The BlueSky-Canada Wildfire Smoke Forecast System

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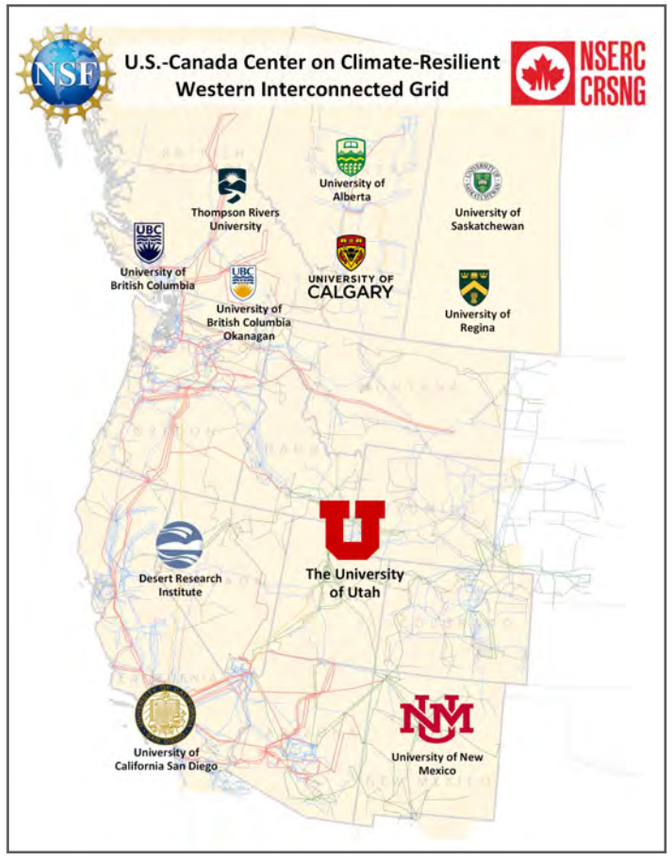
5 June 2024

WFRT
WEATHER FORECAST RESEARCH TEAM

UBC

WIRED GLOBAL CENTER
U.S.-Canada Center on Climate-Resilient Western Interconnected Grid




Mike Eliason/Santa Barbara County Fire Department via AP,

Motivation / Teaser

Bishop Bluffs fire in central BC - 13 Aug 2017

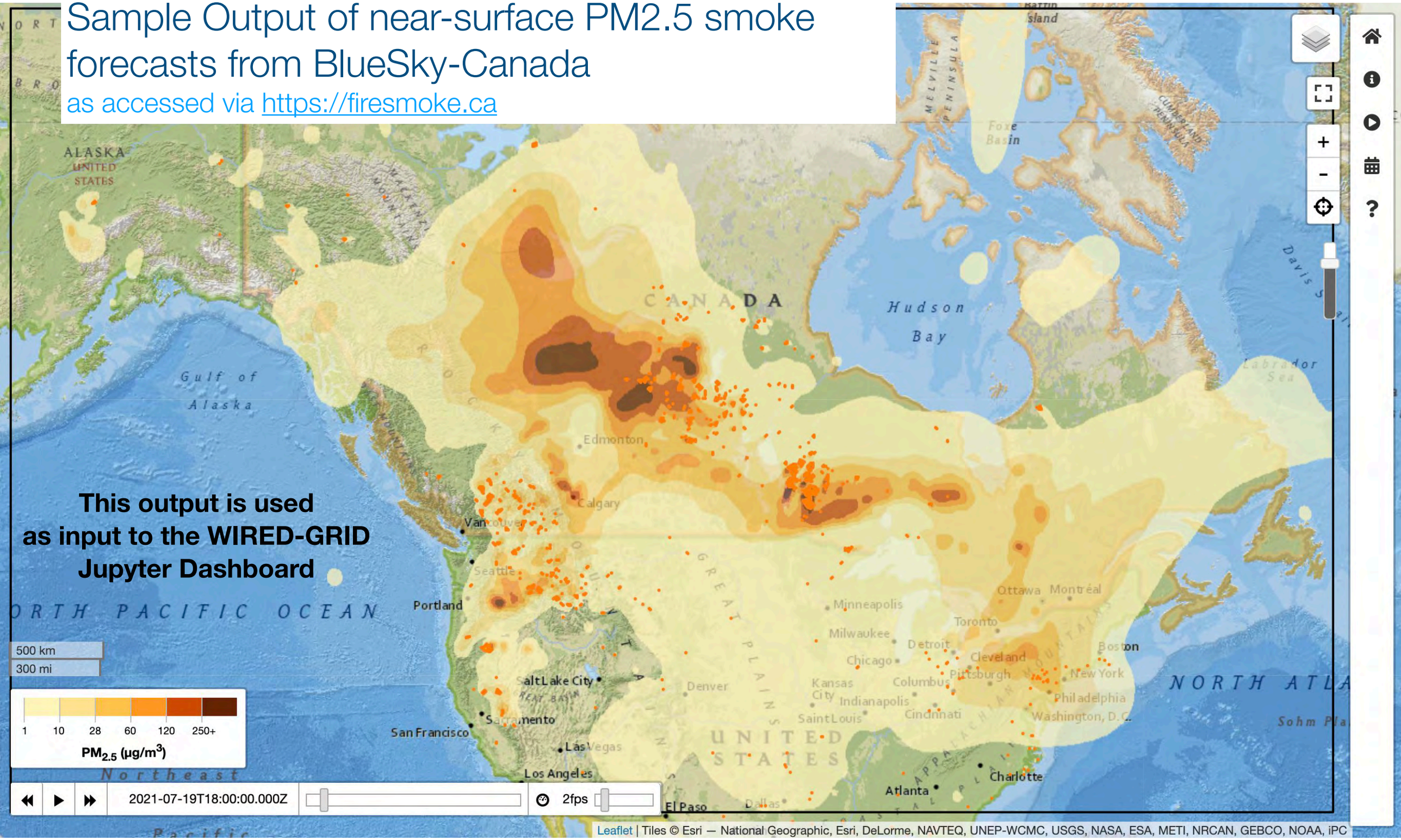
Over 65 BC provincial parks closed in 2017.
Dozens of highways closed. Dozens of towns evacuated.

BlueSky Canada - Overview

Sample Output of near-surface PM2.5 smoke forecasts from BlueSky-Canada

as accessed via https://firesmoke.ca

This output is used as input to the WIRED-GRID Jupyter Dashboard



BlueSky Canada - Overview

Topics:

1. Origin and Development (in USA & Canada)
2. Fire, Fuel & Weather Inputs (from NRCan, NASA, NWS, ECCC)
3. Smartfire reconcilation of fire data (run by UBC)
4. Meteorology Forecasts with the WRF model (run by UBC)
5. BlueSky Computational Pipeline (run by UBC)
6. Tutorials, Other products in Development, Summary

Okanagan Mountain Park
wildfire. 2003
Photo by Steve Devries.

1. Origin & Develoment

BlueSky (USA)

- Created on 2000 by the US Forest Service - AirFire Research Team in Seattle. https://www.airfire.org/data/bluesky - lead by Sue Ferguson.
- Expanded in 2003 to cover continental US (CONUS) - lead by Sim Larkin & colleagues.
- Sonoma Technologies Inc. (STI) hired to write code to find wildfires from satellite "hotspots".
- ~2018 - 2019 updated from the old Bluesky "framework" to a new computational "**pipeline**".
- See : https://tools.airfire.org/websky/v2/run/standard/NAM84-0.15deg/current#viewer

BlueSky-Canada

- ~2007 STI hired by BC & AB Environment Ministries to Canadianize BlueSky.
- 2007 - 2009 UBC hired to make pilot BlueSky runs using UBC weather forecasts.
- 2010 daily operational runs start, focused on BC & AB (western Canada. Later all Canada.)
- Summer 2020 we "Canadianized" the **pipeline** version of BlueSky.
- Created unified domain over Canada, AK, most of CONUS. Web viewers: https://firesmoke.ca

Narasimhan K. Larkin, Susan M. O'Neill, Robert Solomon, Sean Raffuse, Tara Strand, Dana C. Sullivan, Candace Krull, Miriam Rorig, Janice L. Peterson and Sue A. Ferguson, 2009: The BlueSky smoke modeling framework . *International Journal of Wildland Fire* 2009, **18**, 906–920. www.publish.csiro.au/journals/ijwf . DOI: 10.1071/WF07086

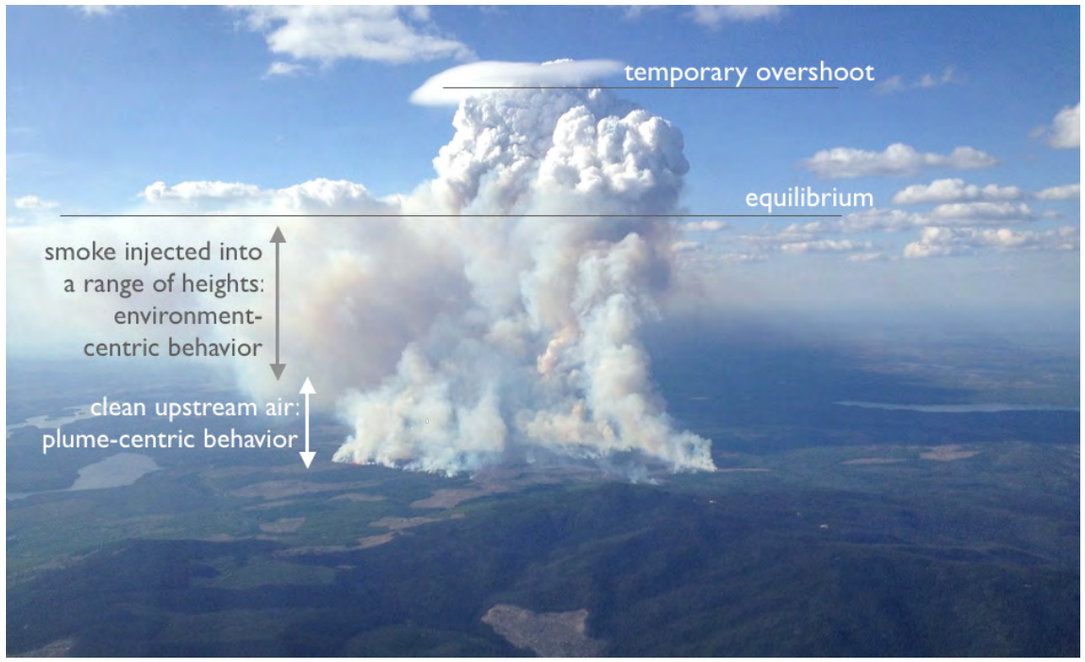
1. Origin & Develoment

BlueSky is a "**system**" connecting many different models that ...

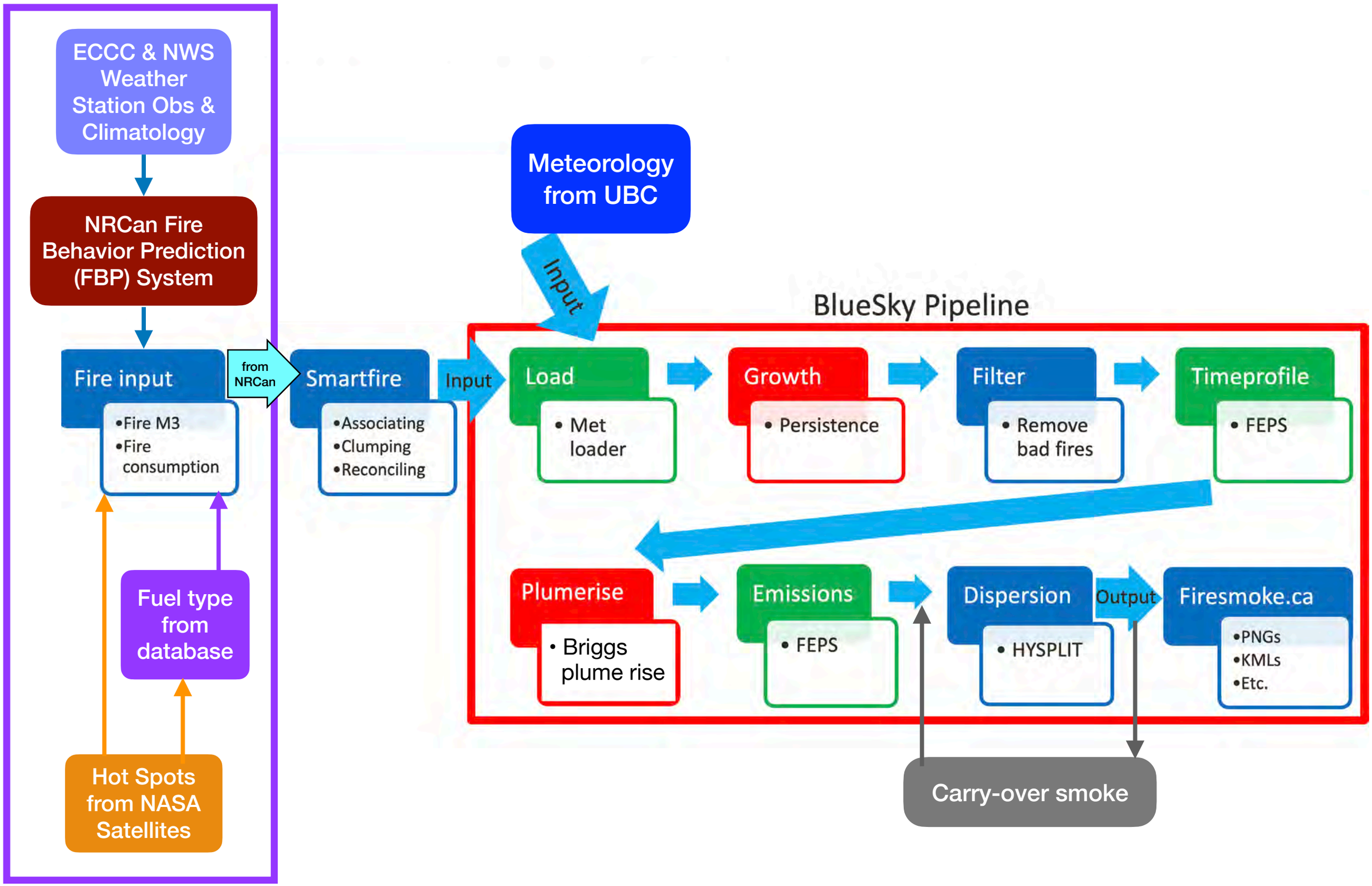
- lookup of fuels information from fuel maps / databases
- calculate total and hourly fire consumption based on fuel loadings and weather information
- calculate smoke (PM2.5) emissions from a fire
- calculate vertical plume-rise profiles produced by a fire
- calculate likely trajectories of smoke parcels given off by a fire
- calculate downstream smoke concentrations at the earth's surface.
- display maps and animations of the forecasts

It relies on inputs from other models

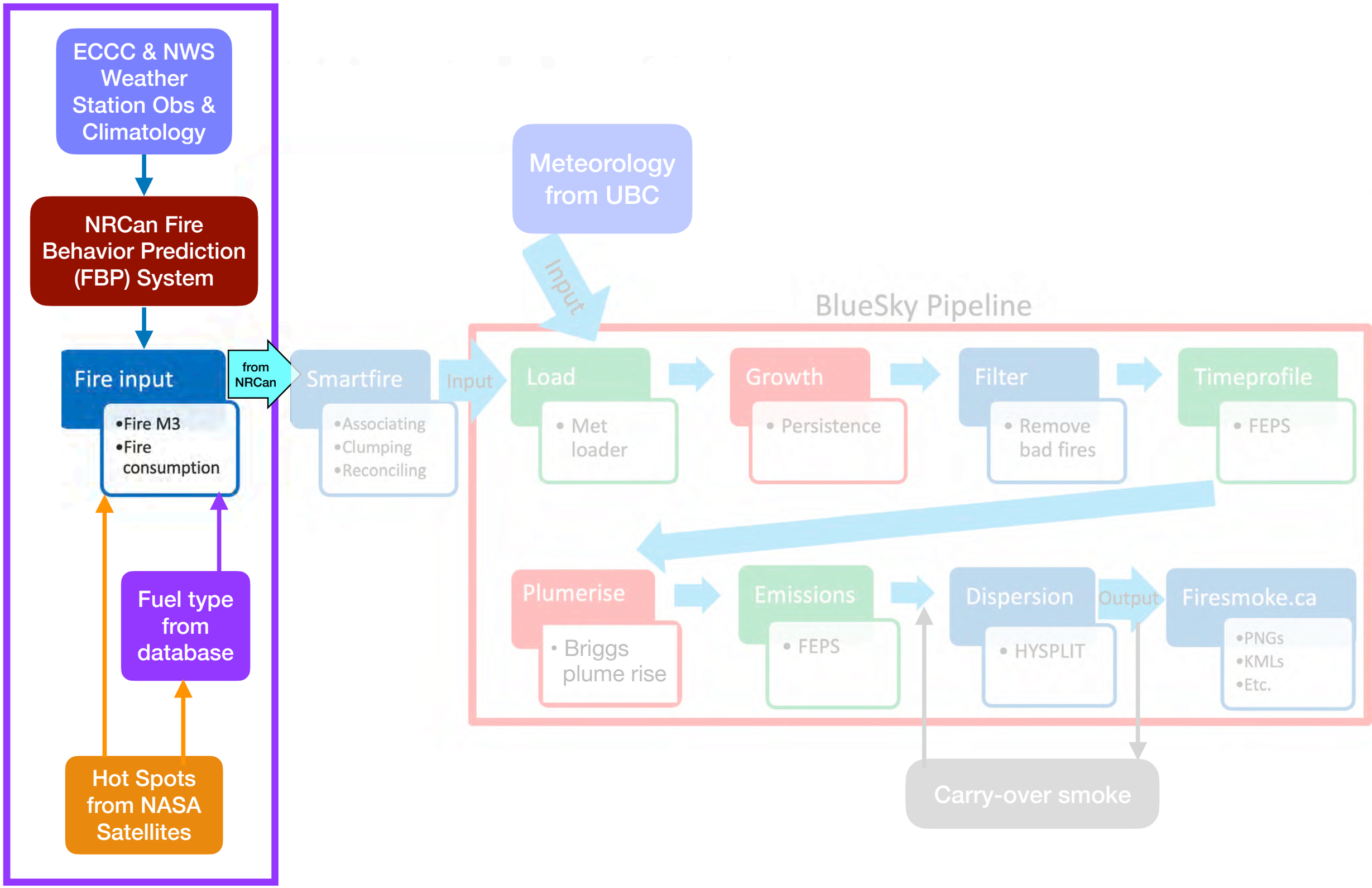
- fire detections, from satellite "hot spots" and ground reports
- reconciliation of fire locations
- numerical weather forecasts on a 3-D grid



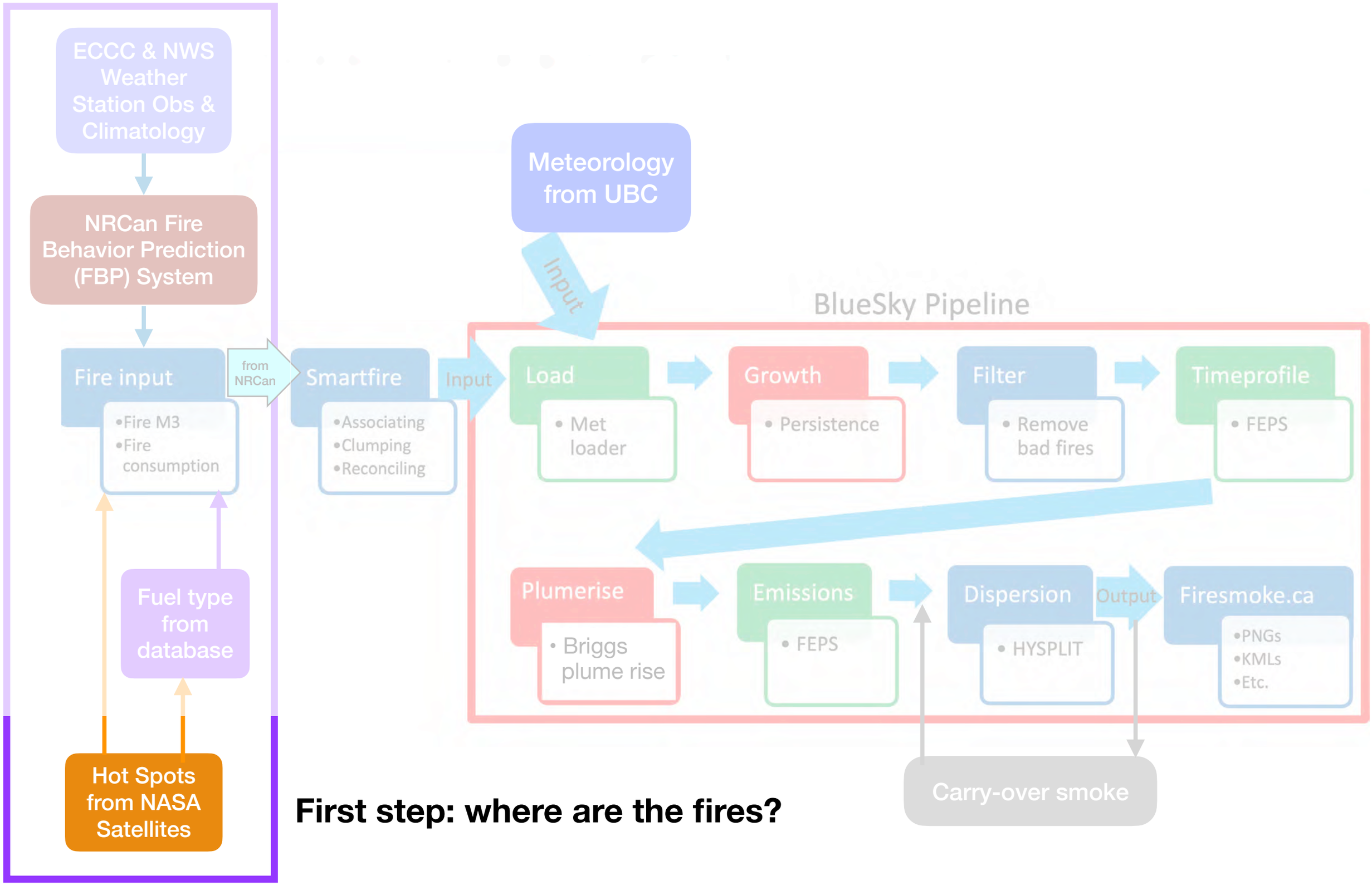
1. The BlueSky System



2. Inputs


ECCC & NWS Weather Station Obs & Climatology
NRCan Fire Behavior Prediction (FBP) System
Fire input
•Fire M3
•Fire consumption
from NRCan
Fuel type from database
Hot Spots from NASA Satellites
Meteorology from UBC
Input
BlueSky Pipeline
Smartfire
•Associating
•Clumping
•Reconciling
Input
Load
• Met loader
Growth
• Persistence
Filter
• Remove bad fires
Timeprofile
• FEPS
Plumerise
• Briggs plume rise
Emissions
• FEPS
Dispersion
• HYSPLIT
Output
Firesmoke.ca
•PNGs
•KMLs
•Etc.
Carry-over smoke

2a. Satellite Observations



First step: where are the fires?

2a. Satellite Observations

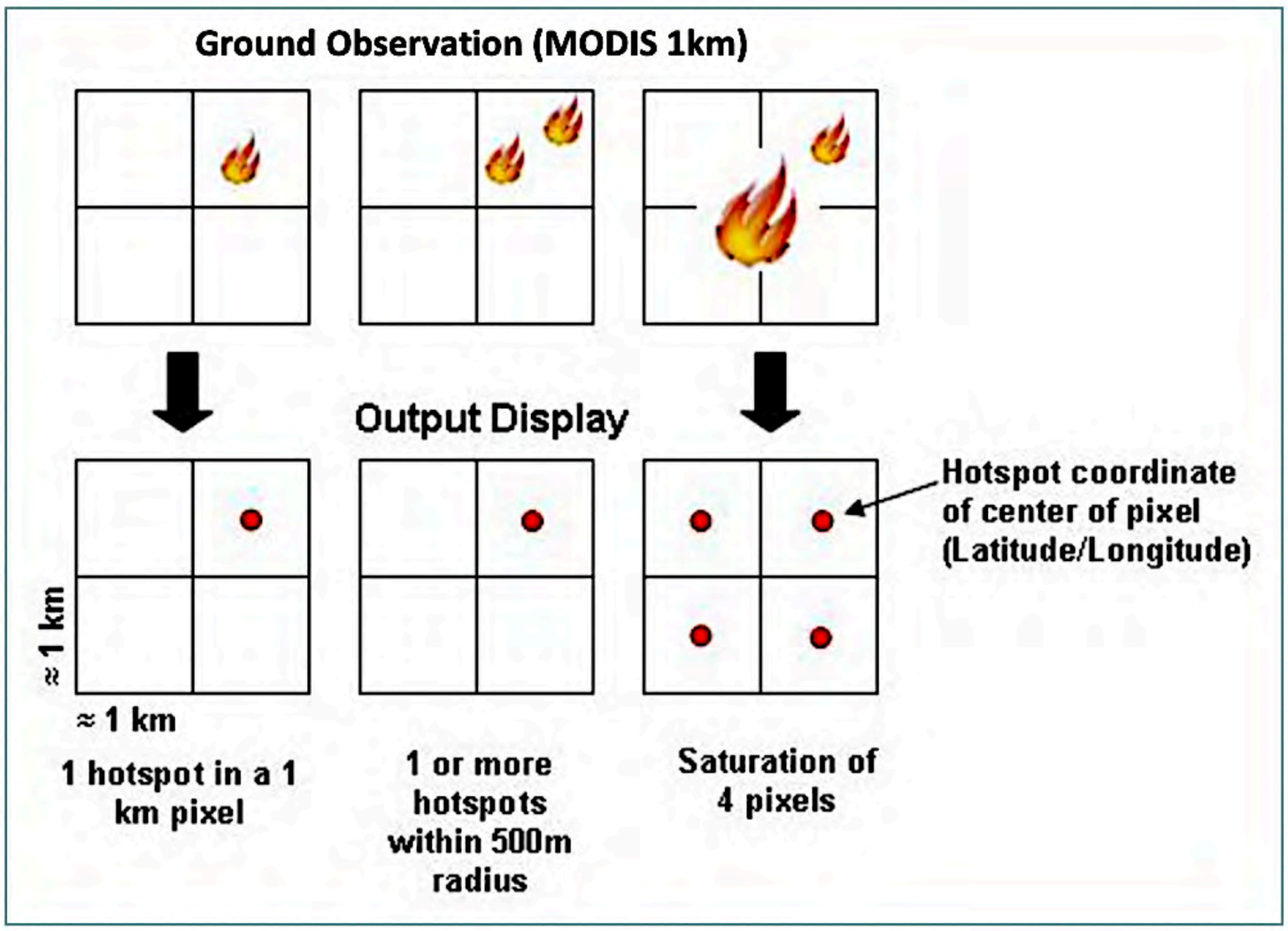
Both wildfire ground reports and satellite hot spots are used to locate wildfires.

What is a Hotspot?

A hotspot is a satellite image pixel with high infrared (IR) intensity, indicating a heat source. Hotspots from known industrial sources are removed; the remaining hotspots represent vegetation fires, which can be in forest, grass, cropland, or logging debris.

https://cwfis.cfs.nrcan.gc.ca/maps/fm3?type=apt

https://sealevel.nasa.gov/missions/aqua

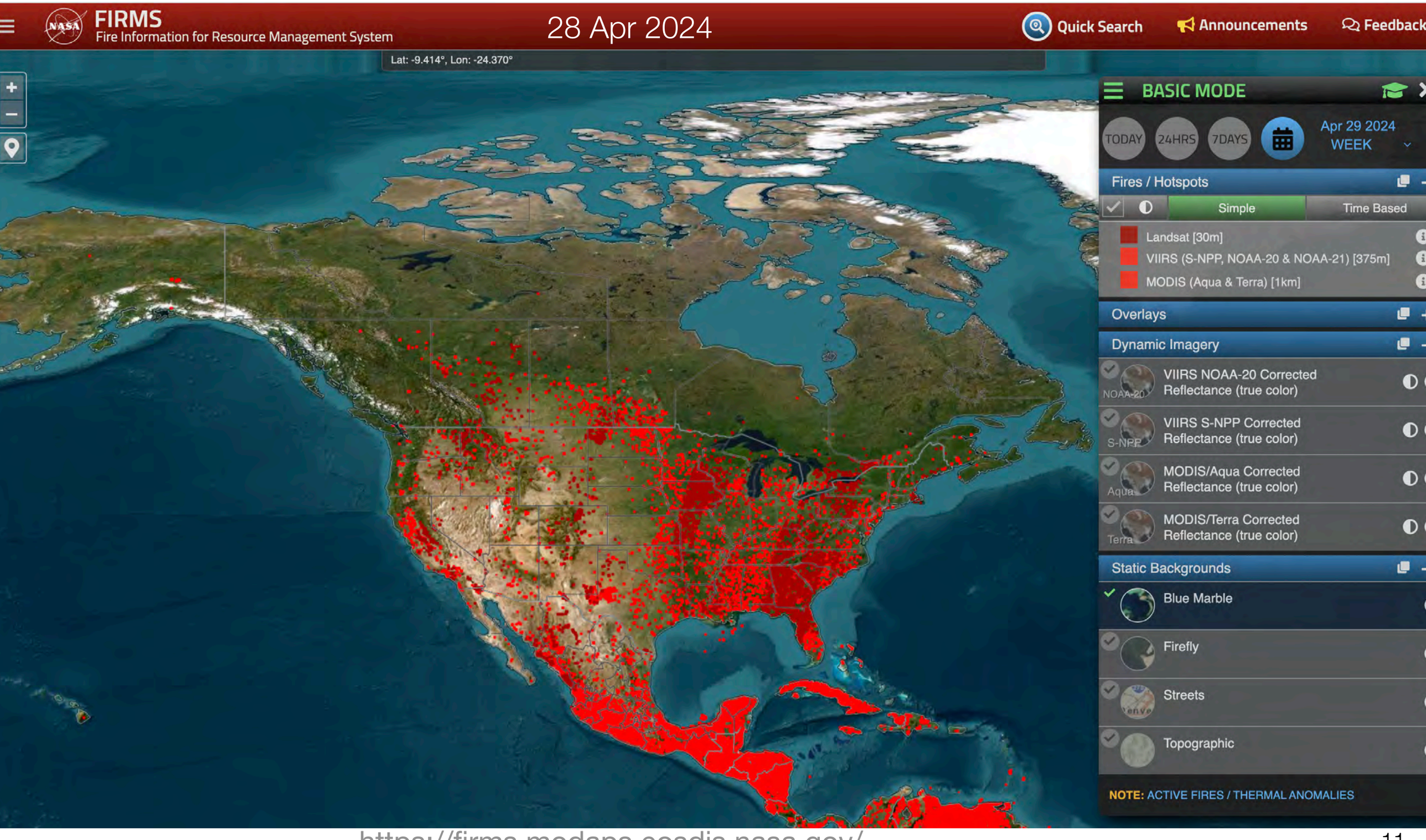


https://www.earthdata.nasa.gov/faq/firms-faq#ed-fire-on-ground

2a. Satellite Observations

NASA's Fire Info for Resource Management System (FIRMS)

(See Appendix to this talk, for satellite jargon.)



https://firms.modaps.eosdis.nasa.gov/

2a. Satellite Observations

https://worldview.earthdata.nasa.gov/

WORLDVIEW

Layers | Events | Data

REFERENCE

- Place Labels
  © OpenStreetMap contributors, Natural Earth
- Coastlines / Borders / Roads
  © OpenStreetMap contributors
- Coastlines
  © OpenStreetMap contributors

FIRES AND THERMAL ANOMALIES

- Fires and Thermal Anomalies (Night)
  Terra / MODIS
  Fire
- Fires and Thermal Anomalies (Day)
  Terra / MODIS
  Fire
- Fires and Thermal Anomalies (Night, 375m)
  NOAA-20 / VIIRS
  Fire
- Fires and Thermal Anomalies (Day, 375m)
  NOAA-20 / VIIRS
  Fire
- Fires and Thermal Anomalies (Night)
  Aqua / MODIS

✓ Group Similar Layers

+ Add Layers | Start Comparison

Search for places or enter coordinates

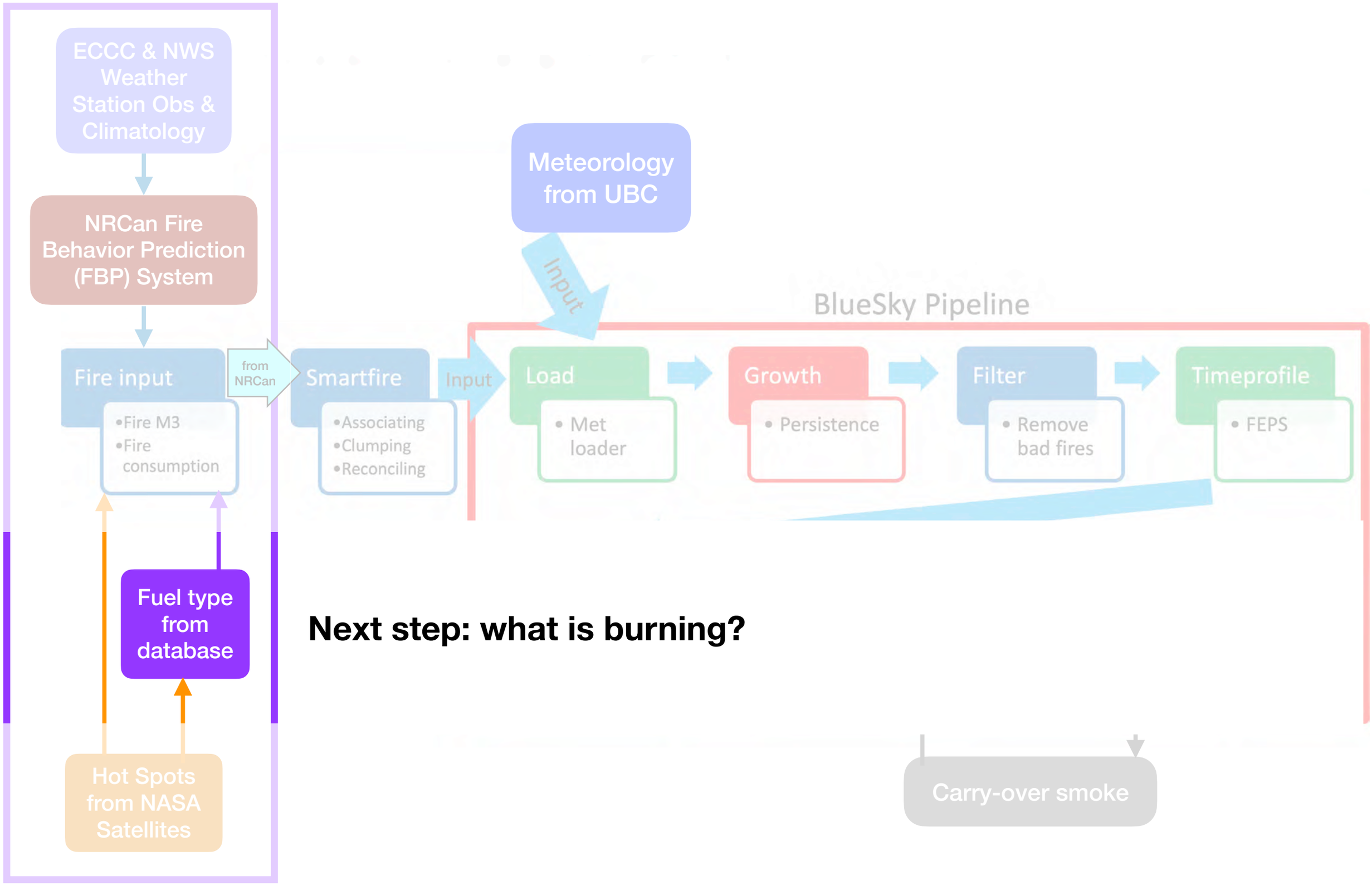
Rivers Park Reserve
Lake Winnipeg
Berens River
Atikaki Provincial Park
Hecla/
Nopiming Provincial Park
Whiteshell Provincial Park

Fires and Thermal An... [3]

17:30

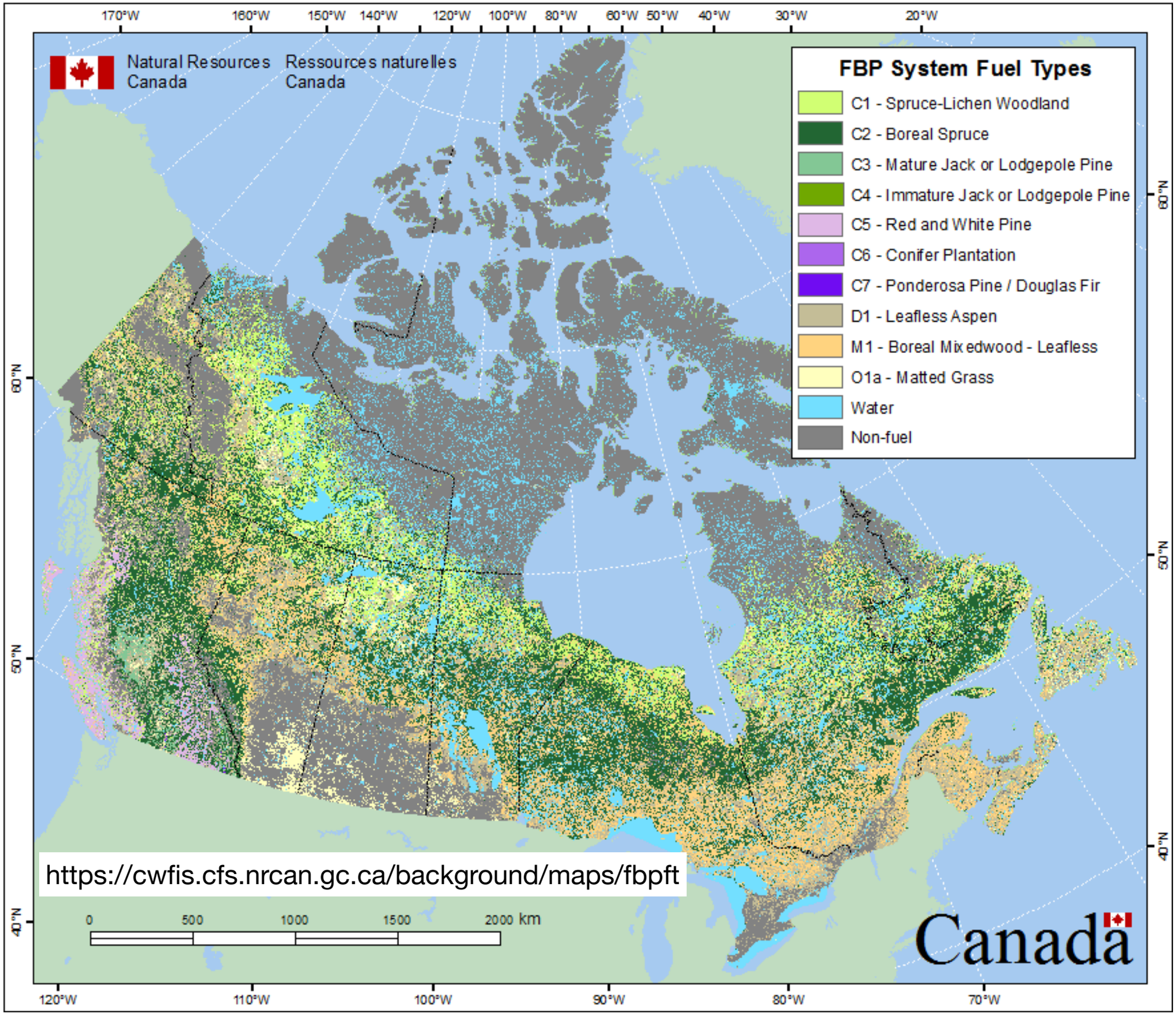
Latitude	51.483 °
Longitude	-95.937 °
Brightness Temperature (Channel 21/22)	334.6 Kelvin
Brightness Temperature (Channel 31)	302 Kelvin
Fire Radiative Power	25.7 MW
Detection Confidence	85 %
Day/Night Flag	Daytime Fire
Along-Scan Pixel Size	1 km
Along-Track Pixel Size	1 km
Acquisition Date	2021-07-17
Acquisition Time	17:30
Satellite	Terra
Collection And Source	Collection 6.1 Near Real-Time processing
Unique Identifier	4397

2b. Fuel Type Database/Map



Next step: what is burning?

2b. Fuel Type Database/Map



Glossary:

FBP = Fire Behavior Prediction system

2b. Fuel Type Database/Map

FBP Fuel Type Descriptions

- C1 - Spruce–Lichen Woodland
- C2 - Boreal Spruce
- C3 - Mature Jack or Lodgepole Pine
- C4 - Immature Jack or Lodgepole Pine
- C5 - Red and White Pine
- C6 - Conifer Plantation
- C7 - Ponderosa Pine–Douglas-Fir
- D1 - Leafless Aspen
- S1 - Jack or Lodgepole Pine Slash
- S2 - White Spruce–Balsam Slash
- S3 - Coastal Cedar–Hemlock–Douglas-Fir Slash
- O1 - Grass
- M1 - Boreal Mixedwood–Leafless
- M2 - Boreal Mixedwood–Green
- M3 - Dead Balsam Fir Mixedwood–Leafless
- M4 - Dead Balsam Fir Mixedwood–Green

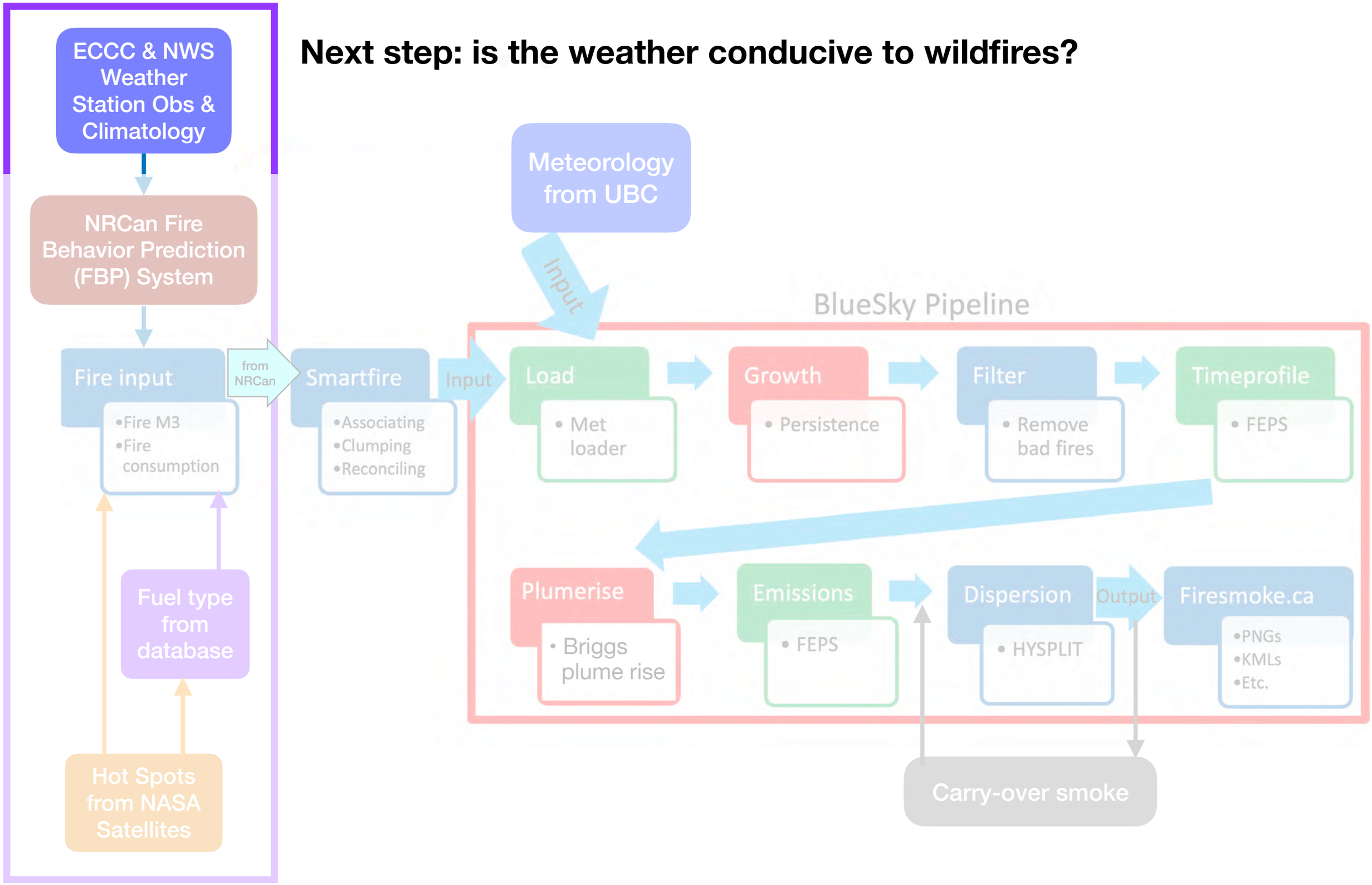
C2 - Boreal Spruce

This fuel type is characterized by pure, moderately well-stocked black spruce (*Picea mariana* (Mill.) B.S.P.) stands on lowland (excluding *Sphagnum* bogs) and upland sites. Tree crowns extend to or near the ground, and dead branches are typically draped with bearded lichens (*Usnea* spp.). The flaky nature of the bark on the lower portion of stem boles is pronounced. Low to moderate volumes of down woody material are present. Labrador tea (*Ledum groenlandicum* Oeder) is often the major shrub component. The forest floor is dominated by a carpet of feather mosses and/or ground-dwelling lichens (chiefly *Cladonia*). *Sphagnum* mosses may occasionally be present, but they are of little hindrance to surface fire spread. A compacted organic layer commonly exceeds a depth of 20–30 cm.

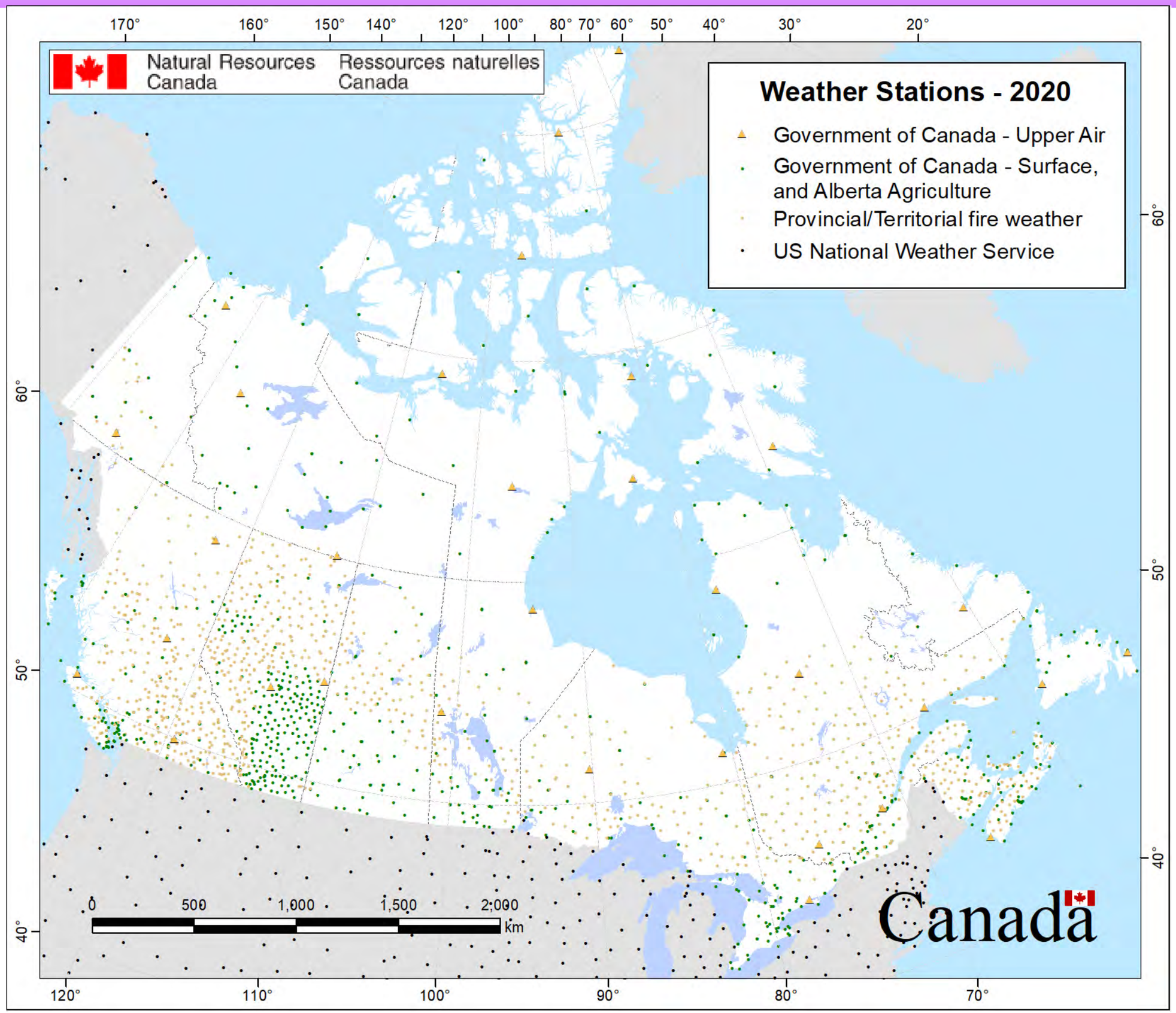
https://cwfis.cfs.nrcan.gc.ca/background/fueltypes/c2

2c. Weather Stations & Climatology

Next step: is the weather conducive to wildfires?



2c. Weather Stations & Climatology

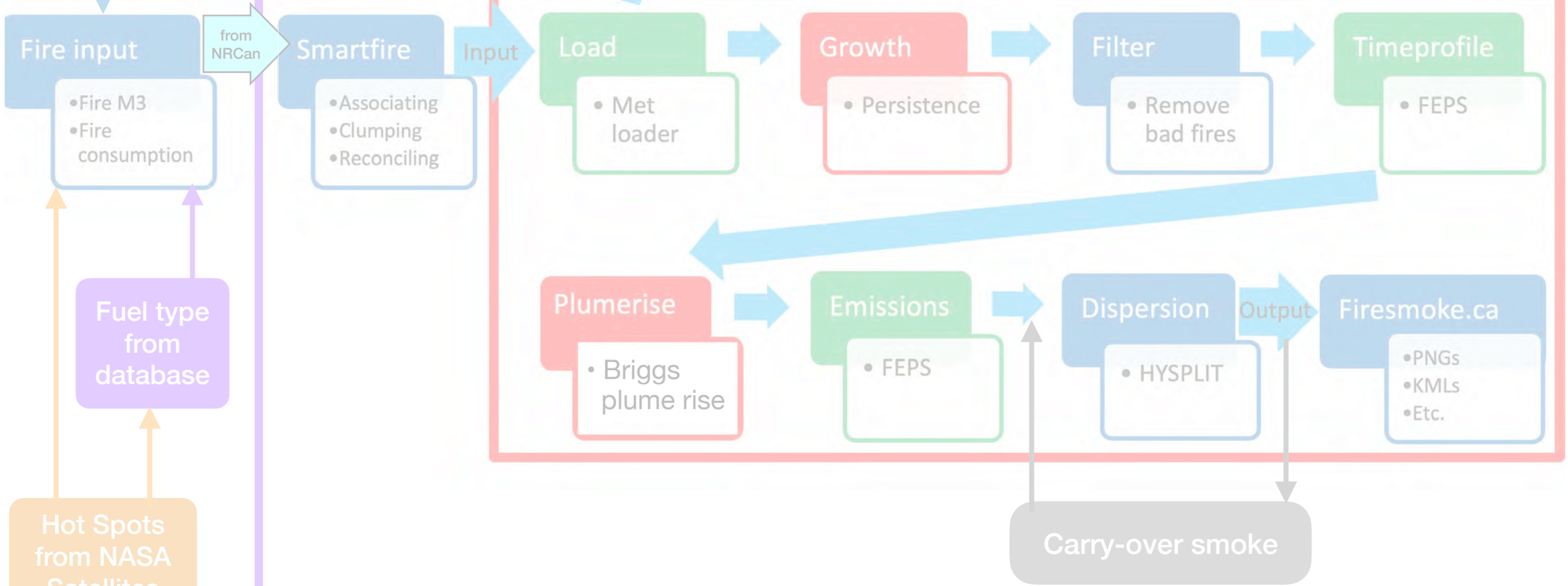


2d. Fire Behavior Prediction System (FBP)

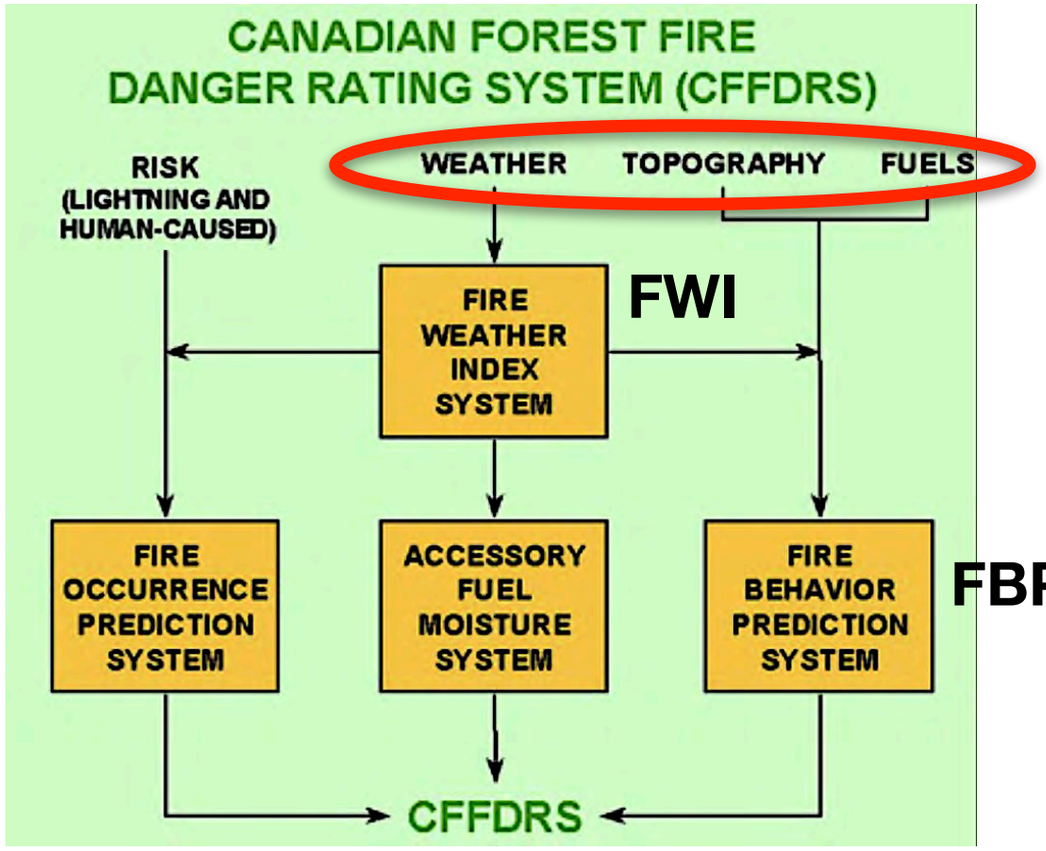
ECCC & NWS Weather Station Obs & Climatology

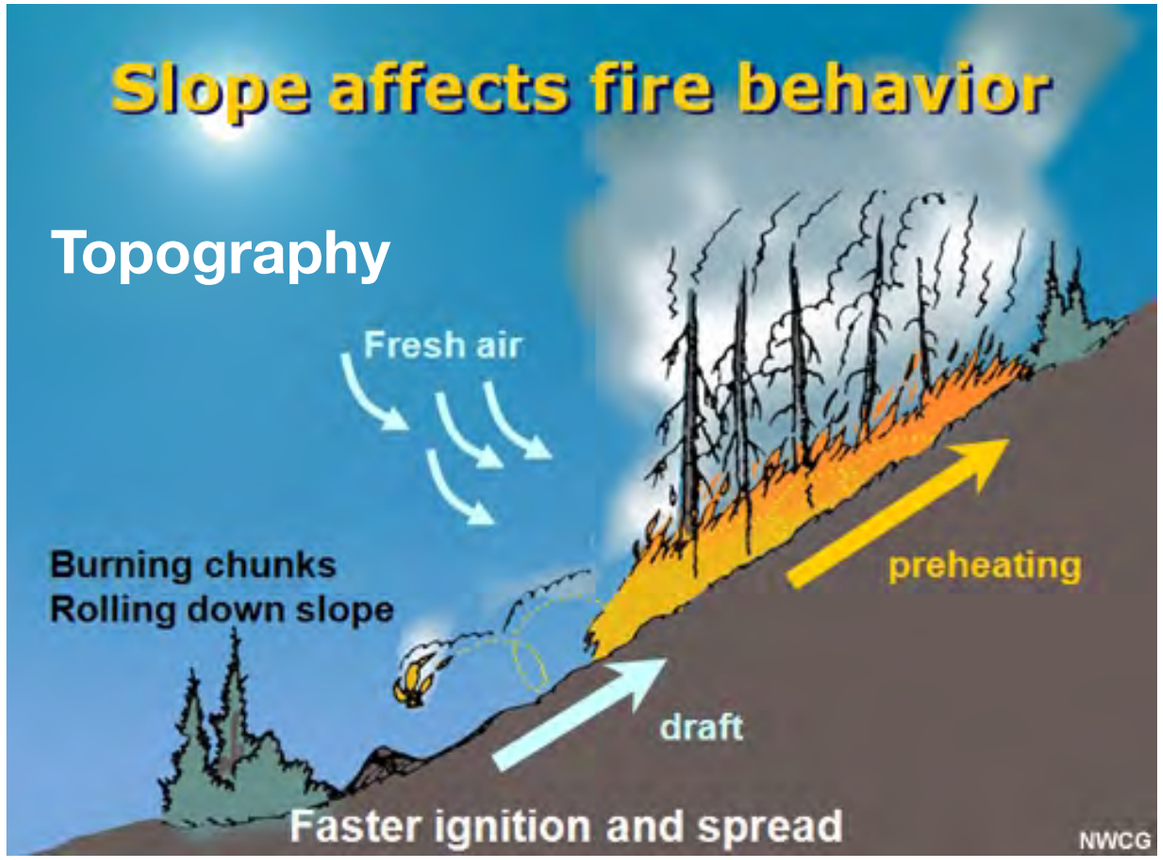
NRCan Fire Behavior Prediction (FBP) System

Next step: how will weather, fuels & terrain influence the fire?

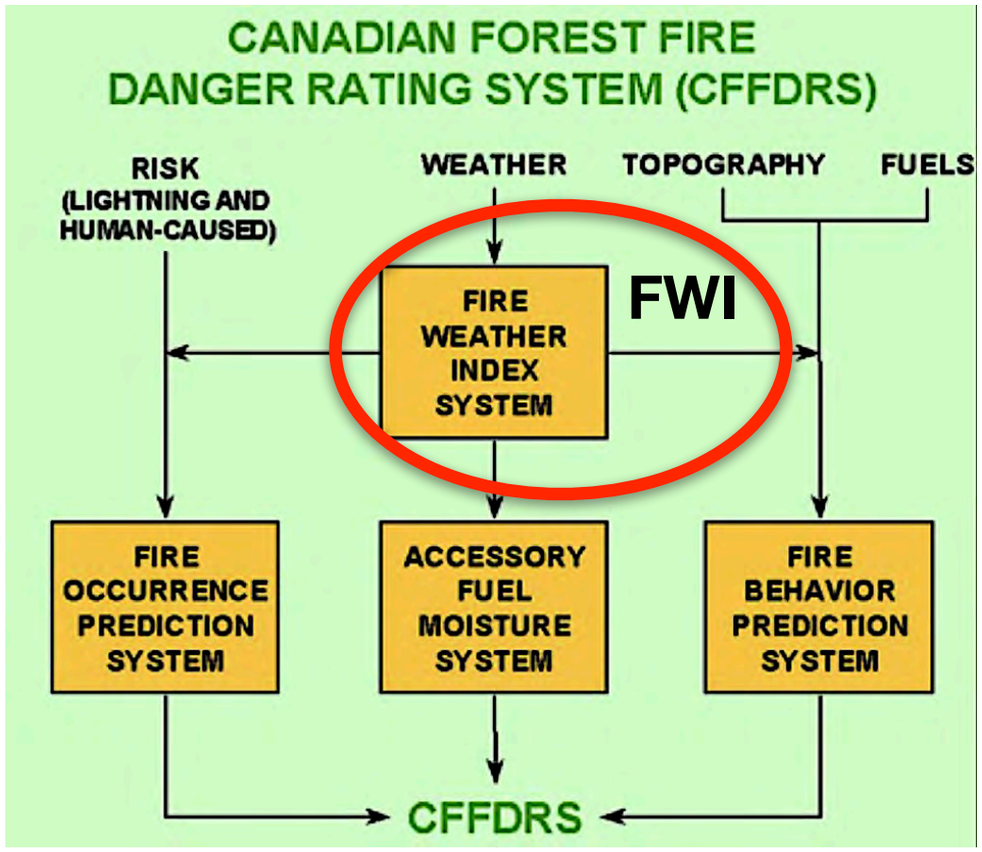


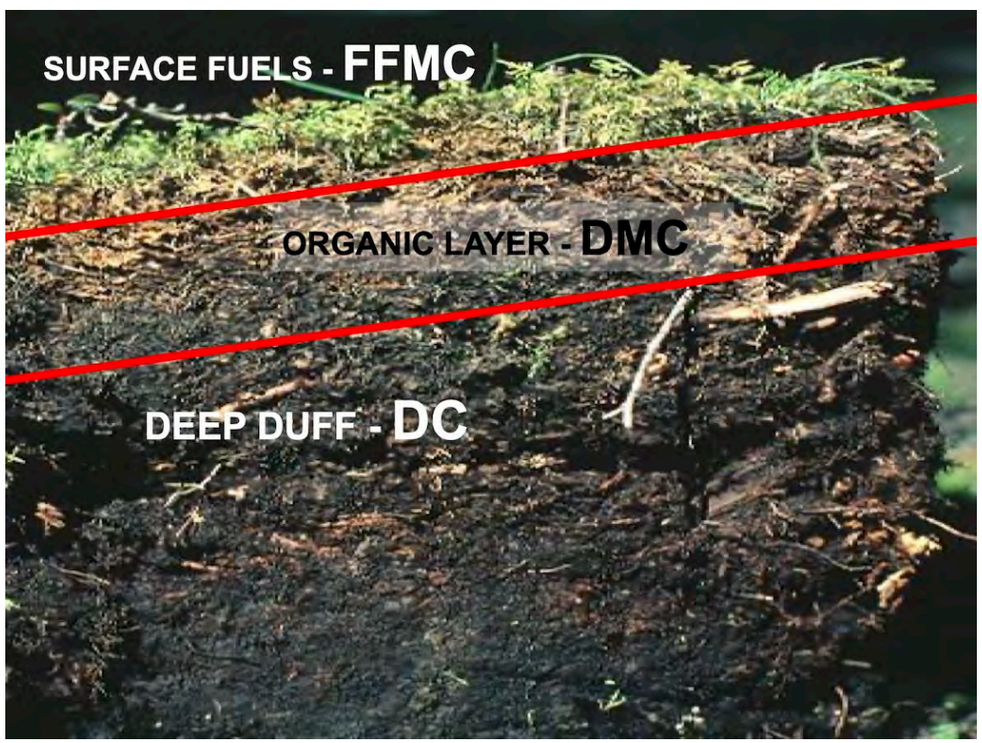
2d. Canadian Forest Fire Danger Rating System (CFFDRS)



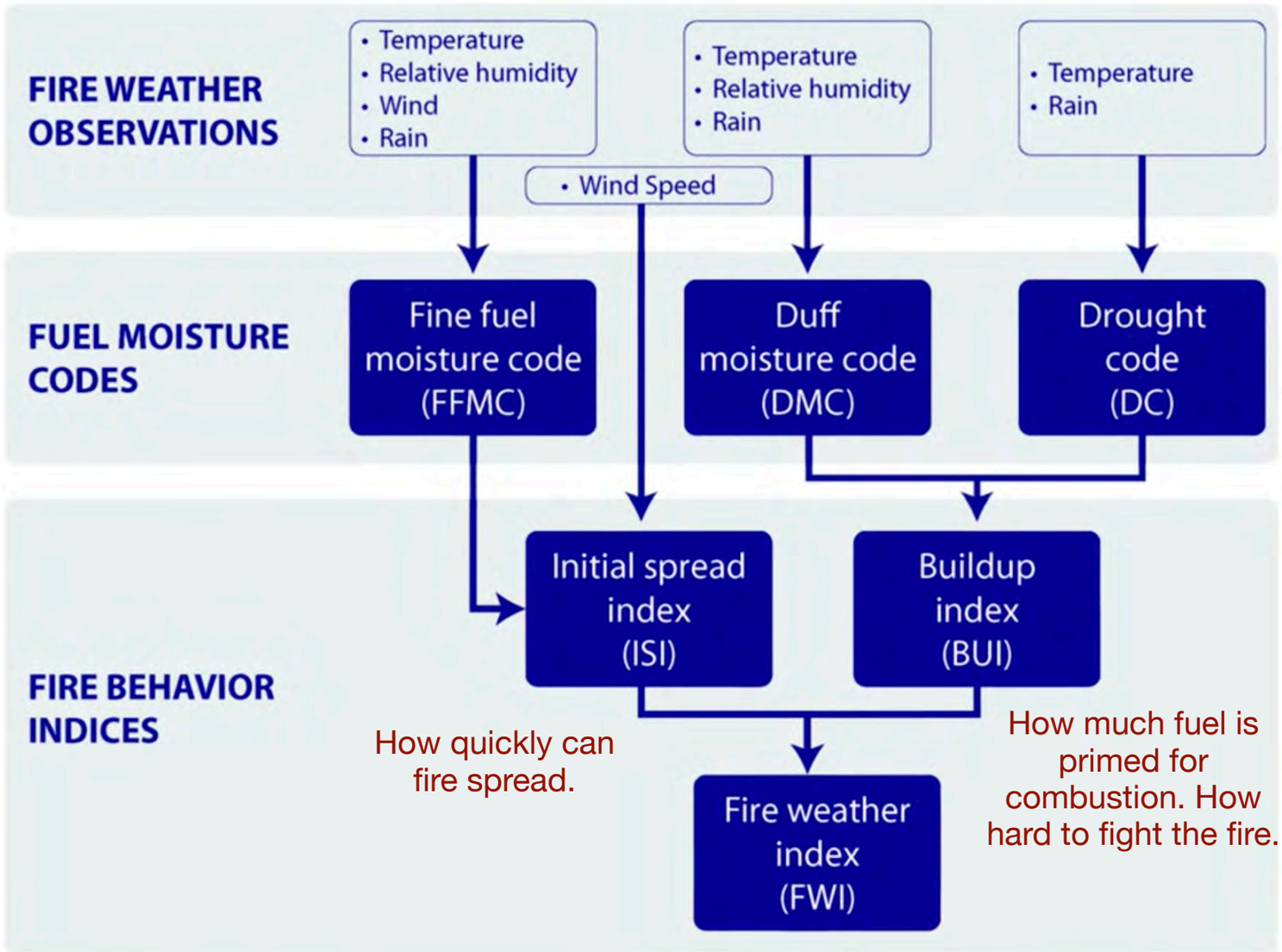


2d. Canadian Forest Fire Danger Rating System (CFFDRS)
Fire Weather Index (FWI) System





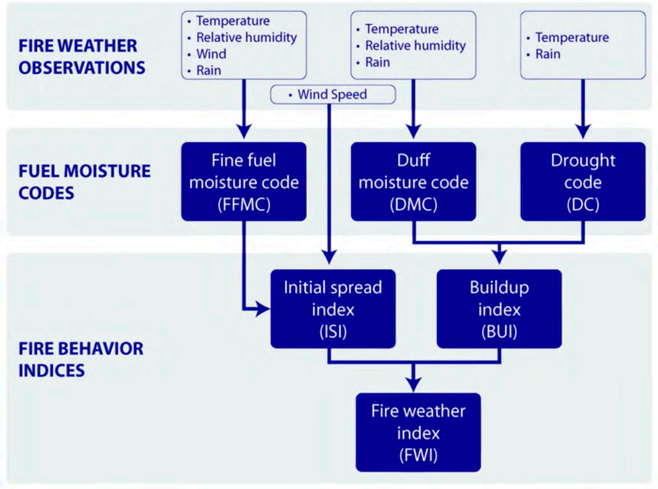
Fire Weather Index (FWI) System



Source: screen capture from BC Wildfire video. https://www.youtube.com/watch?v=ZDB3Qb6F3l0

2d. Canadian Forest Fire Danger Rating System (CFFDRS)
Fire Weather Index (FWI) System

Fire Weather Index (FWI) System



Minnesota "Pocket Card" puts interpretations in firefighter hands

Minnesota DEPARTMENT OF NATURAL RESOURCES

FFMC-Fine Fuel Moisture Code

0-80	Low
81-87	Moderate
88-90	High
91-92	Very High
93+	Extreme

75 Some surface fire spread.
80 Continuous fire spread.
90 Spot fires likely, easy ignition.
92 Extreme fire behavior

ISI-Initial Spread Index

0-4	Low
5-8	Moderate
9-11	High
12-18	Very High
19+	Extreme

<7 Primarily surface fire.
10 High rates of spread likely.
12 Torching more frequent.
20 Extreme fire behavior.

DMC-Duff Moisture Code

0-12	Low
13-27	Moderate
28-41	High
42-62	Very High
63+	Extreme

25 Duff burns, lightning starts become likely.
40 Moderate fire intensity.
50 Extreme fire behavior.
150 Most available fuel moisture is gone.

BUI-Build Up Index

0-19	Low
20-34	Moderate
35-54	High
55-76	VeryHigh
77+	Extreme

30 Heavier fuels involved in combustion.
60 Extended mop-up.
80 Extreme fire behavior in medium and heavier fuels, even with low ISI.
100 Lowland spruce can crown.

DC-Drought Code

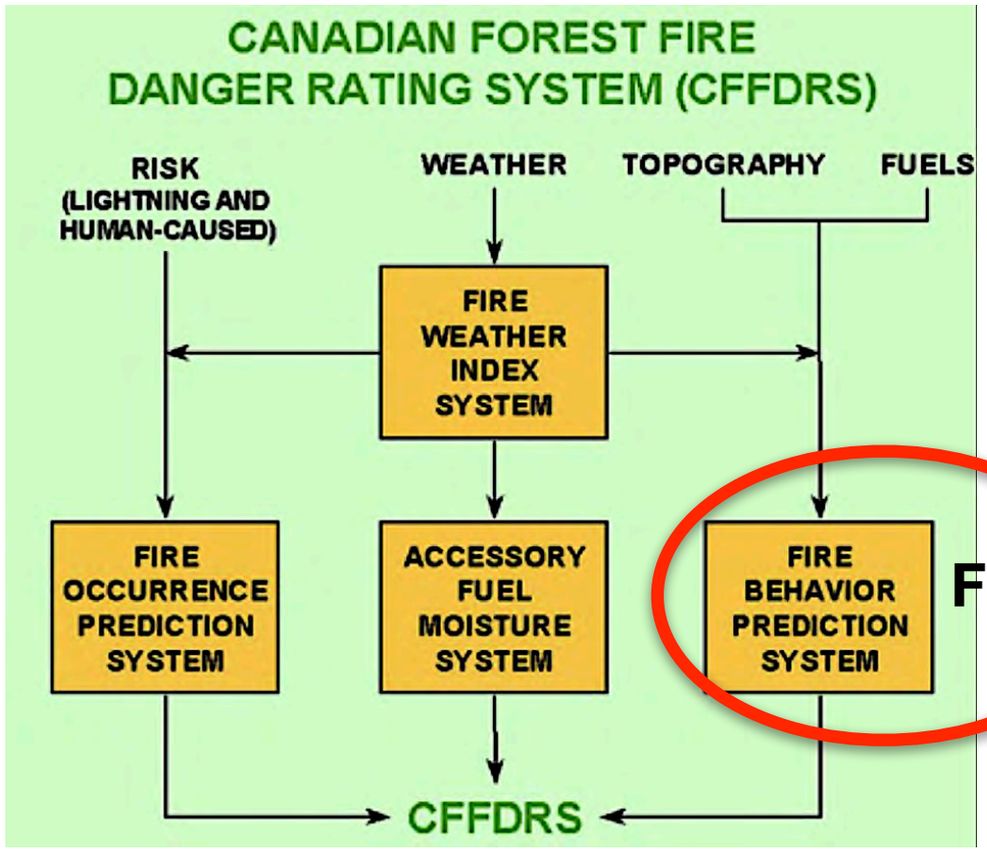
0-79	Low
80-209	Moderate
210-274	High
275-359	VeryHigh
360+	Extreme

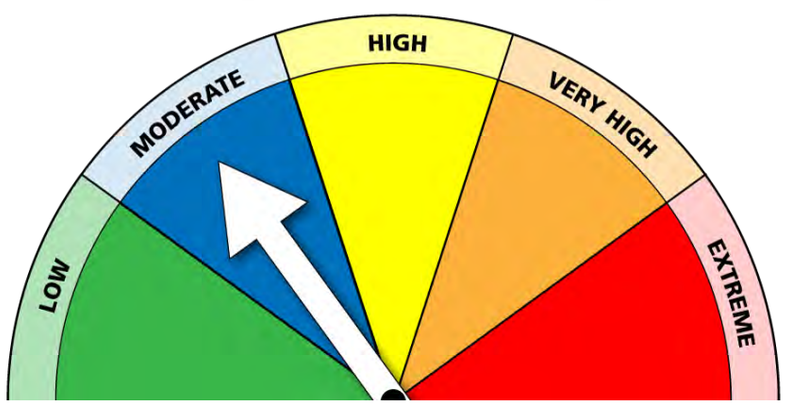
15 Deep organic layers are saturated.
250 Extended mop-up, peat will burn.
300 Deep burning, more persistent fires.

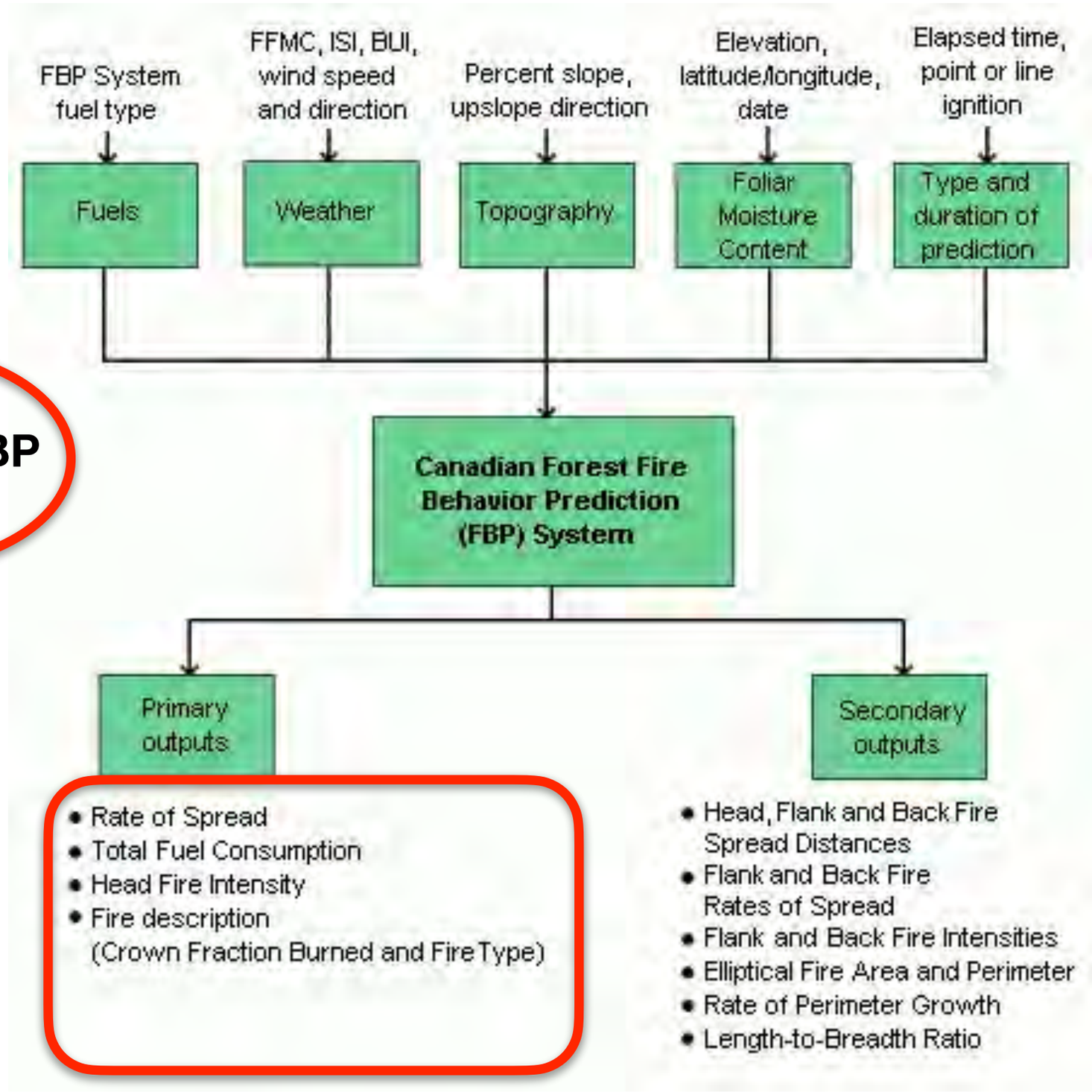
FWI-Fire Weather Index

0-5	Low	Creeping surface fire
6-14	Moderate	Low to moderate spread
15-21	High	Torching, spotting, intermittent crowning.
22-32	VeryHigh	Active crowning possible
33+	Extreme	Major fire development possible

2d. Fire Behavior Prediction System (FBP)

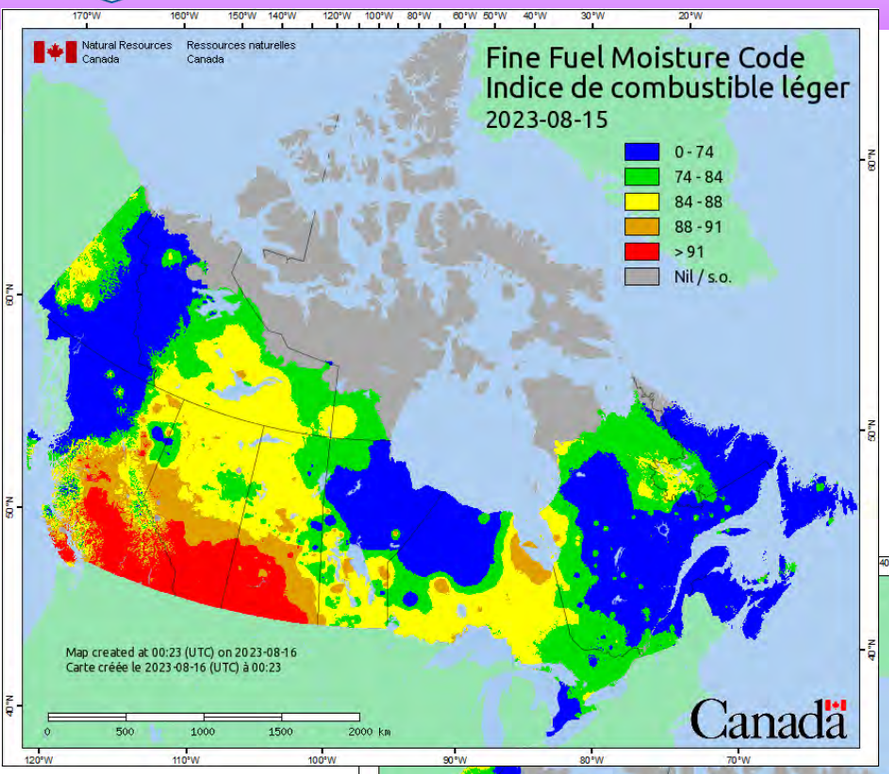


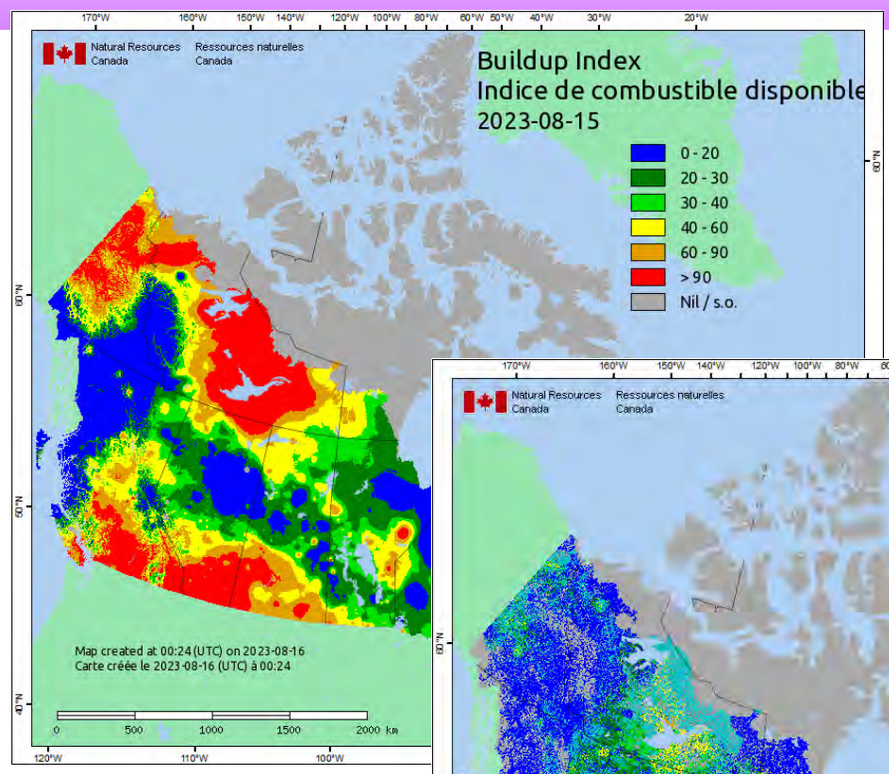


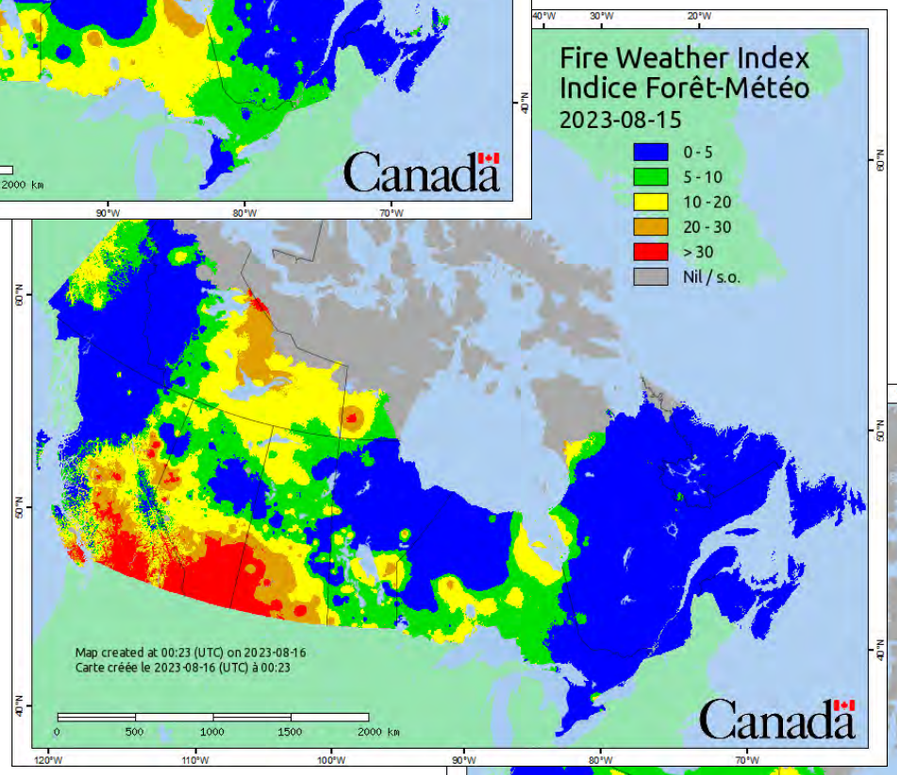


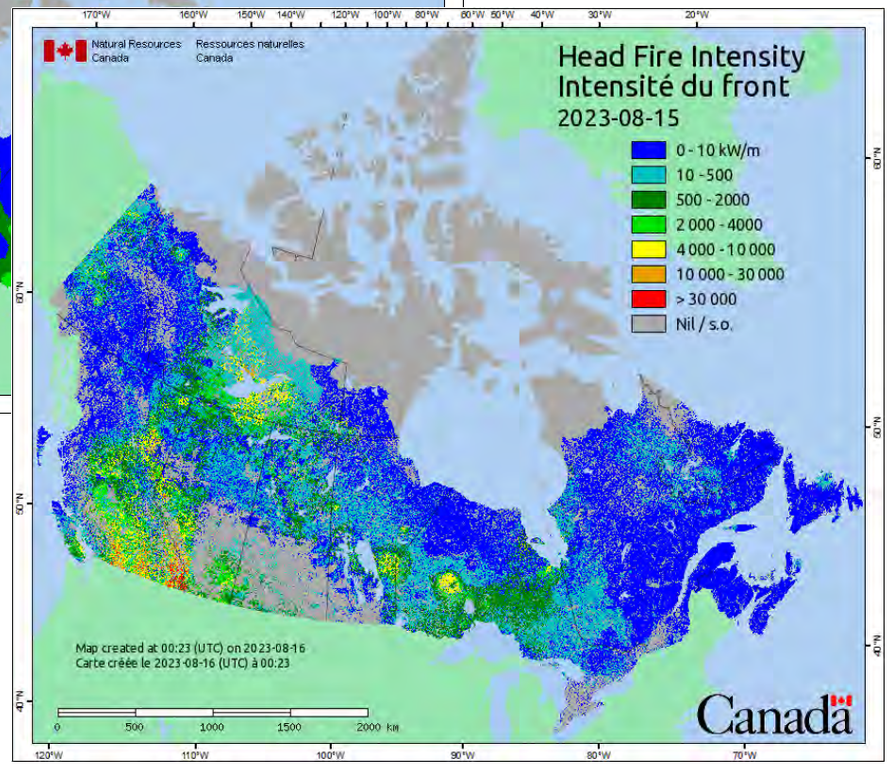
https://cwfis.cfs.nrcan.gc.ca/background/summary/fbp

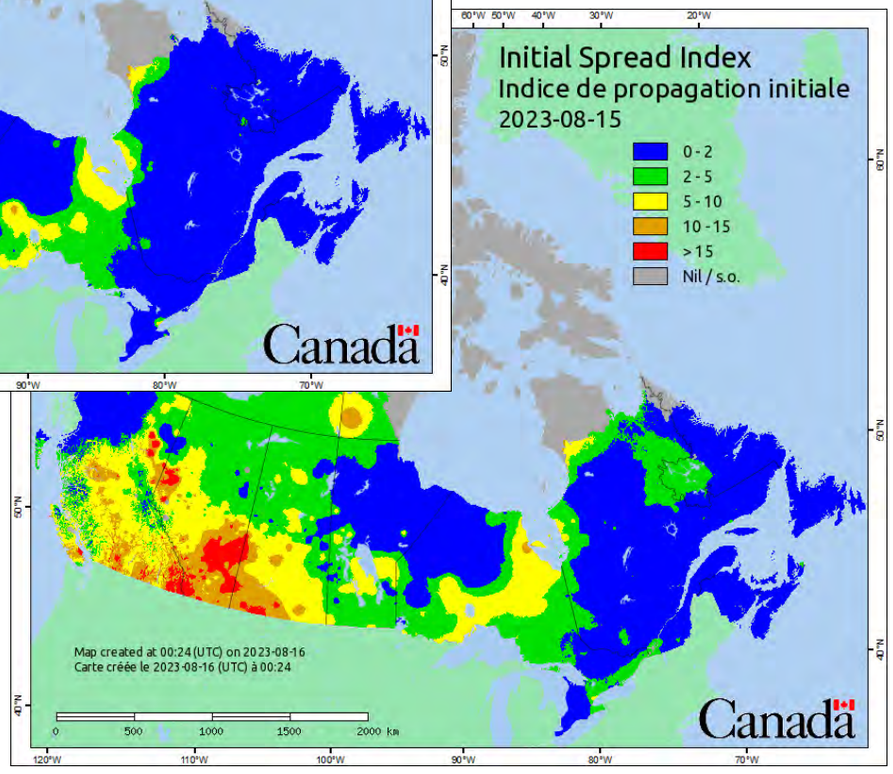
2d. Fire Behavior Prediction System (FBP)











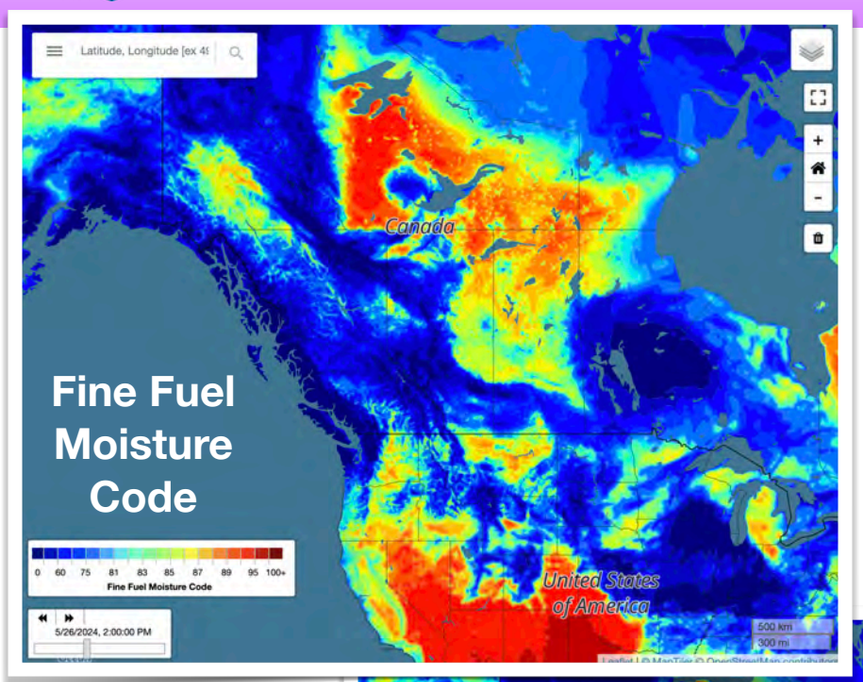
NRCan version

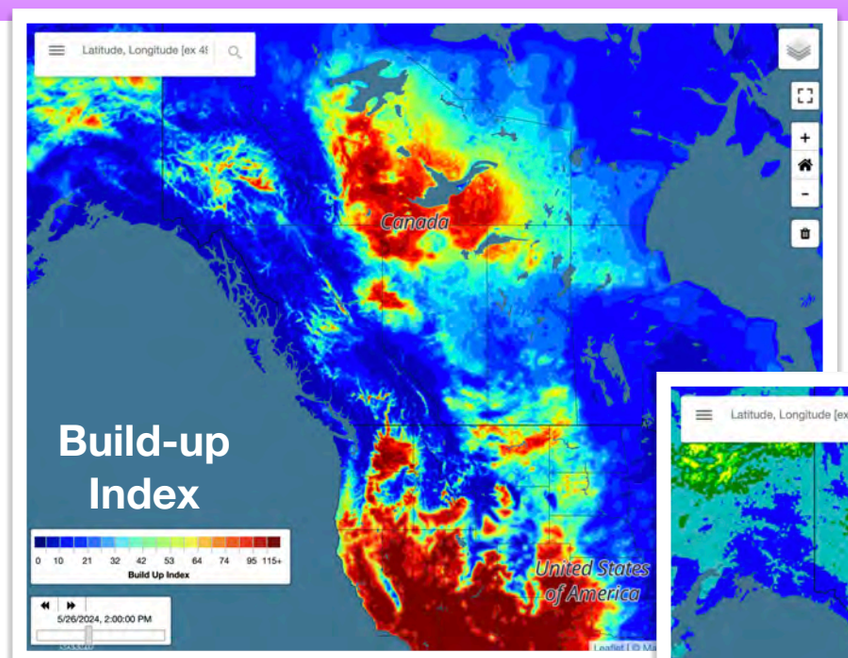
Noon local (standard time) weather data **from weather stations** is interpolated to give these maps of current mid-afternoon conditions

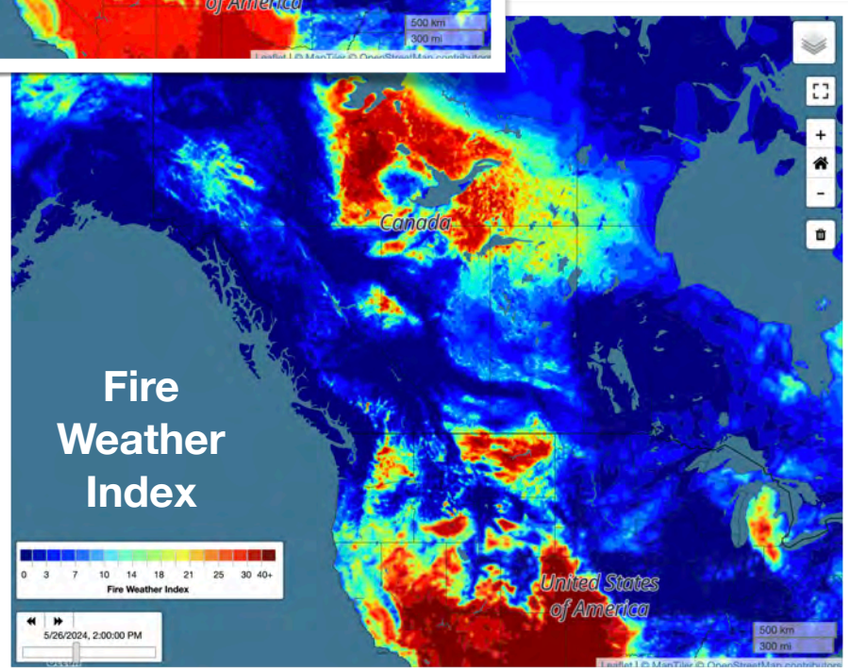
Etc.

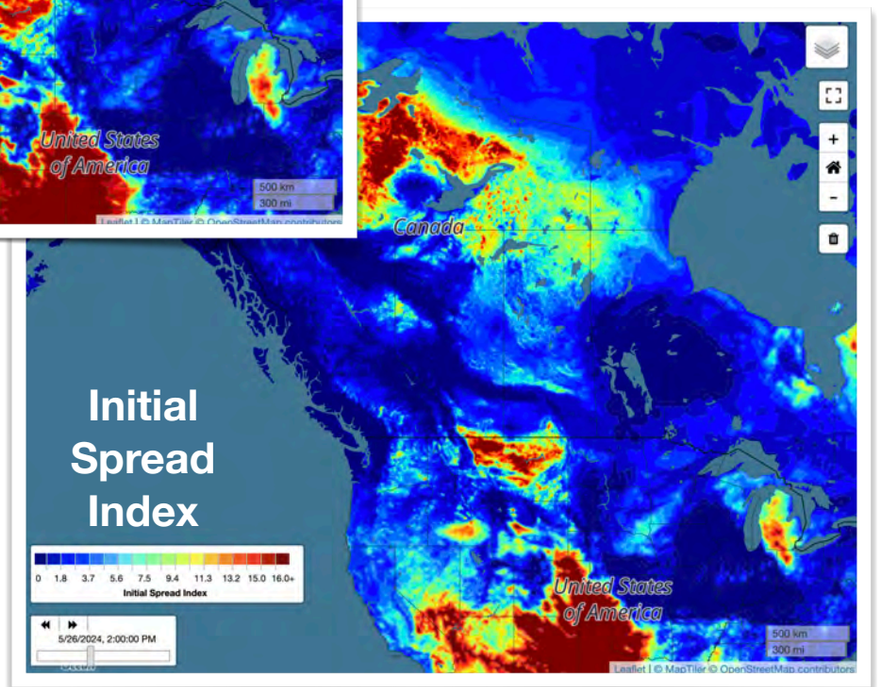
Source: Natural Resources Canada. https://cwfis.cfs.nrcan.gc.ca/maps/fw?type=fdr&year=2023&month=7&day=5.

2d. Fire Behavior Prediction System (FBP)









Rodell-UBC version

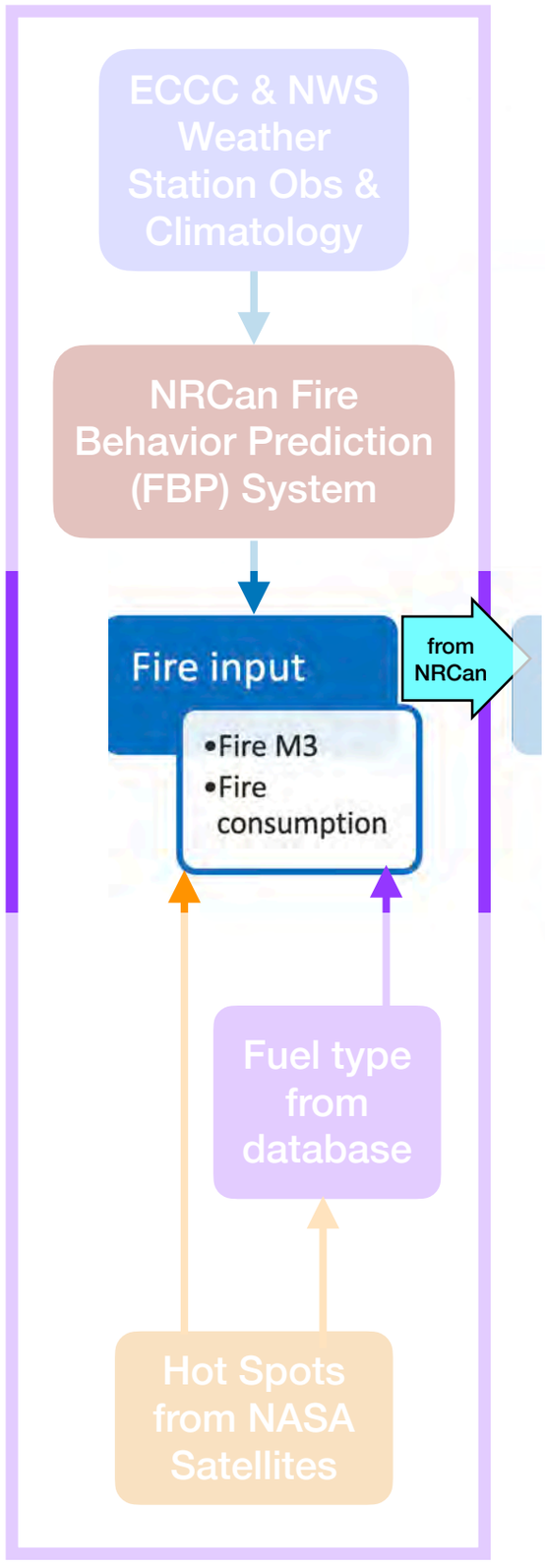
Hourly data **from gridded NWP models** gives higher spatial and temporal resolution.

Etc.

You can view these forecasts from UBC on firesmoke.ca / forecasts/fireweather/

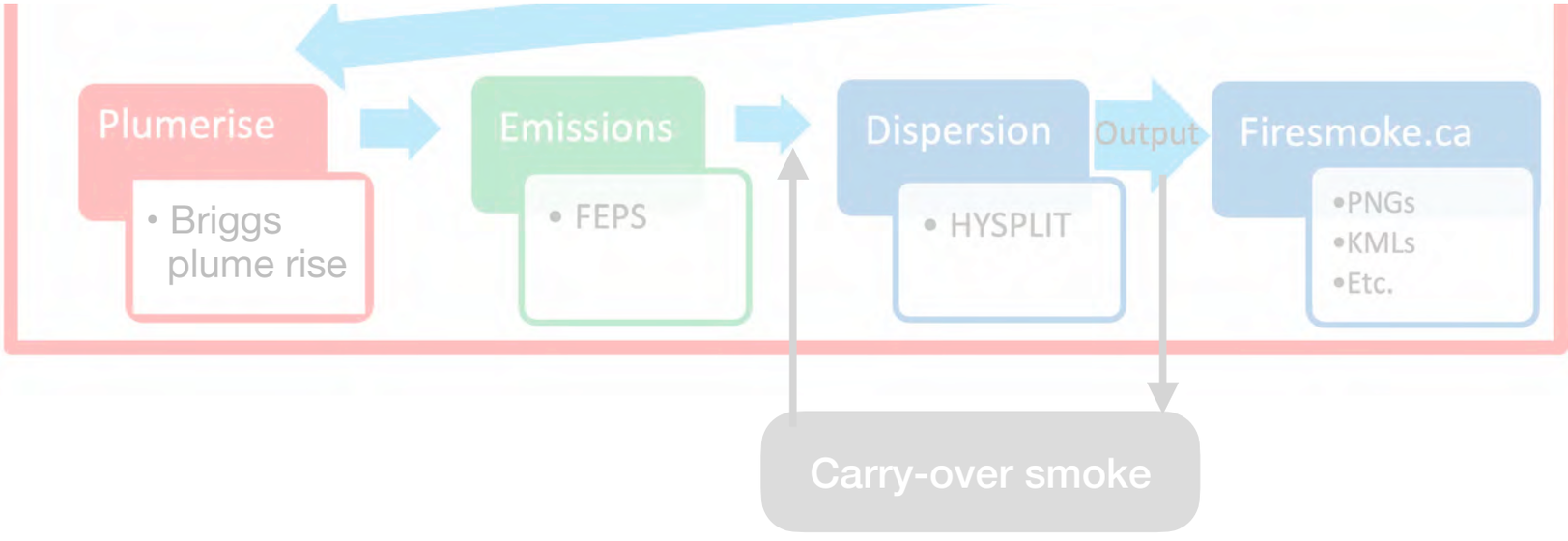
Source: firesmoke.ca

2e. FireM3 inputs to BlueSky



Meteorology from UBC

Next step: enable access to these data.



2e. FireM3 inputs to SmartFire

Canadian Wildland Fire Information System (CWFIS)

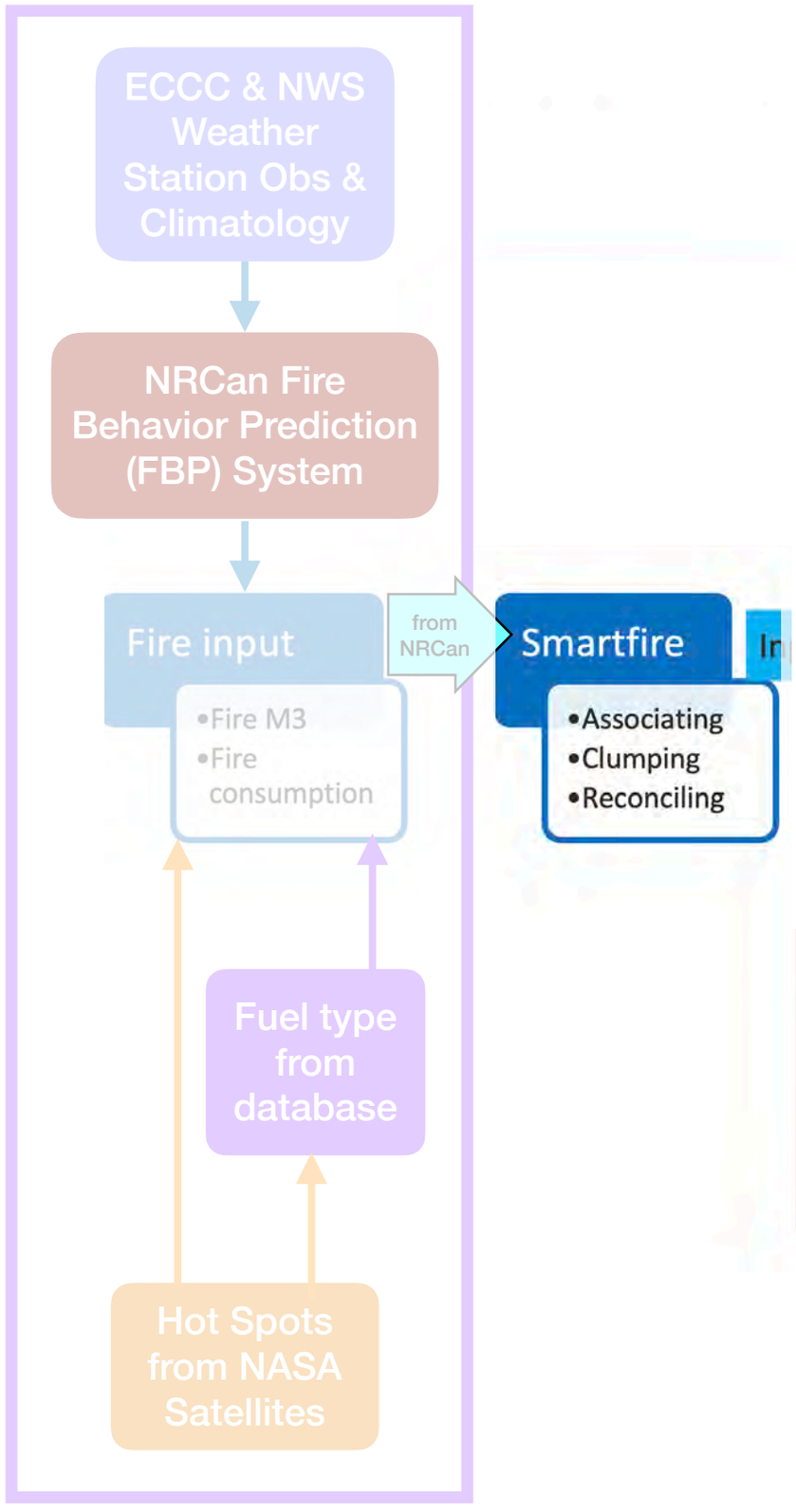
UBC retrives from NRCan,
this data table of
satellite hotspots 7 times/day

and human-generated
"ground reports" 13 times/day

fire weather index
fuel type
rate of spread
surface fuel consumption
total fuel consumption
crown fraction burned
head fire intensity
estimated area

lat	lon	rep_date	source	sensor	fwi	fuel	ros	sfc	tfc	bfc	hfi	estarea
38.9664	-82.765	4/28/24 2:45	NASA_usa	MODIS	19.3	C6	4.23759	0.223011	0.223011	0.386523	284	14.1989
27.3283	-108.179	4/28/24 4:19	NASA_usa	MODIS	34.7	O1a	23.11	0.35	0.35	0.35	2427	4.64205
27.3402	-108.182	4/28/24 4:19	NASA_usa	MODIS	34.7	O1a	23.11	0.35	0.35	0.35	2427	7.96591
27.3165	-108.176	4/28/24 4:19	NASA_usa	MODIS	34.7	O1a	23.11	0.35	0.35	0.35	2427	4.64205
28.257	-107.751	4/28/24 4:21	NASA_usa	MODIS	27.6	O1a	16.2009	0.35	0.35	0.35	1701	7.96591
28.6046	-108.124	4/28/24 4:21	NASA_usa	MODIS	27.6	O1a	16.2009	0.35	0.35	0.35	1701	4.64205
28.2713	-107.738	4/28/24 4:21	NASA_usa	MODIS	27.6	O1a	16.2009	0.35	0.35	0.35	1701	3.53409
28.6086	-108.119	4/28/24 4:21	NASA_usa	MODIS	27.6	O1a	16.2009	0.35	0.35	0.35	1701	4.64205
28.5972	-108.116	4/28/24 4:21	NASA_usa	MODIS	27.6	O1a	16.2009	0.35	0.35	0.35	1701	7.96591
27.7653	-82.0745	4/28/24 6:12	NASA7	VIIRS-I	23.4	low_veg	4.48162	0.185867	0.185867	0.185867	250	14.1989
27.7704	-82.07	4/28/24 6:12	NASA7	VIIRS-I	23.4	O1a	22.4081	1.80989	1.80989	1.80989	12167	14.1989
27.7657	-82.082	4/28/24 6:12	NASA7	VIIRS-I	23.4	M1_50	4.40446	0.967474	0.967474	1.94148	1278	14.1989
38.9647	-82.7638	4/28/24 7:24	NASA6	VIIRS-I	19.3	C6	4.23759	0.245715	0.245715	0.386523	312	14.1989
28.6848	-82.0228	4/28/24 7:26	NASA6	VIIRS-I	23.4	C5	0.989996	0.649484	0.649484	2.0103	193	6.24716
31.0018	-90.6571	4/28/24 7:26	NASA6	VIIRS-I	7	C5	0.0297504	0.153904	0.153904	0.676152	1	14.1989
32.9458	-85.0038	4/28/24 7:26	NASA6	VIIRS-I	11.4	C6	1.56503	0.153837	0.153837	0.324541	72	14.1989
32.9667	-83.6163	4/28/24 7:26	NASA6	VIIRS-I	14.3	C6	2.38398	0.168762	0.168762	0.391544	121	14.1989
27.7602	-82.0705	4/28/24 7:29	NASA6	VIIRS-I	23.4	O1a	22.4081	0.1	0.1	0.1	672	14.1989
27.7639	-82.0696	4/28/24 7:29	NASA6	VIIRS-I	23.4	O1a	22.4081	3.5	3.5	3.5	23529	14.1989
27.7616	-82.062	4/28/24 7:52	NASA7	VIIRS-I	23.4	low_veg	4.48162	1.75	1.75	1.75	2353	14.1989
27.7624	-82.0658	4/28/24 7:52	NASA7	VIIRS-I	23.4	O1a	22.4081	3.5	3.5	3.5	23529	14.1989
32.1774	-102.269	4/28/24 7:52	NASA7	VIIRS-I	54.8	O1a	70.5544	0.2128	0.2128	0.2128	4504	3.89962
30.8959	-84.2852	4/28/24 7:52	NASA7	VIIRS-I	19.8	M1_50	4.05668	0.119913	0.119913	4.18847	146	14.1989

3. Smartfire2

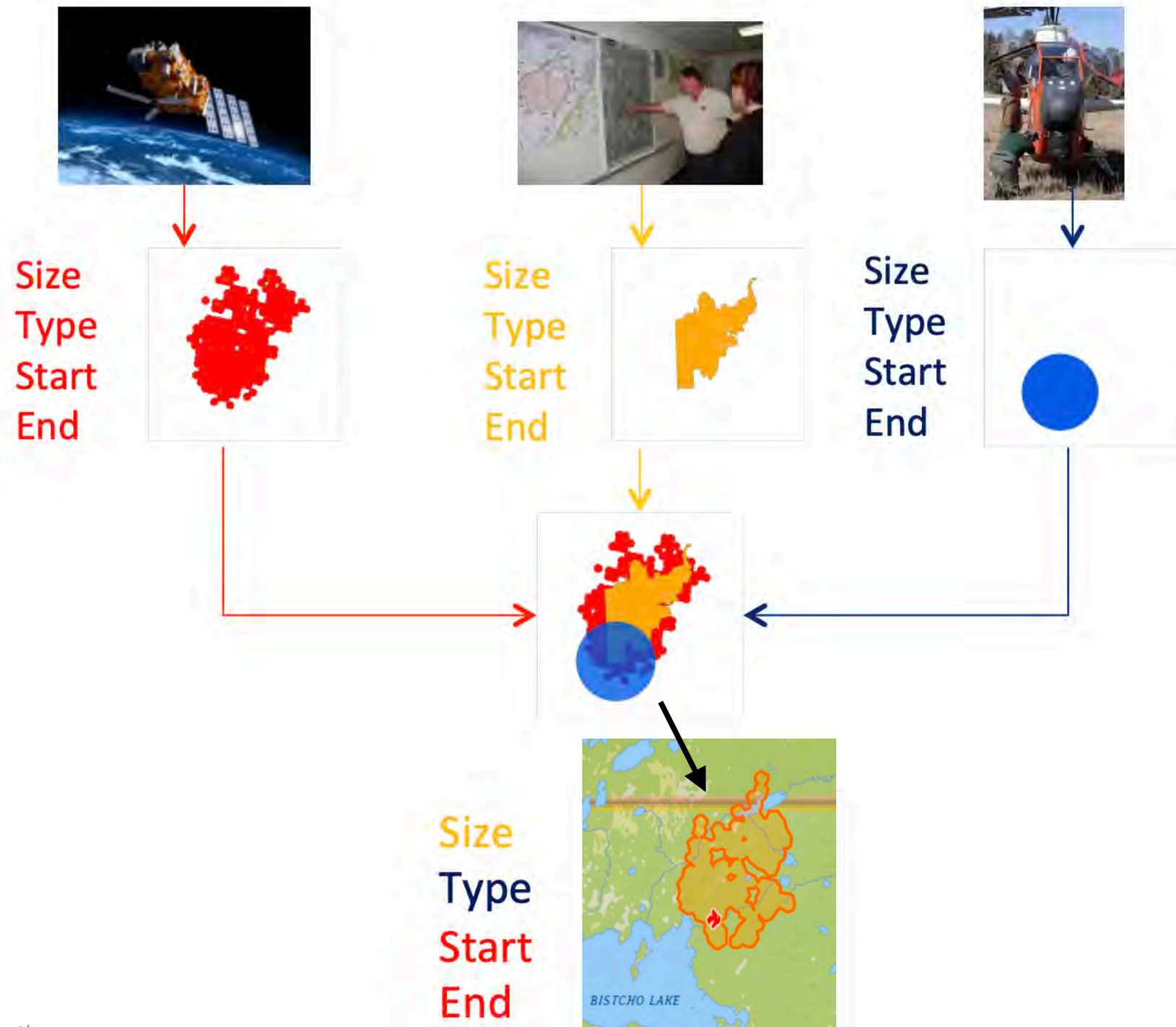


Next step: how can we consolidate the fire info?

3. Smartfire2

A fire data acquisition, reconciliation and GIS database

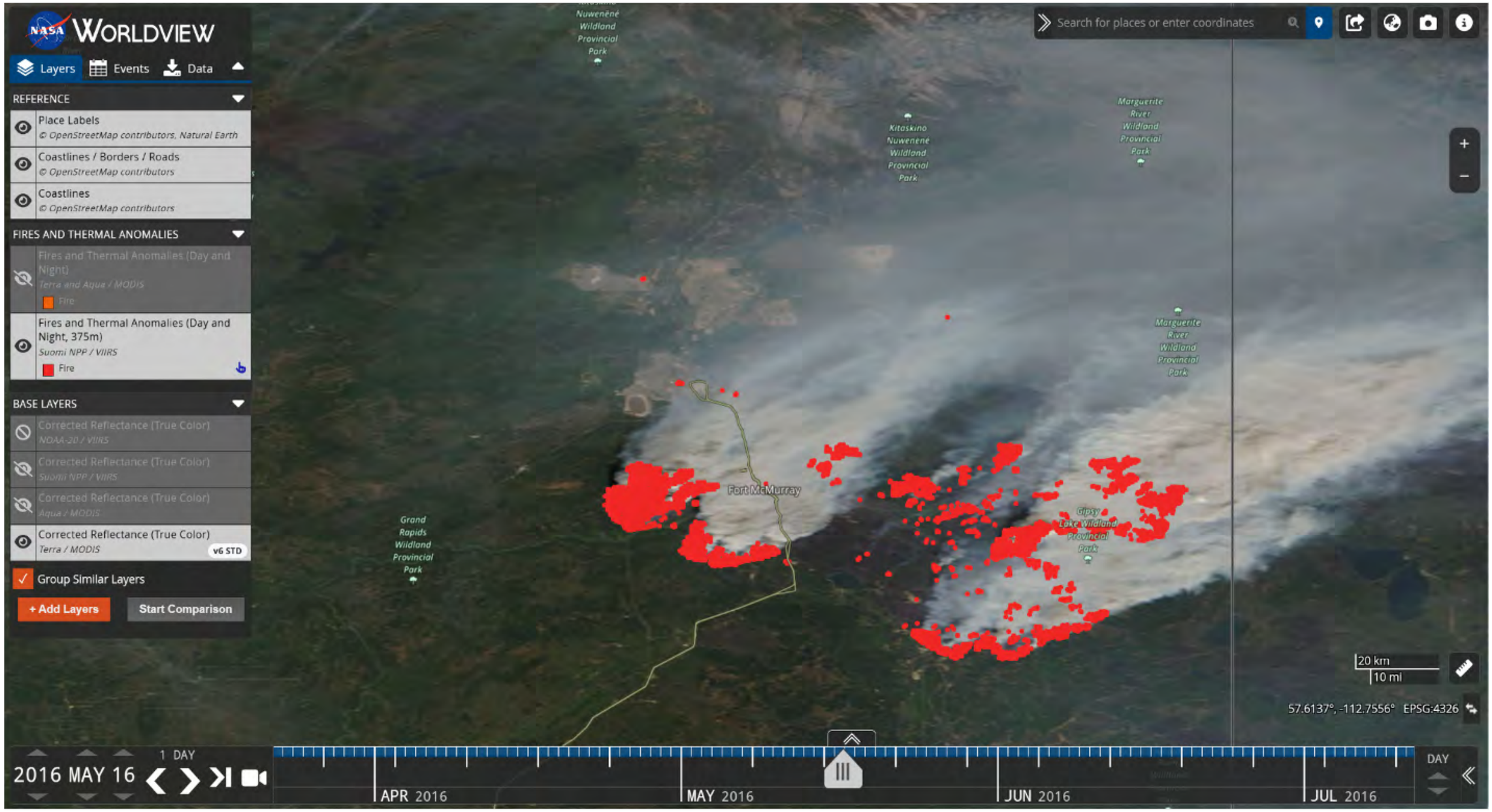
1. Get data from multiple sources
2. Produce fires from each data source separately
3. Associate nearby fires across data sources
4. Reconcile associated fires to create best guess information



from a Larkin, 2013 presentation

3. Smartfire2

Associating - integrates satellite hot spots and ground reports of fires
Clumping - large numbers of hot-spot pixels into smaller number of fires
Reconciling - eliminates duplicates and creates a unified GIS database



Fort McMurray fire

3. Smartfire2

Satellite Mapping Automated Reanalysis Tool for Fire Incident Reconciliation

Created by Sonoma Technology Inc (STI) in collaboration with US NFS AirFire

We run SmartFire2 at UBC 4 times/day, just prior to each BlueSky run.

Sample outputs from Smartfire2, which become input to BlueSky:

Satellite hotspots...

smartfire 2.0

Logged in as **blueop** (log out) admin data events streams

Home » Data » CWFIS-Hotspots » Raw Data » Apr 29, 2024

CWFIS-Hotspots Raw Data for Apr 29, 2024

CSV KML SHP SHP Trimmed

Search:

area_acres	area_meters	bfc	consumption_duff	consumption_flaming	consumption_residual	consumption_smoldering	DateTime_local	end_date	estarea	fuel	fwi	hfi	lat	latitude	lon	longitude	rep_date	ros	sensor	sfc	source	start_date
0	0	0.1	0.4460895802144811	14.227402635528575	0.0	0.0	2024-04-29T00:00:00.000-07:00	2024-04-29T23:59:59.999-02:00	8.54878	M1_50	34.7	4895	26.747	26.747	-108.049	-108.049	2024-04-29 17:07:00	5.11589	MODIS	3.18936	NASAwusa	2024-04-29
0	0	0.35	1.5613135307506838	1.5613135307506838	0.0	0.0	2024-04-29T00:00:00.000-06:00	2024-04-29T23:59:59.999-02:00	8.54878	O1a	34.7	2427	26.8677	26.868	-107.527	-107.527	2024-04-29 04:59:00	23.11	MODIS	0.35	NASA_usa	2024-04-29
0	0	0.35	1.5613135307506838	1.5613135307506838	0.0	0.0	2024-04-29T00:00:00.000-06:00	2024-04-29T23:59:59.999-02:00	8.54878	O1a	34.7	2427	26.8628	26.863	-107.529	-107.529	2024-04-29 08:50:00	23.11	VIIRS-I	0.35	NASA6	2024-04-29
0	0	0.35	1.5613135307506838	1.5613135307506838	0.0	0.0	2024-04-29T00:00:00.000-06:00	2024-04-29T23:59:59.999-02:00	4.98171	O1a	34.7	2427	26.8613	26.861	-107.524	-107.524	2024-04-29 09:15:00	23.11	VIIRS-I	0.35	NASA7	2024-04-29

... and Ground Reports

smartfire 2.0

Logged in as **blueop** (log out) admin data events streams

Home » Data » CWFIS-GroundReports » Raw Data » Apr 29, 2024

CWFIS-GroundReports Raw Data for Apr 29, 2024

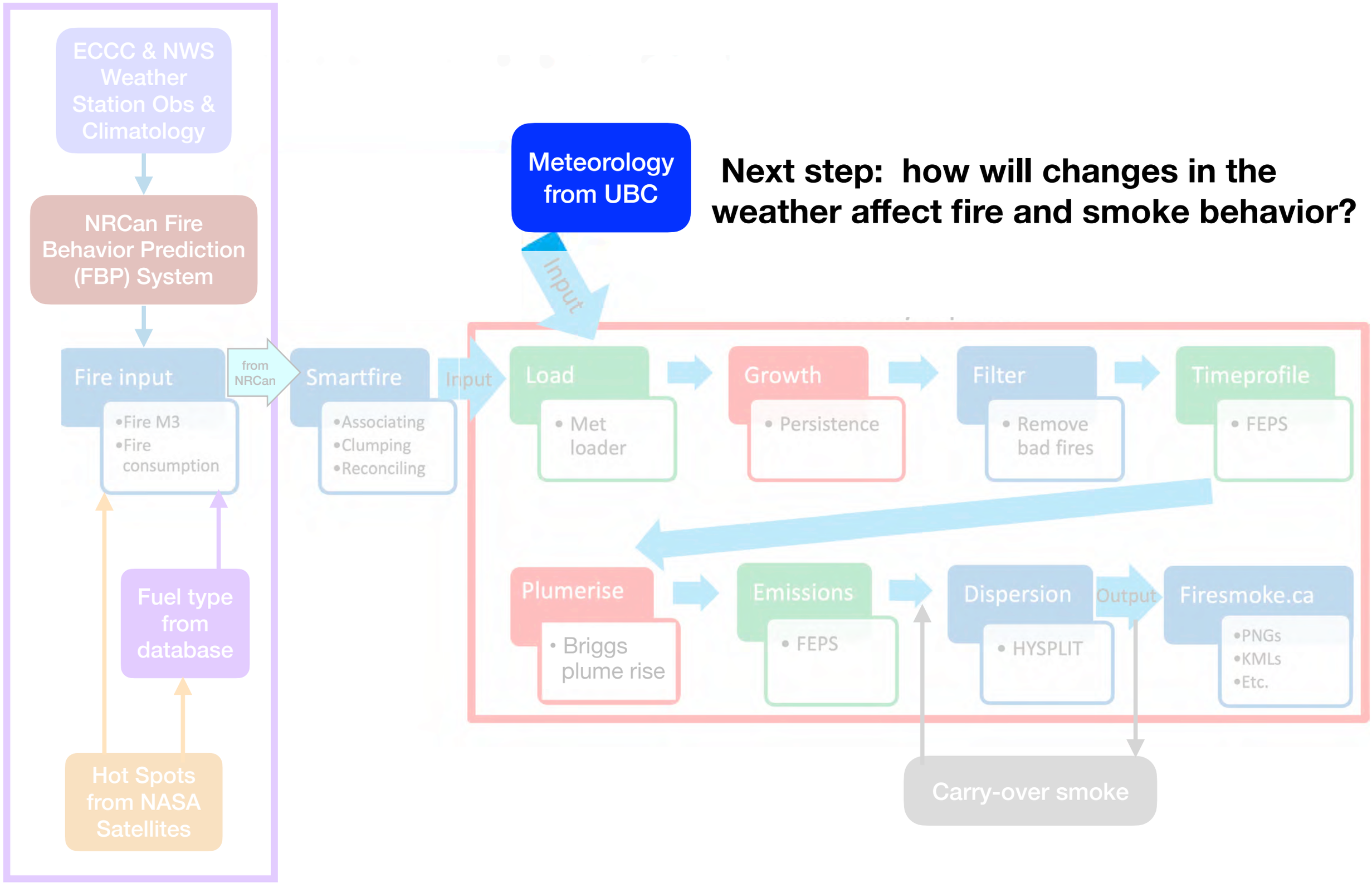
CSV KML SHP SHP Trimmed

Search:

action	agency	area_acres	area_meters	bfc	cause	consumption_duff	consumption_flaming	consumption_residual	consumption_smoldering	DateTime_local	end_date	firename	first_rep_date	hectares	last_rep_date	lat	latitude	location	lon	longitude	sfc	start_date	startdate
FUL	ab	11120	45000000	3.459	H	15.430238579618901	8.51800251043257	0.0	2.946499701079593 7	2024-04-21T00:00:00.000-07:00	2024-04-29T23:59:59.999-02:00	MWF-010-2024	2024-04-27 18:34:30	4500	2024-04-29 12:34:10	57.4876	57.488		-113.499	-113.499	2.57	2024-04-21	2024-04-21 20:00:00
FUL	bc	4448	18000000	2.744	H	12.240698081085363	4.759244219967485	0.0	2.8733484975022865	2024-04-20T00:00:00.000-08:00	2024-04-29T23:59:59.999-02:00	2024-C20117	2024-04-29 10:34:07	1800	2024-04-29 12:34:10	52.6098	52.61		-122.175	-122.175	1.711	2024-04-20	2024-04-20 22:52:00
FUL	pc	2224	9000000	1.367	H	6.098044561531957	0.9871404390261928	0.0	1.4663522521534533	2024-04-15T00:00:00.000-06:00	2024-04-29T23:59:59.999-02:00	2024RM1	2024-04-29 12:34:10	900	2024-04-29 12:34:10	50.7606	50.761		-100.228	-100.228	0.55	2024-04-15	2024-04-15 17:15:49
FUL	pc	2224	9000000	1.367	H	6.098044561531957	0.9871404390261928	0.0	1.4663522521534533	2024-04-15T00:00:00.000-06:00	2024-04-29T23:59:59.999-02:00	2024RM1	2024-04-29 12:34:10	900	2024-04-29 12:34:10	50.7606	50.761		-100.228	-100.228	0.55	2024-04-15	2024-04-15 17:15:49

from a Larkin, 2015 presentation

4. Meteorology Forecasts



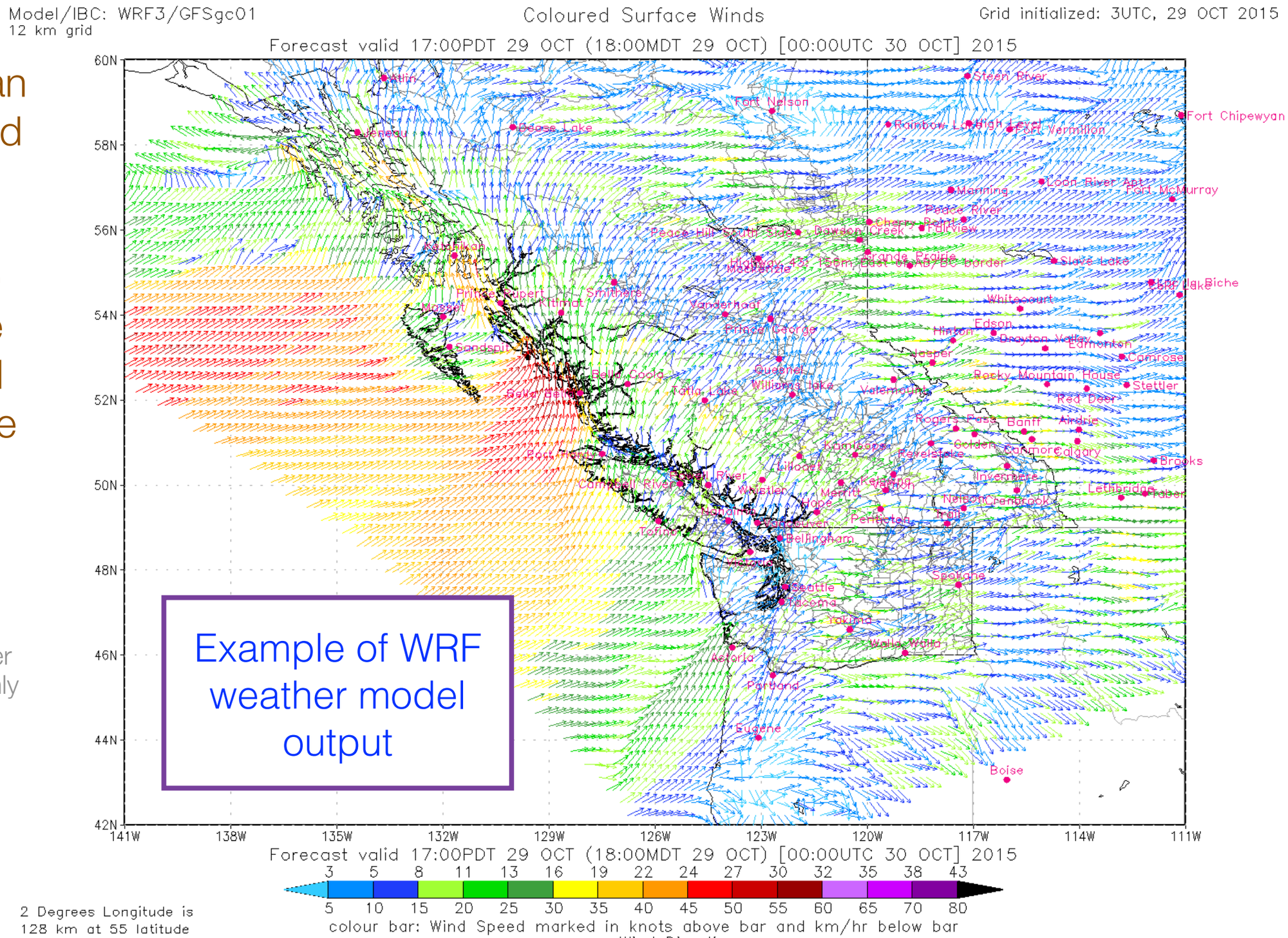
Next step: how will changes in the weather affect fire and smoke behavior?

4. Meteorological Forecasts

Jargon: Computational Fluid Dynamics (CFD) codes are called Numerical Weather Prediction (NWP) models when applied to the atmosphere.

At UBC, we run an NWP model called the **Weather Research and Forecast (WRF-ARW)** model, the most widely used NWP model in the world.

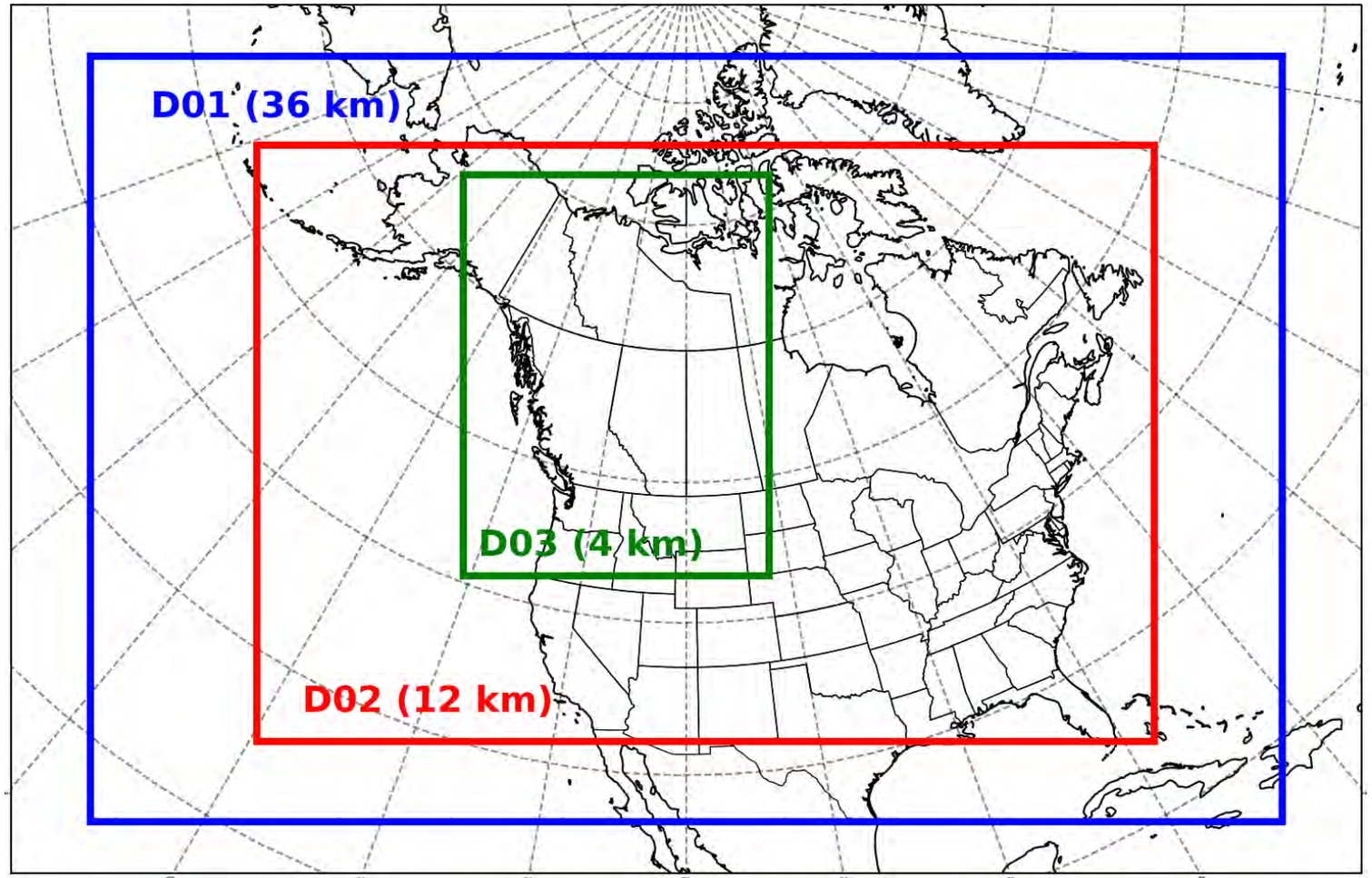
We also run many other models operationally every day, to create a 51-member ensemble forecast. But only the WRF-BlueSky runs are used for BlueSky.



4. Meteorology Forecasts

We make 4 runs each day of nested domains with horizontal grid spacings of Δx = 36 and 12 km, initialized from 00, 06, 12, 18 UTC North American Mesoscale runs. The forecast horizon is 84 hours. Two way grid interactions.

For the 00 UTC initialization, we also run the nested 4 km domain out to a forecast horizon of 60 hours.



4. Meteorology Forecasts

FireSmoke.ca | Home | Services | Resources | Contact

- Smoke Forecasts
- Fire Weather Forecasts
- SmartFire
- Playground
- Data

FireSm anada

You can view these forecasts on firesmoke.ca / forecasts/fireweather/

updated once each day

Canada

United States of America

México

North Pacific Ocean

– Fire Weather Forecast
- Fine Fuel Moisture Code
- Duff Moisture Code
- Drought Code
- Initial Spread Index
- Build Up Index
- Fire Weather Index

– Fire Behavior Forecast
- Head Fire Intensity (kW/m)
- Rate of Spread (m/min)
- Crown Fraction Burned (%)
- Surface Fuel Consumption (kg/m^2)
- Total Fuel Consumption (kg/m^2)

– Weather Forecast
- (•) Temperature (C)
- ( ) Relative Humidity (%)
- ( ) Total Accumulated Precipitation (mm)
- ( ) 3 Hour Accumulated Precipitation (mm
- ( ) Accumulated Snowfall (cm)
- ( ) Wind Speed (km/hr)
- [x] Wind Direction

– Observations
- [ ] Weather Stations
- [ ] Satellite hotspots / Modelled Fires
- [ ] Doppler Radar
- [ ] Air Quality

-75 -65 -55 -45 35 -30 -26 -22 -18 -14 -10 -6 -2 2 6 10 14 18 22 26 30 34 38 42+

Temperature (C) at 2m

d Direction: 169.87°, **Wind Speed:** 9.01 k/h

5/26/2024, 2:00:00 PM

500 km
300 mi

Leaflet | © MapTiler © OpenStreetMap contribu

4. Meteorology Forecasts

Model Information

Weather Research & Forecasting - Advanced Research WRF (WRF-ARW) model:

- Version 4.2.1
- Eulerian, non-hydrostatic, conservative flux form

Mapping/projection:

- Polar stereographic
- Reference latitude = 53.25° (latitude of center of the 36 km domain)
- Reference longitude = -110.00° (longitude of center of the 36 km domain)
- True latitude = 53.25° (true latitude in the 36 km domain)

Dynamics:

- 5th-order advection in the horizontal
- 3rd-order advection in the vertical
- Runge-Kutta 3rd order (RK3) split-explicit time stepping scheme
- Hybrid vertical coordinate (HVC); terrain-following near surface, isobaric in the upper atmosphere
- Moist theta as the thermodynamic prognostic variable

Physics:

- Thompson microphysics (for clouds & precipitation)
- Tiedtke cumulus (for convection)
- Noah LSM (not the same as Noah-MP) Land Surface Model
- MYJ PBL (for boundary layer)
- Eta similarity surface-layer scheme
- RRTMG longwave radiation
- RRTMG shortwave radiation
- YSU gravity wave drag (for orography)

Terrain/land use:

- USGS 30 arc-second horizontal resolution (roughly 900 m) for digital elevation data
- 21 MODIS IGBP categories for land use data

Nesting:

- 2-way
- Coarse-mesh grid = 36 km horizontal grid spacing
- Medium-mesh grid = 12 km horizontal grid spacing
- Fine-mesh grid = 4 km horizontal grid spacing

Vertical layers:

- 55 (HVC)

https://weather.eos.ubc.ca/wxfcst/html-etc/model-metadata/wan00cg-01.html

This is the most computationally intensive part of the BlueSky operation, which we run on Google cloud.

We save (breakpoint) output periodically, if needed to restart the run if it failed partway thru.

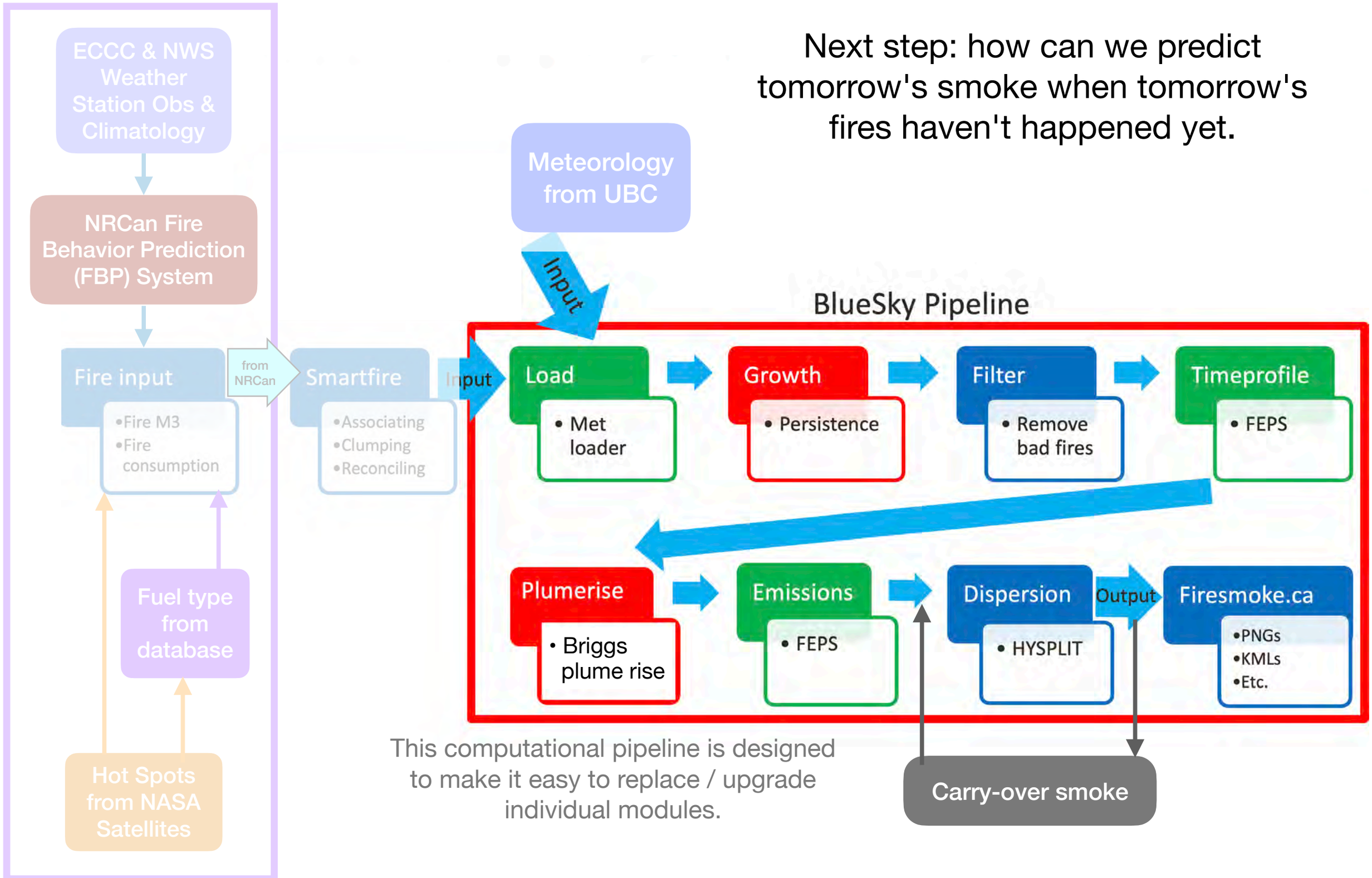
Processors: 2 x 88 vCPU Compute-Optimized H3 Instances (Sapphire Rapids); 176 non-hyperthreaded vCPUs

00 UTC: 6 hour run time, 310 GB output (wrfout output only)

06, 12, 18 UTC: 2 hour run times, 138 GB output each

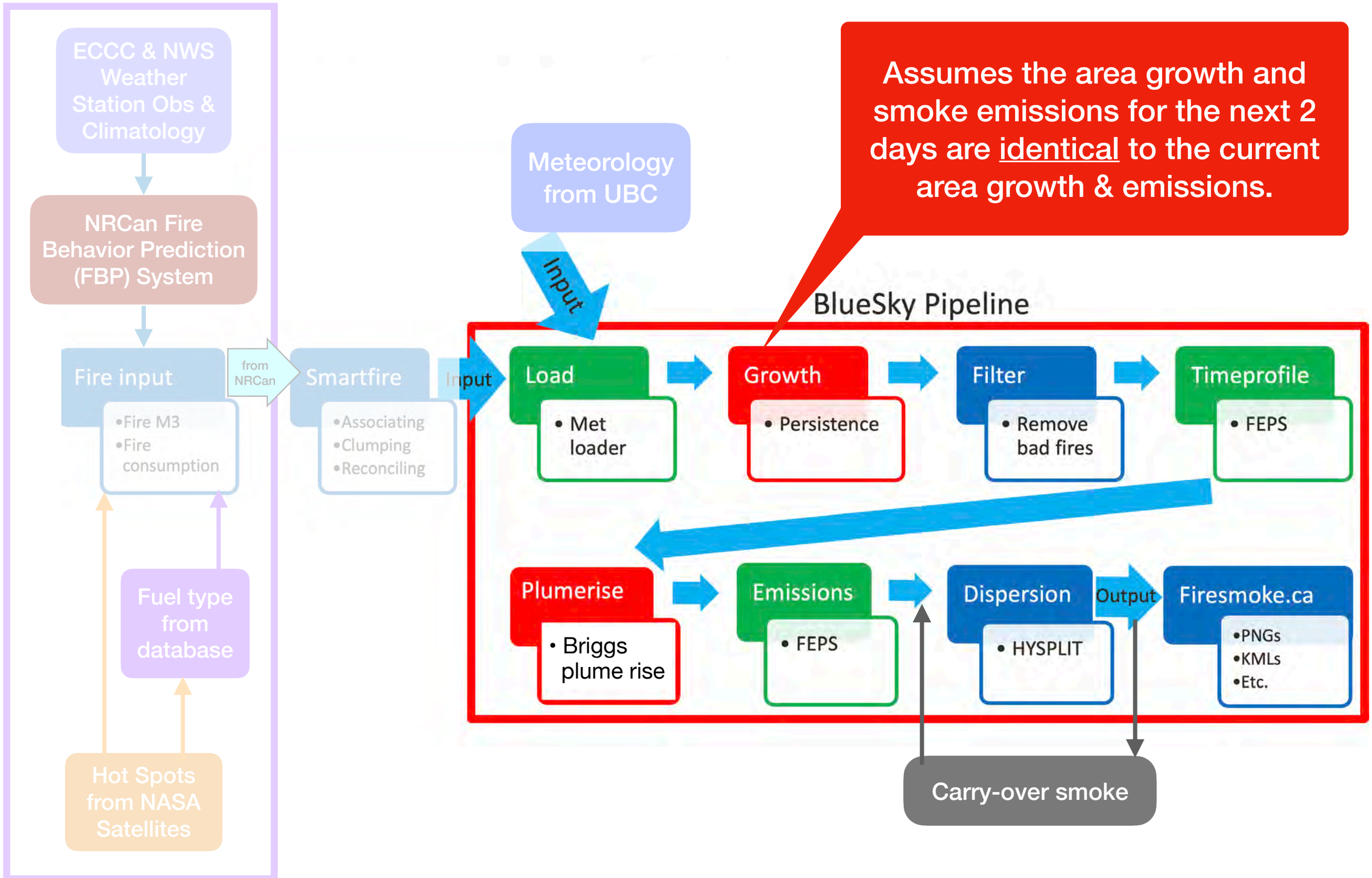
5. BlueSky Pipeline

Next step: how can we predict tomorrow's smoke when tomorrow's fires haven't happened yet.



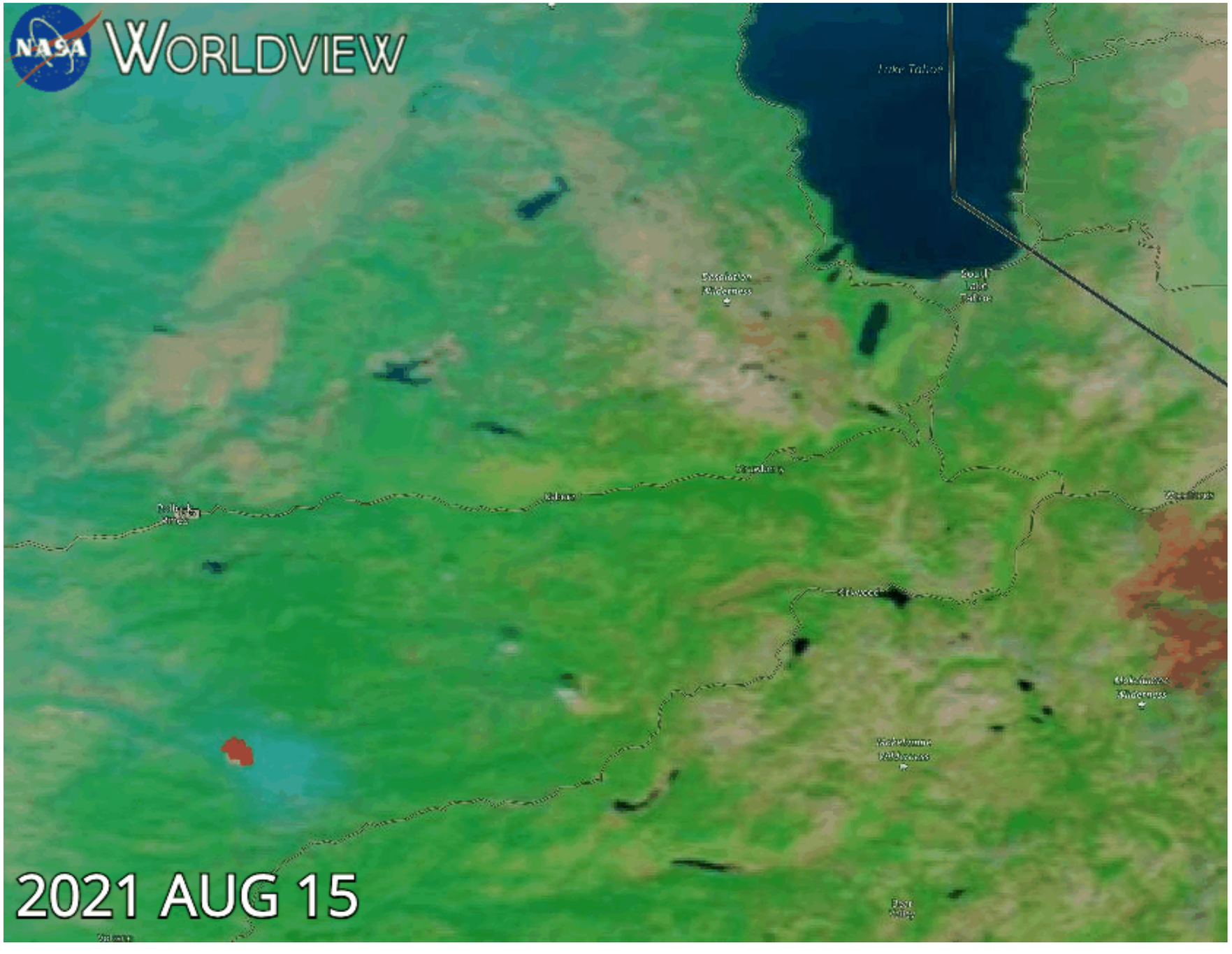
This computational pipeline is designed to make it easy to replace / upgrade individual modules.

5. BlueSky Pipeline



5. BlueSky Pipeline

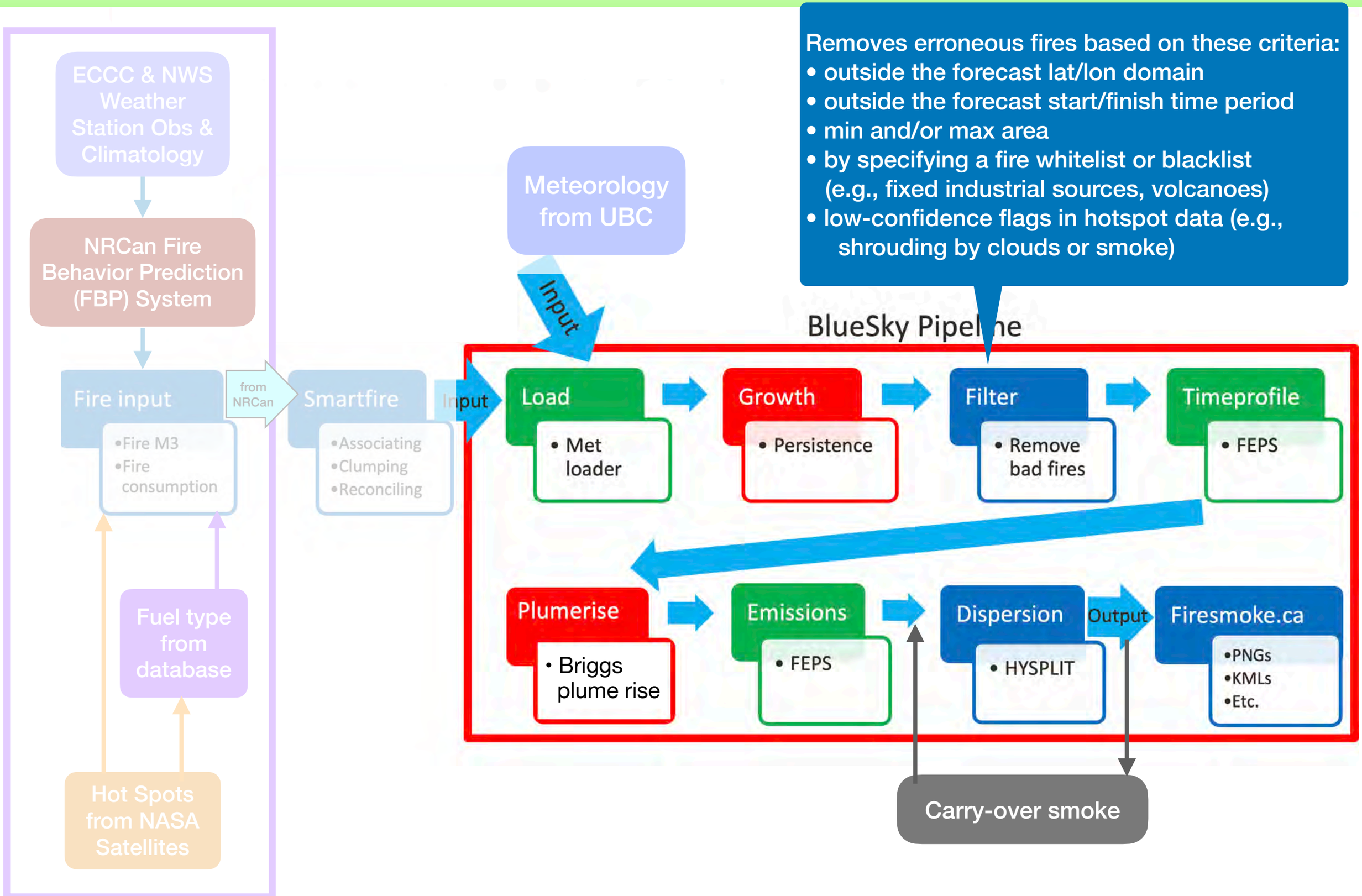
Persistence: Not the best assumption, but practical.



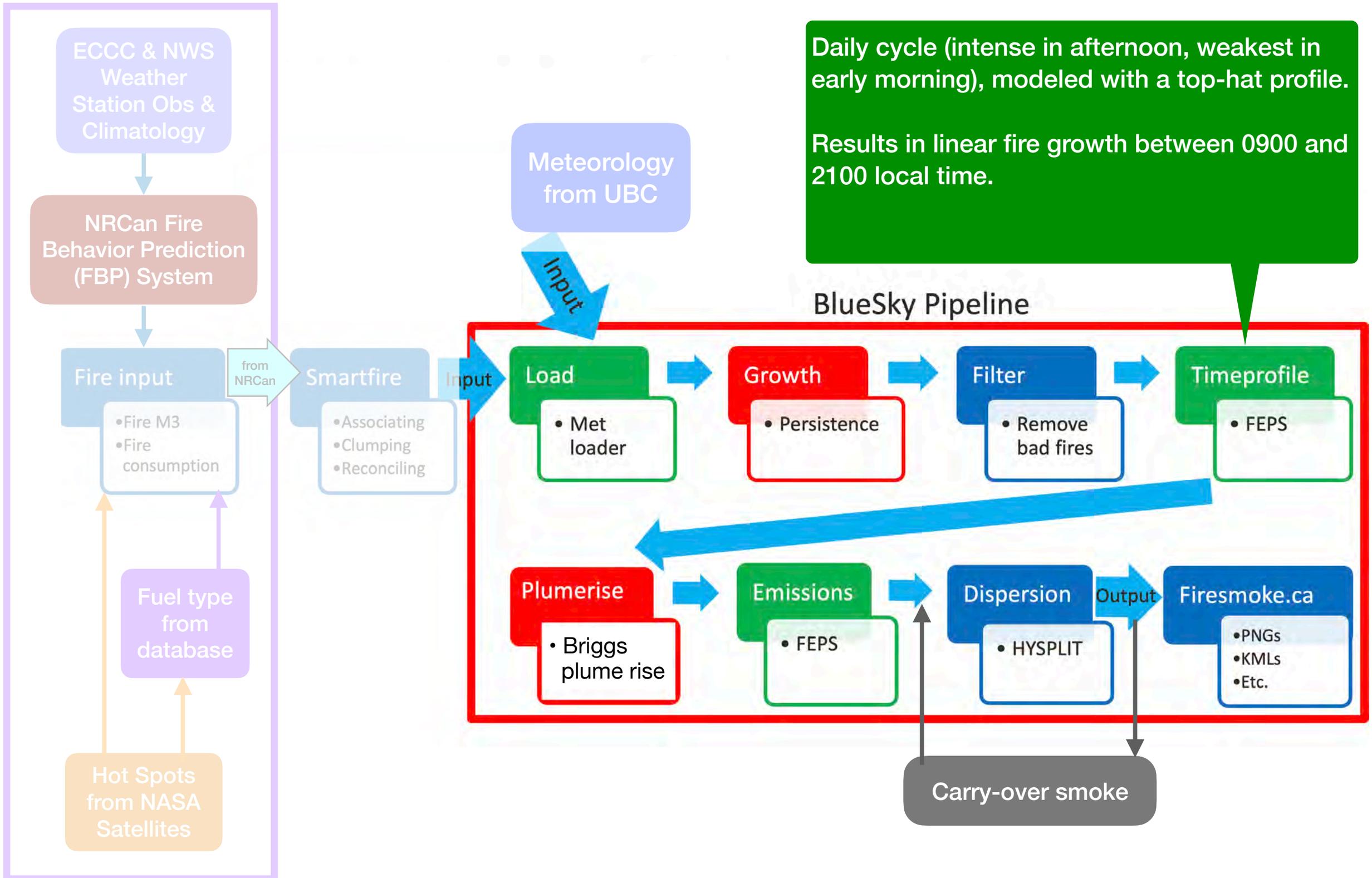
Issues:

- Changes due to active fire supression in future days are unknown.
- Actual future fire perimeters are unknown, thus the type and availability of new fuels are unknown. Thus, heat release, plume rise, and emission rates are unknown.

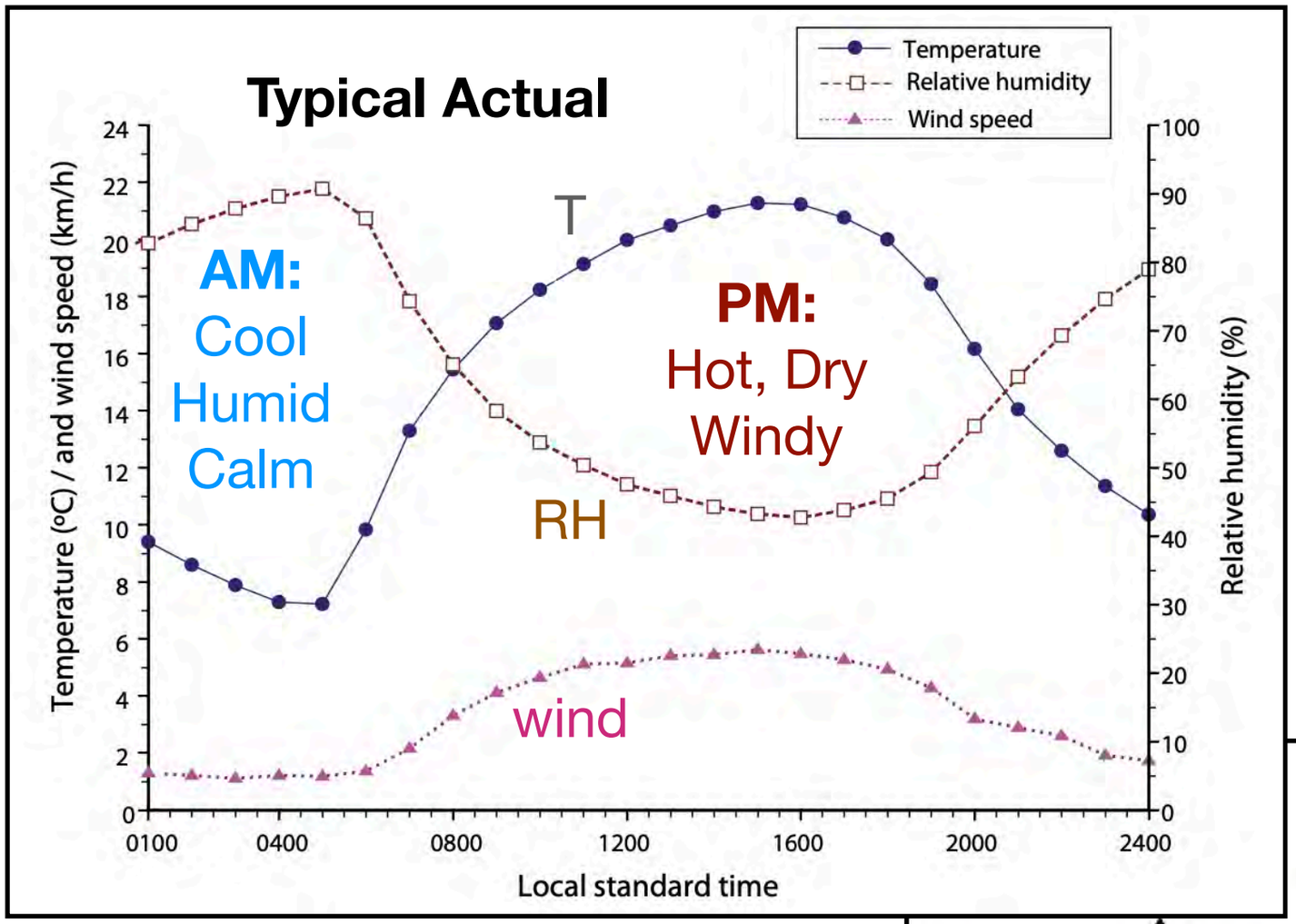
5. BlueSky Pipeline



5. BlueSky Pipeline



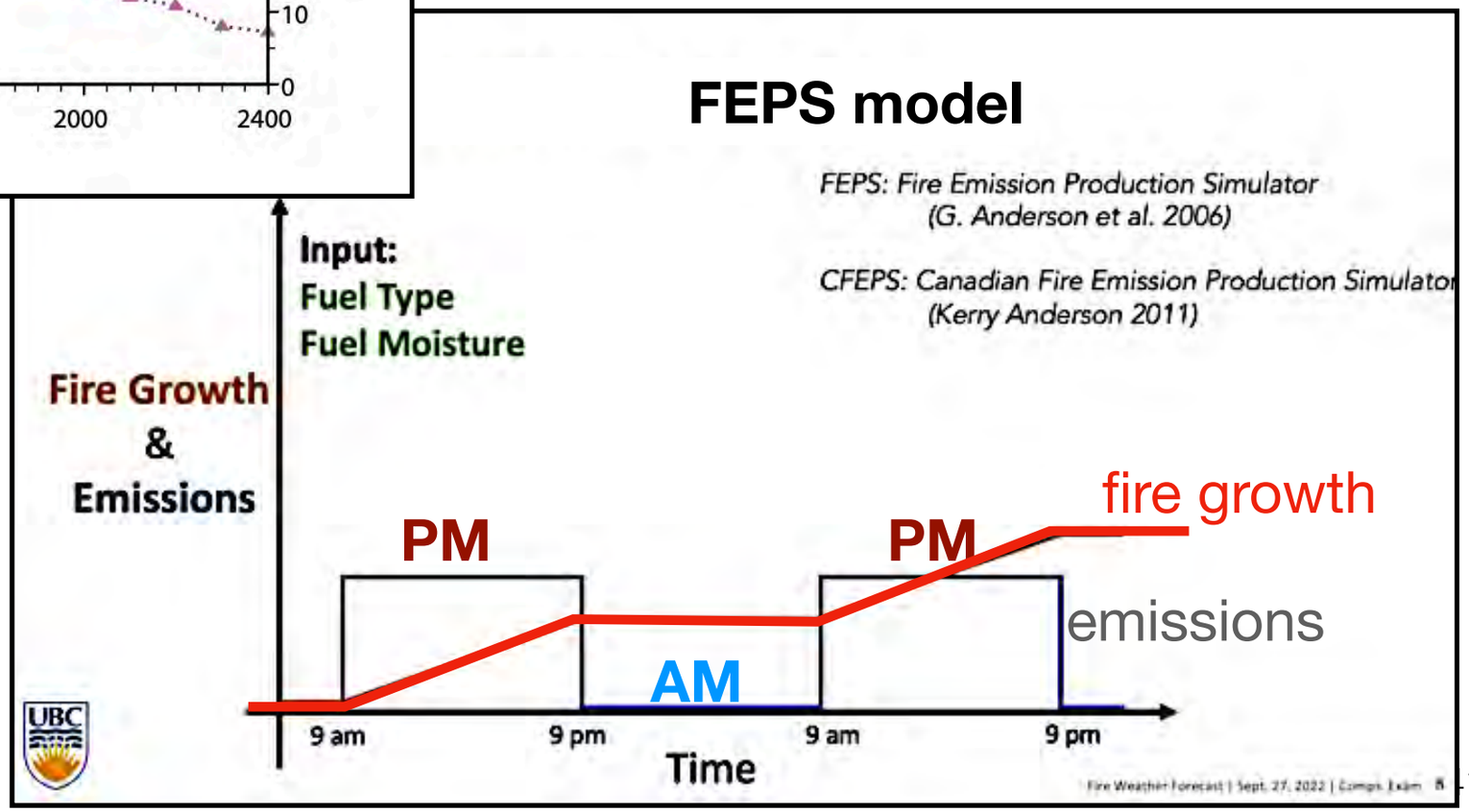
5. BlueSky Pipeline



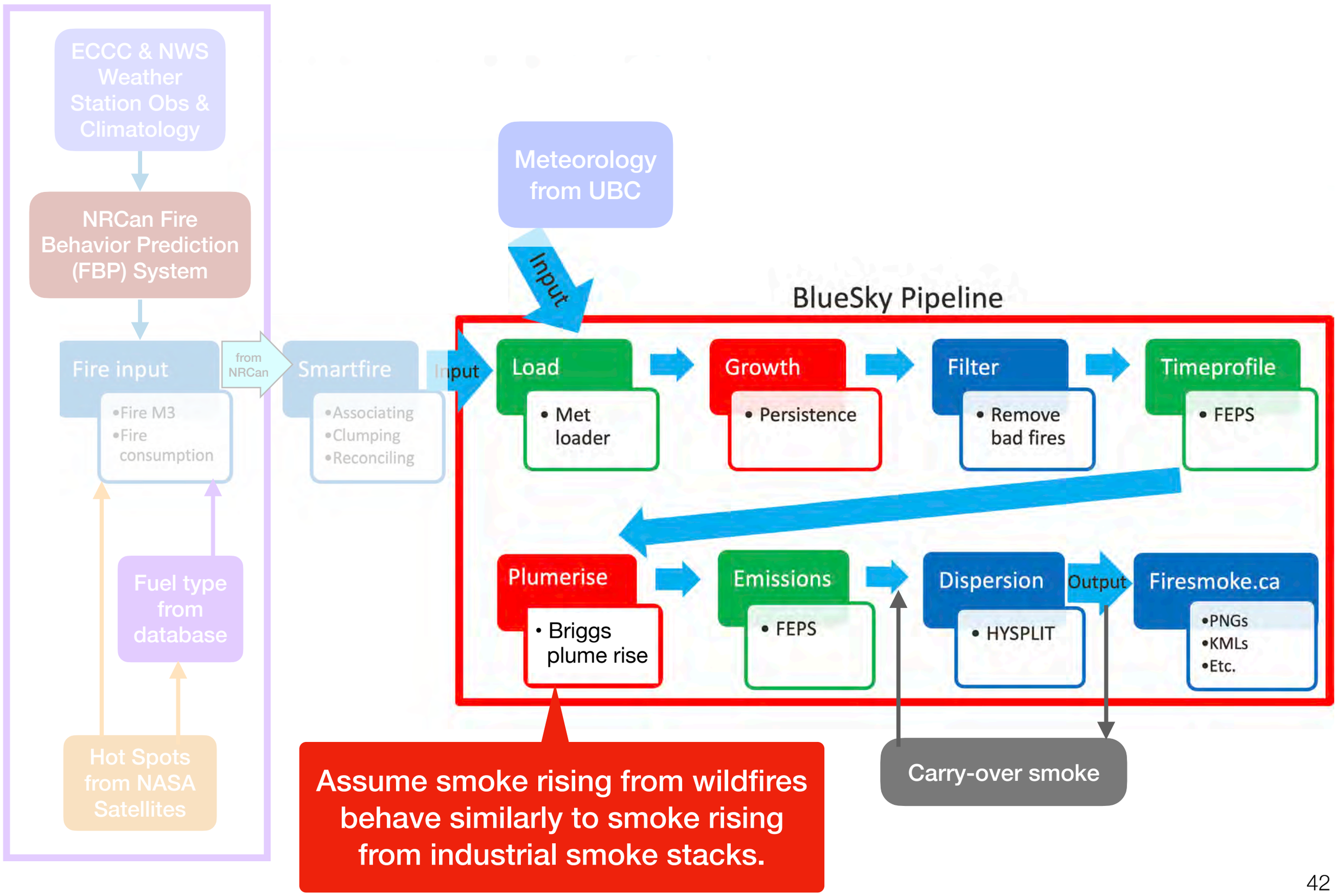
Time Profile

Using Anderson's Fire Emission Production Simulator (FEPS)

vertical axis scaled by fuel types, moisture, & fire growth



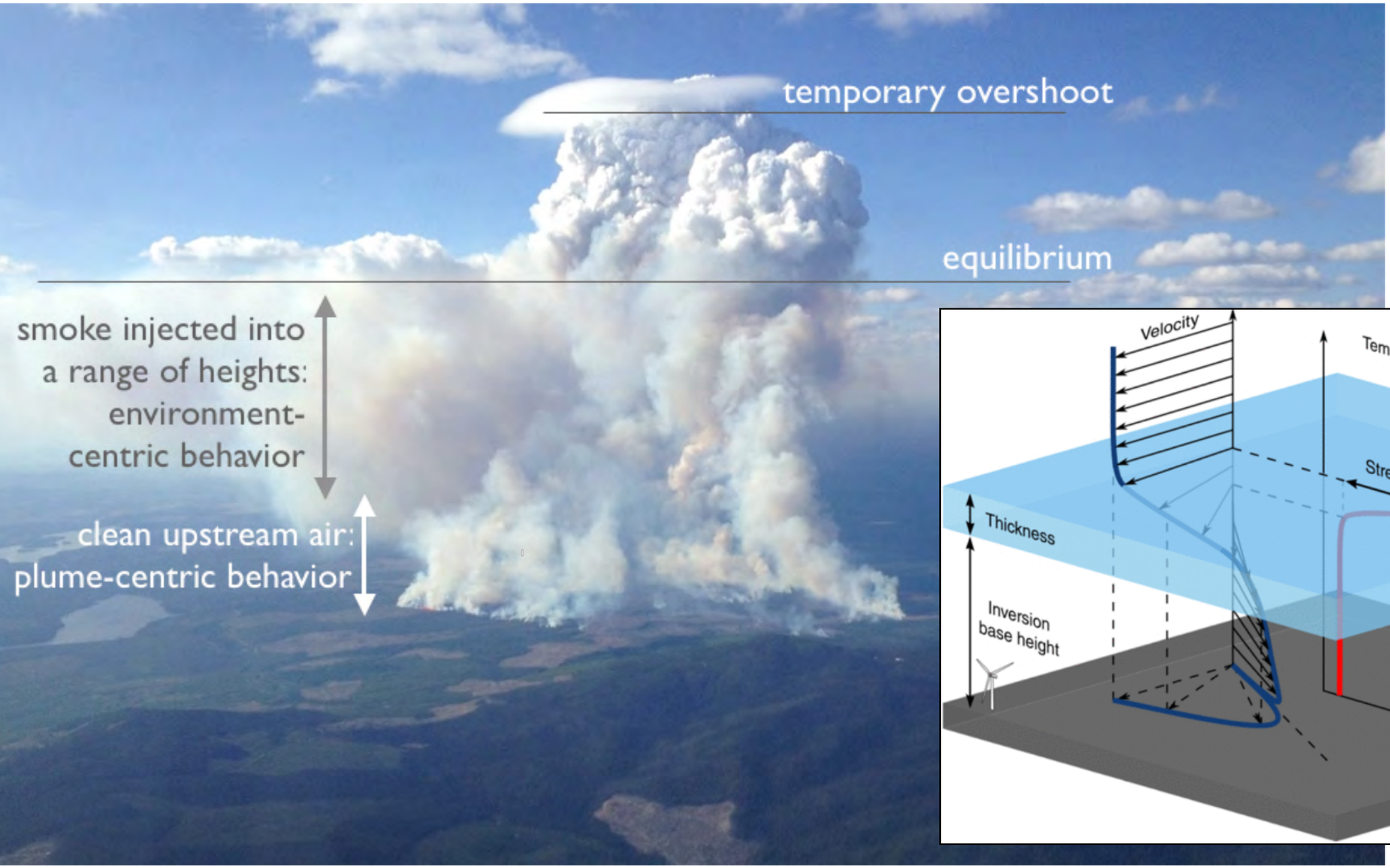
5. BlueSky Pipeline



5. BlueSky Pipeline

Plume Rise

Actual smoke plume rise is strongly dependent on the vertical temperature and wind structure of the lower troposphere. Thus, it uses the meteorology forecasts as an input.



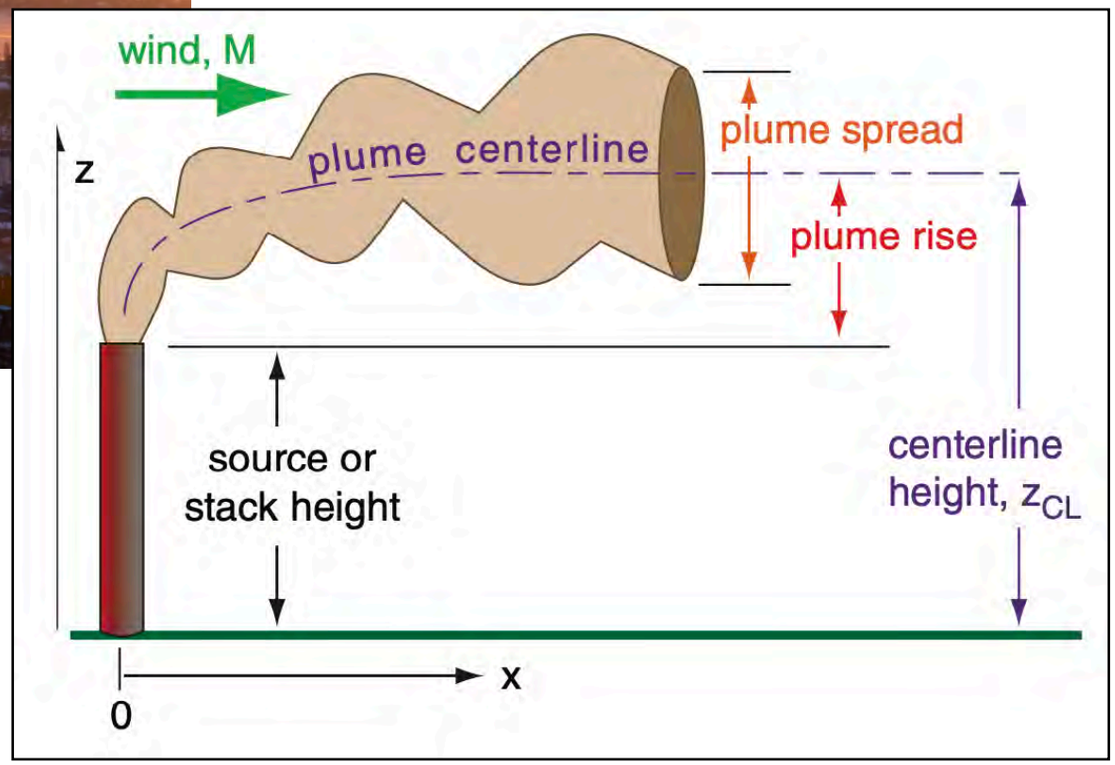
https://images.app.goo.gl/Rfq5P25u3hy42JfV6

5. BlueSky Pipeline

https://carbonfund.org/how-do-greenhouse-gases-contribute-to-global-warming/

Plume Rise

Briggs Plume Rise assumes smoke rises due to its initial upward momentum and buoyancy, and the plume does NOT modify the environment it rises through.



For example, if smoke rises thru a statically neutral atmosphere, then:

$$z_{CL} = z_s + \left[a \cdot l_m{}^2 \cdot x + b \cdot l_b \cdot x^2 \right]^{1/3}$$

Nomenclature: z_{CL} = plume centerline height, z_s = stack height, x = downwind distance, l_m = momentum length scale, l_b = buoyancy length scale, a & b are empirical parameters. (See Stull, 2018: Practical Meteorology, chapter 19 for details.)

5. BlueSky Pipeline

Plume Rise

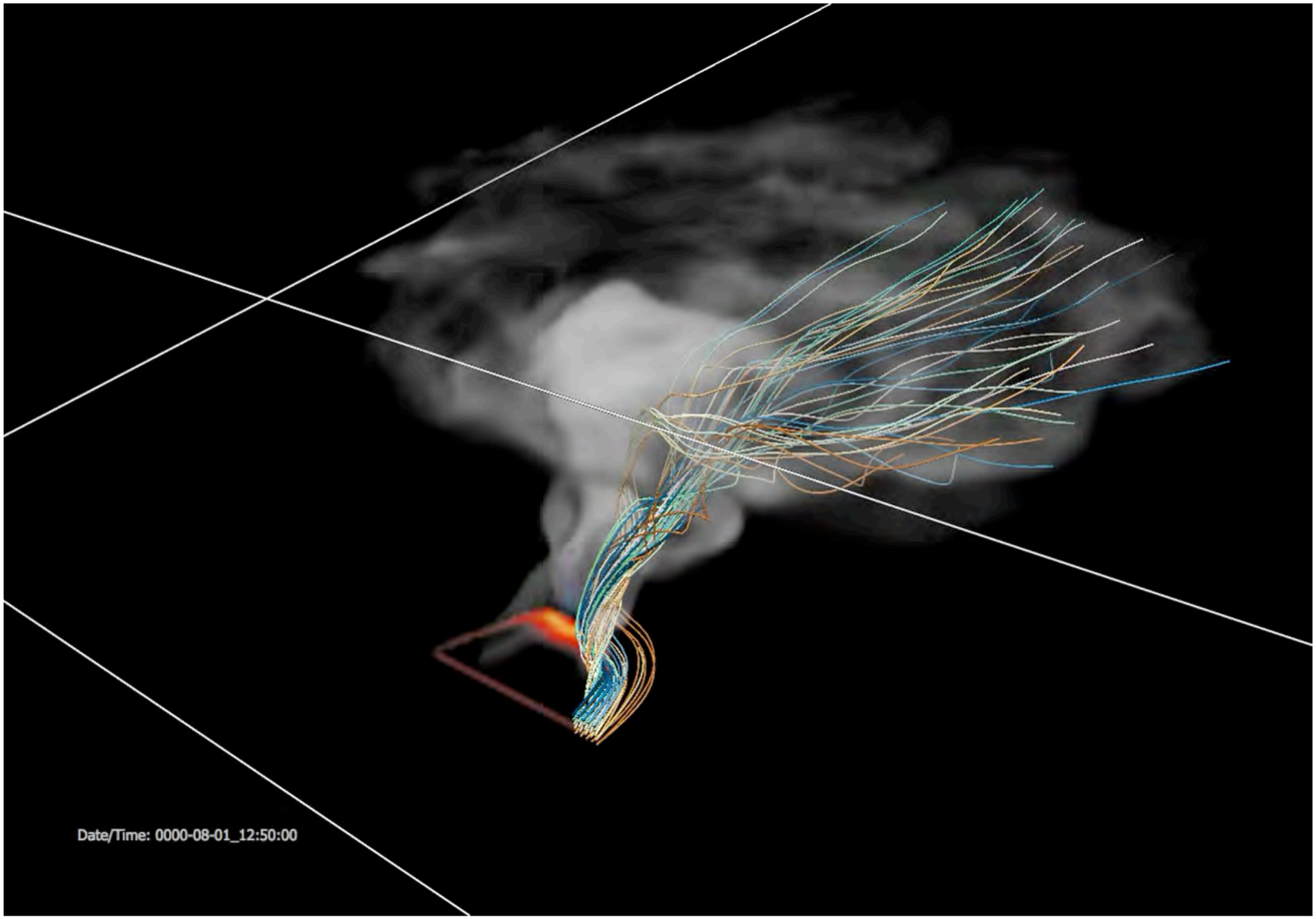
But real fires don't work like smoke stacks, because the fire modifies the environment, causing feedback to modify the fire. For example, note the vortices at each end of the fireline.

Acknowledgement: Alberta Fire, CFS, FP Innovations

5. BlueSky Pipeline

Plume Rise

We study these using Large Eddy Simulation (LES).

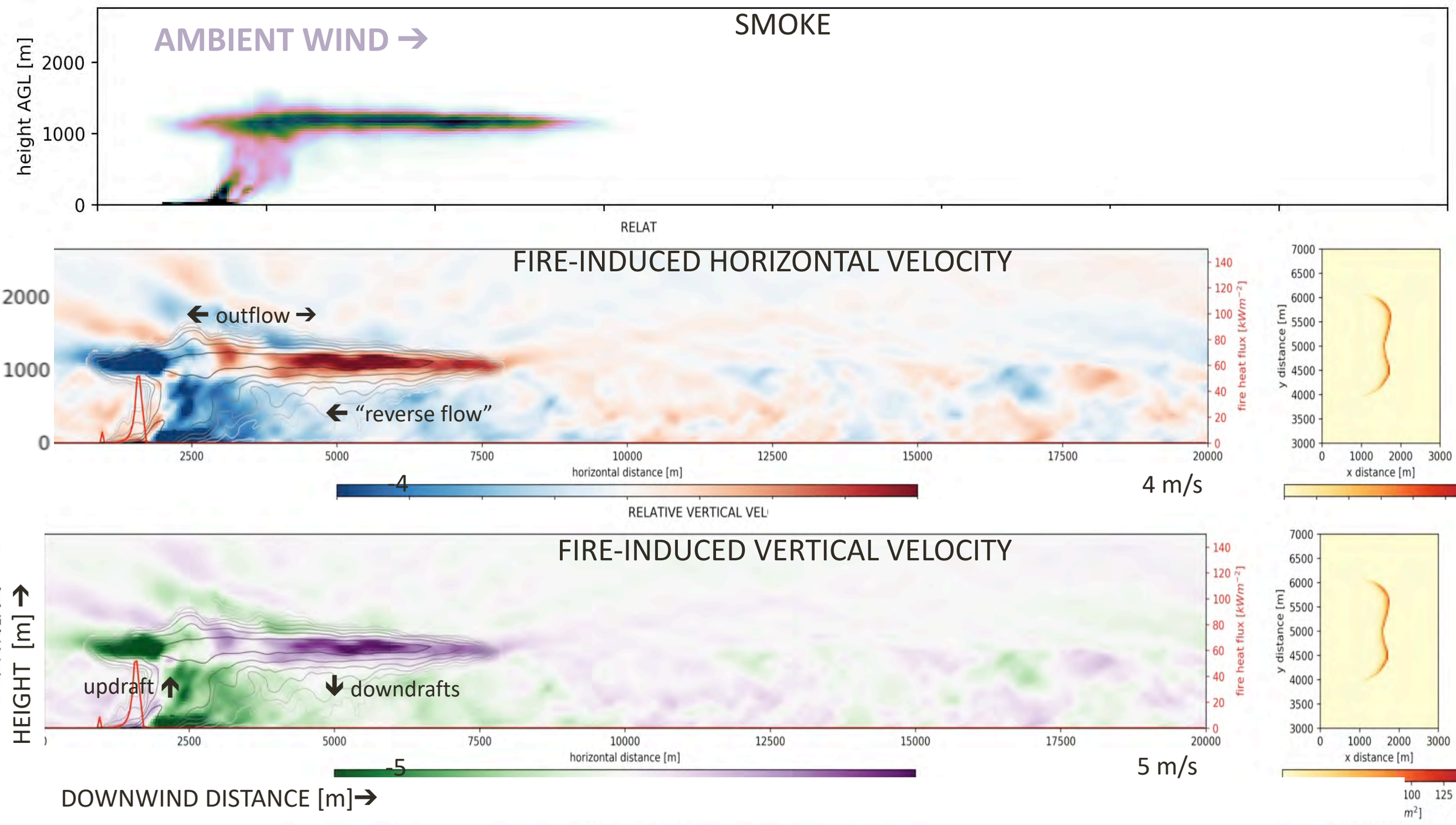


Source: Nadya Moisseeva

5. BlueSky Pipeline

Plume Rise

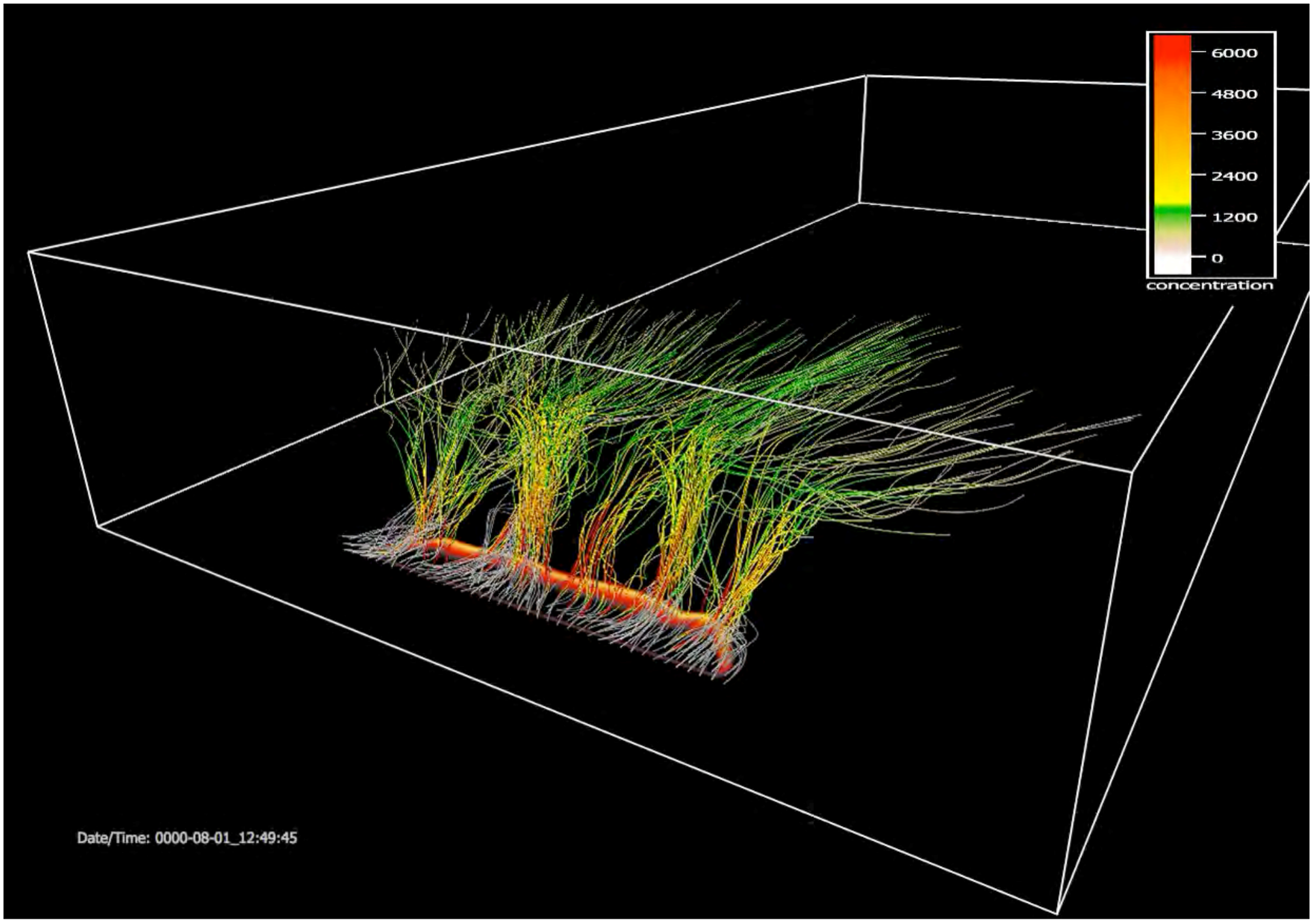
The fire line induces large-scale circulations of the environment.



5. BlueSky Pipeline

Plume Rise

As ambient thermals in the Atmospheric Boundary Layer advect over the fire line, the heat and emissions are organized into concentrated regions of rising air.



Source: Nadya Moisseeva

5. BlueSky Pipeline

Plume Rise

Nadya Moisseeva developed a better plume-rise algorithm.

b) Analysis & Theory,
to improve Plume-rise estimates for BlueSky Forecasts

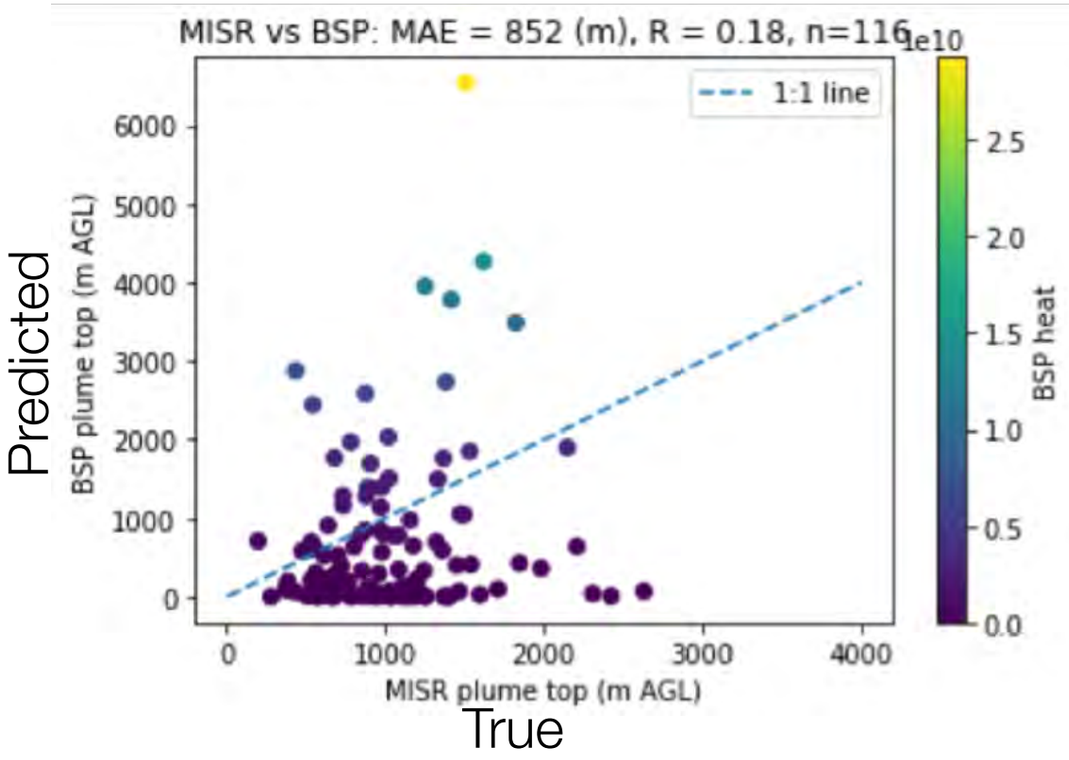
Smoke-plume height is a function of a new fire velocity scale, w_{f*}:

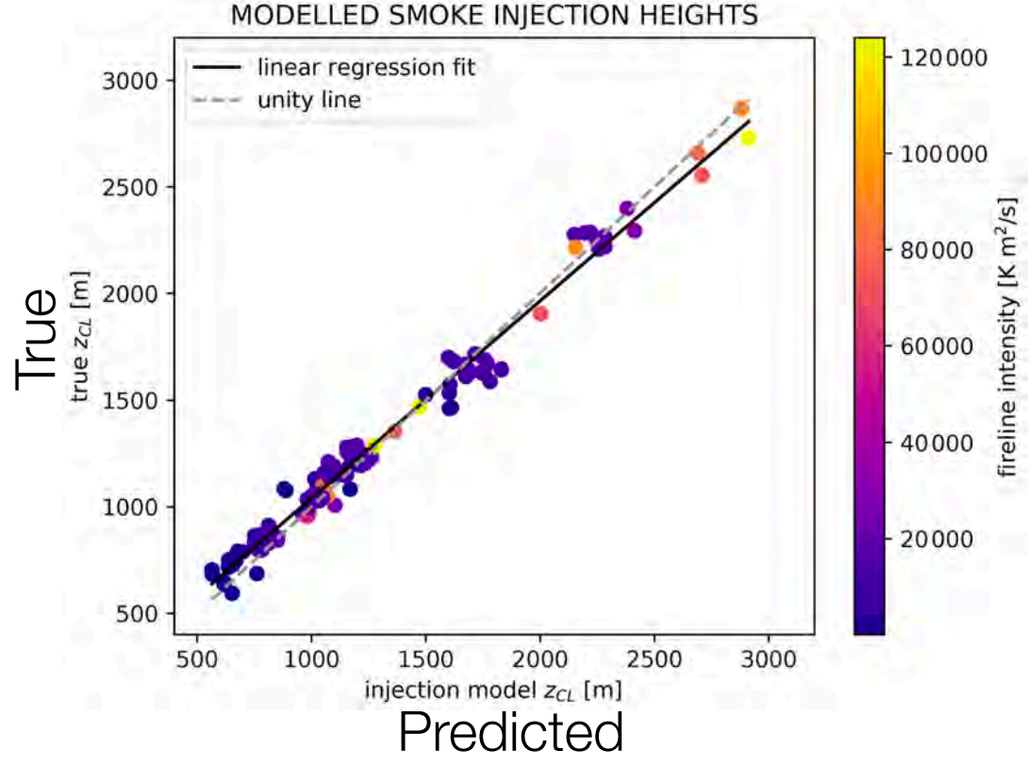
boundary layer height gravity fireline intensity

$$w_{f*} = \left(\frac{z_i \cdot g \cdot \int_0^r I dr}{\int_0^{z_{cl}} d\theta dz} \right)^{\frac{1}{3}}$$

atmospheric profile effects

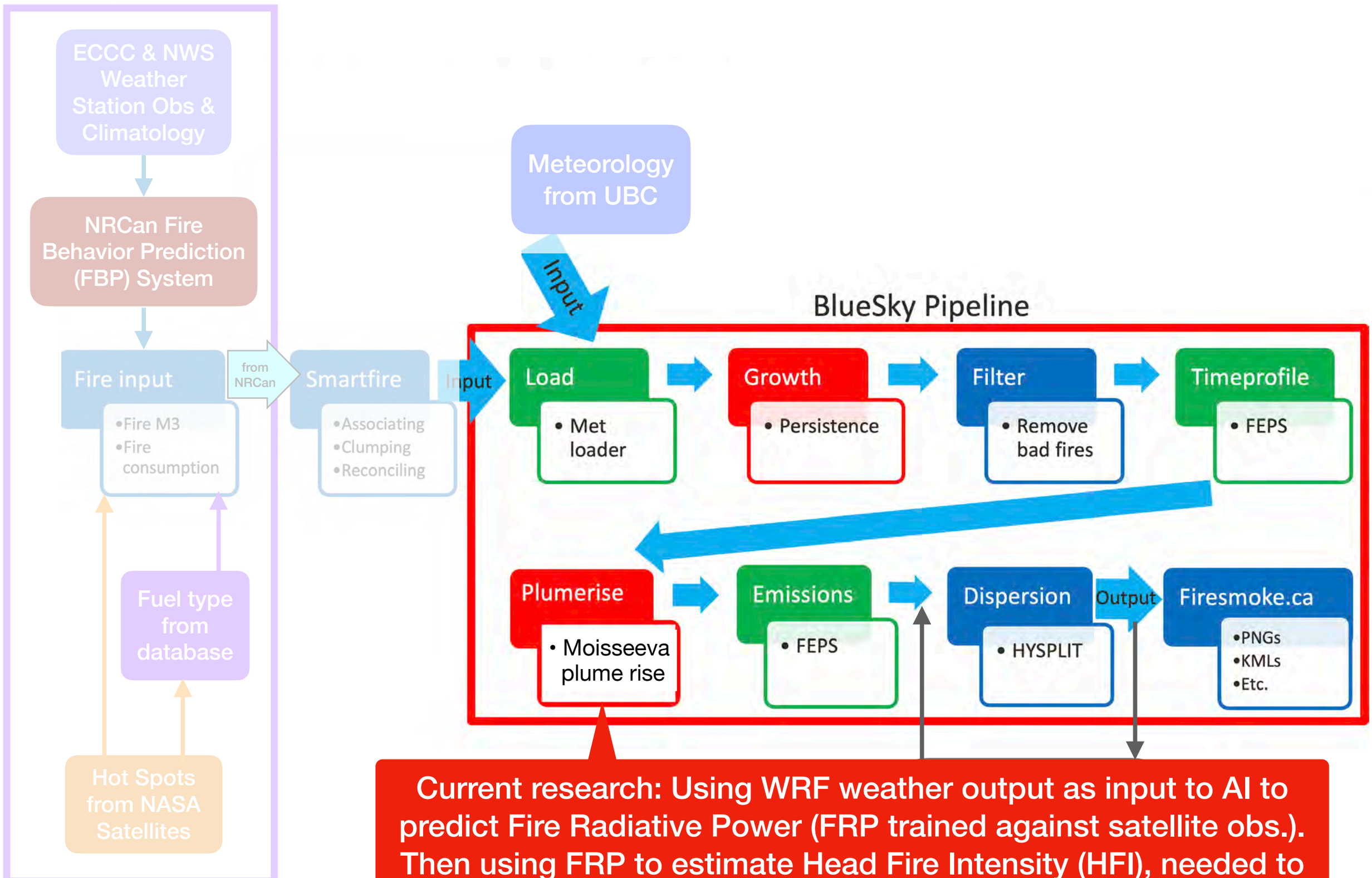
Brigg's smokestack plume model vs. Nadya Moisseeva's CWIPP model





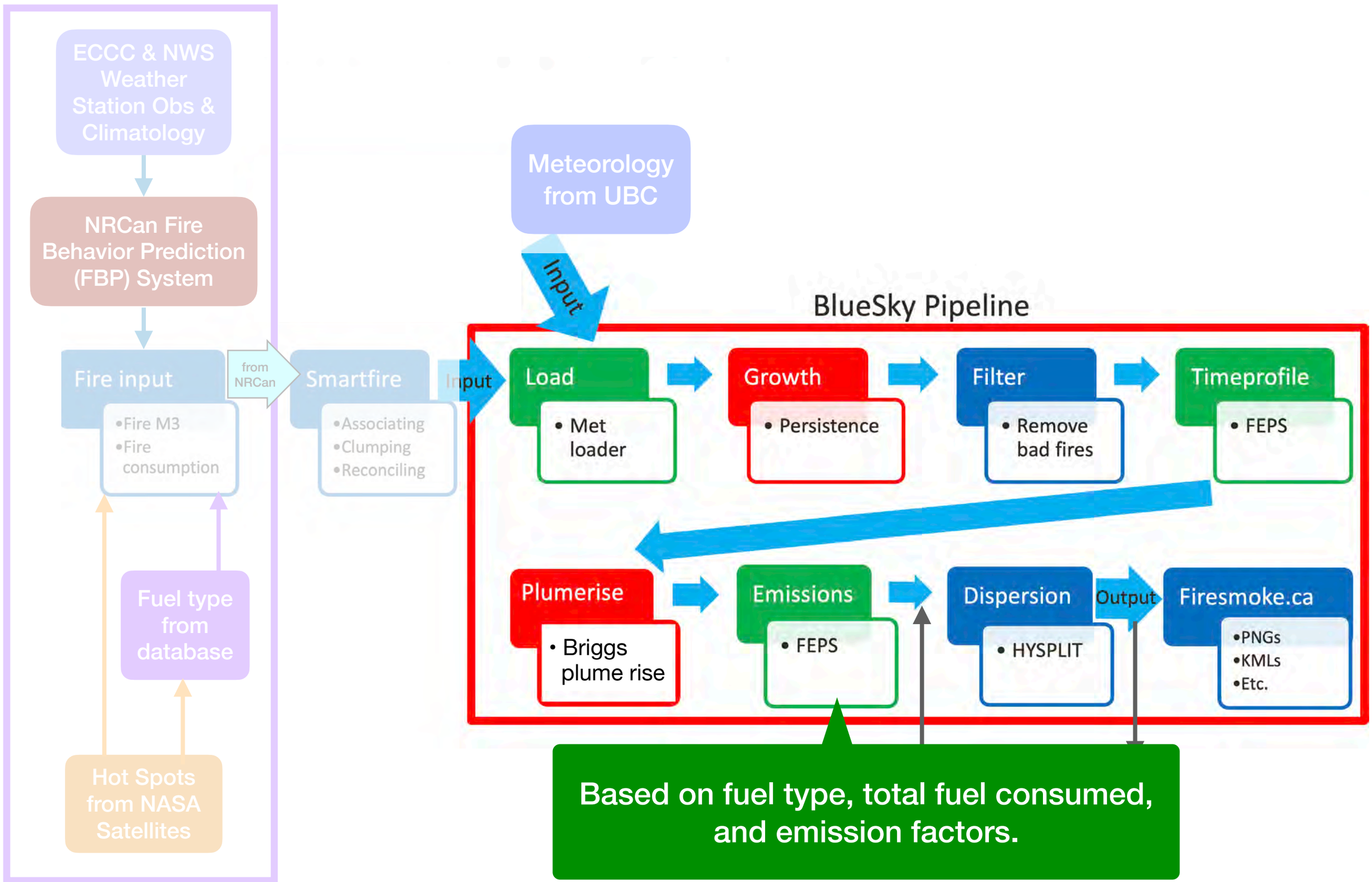
- Moisseeva, N., and R.B. Stull, 2021: Wildfire smoke-plume rise: A simple energy balance parameterization. *Atmos. Chem. Phys.*, 21, 1407–1425, https://acp.copernicus.org/articles/21/1407/2021/acp-21-1407-2021-discussion.html.

5. BlueSky Pipeline



Current research: Using WRF weather output as input to AI to predict Fire Radiative Power (FRP trained against satellite obs.). Then using FRP to estimate Head Fire Intensity (HFI), needed to utilize the Moisseeva plume rise in BlueSky.

5. BlueSky Pipeline



5. BlueSky Pipeline

Emissions

Emission factor = mass of pollutant emitted per total fuel consumed in a wildfire.

Uses FEPS output from FireM3 to estimate total fuel consumed (TFC = surface fuels consumed + crown fuels consumed).

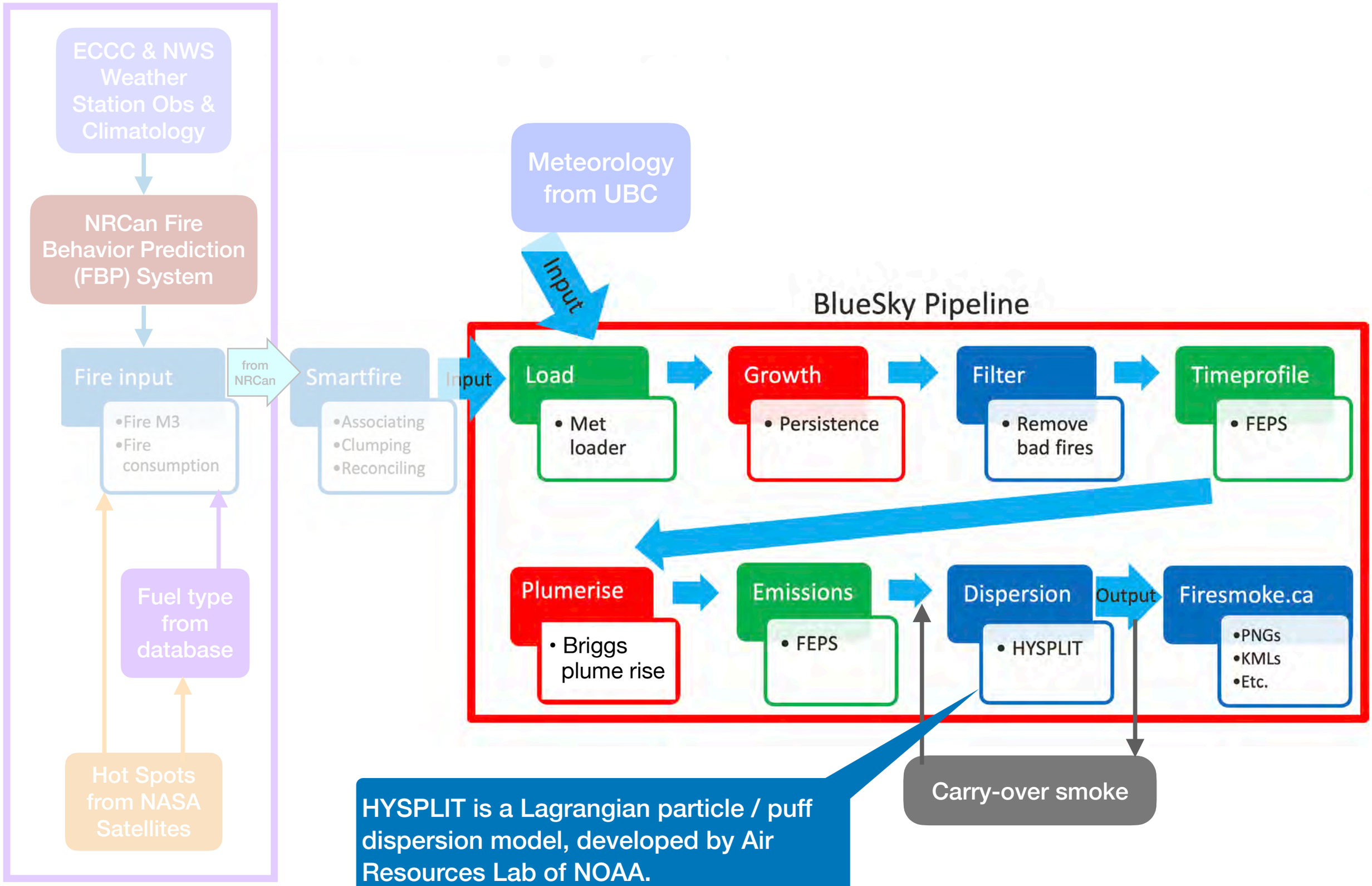
Each fuel type (e.g., black spruce) has an emission factor for each constituent (e.g. PM2.5) based on laboratory experiments.

Examples:

- Ponderosa Pine needles:
  ~18.2 $g_{PM2.5}$ / kg_{fuel} .
- Ponderosa Pine needles & cones:
  ~47.2 $g_{PM2.5}$ / kg_{fuel} .
- Douglas Fir canopy:
  ~19 $g_{PM2.5}$ / kg_{fuel} .
- Jack Pine and Black Spruce:
  ~8.3 $g_{PM2.5}$ / kg_{fuel} .

Urbanski et al, 2022: Fuel layer specific pollutant emission factors for fire prone forest ecosystems of the western U.S. and Canada. Atmospheric Environment: X. Volume 16, December 2022, 10018. https://doi.org/10.1016/j.aeaoa.2022.100188

5. BlueSky Pipeline

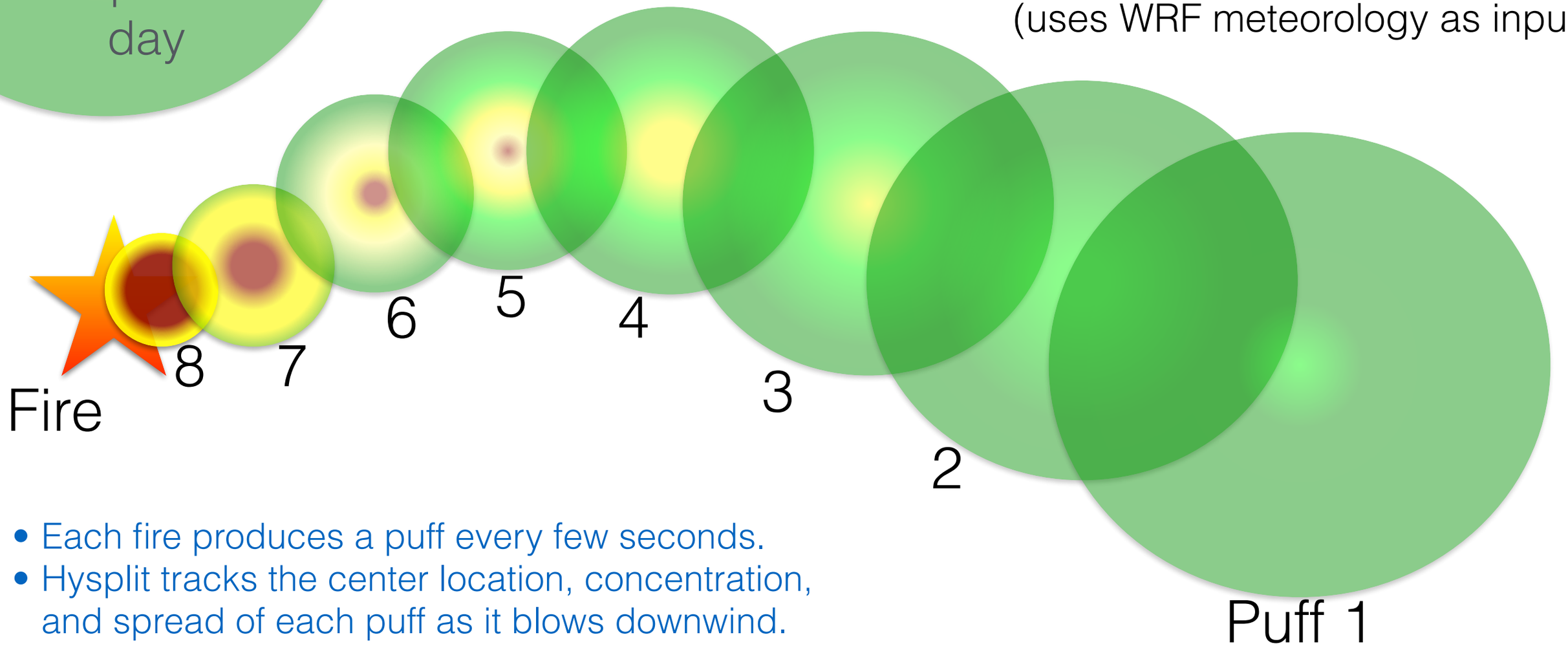


5. BlueSky Pipeline

Carry-over smoke from previous day

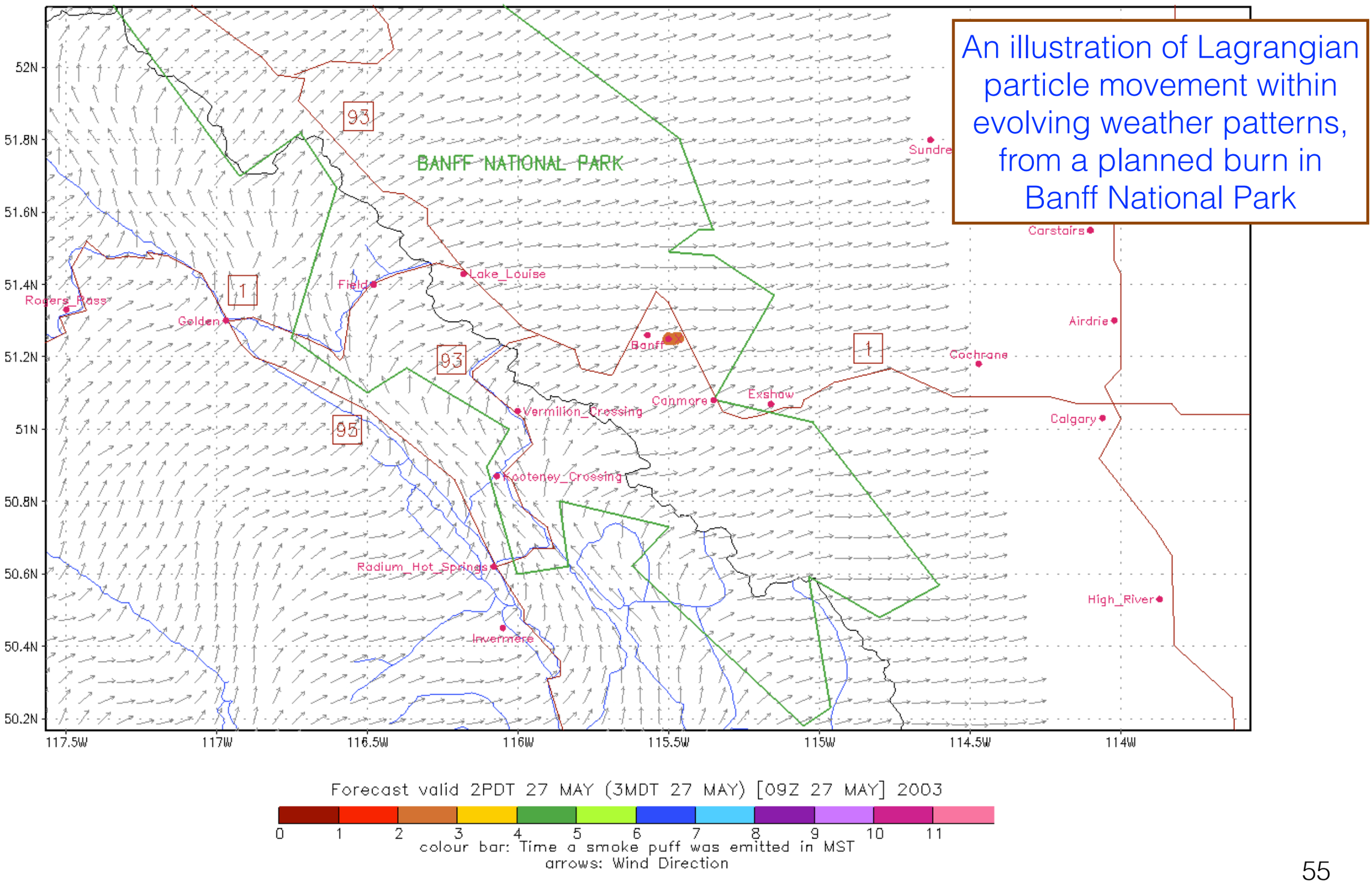
Hysplit (Lagrangian) Dispersion Model

(uses WRF meteorology as input)



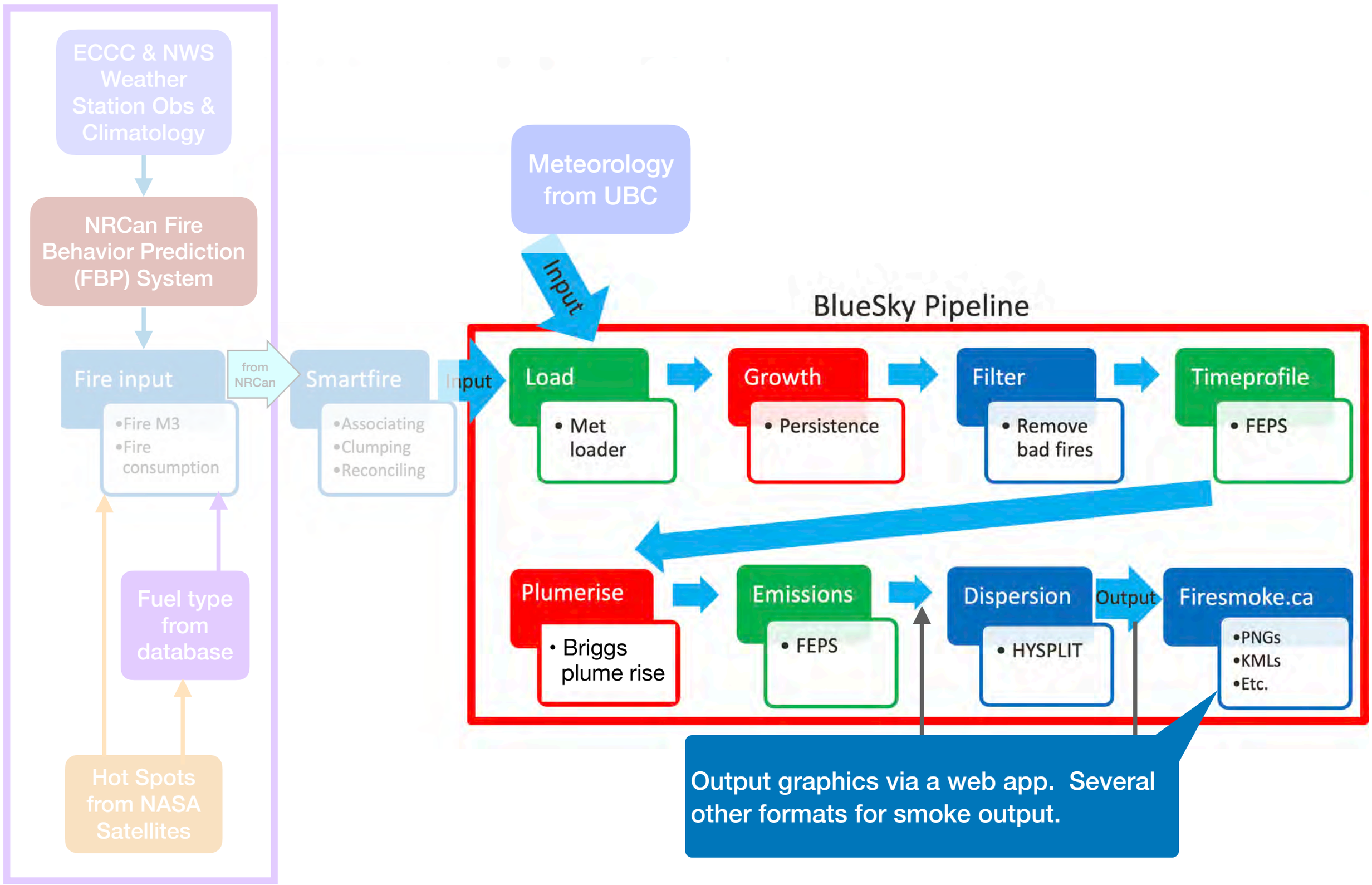
- Each fire produces a puff every few seconds.
- Hysplit tracks the center location, concentration, and spread of each puff as it blows downwind.
- Each puff has its own “age”.
- Puffs are merged in the horiz. or split in the vertical as needed.
- To prevent calculation of an infinite number of puffs, if Npuff > maxPar, then lower-numbered (older) puffs are deleted.
- To prevent calculation of ancient puffs, those puffs older than KHmax are deleted.

5. BlueSky Pipeline



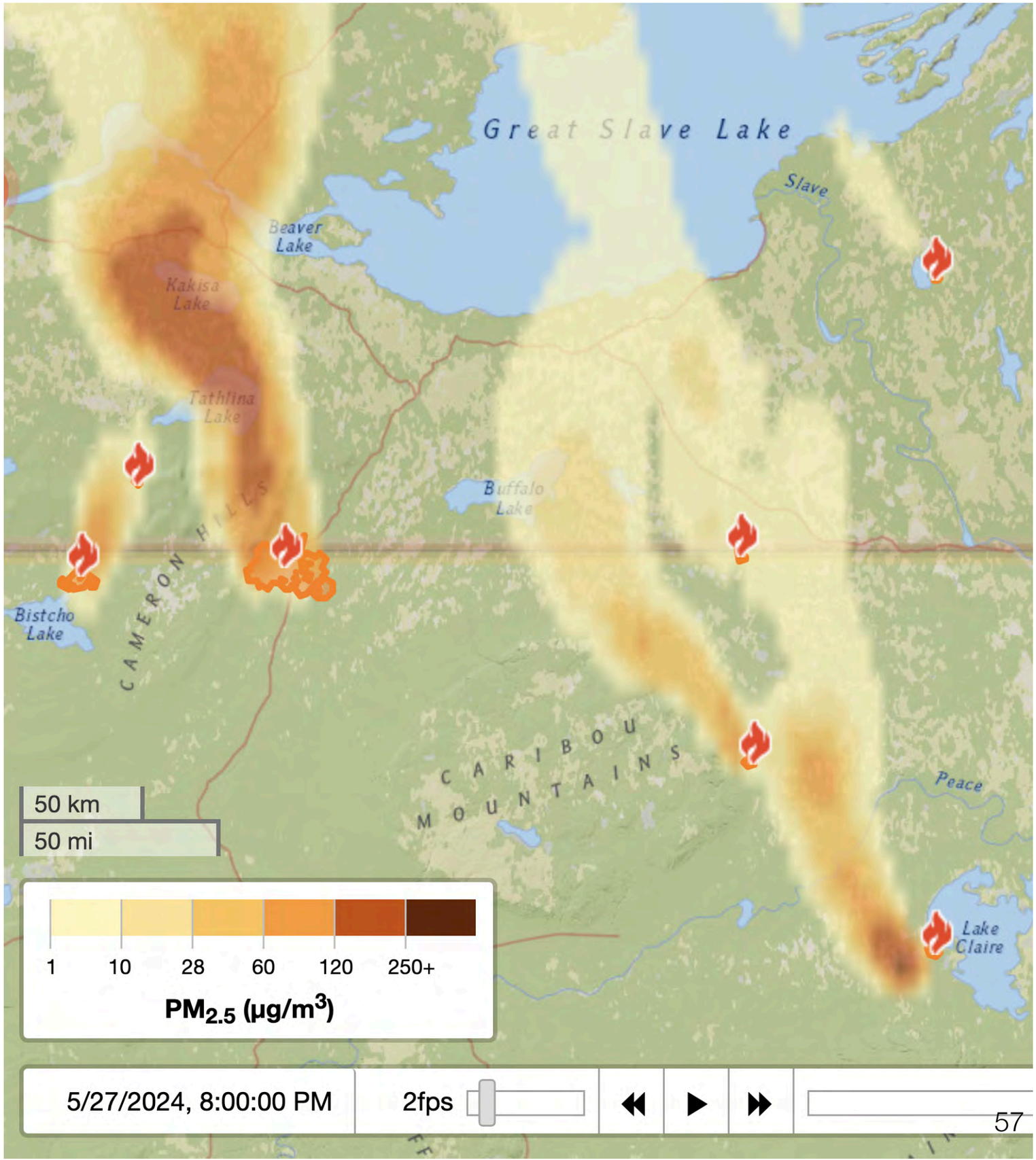
An illustration of Lagrangian particle movement within evolving weather patterns, from a planned burn in Banff National Park

5. BlueSky Pipeline



5. BlueSky Pipeline

Hysplit calculates smoke concentrations at all altitudes in the troposphere. But only PM2.5 concentrations at the surface are displayed on firesmoke.ca .



6. Tutorials, Development, Summary

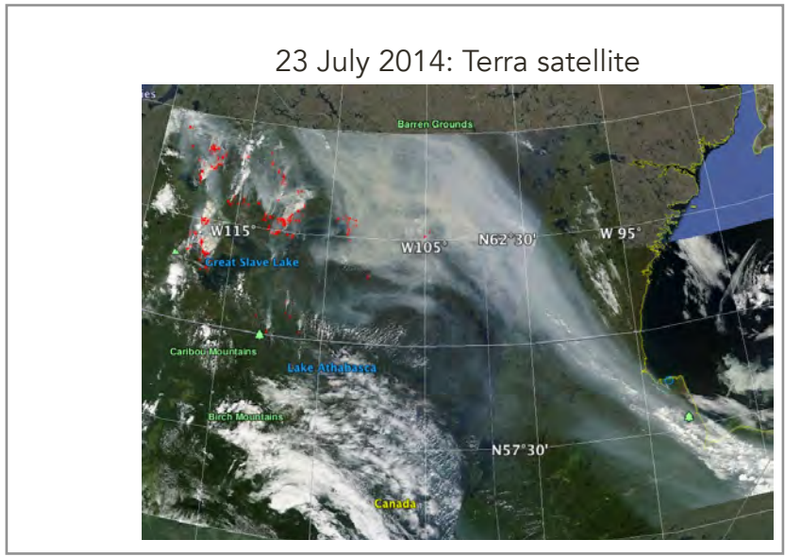
Current Projects to improve BlueSky:

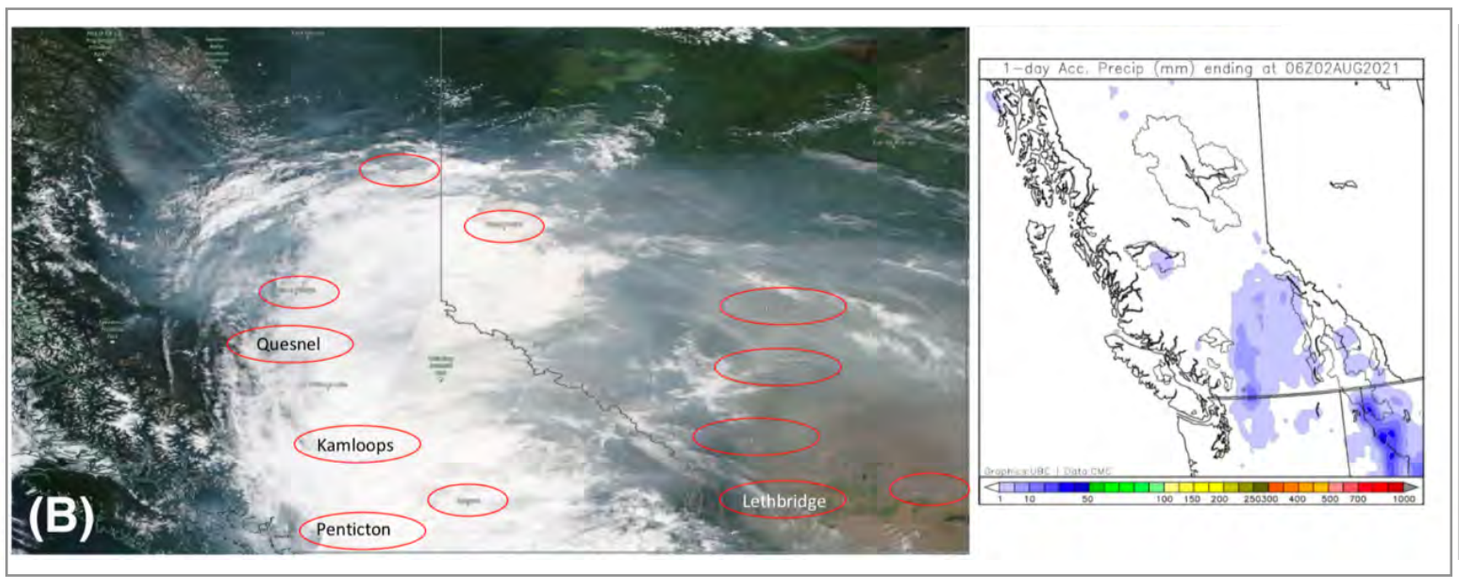
(A) column-integrated PM2.5, to more easily compare with satellite images.

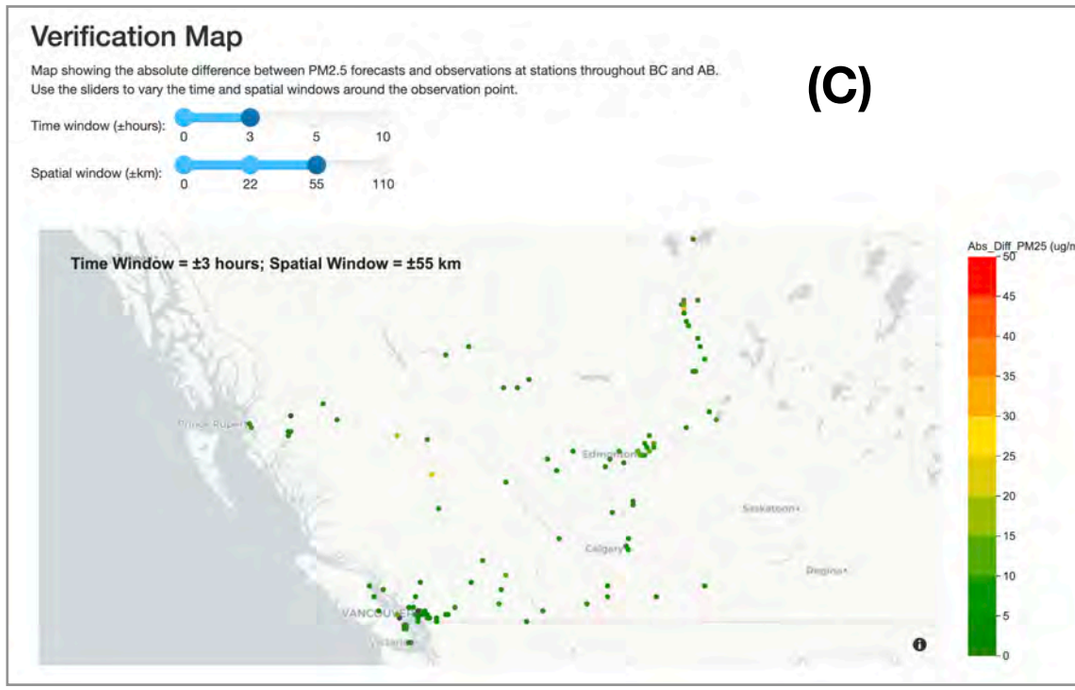
(B) rain-out & wash-out reduction of PM2.5.

(C) interactive real-time verification system of surface PM2.5.

(A) Column-integrated smoke forecasts







Contributors: Rosie Howard, Jiaxin (Elena) Wang, Reagan McKinney, Clinton Macadam

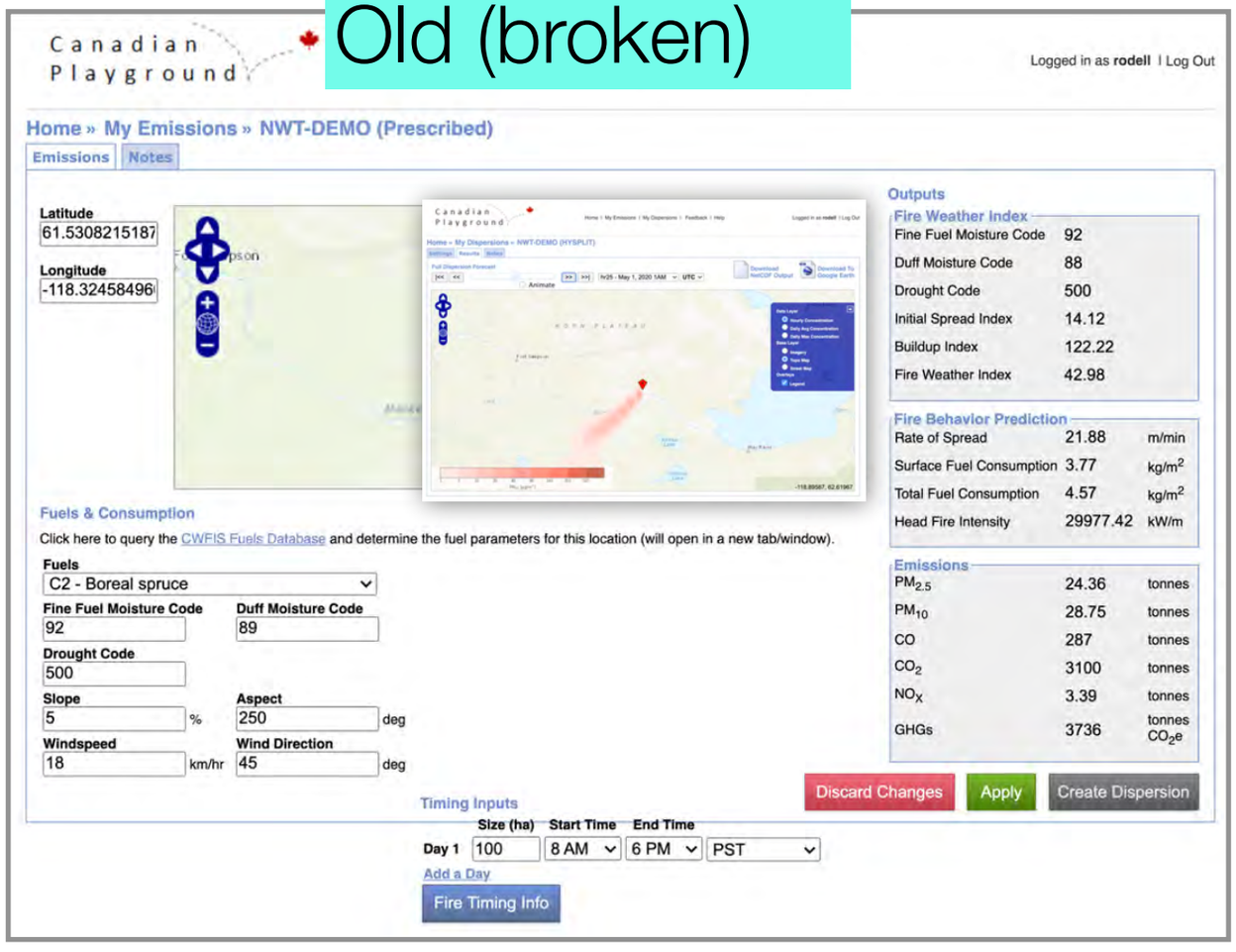
6. Tutorials, Development, Summary

D) BlueSky - PlayGround

To test different emission scenarios.

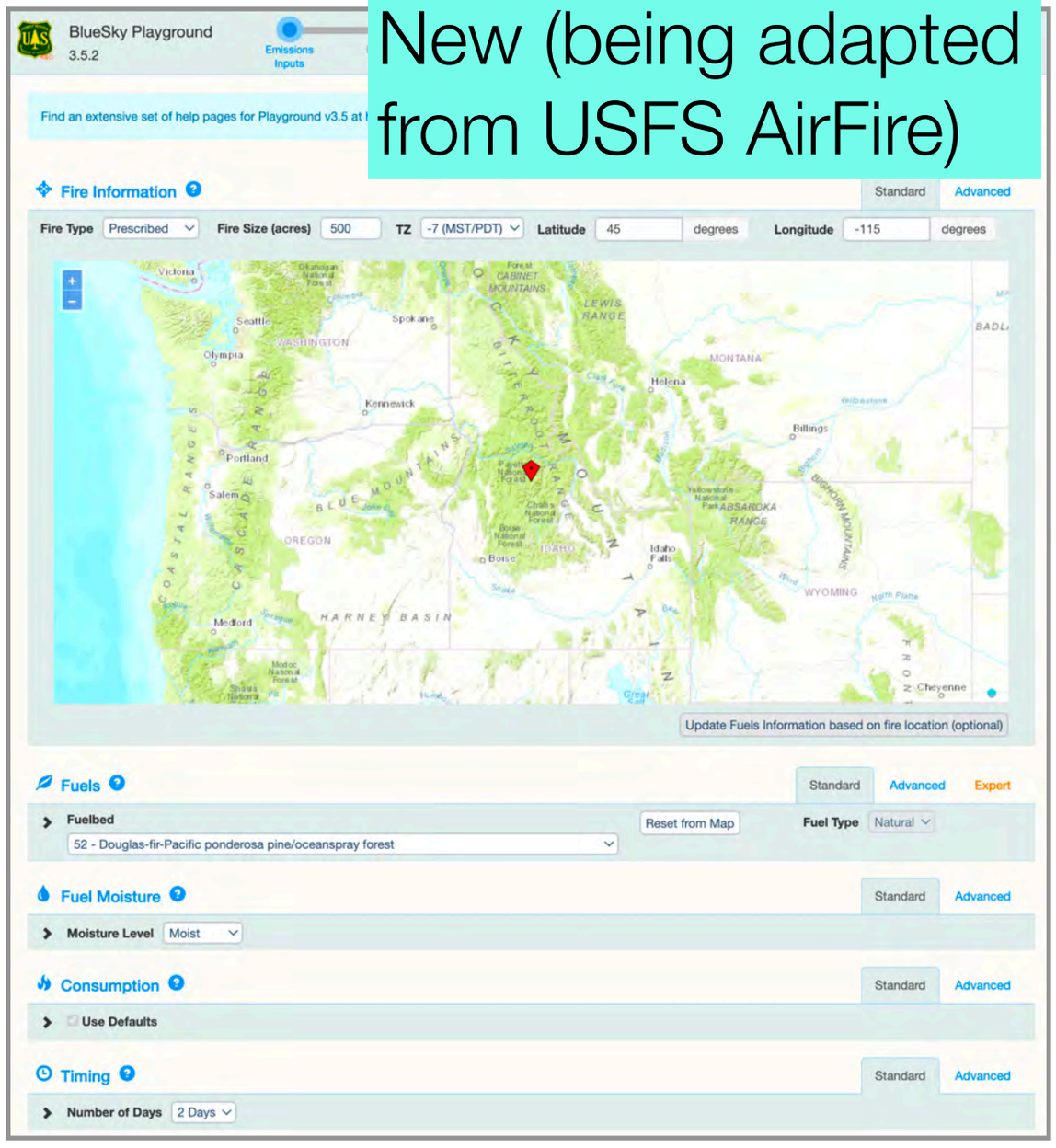
https://firesmoke.ca/playground/login.php?next=/playground/index.php

Old (broken)



https://tools.airfire.org/playground/v3.5/emissionsinputs.php

New (being adapted from USFS AirFire)



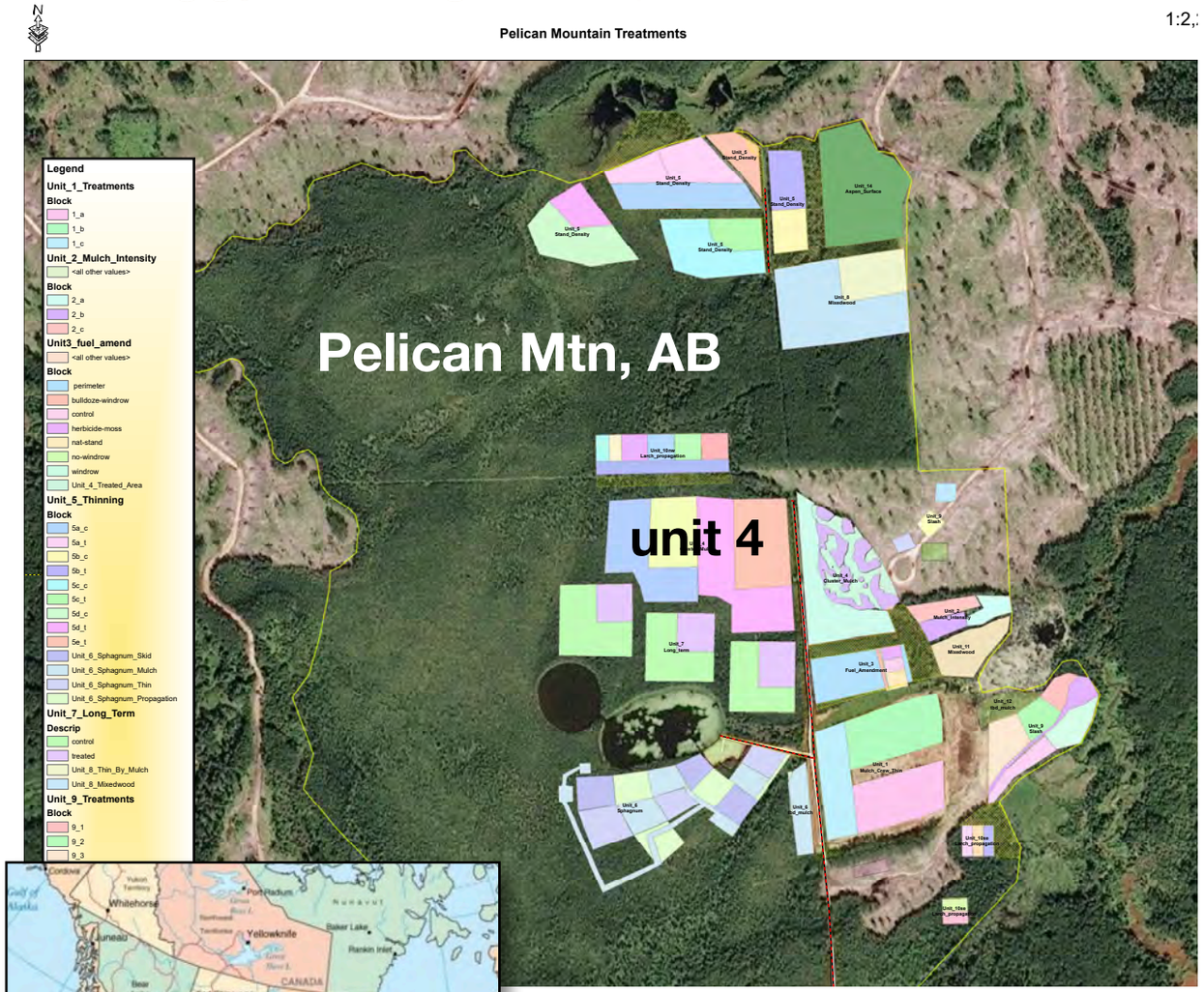
Could be a useful alternative to the Ventilation Index.

Contributors: Nat Scott, Miles Epstein, Roland Schigas

Tutorials, Development, Summary

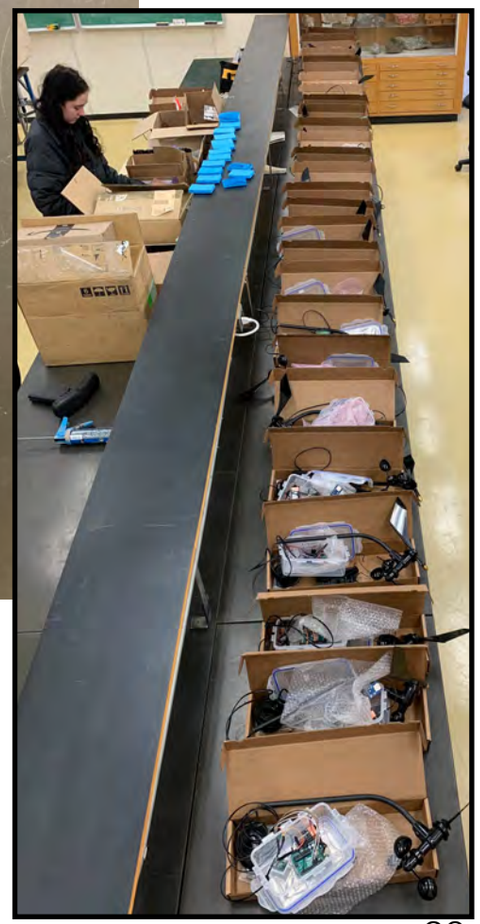
E) Field Experiments

Piggybacking on experimental burns.



F) Instrument development

Design, construction, deployment.

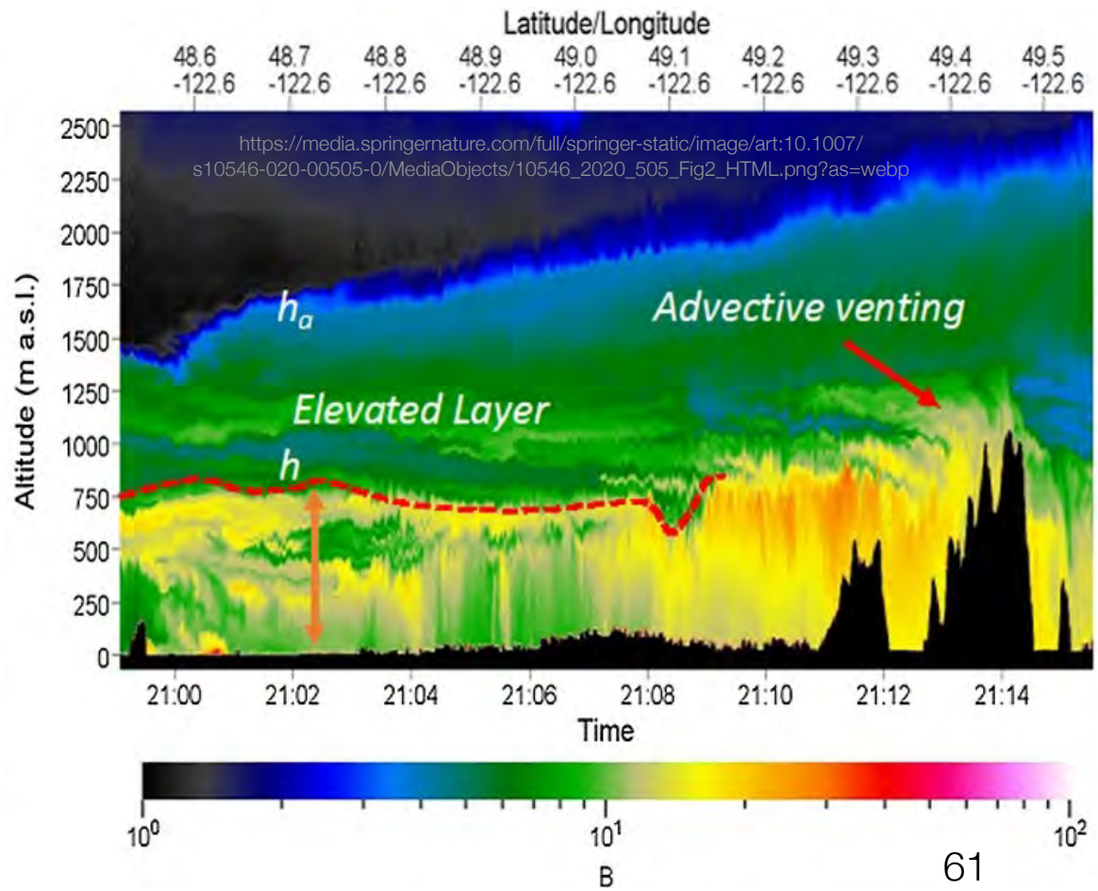


Tutorials, Development, Summary

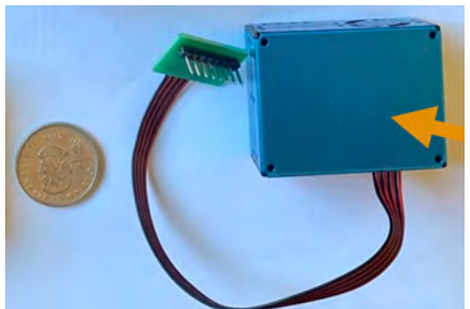
F) More Instrumentation

- In situ AQ sensors, deployed on UBC rooftop for routine obs:
  - 1 SENSIT RAMP sensor: (CO, NO, NO2, O3, SO2, CO2, PM1, PM2.5, PM10)
  - 1 PurpleAir

- PBL lidar / ceilometer, available for routine or field obs.
  - inherited from Ian McKendry / GEOG



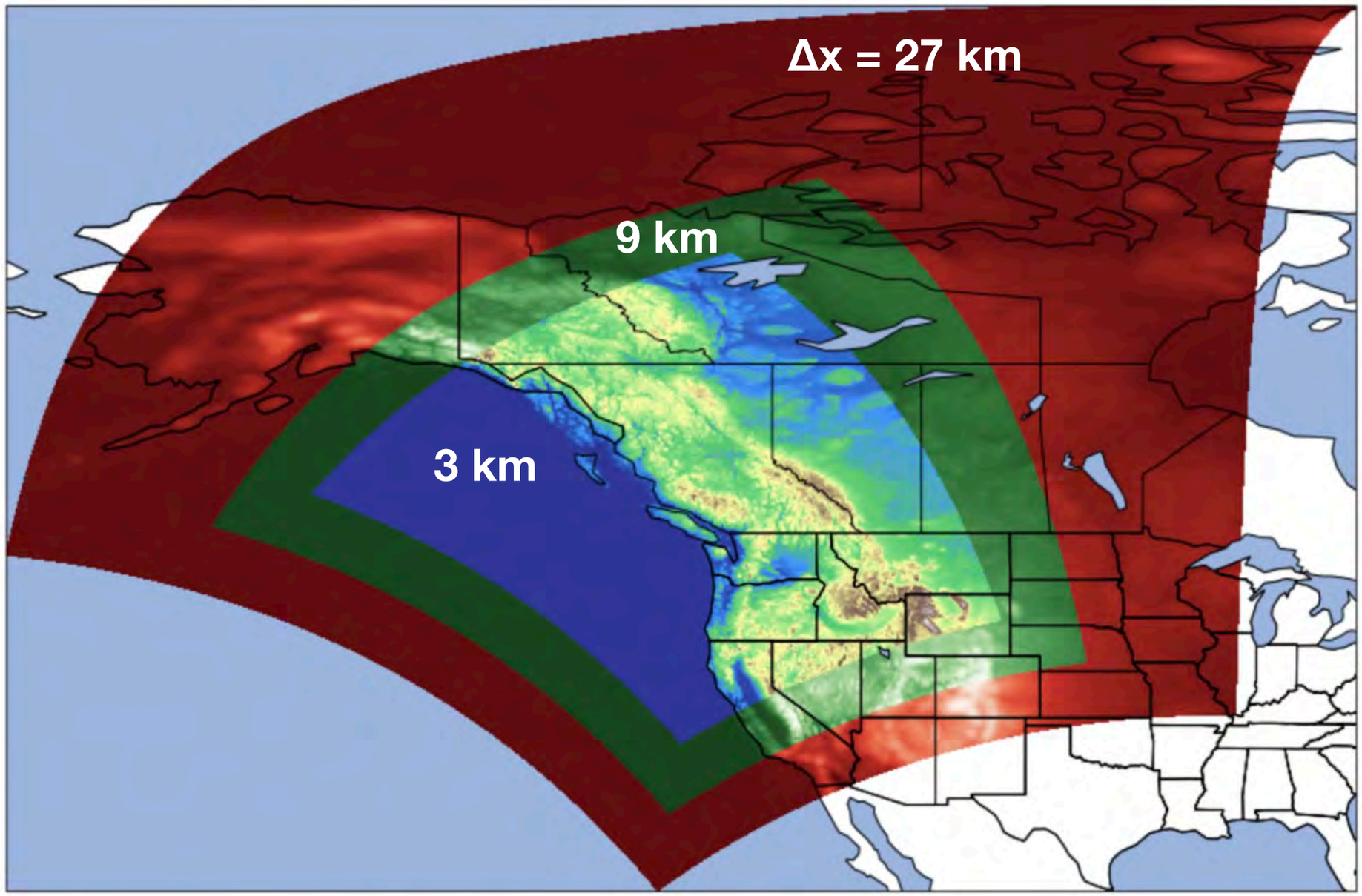
- Homemade expendible AQ sondes: Arduinos with Plantower
  - designed and built by Chris Rodell and Reagan McKinney



Tutorials, Development, Summary

G) ClimatEx: 3 Years of archived WRF weather forecasts

at Δx = 3 km, will soon be publicly available. Sponsored by BC Min. of Forests.



Can be used as meteorology input to dispersion models for Environmental Assessments, screening, permitting, forensics, etc.

ClimatEx details

- Present climate

  Downscaled from ERA5 using WRF.
  One long run for each water year, saving hourly outputs.
  - Year 1: 1 Oct 2020 - 30 Sep 2021. Finished.
  - Year 2: 1 Oct 2021 - 30 Sep 2022. Finished.
  - Year 3: 1 Oct 2022 - 30 Sep 2023. Doing now.

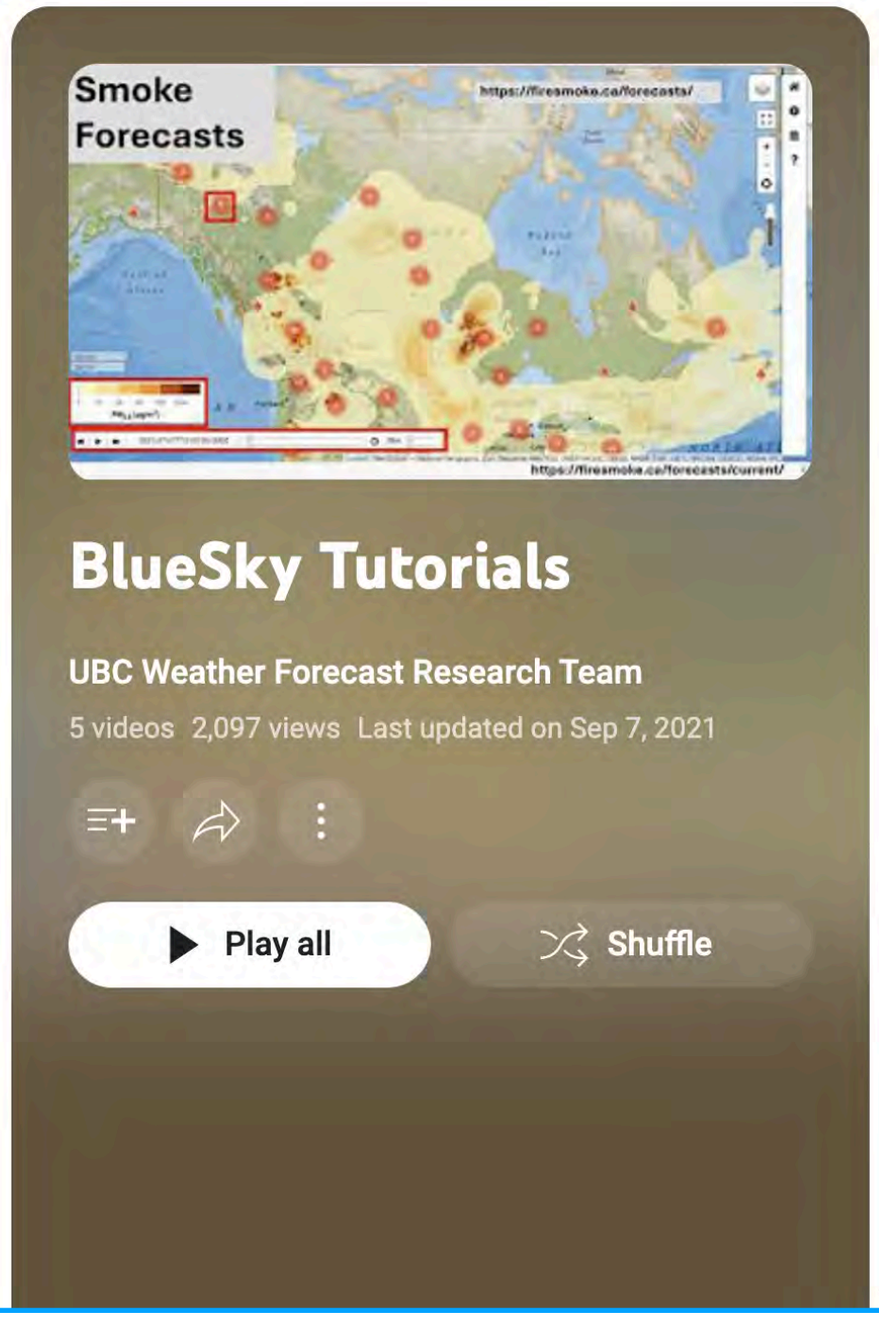
- Future climate scenarios
  - Pseudo-global warming (PGW) datasets at +2 and +3°C (global averaged) warming level, assuming the CMIP6 SSP585 pathway.
  - Method: uses an ensemble of CMIP6 GCMs to compute their individual “deltas” between future and historical climate. The delta amount varies from place to place. At each location, we average the ensemble of deltas. We use those ensemble-average deltas at each location to perturb the ERA5 reanalysis at those locations, which is then used to drive WRF.

6. Tutorials, Development, Summary

H) Online Tutorials

YouTube CA

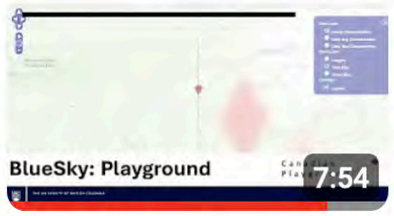
Search



1 

Interpreting BlueSky Smoke Forecasts

UBC Weather Forecast Research Team • 1.6K views • 2 years ago

2 

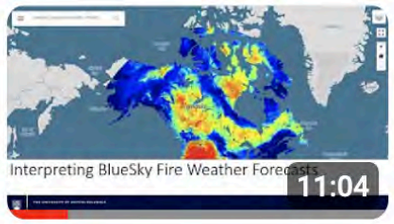
BlueSky Canada Playground - Tutorial

UBC Weather Forecast Research Team • 768 views • 2 years ago

3 

BlueSky: Rapid Response Smoke Forecasting with Playground

UBC Weather Forecast Research Team • 1.8K views • 2 years ago

4 

Interpreting BlueSky Fire Weather Forecasts

UBC Weather Forecast Research Team • 417 views • 2 years ago

5 

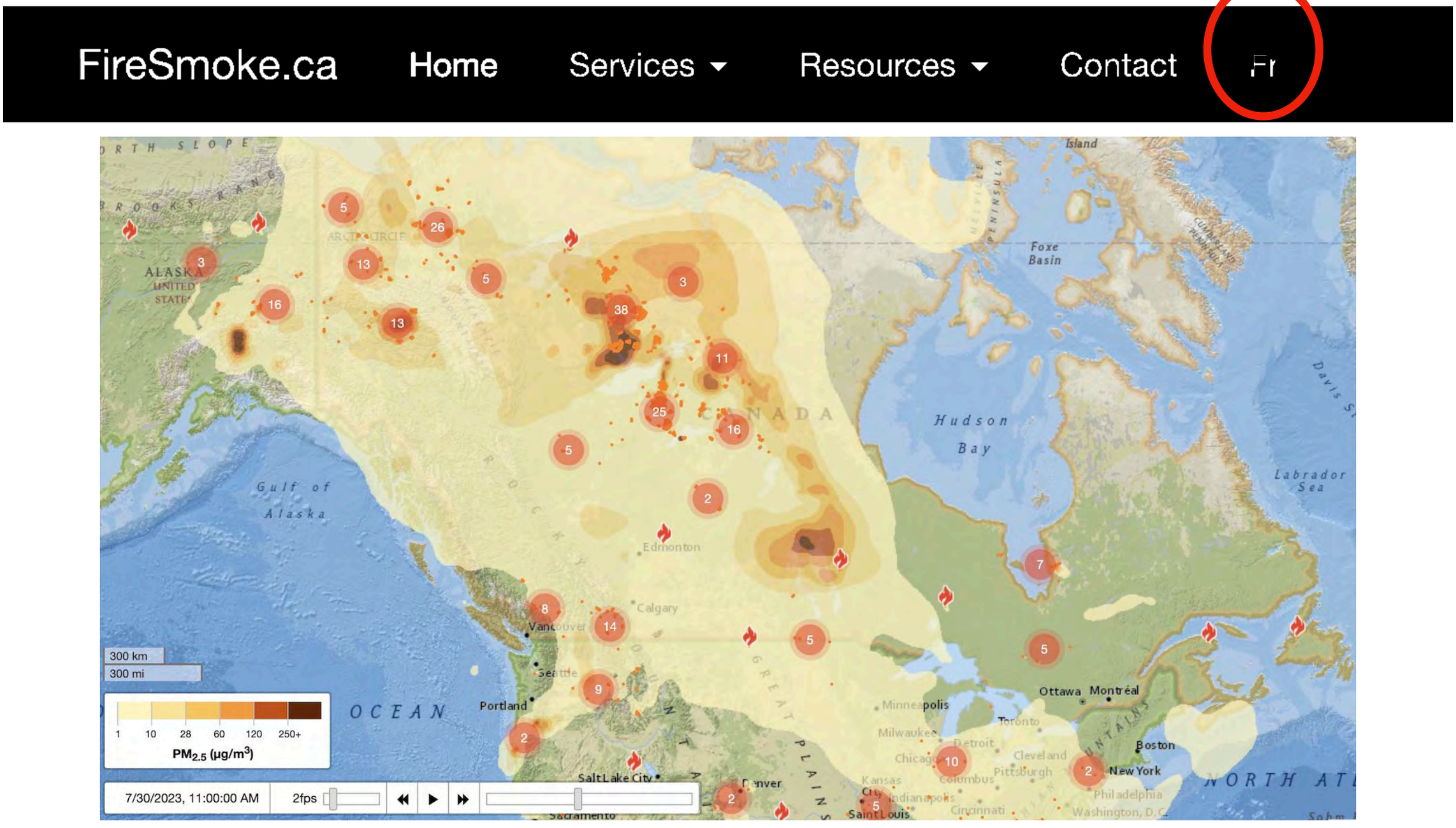
Understanding BlueSky Smoke Forecasts

UBC Weather Forecast Research Team • 196 views • 2 years ago

6. Tutorials, Development, Summary

I) French-language option

https://firesmoke.ca/



6. Thanks to our Sponsors

WIRED GLOBAL CENTER
U.S.-Canada Center on Climate-Resilient Western Interconnected Grid

Current operations supported by:

British Columbia · Alberta · NWT · NSERC CRSNG · Canada (Natural Resources Canada, Canadian Forest Service) · UBC

Development & past operations supported by:

British Columbia · Alberta · NWT

UBC · Canada (Natural Resources Canada / Ressources naturelles Canada; Environment Canada / Environnement Canada; Parks Canada / Parcs Canada) · US Forest Service, Department of Agriculture

Manitoba · Government of Saskatchewan · Ontario

Canada · Canadian Safety and Security Program

Research supported by

NSERC CRSNG · Fraser Basin Council · TU Delft

BC Clean Air Research Fund

The BlueSky-Canada Wildfire Smoke Forecast System

Roland Stull
Roland Schigas, Rosie Howard, Nadya Moisseeva,
Chris Rodell, Tim Chui, Henryk Modzelewski,
Mina Deshler, Liam Buchart, Reagan McKinney,
David Siuta, Anne Seagram, Tobias Schmidt,
Miles Epstein, Nat Scott, Alison Deere, Justin Haw,
Jalena Bennett, Justin Bourdon, Mekdes Tessema,
Matt Fung, Jiaxin (Elena) Wang, Clinton Macadam

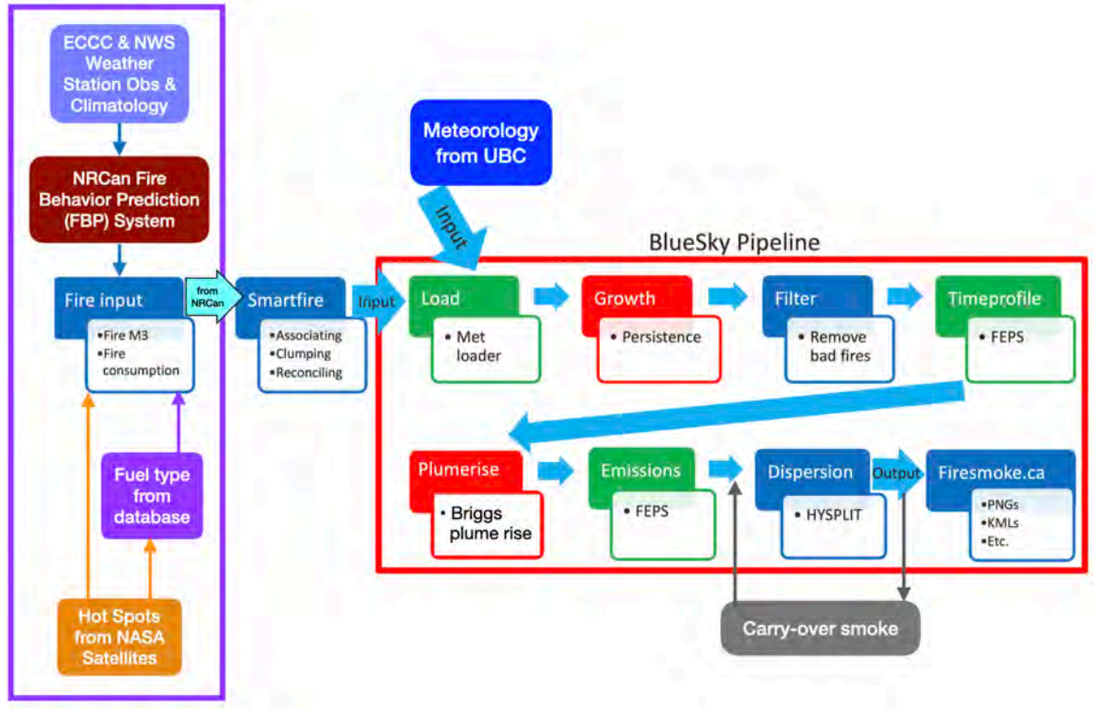
roland.stull@ubc.ca

Questions ?


Donnie Creek wildfire: 2023. BC Wildfire Service.

Topics covered:

1. Origin and Development (in USA & Canada)
2. Weather, Fire, & Fuel Inputs (from NRCan, NASA, NWS, ECCC)
3. Smartfire reconcilation of fire data (run by UBC)
4. Meteorology Forecasts with the WRF model (run by UBC)
5. BlueSky Computational Pipeline (run by UBC)
6. Tutorials, Other products in development, Summary



WFRT WEATHER FORECAST RESEARCH TEAM

WIRED GLOBAL CENTER
U.S.-Canada Center on Climate-Resilient Western Interconnected Grid

UBC

BlueSky Canada - Appendices

More info on the following topics:

A. Weather satellites

B. Recent wildfire threats to BC Hydro infrastructure

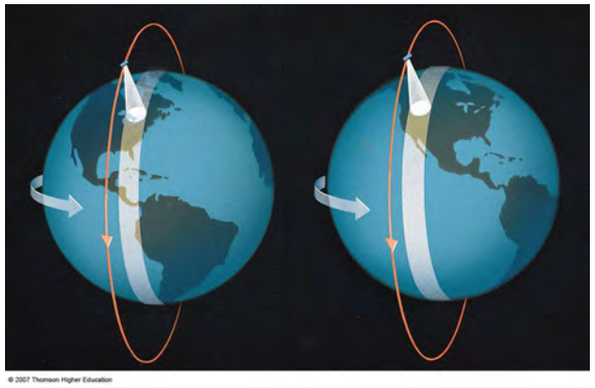
C. Smartfire

D. Another copy of the BlueSky system

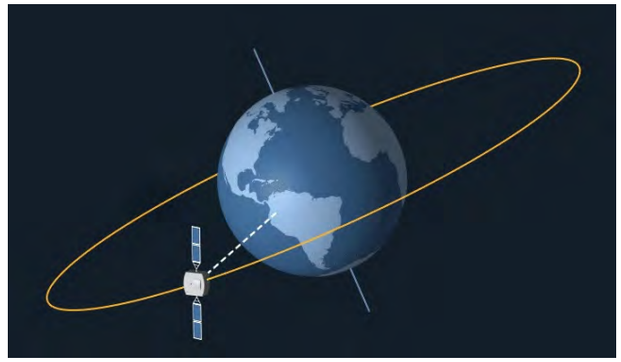
Okanagan Mountain Park
wildfire. 2003
Photo by Steve Devries.

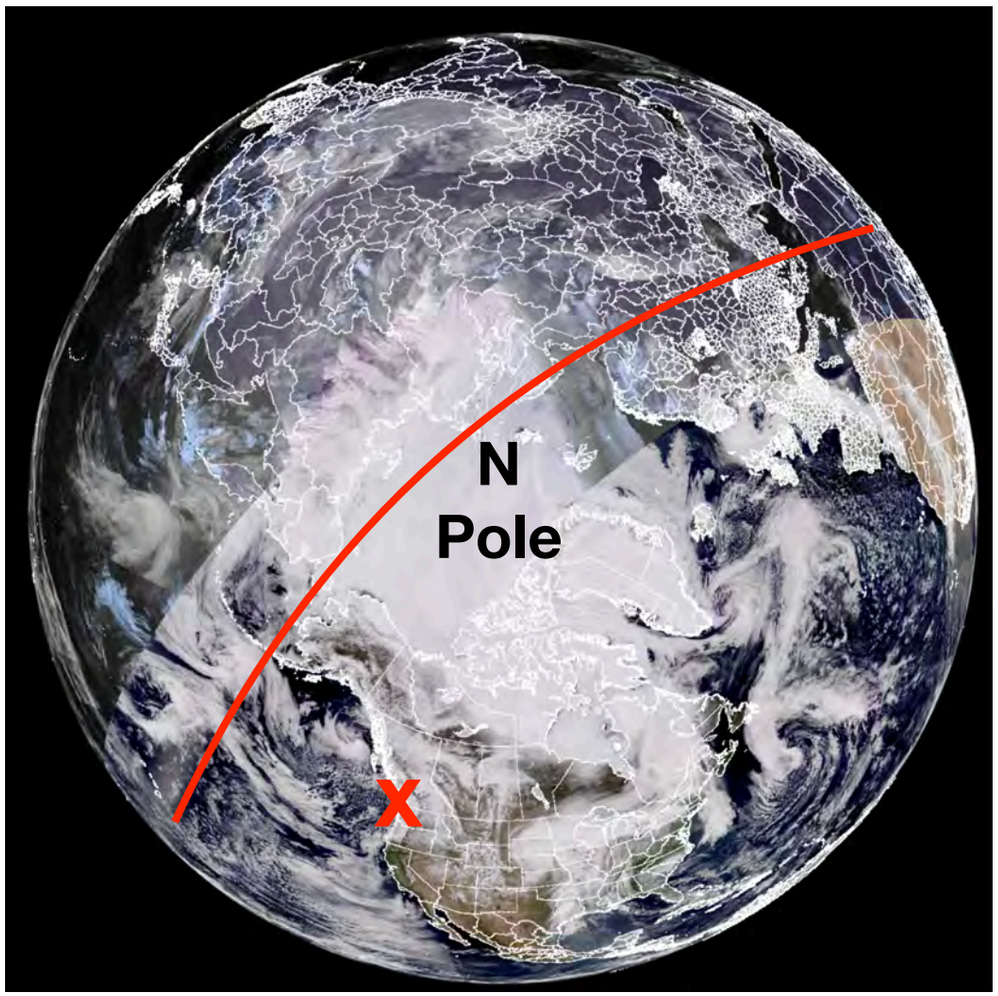
A. Satellite Observations

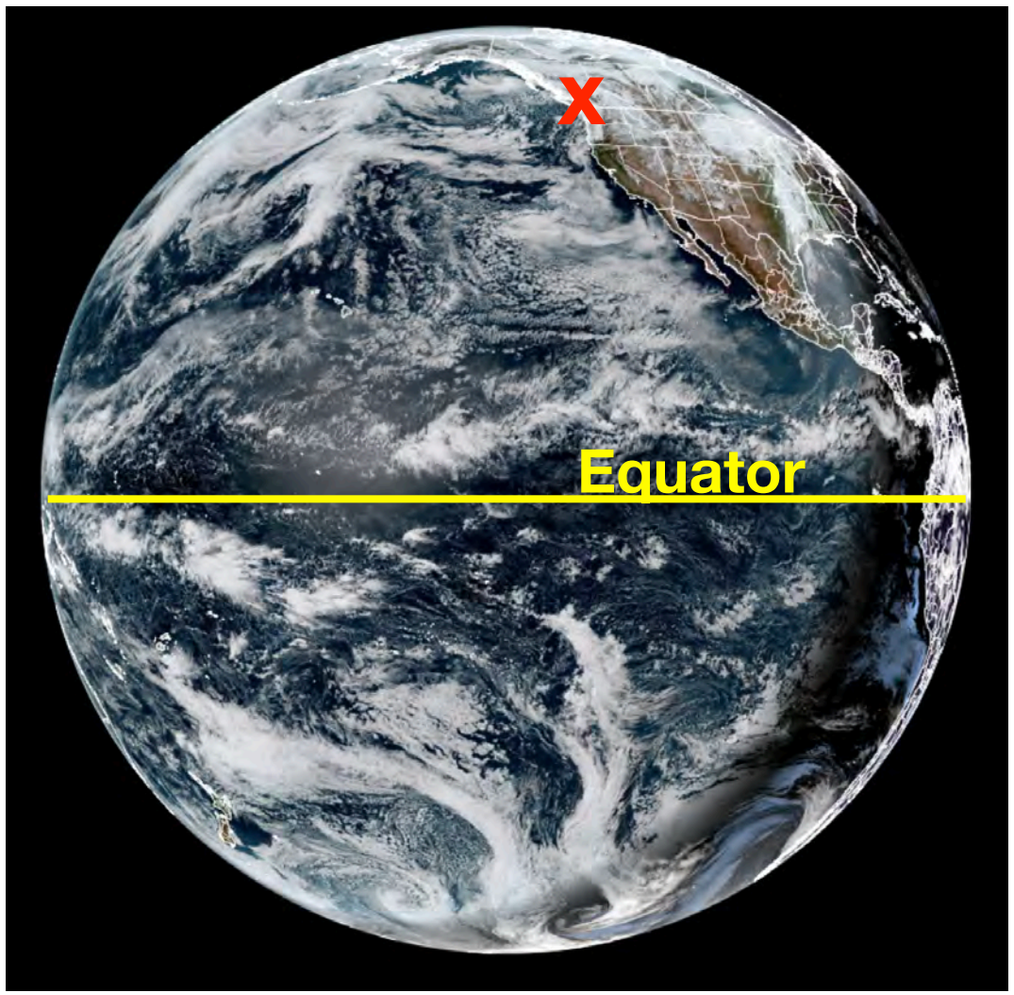
Polar orbiting satellites (POES)



Geostationary satellites (GOES)







X = Vancouver, BC

A. Satellite Observations

Polar orbiting satellites (POES):
Pros: closer to the earth, better resolution, covers high latitudes well.
Cons: Pass over most points on earth only twice per day / satellite.

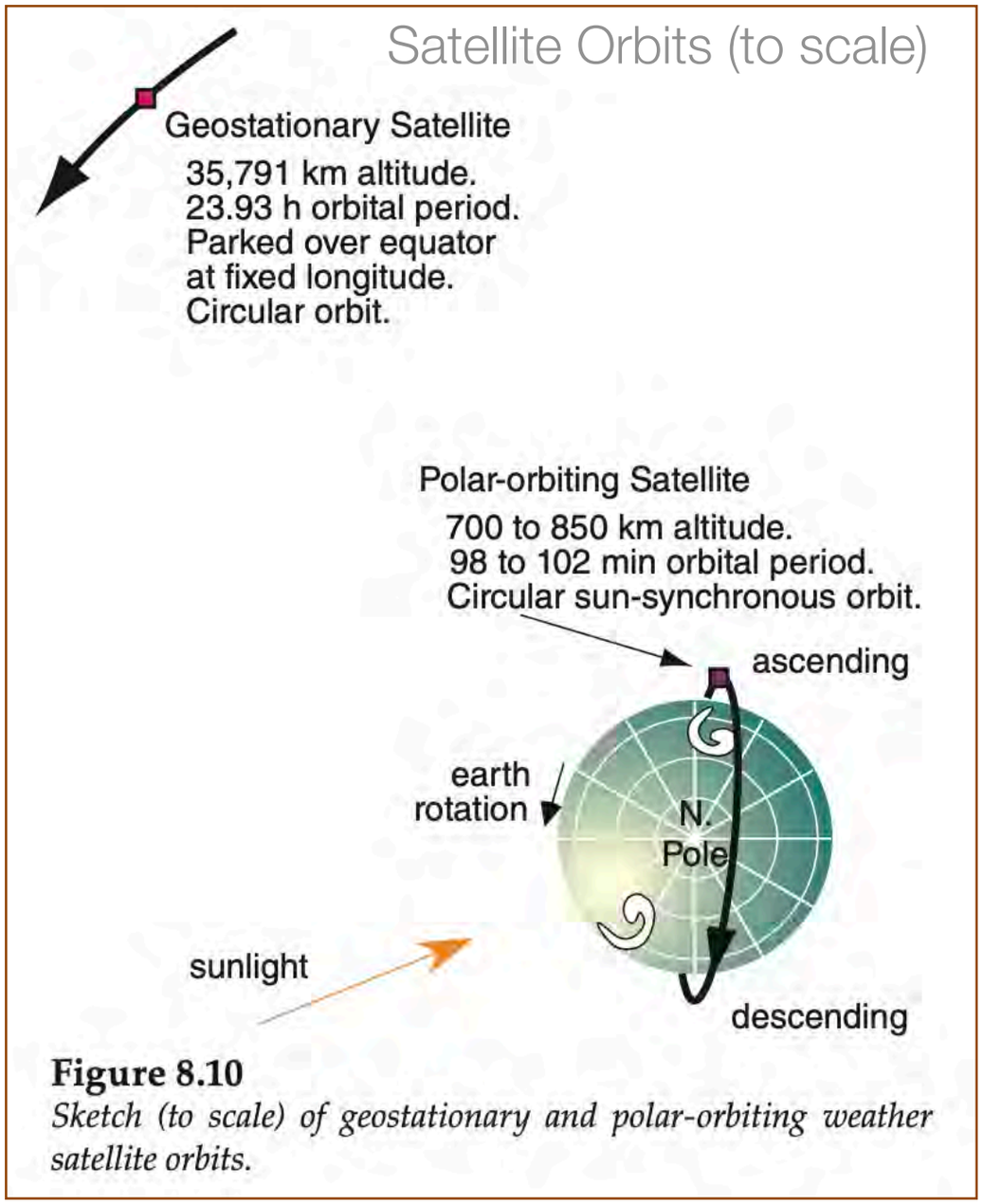
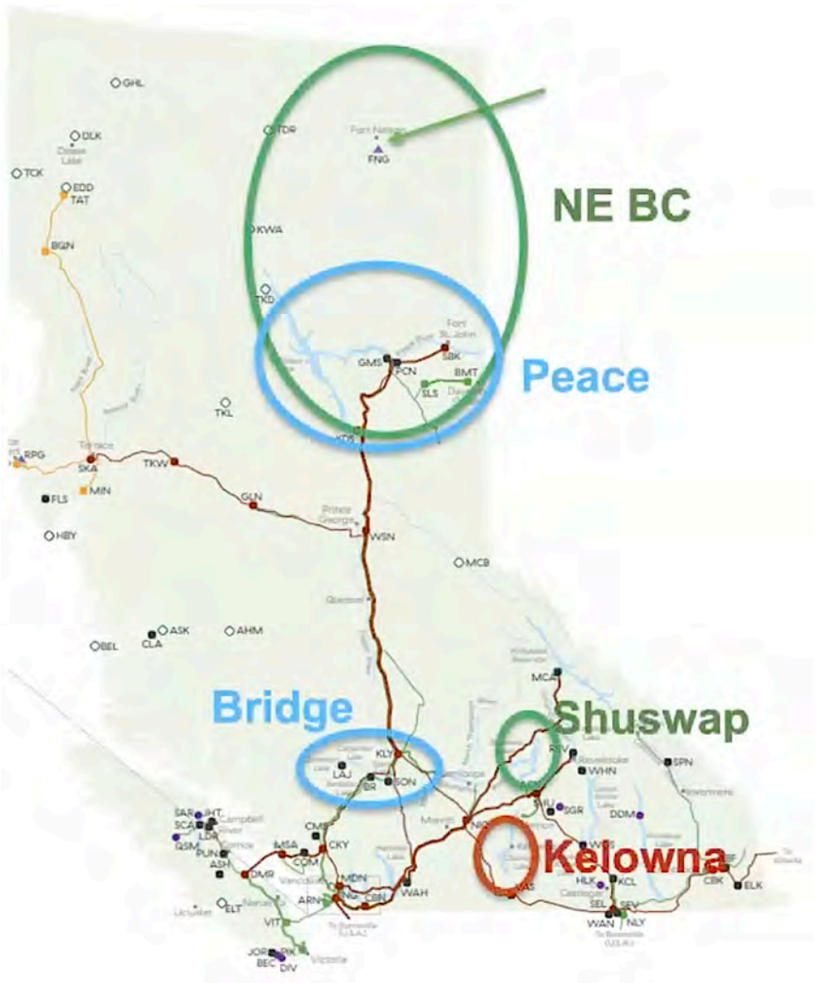


Figure 8.10
Sketch (to scale) of geostationary and polar-orbiting weather satellite orbits.

- NASA satellites detect strong mid-IR thermal emissions from fires. These "**hot spot**" anomalies are used to locate remote wildfires.
- The satellite-derived fire data are from the **MODIS** instrument aboard the polar orbiting Terra and Aqua satellites and the **VIIRS** instrument aboard the joint NASA/NOAA Suomi NPP and NOAA-20 satellites.
- Terra passes over the equator at approximately 10:30am (Day) and 10:30pm (Night) local time, NOAA-20 passes over the equator at approximately 12:40pm (Day) and 12:40am (Night) local time, and Aqua and Suomi NPP passes over the equator at approximately 1:30pm (Day) and 1:30am (Night) local time.
- Provisional hot spots from geostationary satellites GOES & Himawari (Japanese) satellites.
- Glossary:
  -MODIS: Moderate Resolution Imaging Spectroradiometer
  -VIIRS: Visible Infrared Imaging Radiometer Suite
  -Suomi NPP: Suomi National Polar orbiting Partnership
  -NOAA-20: National Oceanic and Atmospheric Admin.

B: Some Examples of Wildfire Threats to Electric Grid Resilience



As reported by BC Hydro meteorologist Dr. Greg West in his 7 Dec 2023 seminar, recent fires caused ...

- Sep 2022 - evacuation of most Bennett dam personnel, in Peace Region
- May 2023 - 73 poles burned, and transmission line severed (until Oct) between AB and Ft. Nelson, in NE BC.
- Jun - threated a wind farm in Tumbler Ridge, in Peace
- Jul - 100 power poles burned in south centeral BC. Evacuation of La Joie & Bridge Riv. dams., causing shut down of Bridge River generation thru Sep.
- Aug - McDougall Cr. fire near Kelowna burned 346 poles, severing 27 km of power lines, & damaged 66 pieces of equip.
- Aug - Bush Cr fire in Shuswap region burned 430 poles, severing 22 km of power lines, & damaged 53 pieces of equip.
- Sep - coastal fires caused evacuation of Clowhom dam facility

Smoke also affects power generation, such as when wildfire smoke shades solar power facilities.

C. Smartfire2

Satellite Mapping Automated Reanalysis Tool for Fire Incident Reconciliation

Created by Sonoma Technology Inc (STI) in collaboration with US NFS AirFire

We run SmartFire2 at UBC 4 times/day, just prior to each BlueSky run.

A fire data acquisition, reconciliation and GIS database

smartfire 2.0

Logged in as **blueop** (log out) admin data events streams

Download data

Operational status

Documentation

Credits and Acknowledgements

What is SMARTFIRE?

The Satellite Mapping Automated Reanalysis Tool for Fire Incident Reconciliation (SMARTFIRE) is an algorithm and database system that operate within a geographic information system (GIS) framework. SMARTFIRE combines multiple sources of fire information and reconciles them into a unified GIS database. It reconciles fire data from space-borne sensors and ground-based reports, thus drawing on the strengths of both data types while avoiding double-counting.

SMARTFIRE and its outputs were designed with the BlueSky Framework in mind, though the Framework can be (and often is) run without SMARTFIRE data. In addition, SMARTFIRE can be useful for purposes beyond its original role of providing fire inputs to the Framework.

Available Data Sources

Name	Available Dates
A+M+I-band-all	2018-08-17 to 2018-08-24
CWFIS-Hotspots	2018-03-01 to 2024-04-29
CWFIS-GroundReports	2018-01-01 to 2024-04-29
2018-hotspots	2018-08-01 to 2018-08-31
A+M+I-band-select	2018-08-17 to

Current Events

These are the top fire events currently being tracked by SMARTFIRE:

Name and Location	Area	Dates

C. Smartfire2

The resulting fire reconciliation stream is available for viewing in the web interface (as shown at right for an individual fire) and for downloading via 12 formats (various flavours of CSV/JSON/ KML/SHP).

We use the "BlueSky-CWFIS" CSV format to download the fire data for all active fires, as input to the BlueSky Computational Pipeline (as shown on the next page).

smartfire 2.0

Logged in as **blueop** (log out)

admin | data | events | streams

Home » Events » CWFIS-Hotspots+GroundReports » Unknown Fire

Unknown Fire

Location	Unknown
Total Area	3,978 acres
First detected	Monday, Apr 22, 2024
Most recently detected	Monday, Apr 29, 2024
Detection confidence	50%
Containment	Unknown
Fire Type	WF

Attributes

bfc: 0.35
consumption_duff: 1.5613135307506838
consumption_flaming: 1.5613135307506838
consumption_residual: 0.0
consumption_smoldering: 0.0
date_created: 2024-04-22
DateTime_local: 2024-04-22T00:00:00.000-06:00
display_name: Unknown Fire
estarea: 7.96591
fire_type: WF
fuel: O1a
fwi: 25.1
hfi: 1490
lat: 28.7163
lon: -108.316
probability: 0.5
rep_date: 2024-04-22 09:45:00
ros: 14.1929
sensor: VIIRS-I
sf2_end_date_uncertainty_source: CWFIS-Hotspots
sf2_growth_weight_source: CWFIS-Hotspots
sf2_name_weight_source: N/A
sf2_shape_weight_source: CWFIS-Hotspots
sf2_size_weight_source: CWFIS-Hotspots
sf2_start_date_uncertainty_source: CWFIS-Hotspots
sf2_type_weight_source: CWFIS-Hotspots
sfc: 0.35
source: NASA7
tfc: 0.35
Time Zone: -6
unique_id: 0a7d9454-5bd8-4a8c-ac05-4300724e818b

Detected As

Name	Source	Area	Start Date	End Date
Unknown Fire	CWFIS-Hotspots	3,978 acres	Monday, Apr 22, 2024	Monday, Apr 29, 2024

History

Date	Area (acres)
2024-04-21	279 acres

D. Computational Pipeline