego, C (2008) Fire activity in Portugal and its relationship to weather and the Canadian Fire Weather Index System. *International Journal of Wildland Fire* ***17, 328-338.***

de Groot, WJ, Field, JRD, Brady, MA, Roswintiarti, O, Mohamad, M (2007) Development of the Indonesian and Malaysian Fire Danger Rating Systems. *Mitigation and Adaptation Strategies for Global Change* ***12, 165-180.***

Tian, X, McRae, DJ, Jin, J, Shu, L, Zhao, F, Wang, M (2011) Wildfires and the Canadian Forest Fire Weather Index system for the Daxing'anling region of China. *International Journal of Wildland Fire* ***20, 963-973.***

Common Misconceptions

- FWI is the name of the system so the FWI must be the most important index
- Forecasts fire behavior
- Calibrations are exportable
- Predicts fire occurrence
- Predicts fuel moisture (beyond the FFM)
- Describes foliar moisture

Questions?