Table 1. Operational Daily Smoke Models – Purpose, Products, Websites, and Contacts

Model Component	Blue Sky Daily Operational Runs (v3.5.1)	HRRR Smoke	FireWork	AIRPACT 5	NOAA/NWS National Air Quality Forecast	BlueSky Canada	Comments
Purpose	Simulate the emissions, transport, and concentration of smoke from wildfire and prescribed fire.	Addresses the need for a coupled meteorological-wildfire smoke forecast model.	To provide numerical guidance (PM2.5 concentrations) to forecasters for inclusion of biomass burning.	Provide timely air quality information to people in the Pacific Northwest region.	Provide next day operational predications for ground level ozone, smoke, and dust.	Smoke forecasts from wildland fires for the air quality, health & safety, emergency management, and science & research communities as well as the public	
Products	Surface levels of PM2.5: • hourly • 3-hr • 24-hour: • daily 1-hr max Daily Emissions (tons) Fuel Bed Fire Growth (acres)	• Fire radiative power • Near-surface smoke • Vertically-integrated smoke • 10m wind • 1hr precipitation • 2 m temperature	PM2.5 (from biomass burning emissions) Ground level: • 24 and 48 hour avg. • Hourly max over 24h/48h • Objective Analysis (forecast with assimilated observations) Total column	Emissions or concentrations of: • Surface PM2.5 • Surface Ozone • N and S Deposition Many meteorological fields and other air pollutants are available. Overlays like HMS polygons are available too.	HYSPLIT Smoke and Dust • Surface • Vertical Integration CMAQ : • Surface Ozone (does not include gaseous emissions from wildfires). • 1-hr and 24-hr total PM2.5 (& bias corrected)	- Hourly surface PM2.5 - 24-hour maximum and average surface PM2.5 - Column-integrated PM2.5 - 4-hour emissions - Ad-hoc on-demand smoke modeling (pile burns, prescribed burns, wildfires)	Daily average PM2.5 is helpful for comparison with EPA AQI which is also 24-hr avg.
Domain	Variable from Canada and CONUS, to sub-regions.	Continental US (CONUS)	North America	Washington, Oregon, Idaho, and parts of MT, CA, NV, UT, and WY	HYSPLIT smoke: North America CMAQ PM2.5 with smoke emissions: CONUS,	Canada, with overlap to US	
Frequency of runs	Once a day for WRF. Twice a day for the NAM domains (00z and 12Z) Up to 4x/day for the NAM 1 km domains	Four times a day Every 6 hours (00, 06, 12 and 18 Z)	Twice daily: 00z and 12z April – October only	Once per day.	HYSPLIT: 1/day (06Z) CMAQ: 2/day (06Z, 12Z)	Meteorology: 4/day (4km@00Z, 12km@06Z/12Z/18Z) Emissions: 6/day Dispersion: 4/day	
Forecast period	36 hours (1 km variable) 60 hours (1.33 km PNW) 72 hours (4 km PNW) 84 hours (12 km CONUS) 48 hours (3 km CONUS) 5 days for 0.5 degrees	36 hours	48 hours	48 hours	48 hours	48 hours	
Website	https://www.airfire.org/data/bluesky-daily/	https://rapidrefresh.noaa.gov/hrrr/HRRRsmoke/	http://weather.gc.ca/firework Development site (pw)	http://www.lar.wsu.edu/airpact/gmap/ap5/ap5smoke.html	http://airquality.weather.gov/ CMAQ PM: http://www.emc.ncep.noaa.gov/mmb/aq/	http://firesmoke.ca/	
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Table 2. Operational Daily Smoke Models - Fire Locations, Fuels, and Emissions

Model Component	Blue Sky Daily Operational Runs (v3.5.1)	HRRR Smoke	FireWork	AIRPACT 5	NOAA National Air Quality Forecast	BlueSky Canada	Comments
Fire location	SMARTFIRE 2 (Satellite-derived from NOAA's HMS system (GOES, MODIS, and AVHRR, VIIRS), and ground-based reported locations.	Visible Infrared and Imaging Radiometer Suite (VIIRS) satellite fire detection and MODIS FRP (for better coverage)	Satellite (AVHRR/MODIS/VIIRS)	SMARTFIRE 2	Satellite Detection (HMS detections but eliminate points in CONUS but do not have a smoke plume attached to them)	SmartFire2, reconciled from AVHRR, MODIS and VIIRS satellite data via the Canadian Wildland Fire Information System (CWFIS)	None of these work well during periods of cloud cover
Fuel Characteristics	FCCS v2	Brazilian Biomass Burning Emissions Parameterization (3BEM) /Global Land Cover database 1km	Canadian Wildland Fire Information System (CWFIS)	FCCS v2.	FCCS v2	Canadian Forest Fire Behavior Prediction (FBP) System, via CWFIS	
Fuel Loading	FCCSv2	3BEM/GOES Wildfire Automated Biomass Burning Algorithm (WF_ABBA)	CWFIS	FCCS v2	FCCS v2	FBP (CWFIS)	
Fuel Consumption	Consume 3	3BEM	Canadian Forest Fire Behavioral Prediction System (FBS)	Consume 3	Consume 3	Consume 3	
Fire Emissions	FEPS	3BEM/EFs from Andraea and Merlot 2001	FEPS	FEPS	Consume 3.	FEPS	
Fire Emissions Temporal Profile	FEPS (assumed diurnal profile)	Gaussian.	FEPS	FEPS	Constant	FEPS	Persistence of yesterday's fire emissions are propagated into the future not always a valid assumption.
Emissions from non-fire sources.	None	No	Modeled specifically using Canadian, US, and Mexican emission from point, area, and mobile sources. BEIS3 is used to calculate biogenic emiss.	Point, area, and non-road mobile sources. Also includes Anthropogenic emissions from British Columbia and Alberta Canada.	HYSPLIT – Smoke: Ag and Rx burning.. CMAQ CONUS: NEI for all anthropogenic source; Ag & Rx burning	No	Regulatory applications need to account for all sources whereas non-regulatory applications may be OK with only accounting for fires.
Smoke allowed to enter domain from outside the domain?	No	No.	Only has seasonal chemical climatology that does not vary with time, except O_3.	Yes	HYSPLIT: Smoke portion only includes smoke within domain but domain is North America. CMAQ: climatological PM and real time dust profiles included at boundary.	No	Very important, so not to get "blind-sided" from outside the modeling domain entering the forecast area.
Background AQ	Carry over smoke from previous model run. Note, did not always run reliably.	Yes. Recycle the smoke from previous model runs, but nothing else other than smoke.	Residual smoke kept in from previous runs to initialize each model run.	AQ boundary conditions from monthly average MOZART runs of 2015. Intend to update to use WACCM for real-time BCON.	HYSPLIT: Only includes residual smoke from previous model runs (for smoke <72 hours old). CMAQ includes 6-hour cycling.	Carryover smoke from previous model run	Residual smoke must be accounted for. Very important.

Table 3. Operational Daily Smoke Model – Meteorology, Chemistry, and Dispersion

Model Component	Blue Sky Daily Operational Runs (v3.5.1)	HRRR Smoke	FireWork	AIRPACT 5	NOAA National Air Quality Forecast	BlueSky Canada	Comments
Meteorological Model	Weather Research Forecast (WRF). UW set up for 4 km and 1.33 km domain. NWS 1 km, 3 km, and 12 km, and GFS at .5 deg.	HRRR	Global Environmental Multi-scale model (GEM).	WRF	NAM v4	WRF v3.7.1 (ARW core, NAM initialization)	It would be nice if there was a midnight-midnight run (local time) for direct comparison with AQI.
Horizontal Resolution	PNW 1.33 km and 4.0 km CONUS 12km, 3 km Variable: NWS 1.0 km	3 km	10 km	4 km.	12 km	4 km (00Z) 12 km (06Z, 12Z, 18Z)	
Vertical Resolution	No layer collapsing, or minimal layer collapsing. Uses full 3-D meteorology.	8 meters = first layer. 50 layers. Eulerian Model. No collapsing of vertical layers.	80 levels up from the surface up to 0.1hPa. First terrain following layer = 40 m.	AIRPACT5 uses the same 37 layers as produced by WRF - no layer collapsing.	HYSPLIT: 100 m first layer, top at 5000 m AGL. CMAQ 50 m first layer, 35 layers to 100 mb. (output layer structure determined separately from input meteorological data.)	WRF: 41 levels HYSPLIT: 5 levels	Height of first layer may be important as surface PM2.5 concentration can be affected by this if PM is not evenly distributed vertically near the surface.
Dispersion Model	HYSPLIT v4.9 (Lagrangian Particle Model)	WRF-Chem (Eulerian Grid Model)	GEM-MACH. (Eulerian Grid Model)	CMAQ (Eulerian Grid Mode)	HYSPLIT v4.9 for smoke (Lagrangian Particle Model)	HYSPLIT v4.9	
Chemical Model	None	WRF-Chem	GEM-MACH/ADOM -II gas phase chemistry, and bin-specific PM sizes (currently only 2 bins fine and coarse)	CMAQ	CMAQ v5 (for O3 and PM2.5)	None	
Plume Rise Characterization	FEPS (offline) - USFS Briggs – NOAA. As configured, calculates final plume rise from Briggs equation, particles injected at height of final plume rise.	Heat flux = FRP/Burnt Area. FRP from VIIRS satellite. WRF-Chem may also use.	Briggs. Heat flux parameterization by fire size (from climatology – fuel size and fire location).	Briggs with calculation dependent on PBL from WRF and Heat Flux from Blue Sky. Height of final rise determines layer height injection	Briggs using HMS derived fire heat rate. Height of final rise determines layer height injection,	Briggs	
Nudging of model fields with observations of AQ?	No	No AQ data assimilation, only for meteorology.	No.(Objective analysis is available for forecasters but not used as input to model)	No	No.	No	
AQ feedback to met model?	No	Yes.	No.	No.	No.	No	
Smoke removal?	Dry deposition, but no wet deposition.	Yes, wet and dry removal.	Yes, both dry and wet deposition.	Yes. Aerosols will be scavenged.	Yes, dry and wet removal and particles older than 72 hours get removed.	Dry deposition only	Can make a big difference when rain or snow moves into the forecast area.

Table 4. Operational Daily Smoke Models – Output Features and Strengths

Model Component	Blue Sky Daily Operational Runs (v3.5.1)	HRRR Smoke	FireWork	AIRPACT 5	NOAA National Air Quality Forecast	BlueSky Canada	Comments
Ability to Export output into Google Earth?	Yes	Yes, but need access to the ftp files.	Yes, via public WMS	No (but WSU is willing to respond to requests to provide outputs for GE).	Yes from NOAA/ARL READY site	Yes	
Ability to loop results?	Yes	Yes	Yes	Yes	Yes	Yes	
Ability to access past runs	Yes	Yes	No in public facing site Yes, in PwP site.	Yes.	Yes	Yes	
Strengths	Longest forecast period. 1.33 km resolution is sufficient to detect nighttime drainage flows of smoke down many but not all river valleys and canyons. This is the only system that attempts to distinguish between wildfires and prescribed fires. Detailed characterization of fuels, consumption and emissions calculation.	Seems to do a better job of getting the timing right of when smoke will disperse from a valley than other models, except FireWork.	Large domain allows international sources of smoke to be included when focusing only on a state or sub-region of a state. Don't get blind-sided by Canadian smoke. Relatively high resolution for such a big domain. Reliability of products being on time. Allows for case-by-case for special products.	Accounts for all sources of PM2.5 including precursors. SOAs. Captures Canadian sources of smoke. Cool Analytics: ability to evaluate forecasts with monitoring data.	HYSPLIT: Full North American coverage and Hawaii. CMAQ: full gas and aerosol chemistry over CONUS/AK/HI through 48 hours 2x/day. All driven by native grid meteorology model outputs.	Sharing of emissions between Canada and US Ad-hoc on-demand emissions modeling and smoke dispersion scenarios (pile burns, prescribed burns, wildfires) Wide spectrum of API's and formats available to view smoke forecasts and share data – web viewer, KMZ, NetCDF, WMS	
Planned Updates	Total column smoke tested in 2017 for production in 2018.	Update to expand the domain for all of North America.	Plume rise Algorithm Improved fire products for emission estimates from Canadian forest service. Higher resolution products.	Updating to use WACCM for Boundary Conditions. Using IDEQ plume rise algorithm.	Temporal smoke emissions; Use of Env. Can. Smoke emissions over CA. extension to 72 hour forecasts.	Improved plume rise models (CFFEPS, VIPER) Improved interoperability with better, full time-series forecasts via GeoServer	