Supplementary Materials: Modeling Multi-Sensor Daily Fire Events in Brazil

Supplementary Materials: Supplementary Materials: Modeling Multi-Sensor Daily Fire Events in Brazil: The DescrEVE Relational Framework for Wildfire Monitoring

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This supplementary file provides extended methodological, implementation, and supporting material for the main manuscript. To improve the readability of the main text, detailed operational context, database mapping, and extended tables/figures are reported here as Supplementary Sections S1–S4.

S1. Operational and regulatory context

S1.1. Institutional and governance context (Brazil)

Within this institutional setting, the Federal Integrated Multi-Agency Coordination Center CIMAN [1] coordinates federal agencies under a shared command structure to improve resource allocation and response efficiency, as mandated by the *PNMIF* [1,2]. The *Sistema Nacional de Informações sobre Fogo* (SISFOGO) [3] organizes Brazil's official geospatial information infrastructure for monitoring fire occurrence across the national territory, integrating satellite-based products to support agencies at federal, state, and local levels. Within SISFOGO, geospatial services such as *DescrEVE Fogo* should be provide the situational picture needed for stakeholders to identify where fires are burning, what types of fires are occurring, and whether they remain active, under control, or already extinct, thereby helping to prioritize firefighting actions across multiple jurisdictions.

S1.2. Upstream data flow details (extended description)

The diagram of the end-to-end processing chain (see Figure S1) show how the system integrates data streams from both polar-orbiting and geostationary satellites into a unified database (*BDQueimadas*), which serves as the primary source of active-fire detections for Brazil. At the top of the workflow, the program continuously receives and collect earth observation data from those satellite constellations carrying the AVHRR, MODIS, and VIIRS sensors, complemented by geostationary platforms such as GOES and MSG.

The AVHRR data are acquired and processed internally at INPE's *Ground Image Division* (DGI), where raw satellite signals received at the Cuiabá–MT and Cachoeira Paulista–SP ground stations are decoded and transformed into Level-1 products [4]. Active-fire detections are then generated through the contextual algorithm described by Pereira et al. [5]. In parallel, MODIS and VIIRS detections are retrieved from NASA's FIRMS system [6], which applies the fire detection algorithms defined in the official Algorithm Theoretical Basis Documents (ATBDs) for each sensor family [7–9].

Although NASA periodically releases updated collections and minor algorithmic revisions for the MODIS and VIIRS active-fire products, the Queimadas Program ingests these detections as part of a single operational archive rather than maintaining parallel "Collection 5" or "Collection 6" time series. In practice, the active-fire database used here behaves as one internally consistent collection over 2003–2025: whenever upstream changes are incorporated into the workflow, they are assumed to preserve continuity at the daily and regional scales considered in this study. Given the spatial and temporal aggregation of our analyses, we therefore interpret the BDQueimadas record as a temporally coherent active-fire series over the 22-year period.

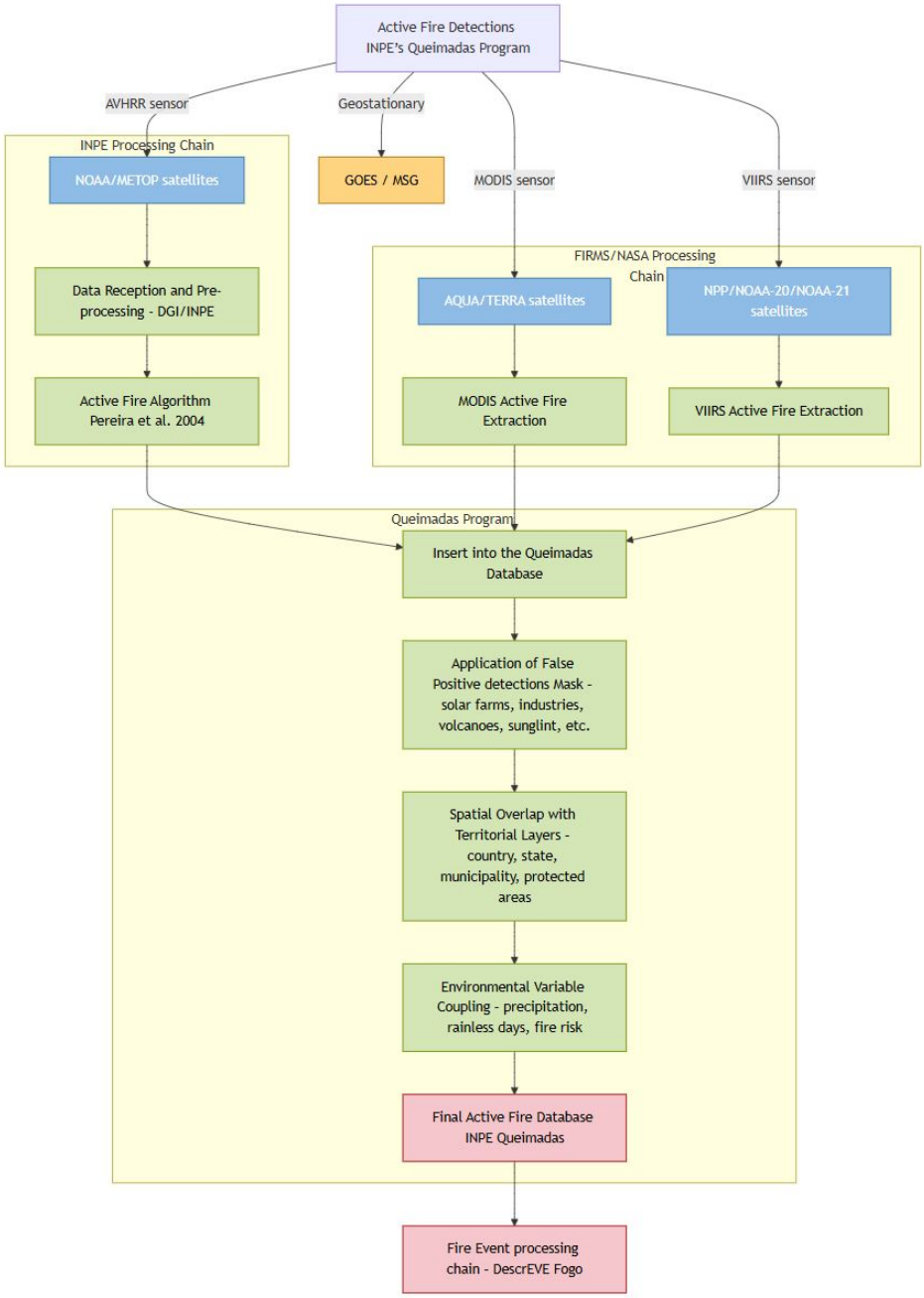


Figure S1. Processing chain of INPE's *Queimadas Program*, showing the integration of data from AVHRR, MODIS, VIIRS, and geostationary sensors into the BDQueimadas database, with subsequent filtering and enrichment steps leading to the final active-fire dataset used in this study.

S2. Database mapping and data dictionary

S2.1. Relational model overview (extended)

See Table S1 for a structured summary of these auxiliary link tables and normalized catalogs, detailing each table's role (provenance, spatial attachment, or semantic catalog), principal keys and constraints used to preserve referential integrity, and the cardinalities that govern their relationships—while intentionally omitting the core entities for fronts and events.

Auxiliary link tables (provenance and spatial attachment).

(a) `front_satellite`. This bridge table records the earth observation platform for each front as pairs (`id_front`, `id_sat`), supporting many-to-many provenance between fronts

Table S1. Auxiliary and normalized tables used in the database mapping. Core entities `focos_bdq_c2`, `fire_front`, `fire_event` are intentionally omitted. See the equations referenced in the main text.

Table	Role in the model	Key fields / constraints	Cardinality
`satellite`	Platform catalog for satellite/sensor families; referenced by provenance links.	`id_sat` (PK), `sat_name`.	1→N into `front_satellite`.
`front_satellite`	Provenance at the front level (front–satellite pairs); avoids duplicating sensor attributes in core tables.	(`id_front`, `id_sat`) composite PK/UK.	N↔N between `fire_front` and `satellite`.
`status_event`	Operational status catalog implementing Eq. 23 (*new*, *active*, *under observation*, *extinct*, *extinct by fusion*).	`id_status` (PK), `status_name`.	1→N into `fire_event`.
`fire_type`	Fire-type catalog for Eq. 35 (*New isolated fire event*, *Possible incipient wildfire*, *Wildfire*).	`id_type` (PK), `type_name`.	1→N into `event_type_fire`; also `event_fire.id_type`.
`event_type_fire`	Stores the chosen type per event (history normalized, orthogonal to the core record).	`id_event` (PK/UK), `id_type`; upsert on `id_event`.	1↔1 with `event_fire`.
`type_region`	Catalog of territorial/environmental classes (`city`, `state`, `biome`, `watershed`, etc.).	`id_type_reg` (PK), `type_name`.	1→N into `region`.
`region`	Reference layer (>14 000 polygons) for administrative/environmental reporting.	`id_region` (PK), `geom`, `id_type_reg`.	N↔N with `event_fire` via `event_region`.
`event_region`	Spatial attachment of events to polygons in `region`; enables roll-ups/drill-downs.	(`id_event`, `id_region`) composite PK/UK.	N↔N between `event_fire` and `region`.

and satellites. It allows auditability of detections (per sensor family) without duplicating attributes in the core front table such as the results discussed in Subsection 3.1 (see main text). *(b)* ***`event_region`***. This bridge attaches events to one or more polygons from the reference layer (`region`) through spatial overlay of the event perimeter with territorial units. The design supports multi-context tagging—an event can simultaneously belong to a municipality, state, biome, basin, or other classes—thus enabling coherent aggregation and reporting across heterogeneous administrative and environmental hierarchies.

Normalized catalogs (stable semantics).

(a) ***`satellite`***. The platform catalog stores stable identifiers for the satellite/sensor families used by the pipeline and is referenced via `front_satellite`. Its schema was intentionally prototyped to streamline the onboarding of additional Earth-observation platforms that may be incorporated into the *Programa Queimadas* active-fire collection.*(b)* ***`status_event`***. The fire event-status catalog enumerates the operational phases defined by Eq. 23 in the main text (e.g., *new isolated fire event*, *active*, *under observation*, *extinct*, *extinct by fusion*) and is referenced directly by `event_fire`. *(c)* ***`type_fire`***. The fire-type catalog provides stable labels for the rule in Eq. 35 in the main text (e.g., *New isolated fire event*, *Possible incipient wildfire*, *Wildfire*). *(d)* ***`event_type_fire`***. To keep the classification history orthogonal to the core record, the chosen type is persisted in a normalized one-to-one table (enforced by an `ON CONFLICT` upsert on `id_event`).

This permits reclassification (e.g., after perimeter growth) without risking inconsistent denormalized copies. Importantly, both `status_event` and `type_fire` are modeled as independent catalogs precisely to accommodate future extensions—such as additional statuses or fire-type categories recommended under Integrated Fire Management without altering the core event schema; new terms can be introduced by catalog insertion while preserving referential integrity across services.

Regional reference layer (multi-context event tagging).

`region` stores $>$14 000 polygons representing the principal territorial and environmental classes used by stakeholders (municipalities, states, macro-regions, agrarian settlements, Indigenous Lands, Conservation Units, biomes, and hydrographic basins). Each polygon is labeled by `id_type_reg`, which links to `type_region` (e.g., `city`, `state`, `biome`, `watershed`). Combined with `event_region`, this enables consistent roll-ups, drill-downs, and cross-cuts across administrative and environmental views without duplicating geometry or attributes.

Although this subsection is implementation-oriented, the level of detail provided here is directly linked to the scientific results in Section 3 in the main text. All event-level metrics discussed in this paper (area, duration, fire type, FRP, and environmental indicators) are computed from these normalized tables, which enforce explicit one-to-many relationships between detections, daily fronts, multi-day events, and their regional descriptors. Making the relational structure explicit clarifies how the conceptual variables introduced in Subsections 2.2.1 and 2.2.2 (as defined in the main text) are materialized as database entities, and ensures that the analytical products can be traced back to well-defined, persistent records in an operational system.

S3. Extended tables

Table S2. Fire event-level presence by polar-orbiting sensor families (any-sensor criterion). For each year, counts indicate the number of fire events that had at least one detection by the specified family. The total corresponds to events with at least one polar-orbiting detection in the year.

	Sensors			Total of Fire Events
Year	MODIS	AVHRR	VIIRS	(per year)
2003	261,149	220,998	0	452,548
2004	194,596	160,539	0	330,073
2005	250,732	149,455	0	377,477
2006	200,956	97,470	0	286,229
2007	280,609	122,117	0	383,647
2008	184,628	108,757	0	282,095
2009	149,911	71,835	0	215,635
2010	229,749	104,517	0	318,309
2011	135,733	53,666	0	183,529
2012	133,250	52,556	303,209	409,435
2013	107,207	29,902	268,503	346,329
2014	124,295	70,208	293,216	404,527
2015	135,990	92,391	319,699	454,703
2016	128,099	94,841	300,268	439,847
2017	119,429	124,126	271,079	423,998
2018	97,402	77,232	238,421	345,997
2019	108,752	73,155	393,270	486,943
2020	115,769	117,780	395,285	538,031
2021	106,866	50,330	403,377	483,145
2022	97,727	28,089	368,143	423,479
2023	96,546	25,179	342,162	395,671
2024	123,257	49,640	341,235	512,323

Notes: "any-sensor" means an event is counted for a family if it had at least one detection by that family in the year.

S4. References

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