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High-resolution landscape fire monitoring: satellite-guided reconstruction of ground-level air pollutants at ten minute and 500 m scale

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Abstract: Extreme landscape fires are intensifying under climate change, yet our ability to monitor the fine-scale evolution and health impacts of associated smoke remains constrained by the resolution, latency, and cloud sensitivity of traditional satellite and model products. This study presents a fused, high-resolution methodology for reconstructing near-ground-level pollutant concentrations (GLCs), including PM_1, $PM_{2.5}$, PM_{10}, and criteria pollutants CO, NO_2, SO_2, and O_3 at 500 m spatial and 10-minute temporal resolution, using Himawari-8/9 geostationary imagery integrated with Copernicus CAMS reanalysis.

Using the "5WH" framework, What, Where, When, Why, and How, we demonstrate a system that dynamically estimates over 60 pollutant fields across fire-affected domains. Target species include PM_1, $PM_{2.5}$, PM_{10}, CO, O_3, NO_2, SO_2, black carbon, and organic carbon, matching or exceeding the spatial and temporal resolution of CAMS reanalysis. Himawari's 16 bands provide rich spectral inputs: visible bands (1–4) for vegetation and aerosols, shortwave IR (5–7) for cloud phase and particle properties, and thermal IR (8–16) for vertical moisture structure, gas discrimination, and surface thermal gradients. Key brightness temperature differences (BTDs), including BTD07–08 (fire/RH), BTD13–11 (SO_2 vs aerosol), and BTD12–16 (O_3 vs CO_2), enable indirect detection even under cloud or haze.

Standard AOD products (e.g. MODIS Deep Blue, JAXA AOD) are hindered by low resolution and cloud masking. Coarse 0.75° CAMS spatial data cannot resolve plume dynamics near terrain, coasts, or urban centres. As demonstrated in composite comparisons, down sampling Himawari imagery to AOD or CAMS scale erases key spatial features. Our system retains native 500 m detail by using spectral deltas and red-band calibration. Land-use regression (e.g. proximity to roads or fires) is inadequate under extreme events, where direction, distance, and dynamic source–receptor relationships dominate. We instead derive buoyant plume rise (via spatial pressure gradients) and thermal plume rise (via spatial temperature gradients), along with ground temperature and wind vectors (U,V), directly from Himawari thermal fields at 500 m and 10-minute resolution, critical inputs for dispersion modelling. Events are located using all available spectral channels and then calibrated against CAMS data to determine their speciation and quantification. Rather than relying on dispersion modelling, we observe the evolving dynamics directly and quantify from the coarse CAMS data applied to precise locations. The method supports both real-time and retrospective analysis. Himawari imagery is processed at 10-minute intervals via a high-throughput pipeline (GDAL, CDO, NCO) on the NCI supercomputing cluster. CAMS fields are resampled in space and time, log-transformed, and used to compute localised slope fields ($\partial Y/\partial X$) against satellite predictors. This enables inference of near-surface pollutant fields even under cloud or observational gaps. Brightness temperature anomalies, spectral gradients, and red-shifted dynamics reveal fire plume emergence and exposure without reliance on conventional AOD, which often fails under bright terrain (dust) or high cloud cover (haze).

Case studies include the 2019–2020 Black Summer fires in southeast Australia. On 10 December 2019, a severe dust storm crossed NSW, producing high winds, dry air, and pre-heating of fuel loads, conditions which then intensified regional fire spread. Our method captured this sequence with improved timing (ten minutes) and spatial resolution (500m) compared to reanalysis. Validation against NSW surface monitors confirms improved magnitude and resolution of $PM_{2.5}$, PM_{10} and O_3 fields. An expanded analysis of the Kalimantan peat fires (Sept 2019) evaluates ozone and PM signatures across Indonesia, Malaysia, and Vietnam. We demonstrate how regional dynamics differentiate between local photochemistry and transboundary smoke transport, with implications for accountability and mitigation.

This approach overcomes key limitations of traditional AOD-based systems by operating in native Himawari resolution and frequency, with demonstrated sensitivity to rapid-onset, fine-scale hazards missed by conventional reanalysis. It enables high-granularity exposure reconstruction, supports public health and epidemiological applications, and is scalable to other under-monitored, fire-prone regions in Australasia and Southeast Asia. By fusing geostationary satellite data, high-frequency dynamic modelling, and surface calibration, this method advances exposure risk assessment and improves air quality communication under a changing climate.

Keywords: *environmental modelling, landscape fires, air pollution, health impact assessment, climate change*

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