Identifying Smoke-Impacted Regions using the Optical Properties of Brown Carbon Aerosol

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Detecting Biomass Burning Smoke is Tricky… But Brown Carbon Can Help

We use the optical properties of Brown Carbon aerosols (BrC) in the UV to detect regions impacted by biomass burning smoke.

- BrC is a significant component of fresh biomass burning smoke, with $\tau \sim$ 15-28h *[e.g., Wong et al. 2019]*
- BrC absorbs strongly in the ultraviolet and can be used to differentiate smoke (e.g. from other sources of CO and Black Carbon) *[e.g., Wang et al., 2016; Mok et al., 2016]*
- We use OMI absorption aerosol optical depth (AAOD) and aerosol optical depth (AOD) in a UV wavelength window (354nm-388nm) to estimate BrC presence during smoke events

Overview of Methodology

We use OMI measurements of AAOD and AOD in the UV to examine differential absorption of aerosols according to wavelength.

- We use the 354nm – 388nm wavelength window.
- AAOD is used to calculate the Absorption Ångstrom Exponent (AAE) and AOD is used to calculate the Extinction Ångstrom Exponent (EAE). E.g:

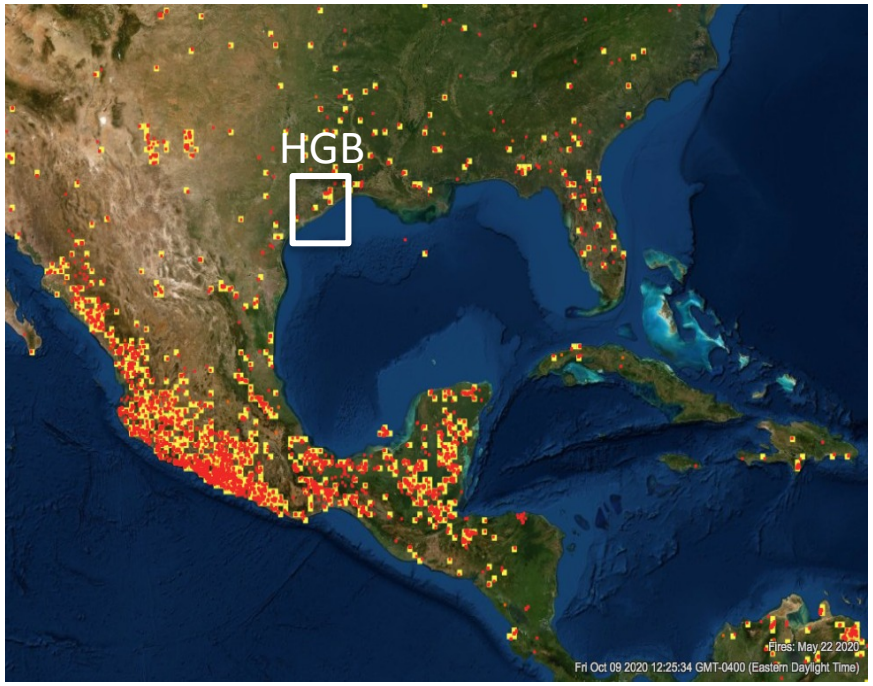
$$AAE(\lambda_1, \lambda_2) = -\frac{\ln\left(\frac{AAOD_{\lambda_1}}{AAOD_{\lambda_2}}\right)}{\ln\left(\frac{\lambda_1}{\lambda_2}\right)}$$

- AAE of 1: Black Carbon; AAE 2-4: Increasing BrC dominance *[e.g., Wang et al., 2016]*
- EAE used as an additional filter to extract biomass burning regimes in AAE signal *[e.g., Russell et al., 2010]*
- We use a k-means clustering method to extract different AAE vs. EAE regimes in different biomass burning scenarios

Case Study: Houston-Galveston-Brazoria (HGB) region, TX

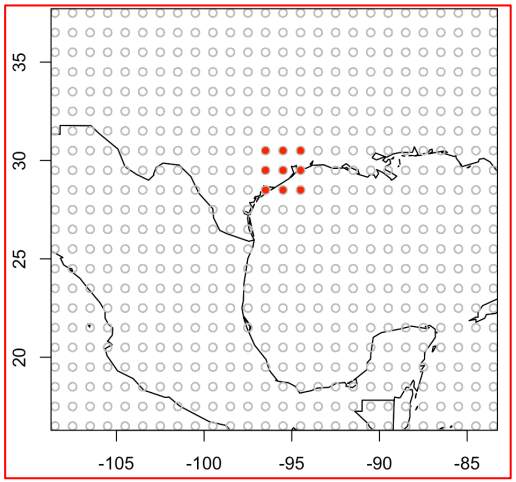
- We test our method in the HGB region, a region impacted by agricultural fires in the Yucatán during April and May.
- OMI AAOD and AOD 354nm-388nm:
  - ✓ 99 days spanning 2005-2020
  - ✓ 52 occurred during April/May peak smoke months, and 47 of those days were known or suspected smoke intrusions *[Wang et al., 2018]*
  - ✓ 47 days were randomly selected from non-April/May throughout the 2005-2020 period
- Ran HYSPLIT back trajectories for a subset of key days

Fire Counts, May 22 2020
(NASA FIRMS/VIIRS data)



1 — 100+

Case Study: Houston-Galveston-Brazoria (HGB) region, TX



Time resolution: 48h averages to minimize missing pixels due to cloud cover. Given τ of 15-28h this could decrease BrC signal strength.

λ_1 , λ_2 (nm)	OMI Product	Resolution
354, 388	OMAERUVd	1°×1°
354, 500	OMAERUVd	1°×1°
388, 500	OMAERUVd	1°×1°
342.5, 388	OMAEROe	0.25°×0.25°
342.5, 442	OMAEROe	0.25°×0.25°
342.5, 463	OMAEROe	0.25°×0.25°
342.5, 483.5	OMAEROe	0.25°×0.25°
388, 442	OMAEROe	0.25°×0.25°
388, 463	OMAEROe	0.25°×0.25°
388, 483.5	OMAEROe	0.25°×0.25°
442, 463	OMAEROe	0.25°×0.25°
442, 483.5	OMAEROe	0.25°×0.25°
463, 483.5	OMAEROe	0.25°×0.25°

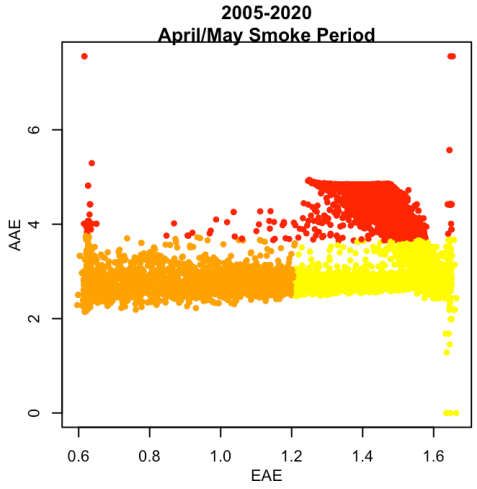
HGB Case Study: Results for 2005-2020

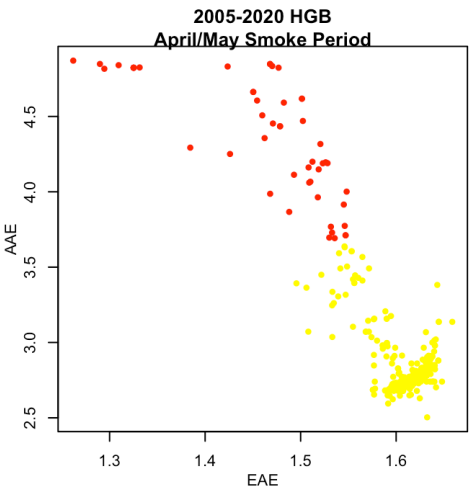
AAE vs EAE: Full Region

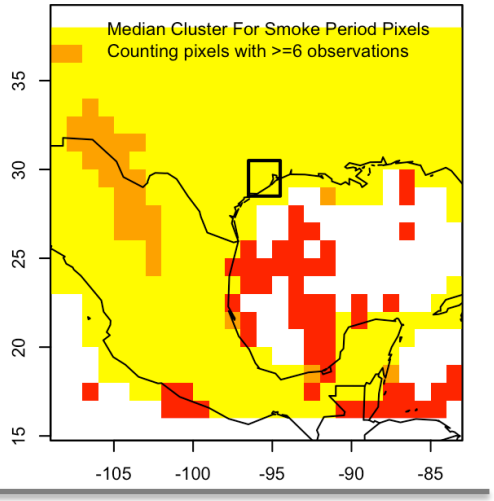
AAE vs EAE: HGB Region

MEDIAN CLUSTER ID

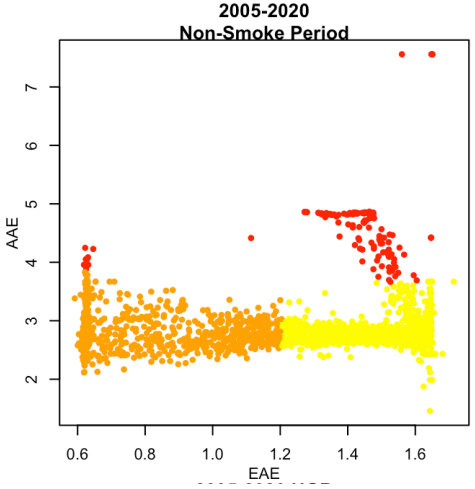
SMOKE PERIOD

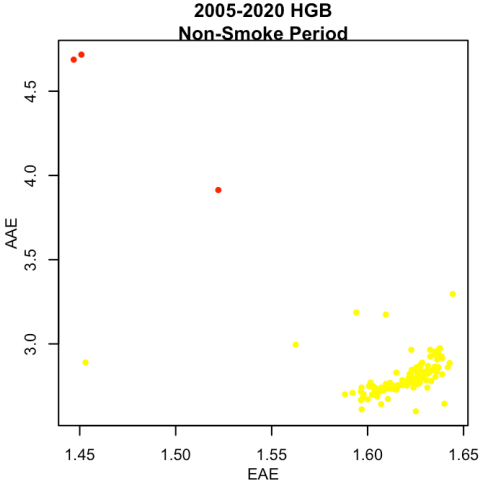


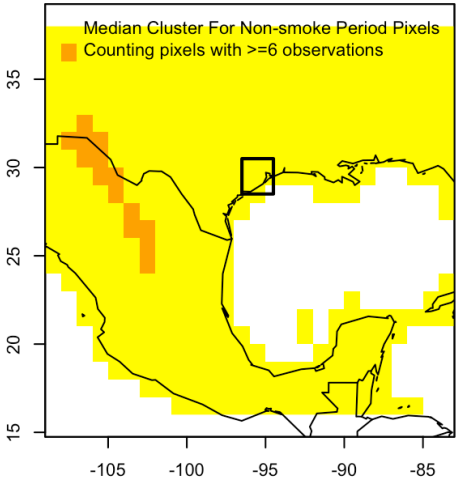


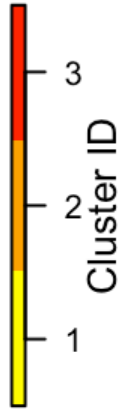


NON-SMOKE PERIOD

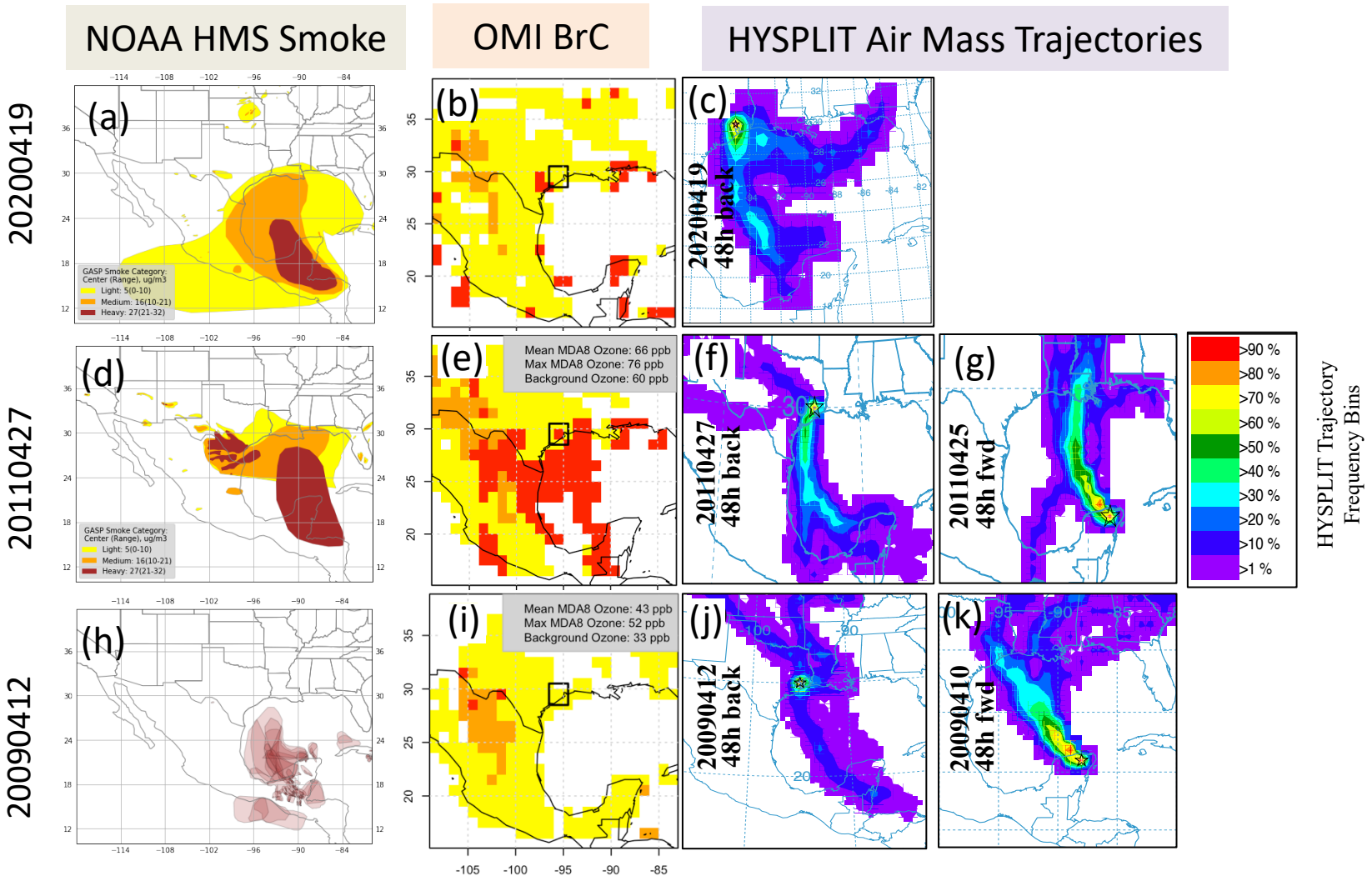






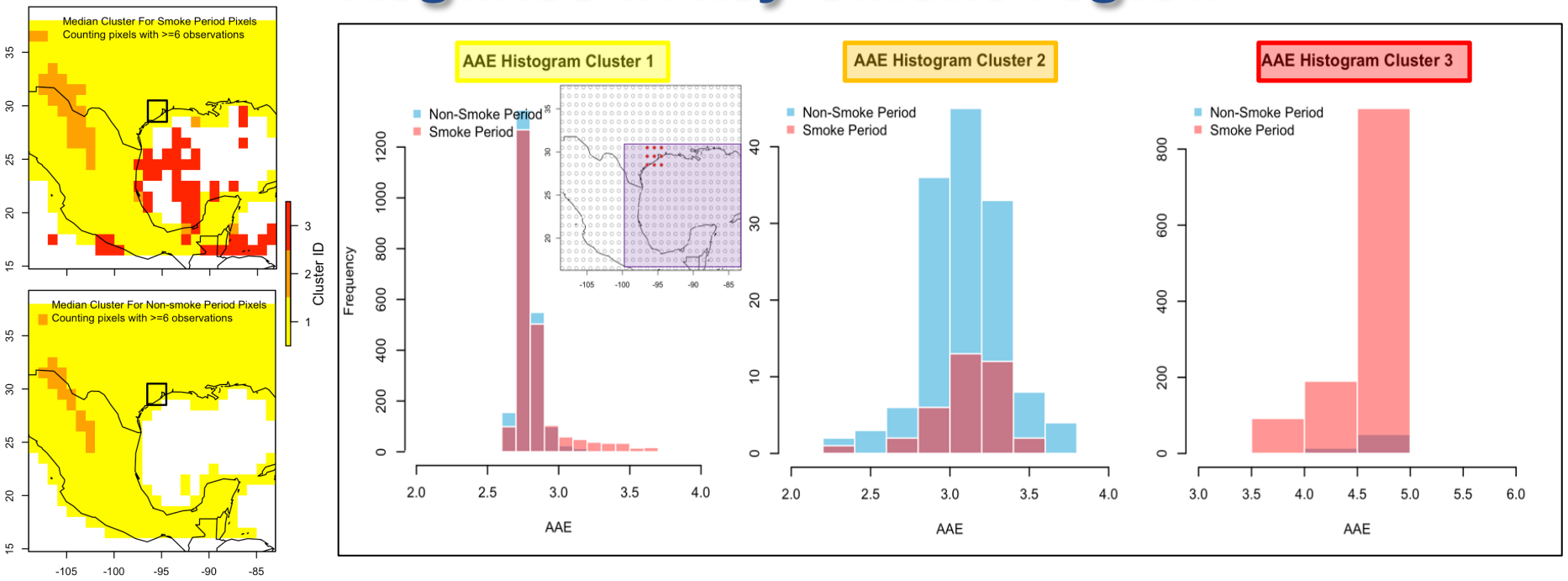


HGB Case Study: Results for Specific Dates



Smoke Data/Ozone Data: Wang et al. [2018]

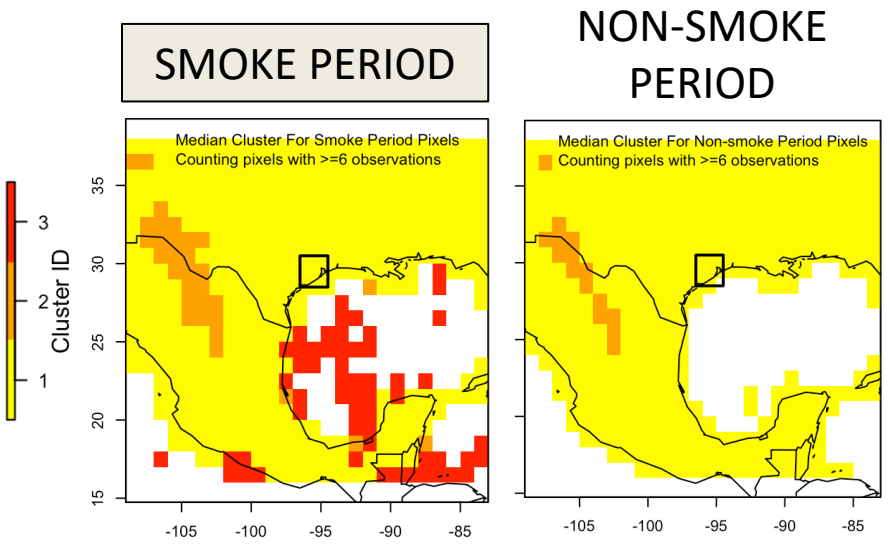
HGB Case Study: Summary of AAE and EAE Regimes in key smoke region



- Yellow Cluster 1: *mixture* of smoke given skew to higher AAE values in Smoke Period.
- Orange Cluster 2 is spatially consistent across seasons and does not appear to be biomass burning related.
- Red Cluster 3: consistent in AAE magnitude it represents throughout year, but far more frequent in Smoke Period

HGB Case Study: Summary of AAE and EAE Regimes in key smoke region

- Yellow Cluster 1 and Red Cluster 3: Share similar EAE regimes in addition to AAE regimes suggesting biomass burning smoke.
- Orange Cluster 2: AAE regime similar to biomass burning smoke, but EAE regime suggests different composition than Clusters 1 and 3.
- Presence of BrC seems to be indicated in AAE regimes of ~2-5 *and* EAE regime of ~1.5



	Mean AAE ± SD	Mean EAE ± SD	Smoke Period Prevalence	Non-smoke Period Prevalence
Cluster 1 (Yellow)	2.8±0.1	1.6±0.1	77%	90%
Cluster 2 (Orange)	2.9±0.3	0.82±0.2	8%	8%
Cluster 3 (Red)	4.5±0.4	1.4±0.1	15%	2%

Summary & Future Work

- We use OMI AAOD and AOD from 354nm-388nm to estimate BrC during smoke events.
- The AAE/EAE ratio shows promise in identifying pixels impacted by smoke, analyzed using k-means clustering.
- EAE is used as a second-level filter for AAE, enabling finer-resolution interpretation (e.g. “BrC-dominant/heavy smoke”, “BrC-mixtures/light smoke”, and “non-smoke”).
  - The AAE regimes of Clusters 1, 2, and 3 all suggest BrC influence (~2-5), but the EAE regime of Cluster 2 (~0.8) differs significantly from Clusters 1 and 2 (~1.5).
- The Cluster 3 regime consistently represented BrC-dominated smoke and occurred primarily during the April/May peak Yucatán smoke months. Cluster 3 AAE values agree with previous studies examining BrC and BB smoke.
- Yellow Cluster 1 has a broader range of aerosol mixtures than Clusters 2 and 3, with AAE values skewed high in the Smoke Period, suggesting more BrC presence.
- Forward and Backward HYSPLIT Trajectories provide important supporting information for interpreting potential smoke impacts using this method.
- Issues: Substantial missing pixels due to cloud interference with AOD and AAOD.
- Future Work: Use upcoming (2022) higher resolution (~4km) TEMPO mission data. Incorporation of additional explanatory variables related to smoke (e.g., HCHO, NO_2).

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