August 11, 2020

Mr. Sean Carney
Finite Carbon
435 Devon Park Drive, 700 Building
Wayne, Pennsylvania 19087

Dear Mr. Carney:

The California Air Resources Board (CARB) has reviewed the application for determination of Direct Environmental Benefits in the State of California (DEBS) submitted by Finite Carbon on behalf of the Spokane Tribe of Indians pursuant to the California Cap-and-Trade Regulation (Cal. Code Reg., tit. 13, § 95989, subd. (b)).

The application, dated January 14, 2020, provided a detailed report presenting evidence that large wildfires in Washington can affect air quality in California. In addition, the offset project has demonstrated through its fire management plan that the offset project operator, the Spokane Tribe of Indians, has committed to certain forest management activities to reduce major wildfire events. Therefore, the offset project provides for the reduction or avoidance of emissions of air pollutants associated with wildfire smoke that are not credited pursuant to the 2015 Compliance Offset Protocol U.S. Forest Projects in the State of California. It is the determination of CARB staff that the Finite Carbon-Spokane Tribe of Indians Improved Forest Management Project provides DEBS.

CARB Project ID	*Project Name*	*Provides DEBS*
CAFR6314	Finite Carbon-Spokane Tribe of Indians Improved Forest Management Project	Yes

If you have any questions regarding this response, please contact Jason Gray, Chief, Climate Change Program Evaluation Branch, at (916) 324-3507 or via email at Jason.Gray@arb.ca.gov.

Sincerely,

Richard W. Corey
Executive Officer

cc: Billy Joe Kieffer, Director
Department of Natural Resources
Spokane Tribe of Indians

Jody Hill
Chief Financial Officer
Spokane Tribe of Indians

Edie Chang
Deputy Executive Officer

Rajinder Sahota, Chief
Industrial Strategies Division

Jason A. Gray, Esq., Chief
Climate Change Program Evaluation Branch
Industrial Strategies Division

Wesley Dyer
Attorney

CAR1314/CAFR6314
Finite Carbon – Spokane Tribe of Indians IFM
Reporting Period 1
Start Date: 9/18/2018
End Date: 4/15/2019
RFI Submittal Date: 1/14/2020

Re: RFI Submittal Supplement: Application for Determination of Direct Environmental Benefits (DEBs) to California

Dear Mr. Shelby,

Finite Carbon, on behalf of the OPO, Spokane Tribe of Indians, submits the following application for the determination of Direct Environmental Benefits (DEBs) to California for the compliance forest offset project "Finite Carbon – Spokane Tribe of Indians IFM" (ARB ID#: CAFR6314; OPR ID#: CAR1314).

The California Cap and Trade Regulation defines a Direct Environmental Benefit as follows: "Direct environmental benefits in the State refers to the reduction or avoidance of emissions of any air pollutant in the state or the reduction or avoidance of any pollutant that could have an adverse impact on waters of the state." (§ 95802)

A subsequent section of the Cap and Trade Regulation provides the following on how DEBs will be evaluated (§ 95989):
"Any project located outside the State of California may submit the following information to ARB to enable a determination of whether the project provides direct environmental benefits in the State. Such determination must be based on a showing that the offset project or offset project type provides for the reduction or avoidance of emissions of any air pollutant that is not credited pursuant to the applicable Compliance Offset Protocol in the State or a reduction or avoidance of any pollutant that is not credited pursuant to the applicable Compliance Offset Protocol that could have an adverse impact on waters of the State.

1) Scientific, peer-reviewed information or reports supporting a claim that the offset project or offset project type results in this type of reduction or avoidance of any pollutant in the State;
2) Governmental reports from local, state, or national environmental, health, or energy agencies, or multinational bodies (such as the Intergovernmental Panel on Climate Change) supporting a claim that the offset project or offset project type results in this type of reduction or avoidance of any pollutant in the State; or
3) Monitoring or other analytical data supporting a claim that the offset project or offset project type results in this type of reduction or avoidance of any pollutant in the State."

The Finite Carbon – Spokane Tribe of Indians IFM compliance forest offset project provides DEBs to California through the reduction or avoidance of air pollutant emissions related to wildfires that can severely impact air quality in the State of California. As an improved forest management project under the Compliance Offset Protocol for U.S. Forest Projects (June 25, 2015) ("Offset Protocol"), the Spokane Tribe of Indians ("Spokane Tribe") have committed to certain forest management activities that will contribute to lowering the fire risk for the entire Project Area, thus reducing or avoiding the potential for a large wildfire event that would release large quantities of air pollutants, including those not credited pursuant to the Offset Protocol.

This reduction of fire risk on the Project Area is reflected in the project's reversal risk rating; 8.71% with a fire risk score of 2% which is the lowest score for this category. The Spokane Tribe follow a detailed Fire Management Plan that strategically defines programs and activities to manage wildfires, prescribed fires, and fuel levels across the Project Area. In addition to current activities, the Spokane Tribe will be able to use proceeds from offset credit sales to invest in additional forest management activities to further the objective of creating and maintaining a healthy forest resilient to wildfire in the long-term.

As part of this application, please see the attached technical report detailing the "Evaluation of Eastern Washington Wildfire on California Air Quality" completed by Cramer Fish Sciences at the request of the OPO and Finite Carbon. The report presents evidence to support the claim that the Spokane project provides DEBs to California by satisfying the evaluation criteria set forth in Section 95989 of the Regulation.

Sincerely,
Sean Carney

President, Finite Carbon

CRAMER FISH SCIENCES®
An Employee Owned Consulting Company

Watershed Sciences Lab
1125 12th Avenue NW, Suite B-1
Issaquah, WA 98027
206-612-6560
www.fishsciences.net

Date: January 8, 2020

To: Finite Carbon

From: Kai Ross, Biometrician, and Phil Roni, Principal Scientist, Cramer Fish Sciences

Subject: Evaluation of Eastern Washington Wildfires on California Air Quality

EXECUTIVE SUMMARY

Smoke from wildfires can impact air quality not only locally but long-distances from the fire source. To analyze the potential of eastern Washington wildfires to impact air quality in California, we examined five data sources including: 1) historical wildfire data, 2) satellite imagery, 3) NOAA Office of Satellite Product Operations (OSPO) weather reports documenting smoke plumes, 4) a smoke dispersion model, and 5) a smoke simulation model. Based on historical wildfire data and satellite imagery available since 2001, we located 40 fires greater than 10,000 acres burned with smoke plumes moving in a southern direction. Of these fires, 25 were in eastern Washington and 15 fires were in eastern Oregon. The NOAA OSPO had several days with satellite smoke text that described smoke moving towards California. Moreover, the NOAA OSPO specifically describes satellite imagery from certain dates where smoke from wildfires in Washington and Oregon is moving into California. The NOAA OSPO satellite smoke text also corroborates the smoke dispersion model of vertically integrated smoke for some days that predict smoke movement from eastern Washington to California. In addition, a somewhat consistent high-altitude cyclonic wind pattern that occurs along the Pacific coast that circulates air in a clockwise direction can create conditions that could potentially transport smoke from a large wildfire in eastern Washington to California. Finally, simulations we conducted using the BlueSky Smoke simulation model implemented by Parks Canada show that under current conditions, a 10,000-acre wildfire in eastern Washington can transport smoke south into Oregon and presumably California. Therefore, based on the multiple data sources that we examined, there is considerable evidence that smoke from wildfires in eastern Washington can impact air quality in California.

BACKGROUND AND METHODS

Wildfire in forested regions can severely impact air quality (e.g., Ames et al. 2004; Lassman et al. 2017). Wildfires release large quantities of CO_2, CO, particulate matter less than 2.5 micrometers ($PM_{2.5}$), and precursors for tropospheric ozone (O_3) (Jaffe and Wigder 2012; Mallia et al. 2015). These aerosols all contribute to haze (McMeeking et al. 2006), and can have potential negative health effects at high concentrations (see Kochi et al. 2010 for a review). It has been shown that through active management and fuel reductions, managers can alter the behavior and severity of future wildfires (Martins and Omi 2002; Graham et al. 2004; Stevens-Rumann et al. 2013). The extent to which wildfire affects air quality can be highly variable depending on many parameters that drive smoke generation and transport. Moreover, predicting the dispersion of wildfire smoke can be challenging as it is dependent upon multiple contributing factors including topography, localized climatic and metrological inputs, fuel loading, and alternate sources of airborne contaminants (Ames et al. 2004).

Because large wildfires are rare events, it is difficult to design studies to analyze their effects. Studies that have successfully analyzed large-scale wildfire's resulting smoke plumes and dispersion relied on opportunistic data collection dependent on a network on *in-situ* instrumentation (Colarco et al. 2004; Preisler et al. 2015; Lassman et al 2017). These studies are relatively rare and we were unable to locate any published analyses on fires from eastern Washington. However, there is extensive data on historic wildfire location, duration, and size as well as imagery, and weather reports documenting smoke plumes.

Given the lack of peer reviewed studies, we sought out information about historic fires that have occurred in eastern Washington and Oregon and looked for evidence that smoke from these wildfires influenced air quality in California. In particular, we used five data sources to determine wildfire smoke transport and potential impacts on California air quality including: 1) historical wildfire data, 2) satellite imagery, 3) NOAA weather reports documenting smoke plumes, 4) a smoke dispersion model, and 5) a smoke simulation model.

First, we gathered historical fire locations and metadata from the Federal Fire Occurrence Website (FFOW; USGS 2019), the Washington Department of Natural Resources (WADNR; WADNR 2018a; WADNR 2018b; WADNR 2019), and the Oregon Department of Forestry (ODF 2019). All historical fire locations were then filtered to locations in Washington and Oregon east of the Cascade Mountains and for fires that occurred from 2001 through the present. A common definition for a "large fire", which has interaction between its own convection column and weather conditions above the surface, is class E, or 300-1,000 acres burned. However, considering the distance between Washington and California, we felt it was most appropriate to consider larger fires, such as those in class G, or 5,000 acres or more burned (USFS 2003; NWCG 2019). Additionally, in a preliminary analysis that looked at fires only in northeastern Washington, all fires with southern direction plumes were greater than 10,000 acres burned. Therefore, we only looked at fires that were 10,000 acres or more burned in eastern Washington and Oregon.

Second, for each of the fires, satellite imagery was reviewed in NASA Worldview (NASA 2019). Beginning on the reported start date for each fire and continuing until there was no visible smoke or thermal anomalies present near the fire location, satellite imagery was visually assessed to determine if a smoke plume was present for each day. A smoke plume was an obvious band of smoke originating from the particular fire being assessed (see **Figure 1** for example). Both the Terra (moves over the equator in the morning) and Aqua (moves over the equator in the afternoon) Moderate Resolution Imaging Spectroradiometer (MODIS) satellite images were reviewed if both were available for each day. For each day that had a smoke plume present for an individual fire, the plume direction was noted. If a southern direction smoke plume was noted for any day of a fire, the plume direction was noted, and the maximum extent of the plume spread was measured. Plume extent was conservatively measured as the length of the plume where the bare ground could not be seen through the smoke.

Third, for the fires with southern direction smoke plumes, wind and weather patterns were assessed. Although meteorological data was available, analyzing the data to describe broad weather patterns is not trivial, and benefits from both training and experience. Rather than rely on amateur interpretations, we sought information from reliable authorities to describe these broad weather patterns. In particular, we used the "satellite smoke text" produced by the NOAA Office of Satellite and Product Operations (OSPO) to describe weather conditions in the Pacific Northwest, and California in particular, at the time of the southern direction smoke plume. The OSPO "satellite smoke text" contains a narrative description of the smoke seen in satellite imagery, written by trained NOAA staff that are familiar with the data and weather patterns, and is updated twice daily (OSPO 2019).

Fourth, for some recent (2016-2019), larger plumes we looked at vertically integrated smoke from the High-Resolution Rapid Refresh Smoke (HRRR-Smoke) dispersion model (Torres and Ahmadov 2019) to see if smoke was predicted to move from Washington to California. The HRRR-Smoke simulates smoke dispersion over complex terrain, both at the earth surface and aloft in the atmosphere (Torres and Ahmadov 2019).

Finally, large wildfires are rare events, and the lack of a historic fire that meets certain conditions or criteria, does not preclude the possibility of it occurring. To highlight this point, we simulated a 10,000-acre fire in eastern Washington on August 19, 2019 using an online implementation of the BlueSky Smoke simulation framework (Fusina et al. 2007) developed by Parks Canada (http://firesmoke.ca/playground/). We set the fire's fuel mixture to represent a mixed ponderosa pine, doulas fir regime that is common in forested land in eastern Washington, and used default settings for other simulations parameters.

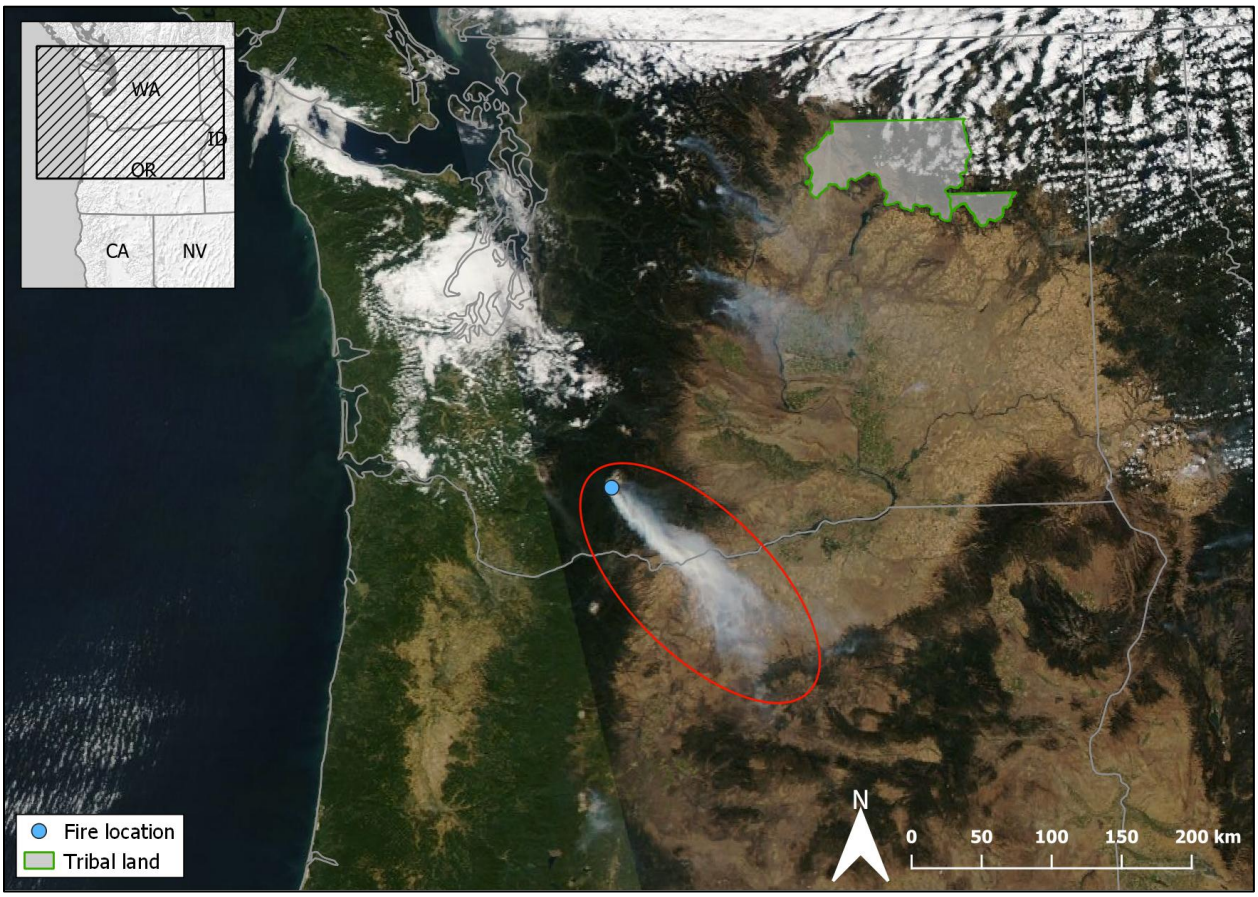

Figure 1. Example of a smoke plume circled in red that was noted while looking through aerial imagery. Colville (west) and Spokane (east) tribal lands are outlined in green.

RESULTS

Since 2001, we located 40 fires greater than 10,000 acres burned with smoke plumes moving in a southern direction (**Table 1**). Of these fires, 25 were in eastern Washington (**Figure 2**) and 15 fires were in eastern Oregon (**Figure 3**). Smoke plumes ranged from 10 to 675 km in length (**Table 1**). The NOAA OSPO had several days with satellite smoke text that described smoke moving towards California. Listed below are four examples of NOAA OSPO text and associated aerial imagery of the smoke. In the Appendix there

are additional examples of NOAA OSPO satellite smoke text that describes a general pattern of smoke movement into California.

1. A large southern direction smoke plume was observed in satellite imagery on August 20, 2018 (**Figure 4**). In addition, the HRRR-Smoke model simulated vertically integrated smoke dispersion west from Washington State into the Pacific Ocean and back east into California (**Figure 4**). The descriptive smoke text narrative published the morning of August 21, 2018, OSPO satellite smoke text states:

   > "Continued wildfire activity predominately in British Columbia and Washington State, with additional activity throughout the remainder of the western U.S., continues to produce areas of thick smoke. From Washington and west-central British Columbia, the thickest smoke is drifting south and west over the Pacific Ocean, where it diffuses into light and medium-density smoke and turns back eastward and inland over northern California and Oregon. Here, further fire activity adds locally thick smoke to the plume, which continues east-northeastward across Nevada, Idaho, and Wyoming."

2. Satellite imagery shows southern direction plumes in Washington (**Figure 5**) and the NOAA OSPO descriptive smoke text published August 30, 2017 states:

   > "Wildfires throughout California, Oregon, Washington, Idaho, Montana, and British Columbia have been observed producing a large smoke plume of varying density. This large smoke plume is riding around the periphery of a ridge over the western CONUS[1], traveling over eastern Montana and south along the eastern edge of the Rocky Mountains. Some of this smoke has also drifted northward across western Canada. Many of the smoke plumes emanating from individual wildfires are of moderate to heavy density, which is contributing to the moderately thick smoke plume that exists from northern and central California into the Dakotas."

3. Satellite imagery shows a thin covering of smoke across Washington, Oregon, and California on September 24, 2012 (**Figure 6**) and the NOAA OSPO descriptive smoke text published on the date states:

   > "While there seemed to be a diminishing amount of new smoke being produced by the Western wildfires this evening there is still plentiful remnant smoke. The thickest smoke, over western Oregon and Washington, extended to the south along and off the California coast and then wrapped eastward into southern California near Santa Barbara."

4. Satellite imagery shows a thin band of smoke over the Pacific Ocean (**Figure 7**) and the NOAA OSPO descriptive smoke text published September 14, 2012 states:

   > "Thin upper level smoke that rotated northwest then westward over B.C. and the Pacific Ocean from the Pole Creek fire a few days ago has wrapped behind the cold front of a weak cyclone that is moving onshore across WA. The thin smoke extends from the SW of this cyclone along the coastal range of Oregon and far NW CA along the nearest 50-100 km of the Pacific. This smoke is moving quickly south."

Additionally, we note that there is a somewhat consistent high-altitude cyclonic wind pattern that occurs along the Pacific coast that circulates air in a clockwise direction. Depending on the year, this gyre moves north and south, and can create conditions that could potentially transport smoke from a large wildfire in eastern Washington to California (see **Figure 8**, **Figure 9**, and **Figure 10** for examples of the gyre in August). Corroborating this potential mechanism for smoke transport, we found NOAA OSPO smoke

[1] CONUS = Continental United States

descriptions that describe this high-altitude cyclonic wind pattern transporting smoke from Washington to California:

> "DESCRIPTIVE TEXT NARRATIVE FOR SMOKE/DUST OBSERVED IN SATELLITE IMAGERY THROUGH 0200Z August 18, 2012
>
> Remnant smoke is mixed with new smoke from the many large wildfires across Idaho, Washington, Oregon and northern California and stretches across the entire US from the Pacific northwest coast into the Great Basin and central Rockies through the central into northern Texas, across the lower Mississippi Valley and the Tennessee Valley and then curving back up the Atlantic seaboard from the coastal Carolinas into New England and Nova Scotia. Much of the area had moderate density smoke, although elevated above the surface. Areas of dense smoke were seen from New England down to the mid-Atlantic coast and in patches across Wyoming, Colorado and western Kansas. Larger areas of dense smoke were observed near the fires in Idaho, Washington, Oregon and California. A branch of thin smoke was also seen moving to the west southwest across southern California and into the Pacific. This is smoke which has circulated clockwise around the Great Basin from the fires in northern California and Idaho."

Finally, results of the 24-hour smoke plume simulation from the BlueSky Smoke simulation framework implemented by Parks Canada show a strong plume moving south, southwest (**Figure 11**). To reiterate, no fire occurred on this date, but simulation shows that if a fire was to occur, there would be a strong southern directionality to the resulting smoke plume.

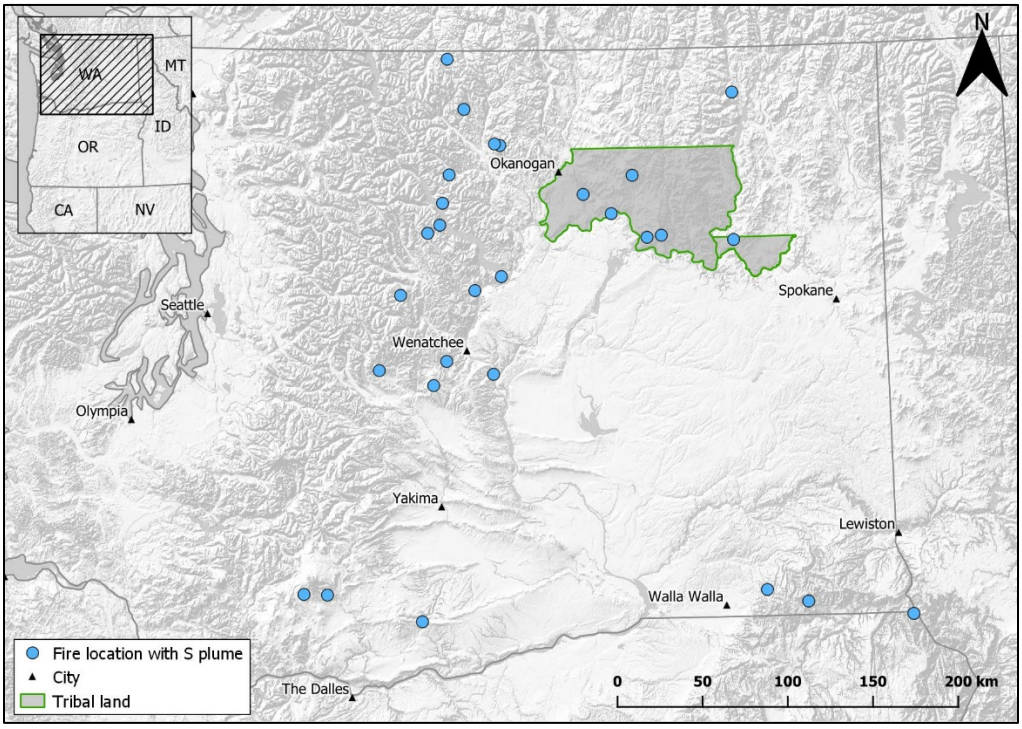

Figure 2. Historical fire locations that occurred from 2001-2019, were in Washington, and were observed to have a southern direction smoke plume. Colville (west) and Spokane (east) tribal lands are outlined in green.

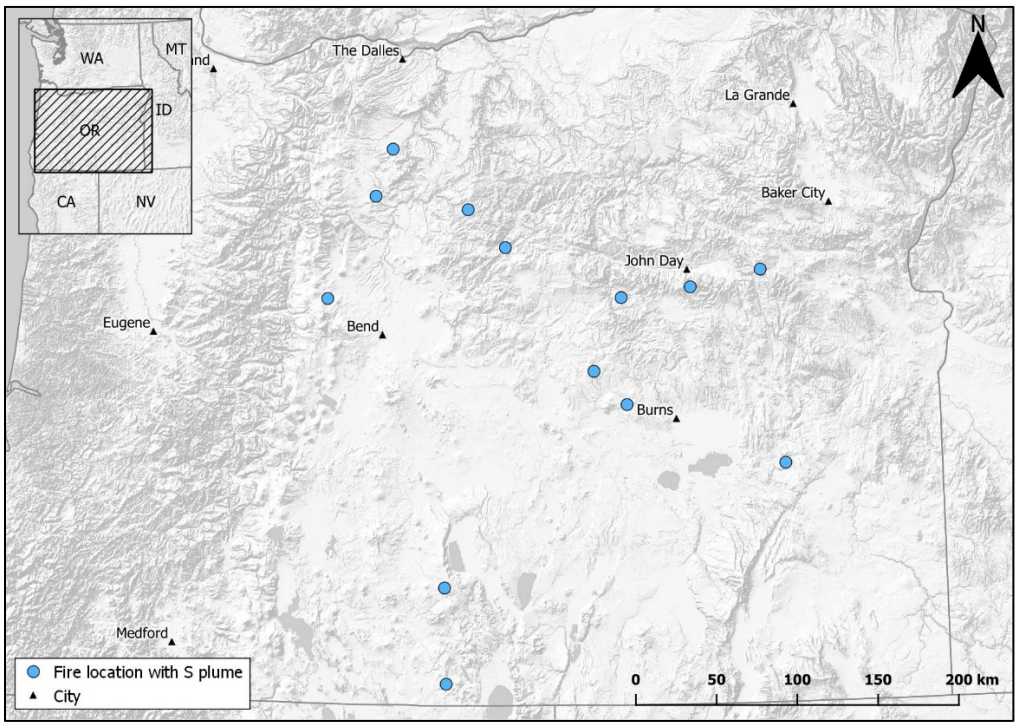

Figure 3. Historical fire locations that occurred from 2001-2019, were in Oregon, and were observed to have a southern direction smoke plume.

Table 1. Fire names, general information, and smoke plume notes and lengths for all fires in Washington and Oregon that were reviewed and found to have a southern (S) direction plume. Fires are listed by state, then by year, and then alphabetically by assigned fire name.

Fire name	State	Acres burned	Year	Start Date	Smoke plume direction notes	Longest S plume length	Longest S plume date
Rex Creek Complex	WA	55,913	2001	8/12/2001	N, SW	85 km	8/18/2001
Deep Harbor	WA	29,700	2004	7/18/2004	W, NE, SE	288 km	7/30/2004
W Omak Lk	WA	11,330	2005	7/12/2005	SE	71 km	7/13/2005
Columbia Complex	WA	109,402	2006	8/21/2006	E, NE, NW, SW	83 km	9/7/2006
Tripod Complex	WA	113,011	2006	7/24/2006	S, E, NE, SW	142 km	8/25/2006
Manila Creek	WA	26,805	2007	9/10/2007	N, SE, SW	80 km	9/14/2007
Columbia River Road	WA	22,155	2008	8/7/2008	SE	10 km	8/11/2008
Buffalo Lake Road	WA	11,299	2012	8/14/2012	SW	25 km	8/15/2012
Cache Creek	WA	73,695	2012	8/21/2012	N, NE, SE	38 km	8/24/2012
Cascade Creek	WA	20,296	2012	9/8/2012	N, S, E, W, NE, NW, SE	134 km	10/2/2012
Table Mountain	WA	43,874	2012	9/8/2012	N, E, SE, SW	675 km	9/20/2012
Colockum Tarps	WA	80,053	2013	7/27/2013	S, E, SE, SW	50 km	7/28/2013
Milemarker 28	WA	26,093	2013	7/24/2013	E, SE	62 km	7/27/2013
Carlton	WA	255,575	2014	7/14/2014	N, E, NE, SE	175 km	7/17/2014
Chiwaukum Creek	WA	14,435	2014	7/15/2014	E, SE	85 km	7/17/2014
Duncan	WA	13,650	2014	7/16/2014	N, E, NE, SE	37 km	7/17/2014
Butte Creek	WA	78,759	2015	8/13/2015	S, E, NE	58 km	8/18/2015
Carpenter Road	WA	63,972	2015	8/13/2015	N, S, NE, SE	37 km	8/18/2015
North Star	WA	218,138	2015	8/13/2015	N, S, E	78 km	8/18/2015
Reach	WA	88,484	2015	8/14/2015	E, SW	46 km	8/16/2015
Renner	WA	13,794	2015	8/17/2015	SE	95 km	8/21/2015
Diamond Creek	WA	127,786	2017	7/23/2017	N, E, NE, SE	57 km	8/31/2017
Jolly Mountain	WA	36,817	2017	8/11/2017	N, E, SE	50 km	8/24/2017
Crescent Mountain	WA	51,972	2018	7/29/2018	E, NE, SW	210 km	8/20/2018
McLeod	WA	22,875	2018	8/11/2018	E, W, NE, SE	57 km	8/20/2018
Egley	OR	55,420	2007	7/6/2007	E, NE, SW	52 km	7/8/2007
Silver Fire	OR	31,625	2007	7/7/2007	E, NE, SW	32 km	7/8/2007
Barry Point	OR	38,444	2012	8/6/2012	N, W, NE, NW, SE	95 km	8/13/2012
Cache Creek	OR	73,500	2012	8/20/2012	NE, SE	40 km	8/24/2012
Bailey Butte	OR	10,277	2014	7/13/2014	S, E, SW	64 km	7/18/2014
Donnie Brook	OR	22,763	2014	7/13/2014	E, SW	25 km	7/18/2014
Murderers South	OR	64,531	2014	7/31/2014	NE, SE	60 km	8/6/2014
Saddle Draw	OR	280,141	2014	7/14/2014	E, NE, SW	72 km	7/15/2014
Berry Creek	OR	101,028	2015	8/12/2015	N, E, NE, SE	90 km	8/19/2015
County Line 2	OR	66,613	2015	8/12/2015	N, S, E, NW	35 km	8/17/2015
Grizzly	OR	75,530	2015	8/13/2015	S, E, NE	57 km	8/18/2015
Rail	OR	43,799	2016	7/31/2016	E, NE, SE	55 km	8/27/2016
Milli 0843	OR	24,079	2017	8/11/2017	N, NE, SE	74 km	8/18/2017
Nena Springs	OR	68,135	2017	8/8/2017	SE	59 km	8/9/2017
Watson Creek 360	OR	58,753	2018	8/15/2018	E, NE, SE	78 km	8/20/2018

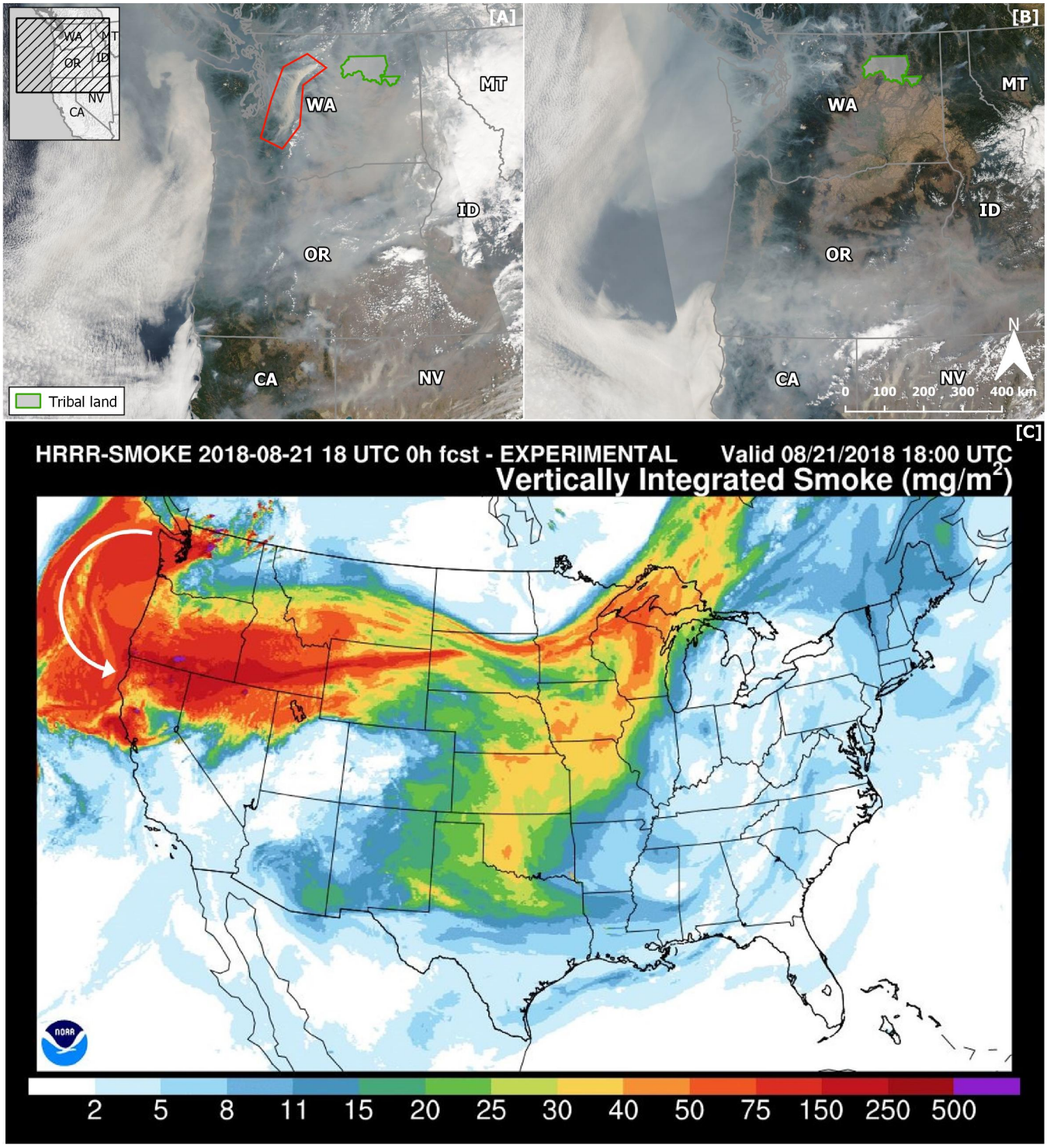

Figure 4. Satellite imagery of large smoke plume (red polygon) from the afternoon of August 20, 2018 (A – top left) and dispersing smoke from morning of August 21, 2018 (B – top right), which is described in NOAA OSPO descriptive smoke text as "drifting south and west over the Pacific Ocean, where it diffuses into light and medium-density smoke and turns back eastward and inland over northern California and Oregon". Though the smoke (grey/yellow color) mixes with the clouds (white color) over the ocean, both the smoke and clouds move in the direction described in the NOAA OSPO descriptive smoke text. Colville (west) and Spokane (east) tribal lands are outlined in green. In addition, the HRRR-Smoke dispersion model (Torres and Ahmadov 2019) of vertically integrated smoke from the morning of August 21, 2018 (C – bottom) predicted the smoke to move west from Washington into the Pacific Ocean, then back east into California as shown with the white arrow.

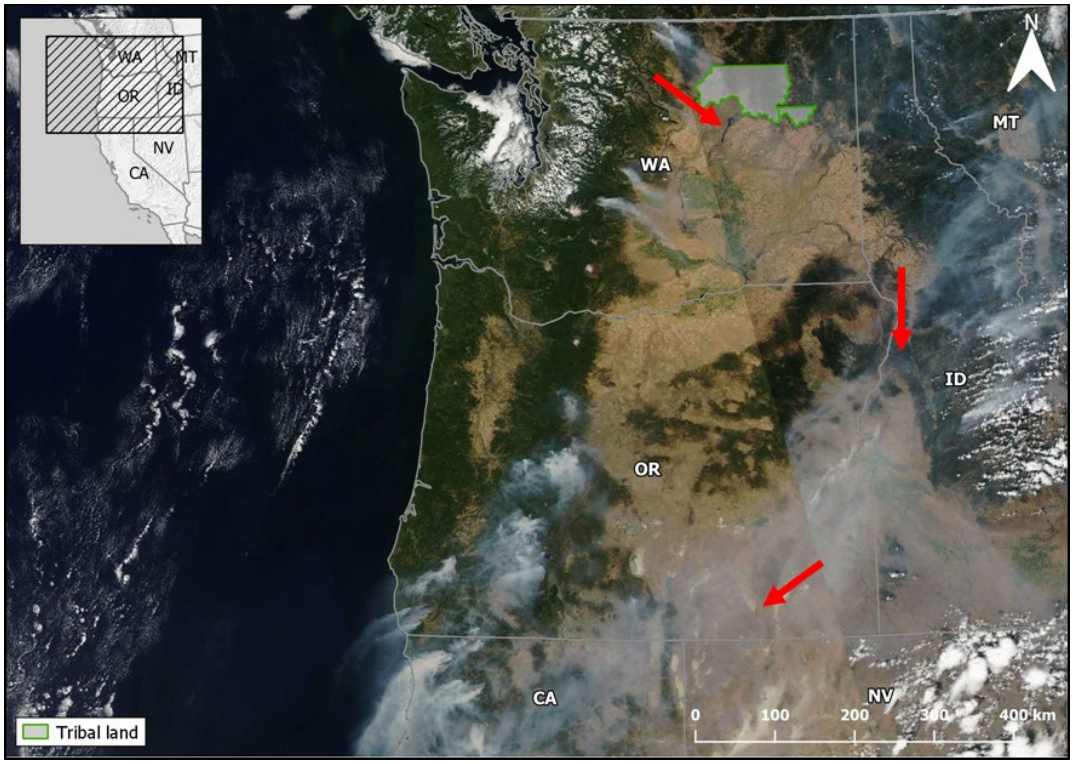

Figure 5. Satellite imagery of smoke from August 31, 2017. NOAA OSPO description describes transport of smoke from wildfires in Washington and Oregon to California along the edge of the Rocky Mountains. Colville (west) and Spokane (east) tribal lands are outlined in green.

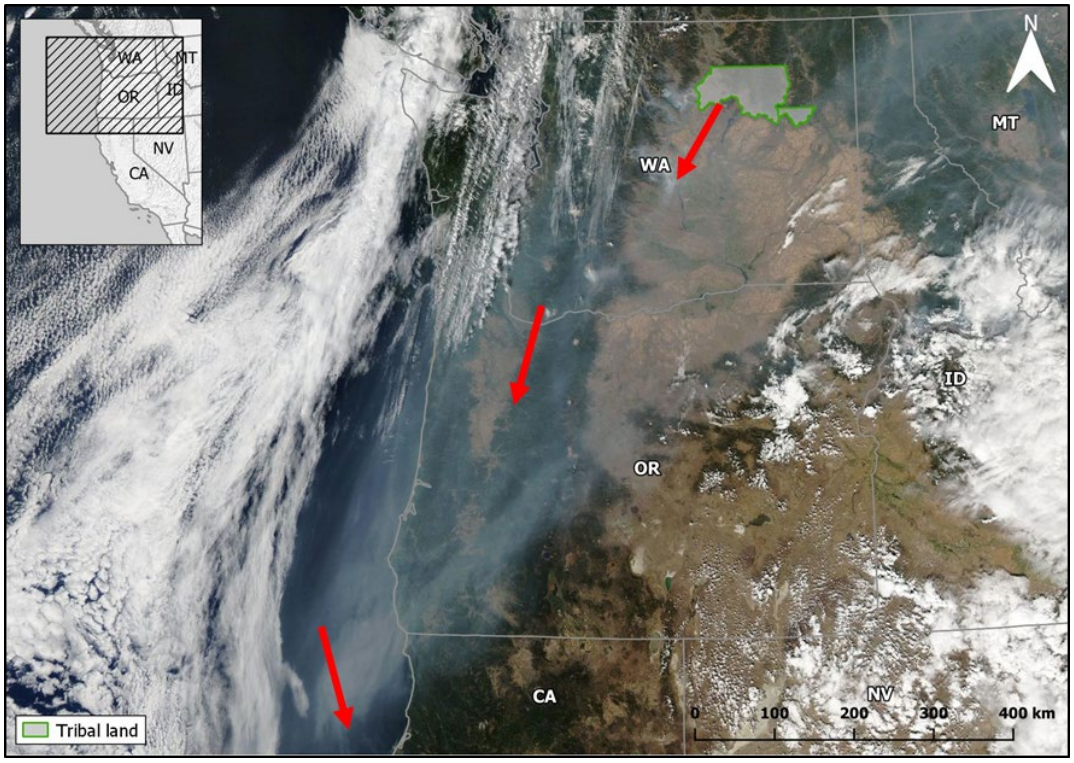

Figure 6. Satellite imagery of smoke from September 24, 2012. NOAA OSPO description describes transport of smoke from wildfires in Washington and Oregon to California along the Pacific coast. Colville (west) and Spokane (east) tribal lands are outlined in green.

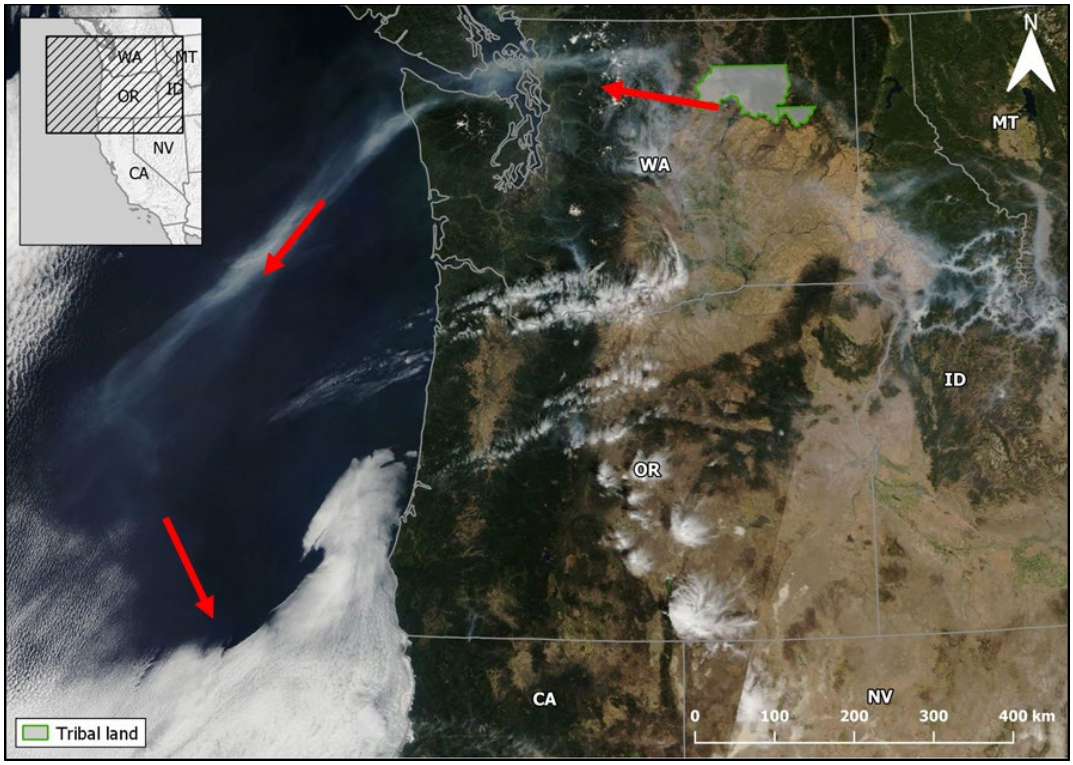

Figure 7. Satellite imagery of smoke from September 13, 2012. NOAA OSPO description describes transport of smoke from wildfires in Washington and Oregon to California through a weak cyclone in the Pacific. Colville (west) and Spokane (east) tribal lands are outlined in green

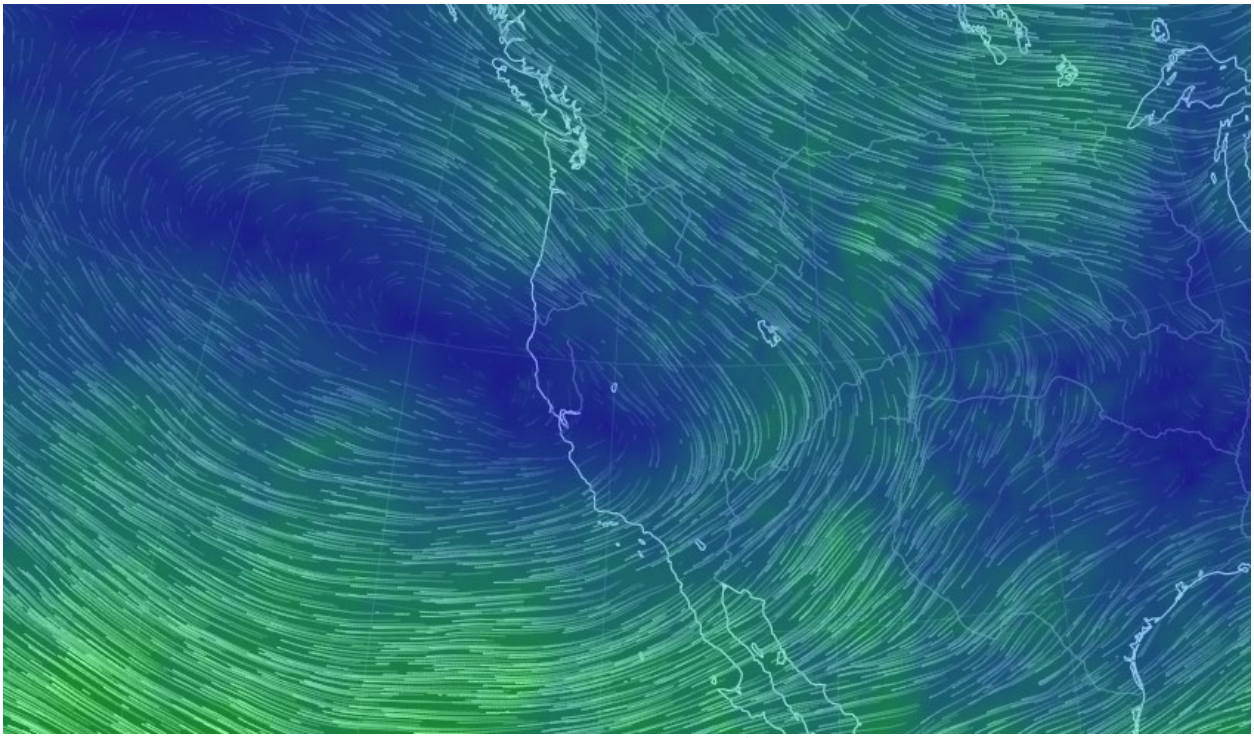

Figure 8. Depiction of high-altitude (70 hPa) wind patterns on August 14th, 2019 along the Pacific coast that circulated air in a clockwise direction. Image captured from https://earth.nullschool.net/#2019/08/15/0700Z/wind/isobaric/70hPa/.

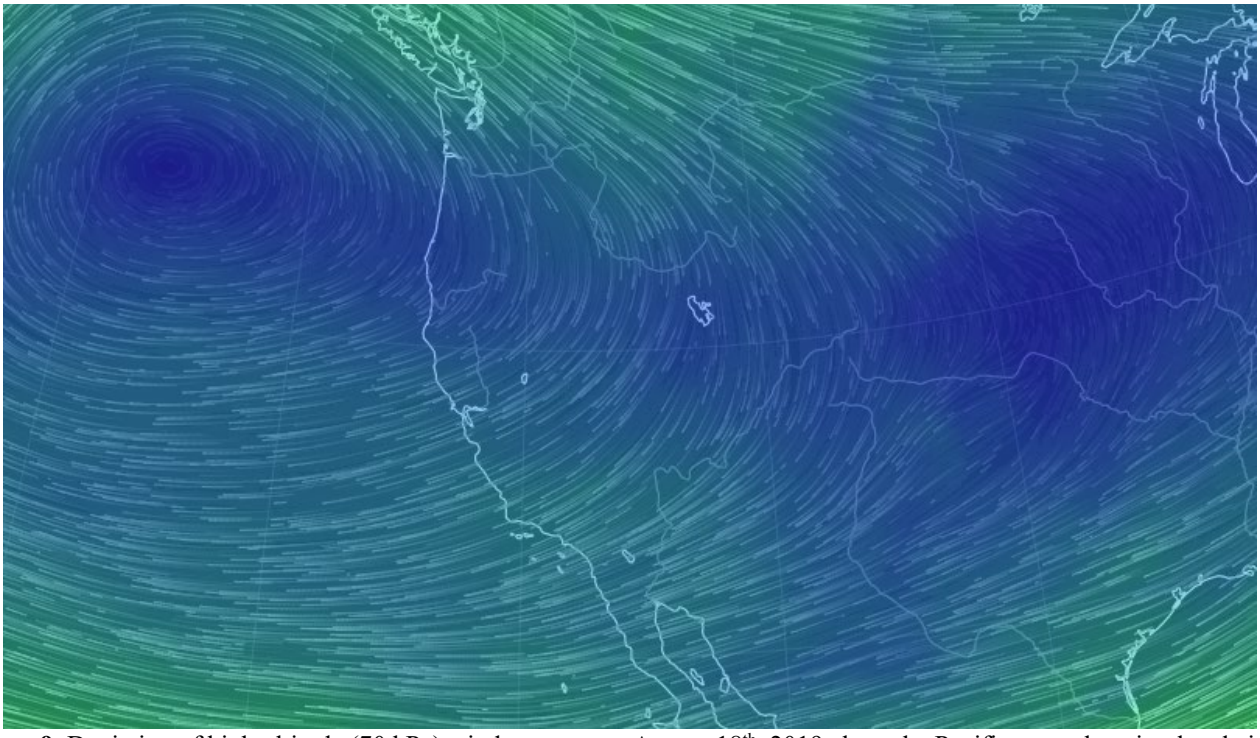

Figure 9. Depiction of high-altitude (70 hPa) wind patterns on August 18th, 2019 along the Pacific coast that circulated air in a clockwise direction. Image captured from https://earth.nullschool.net/#2018/08/19/0700Z/wind/isobaric/70hPa/.

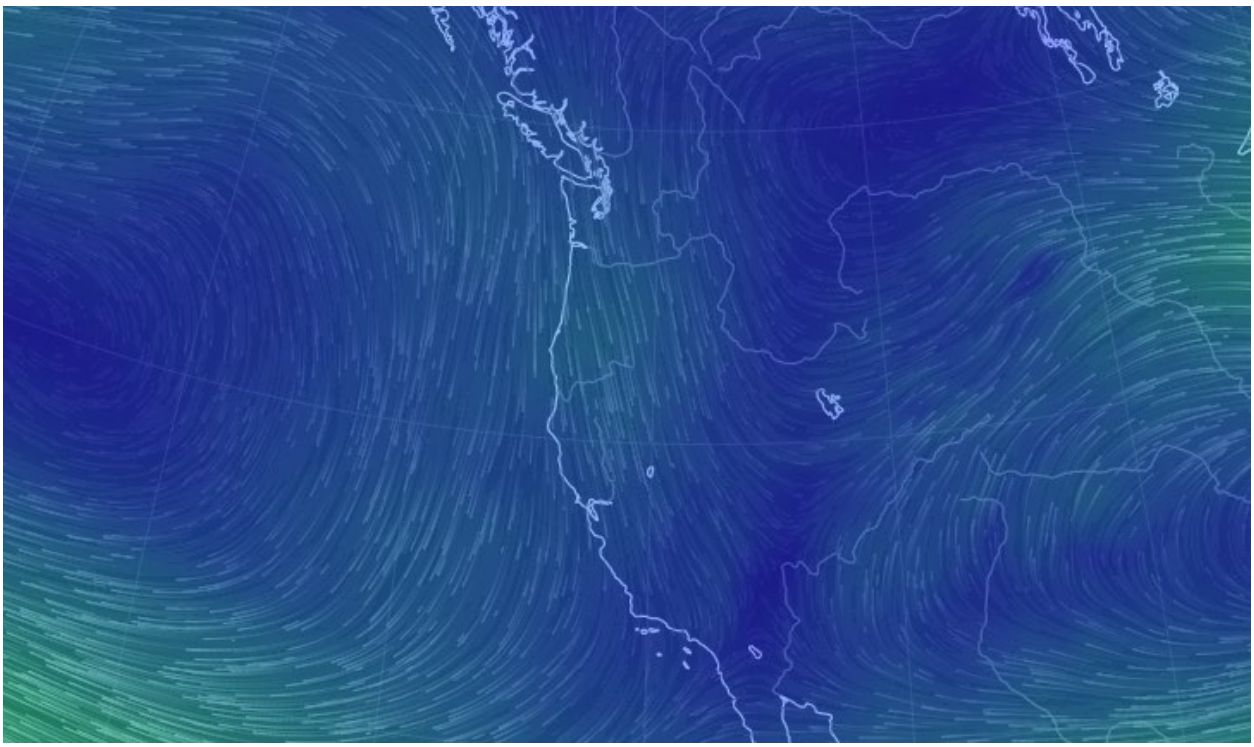

Figure 10. Depiction of high-altitude (70 hPa) wind patterns on August 14th, 2017 along the Pacific coast that circulated air in a clockwise direction. Image captured from https://earth.nullschool.net/#2017/08/15/0600Z/wind/isobaric/70hPa/.

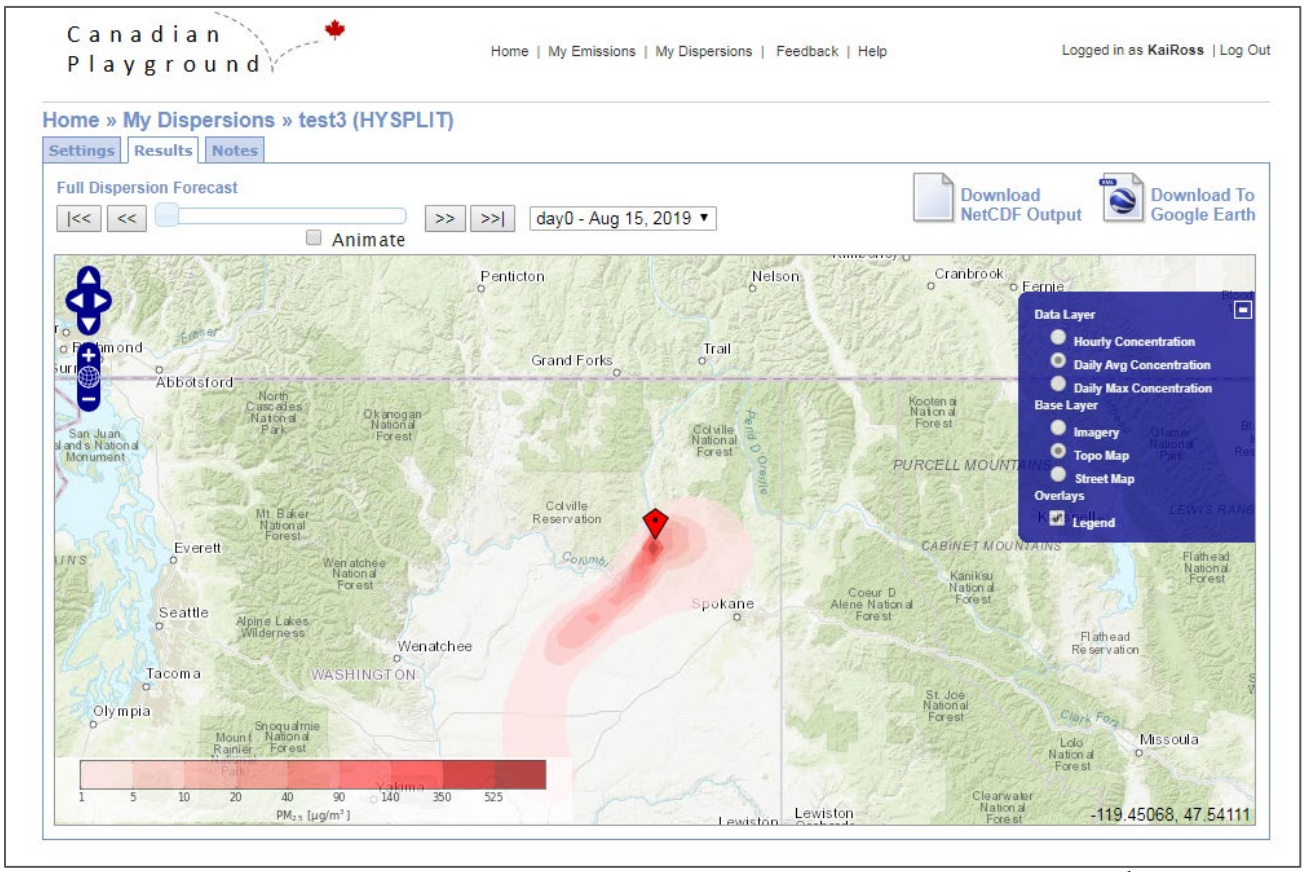

Figure 11. Screen capture of simulated smoke dispersion in 24 hours from a 10,000-acre fire on August 15th, 2019. Note the strong southern directionality of the smoke plume.

CONCLUSIONS

Based on our visual analysis of historical fires and satellite imagery, there are fires in eastern Washington and Oregon that have smoke plumes that travel in a southern direction. Moreover, the NOAA OSPO has several dates during the wildfire season where satellite smoke text describes smoke moving in a southern direction. In addition, the NOAA OSPO specifically describes satellite imagery from certain dates where smoke from wildfires in Washington and Oregon is moving into California. The NOAA OSPO satellite smoke text also corroborates the HRRR-Smoke model of vertically integrated smoke for some days that predict smoke movement from eastern Washington to California. In addition, a somewhat consistent high-altitude cyclonic wind pattern that occurs along the Pacific coast that circulates air in a clockwise direction can create conditions that could potentially transport smoke from a large wildfire in eastern Washington to California. Finally, in addition to the historic fire records, simulations we conducted using the BlueSky Smoke simulation framework implemented by Parks Canada show that under current conditions, a 10,000-acre wildfire in eastern Washington can transport smoke south into Oregon and presumably California. In total, from the multiple data sources we utilized, there is considerable evidence that smoke from wildfires in eastern Washington can travel in a southern direction and impact air quality in California.

LITERATURE CITED

Ames, R. B., D. G. Fox, W. C. Malm, and B. A. Schichtel. 2004. Preliminary apportionments of carbonaceous aerosols to wild fire smoke using observations from the IMPROVE network. Paper #76 in regional and global perspectives on haze: causes, consequences and controversies. Visibility Specialty Conference, Air and Waste Management Association, Asheville, North Carolina.

Colarco, P. R., M. R. Schoeberl, B. G. Doddridge, L. T. Marufu, O. Torres, and E. J. Welton. 2004. Transport of smoke from Canadian forest fires to the surface near Washington, D.C: injection height, entrainment, and optical properties. Journal of Geophysical Research: Atmospheres 109:D06203. doi:10.1029/2003JD004248.

Fusina, L., S. Zhong, J. Koracin, T. Brown, A. Esperanza, L. Tarney, and H. Preisler. 2007. Validation of BlueSky Smoke Prediction System using surface and satellite observations during major wildland fire events in Northern California. Pages 403–408 *in* B. W. Butler and W. Cook, editors. The fire environment—innovations, management, and policy. Conference Proceedings RMRS-P-46CD. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado.

Graham, R., S. McCaffrey, and T. Jain. 2004. Science basis for changing forest structure to modify wildfire behavior and severity. General Technical Report RMRS-GTR-120. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado.

Jaffe, D. A., and N. L. Wigder. 2012. Ozone production from wildfires: a critical review. Atmospheric Environment 51:1-10.

Kochi, I., G. H. Donovan, P. A. Champ, and J. B. Loomis. 2010. The economic cost of adverse health effects from wildfire-smoke exposure: a review. International Journal of Wildland Fire 19:803-817.

Lassman, W., B. Ford, R. W. Gan, G. Pfister, S. Magzamen, E. V. Fischer, and J. R. Pierce. 2017. Spatial and temporal estimates of population exposure to wildfire smoke during the Washington state 2012 wildfire season using blended model, satellite, and *in situ* data. GeoHealth 1:106-121.

Mallia, D. V., J. C. Lin, S. Urbanski, J. Ehleringer, and T. Nehrkorn. 2015. Impacts of upwind wildfire emissions on CO, CO_2, and $PM_{2.5}$ concentrations in Salt Lake City, Utah. Journal of Geophysical Research: Atmospheres 120:147-166

Martinson, E. J., and P. N. Omi. 2002. Performance of fuel treatments subjected to wildfires. Pages 7–14 *in* United States Forest Service. Fire, fuel treatments, and ecological restoration. Conference Proceedings RMRS-P-29. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado.

McMeeking, G. R., S. M. Kreidenweis, M. Lunden, J. Carrillo, C. M. Carrico, T. Lee, P. Herckes, G. Engling, D. E. Day, J. Hand, N. Brown, W. C. Malm, and J. L. Collett Jr. 2006. Smoke-impacted regional haze in California during the summer of 2002. Agricultural and Forest Meteorology 137:25-42.NASA (National Aeronautics and Space Administration). 2019. NASA Worldview – Earth Observing System Data and Information System (EOSIDS). Available at URL: https://worldview.earthdata.nasa.gov/.

NWCG (National Wildfire Coordinating Group). 2019. Glossary: size class of fire. Available at URL: https://www.nwcg.gov/term/glossary/size-class-of-fire.

ODF (Oregon Department of Forestry). 2019. Oregon Department of Forestry fires statewide dataset. Available at URL: https://www.oregon.gov/ODF/AboutODF/Pages/MapsData.aspx.

OSPO (Office of Satellite Products and Operations). 2019. Satellite smoke text product produced by the NOAA Satellite Products and Services Division. Available at URL: https://www.ssd.noaa.gov/PS/FIRE/smoke.html.

Preisler, H. K., D. Schweizer, R. Cisneros, T. Procter, M. Ruminski, and L. Tarnay. 2015. A statistical model for determining impact of wildland fires on Particulate Matter ($PM_{2.5}$) in Central California aided by satellite imagery of smoke. Environmental Pollution 205:340-349.

Raymond, C. L., and D. L. Peterson. 2005. Fuel treatments alter the effects of wildfire in a mixed-evergreen forest, Oregon, USA. Canadian Journal of Forest Research 35:2981-2995.

Torres, J., and R. Ahmadov. 2019. High-Resolution Rapid Refresh Smoke (HRRR-Smoke) experimental forecasting model. Developed at National Oceanic and Atmospheric Administration Earth System Research Laboratory – Global Systems Division in collaboration with the National Environmental Satellite, Data, and Information Service and National Aeronautics and Space Administration. Available at URL: https://rapidrefresh.noaa.gov/hrrr/HRRRsmoke/.

USFS (United States Forest Service). 2003. Fire Terminology. Available at URL: https://www.fs.fed.us/nwacfire/home/terminology.html.

USGS (United States Geological Survey). 2019. Federal Fire Occurrence Website. U.S. Department of the Interior. Available at URL: https://wildfire.cr.usgs.gov/firehistory/index.html.

WADNR (Washington Department of Natural Resources). 2018a. Washington Large Fires 1973 – 2017. WADNR GIS Open Data. Available at URL: http://data-wadnr.opendata.arcgis.com/datasets/washington-large-fires-1973-2018.

WADNR (Washington Department of Natural Resources). 2018b. DNR Fire Statistics 1970 – 2007. WADNR GIS Open Data. Available at URL: http://data-wadnr.opendata.arcgis.com/datasets/dnr-fire-statistics-1970-2007.

WADNR (Washington Department of Natural Resources). 2019. DNR Fire Statistics 2008 – present. WADNR GIS Open Data. Available at URL: http://data-wadnr.opendata.arcgis.com/datasets/dnr-fire-statistics-2008-present.

APPENDIX

There were additional NOAA OSPO satellite smoke text narratives that described the overall pattern of fire smoke in a southern direction and/or moving towards California:

> *July 25, 2005*: "Several fires were observed producing smoke plumes across portions of Washington, Oregon, northern Idaho, and western Montana. The smoke plumes were spreading mostly to the south or southeast."
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> *August 3, 2005*: "A fire near Sitkum in Coos County in southwest Oregon is producing a narrow smoke plume that extends southwestward off the coast into the Pacific where it turns to the south. It then runs about 150 km off the California coast to west of Mendocino County."
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> *August 25, 2006*: "The large fires in Okanogan County of Washington have been produced locally dense smoke that is moving to south SW since this morning. The smoke have become a shape of strip with about 60 km width whose dense portion have extended as long as 470 km and thin portion has traveled 120 km more than the dense portion to central western Oregon. Fires in central Columbia County of southeastern Washington are generating moderately dense areas of smoke extending into Umatilla and Union counties of Oregon. A big fire in Grant County of Oregon is producing a moderately dense plume of smoke fanning out to the south which has covered most of Grant, Marney, Lake, and Klamath counties of Oregon from north. Another fire in Benton County in western Oregon produced a moderately dense puff of smoke moving south and now the smoke is influencing Lake County."
>
> *October 1, 2012*: "An area of light density smoke is observed off the coast of California. This is likely remnant smoke from the wildfires in Washington and Idaho."