

**Supplementary material for Guyot et al.**  
**Mobile weather radar to provide intelligence on wildfire hazards**

**Supplementary Material 1: Dataset and methods for Wallangara demonstration case**

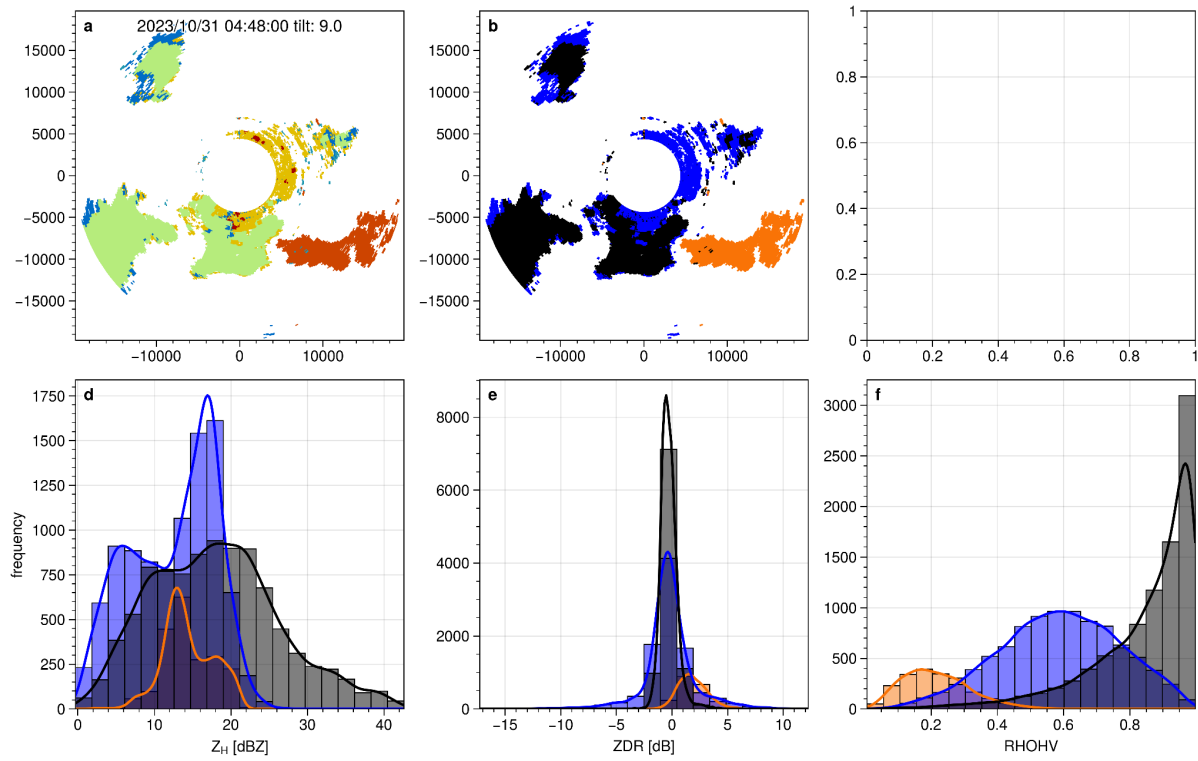
This radar dataset consists of full volumes including 12 tilts each (from 3 to 25 degrees with steps of 2 degrees), timestamps every two minutes, and was filtered with  $\text{SNR} < 2$ , for range  $< 40$  km, and altitude  $< 12$  km to avoid spurious echoes. The first step in the radar data processing consisted of echo segmentation following the methodology described in Segmentation of polarimetric radar imagery using statistical texture. As in Guyot et al. (2023), statistical texture fields were first derived from the polarimetric variables RHOHV and ZDR using a moving-window approach to characterise local spatial variability. These texture fields were then combined with the original radar variables (DBZH, VRADH, WRADH, ZDR, RHOHV) and the altitude of each radar voxel to form a multidimensional feature space. A Gaussian Mixture Model (GMM) was applied to this feature set, and the optimal number of clusters was determined objectively (six clusters). The resulting clusters were subsequently interpreted and labelled based on their polarimetric and spatial characteristics, yielding a classification of radar echoes into ground clutter, rainfall, and pyrometeors (Sup Fig. 1A). No hail or clear-air biological echoes (e.g. insects) were observed during this event; therefore, no clusters were defined for these classes. The segmentation approach follows the same general concept as the initial classification method proposed by McCarthy et al. (2020) using the same radar platform. However, two key modifications were introduced. First, additional statistical texture fields were incorporated, which are particularly beneficial when processing full radar volumes (i.e. stacked PPIs), as they enhance discrimination between heterogeneous and homogeneous echo regions. Second, a two-step segmentation strategy was implemented for pyrometeors. The initial segmentation step isolates pyrometeor echoes from other classes (e.g. rainfall and ground clutter). A subsequent segmentation is then applied exclusively to the extracted pyrometeor class to identify, where present, voxels potentially containing highly elongated, anisotropic pyrometeors (e.g. firebrands) characterised by large axis ratios.

The results of that segmentation can be seen in Fig. S1 for a selected time and for the lowest PPI sweep (3 degree). Data within the 5 km range of the radar have been excluded as the radar was running a dual PRF, and introduced artefacts due to change in sensitivity at the 5 km mark. In any case, there was no data of interest (pyrometeor or rainfall) within that 5 km radius. The first panel shows the initial 6 clusters, with 3 clusters linked to rainfall (yellow, blue and red), 2 linked to ground clutter (clear and dark green), and one to pyrometeors (dark orange). This initial classification was then re-labelled into the three classes of ground clutter, rainfall and pyrometeors as shown in Fig. S1 b and the histograms of Fig. S1 c-e depicting DBZH, RHOHV and ZDR. One can see the strong overlap between these

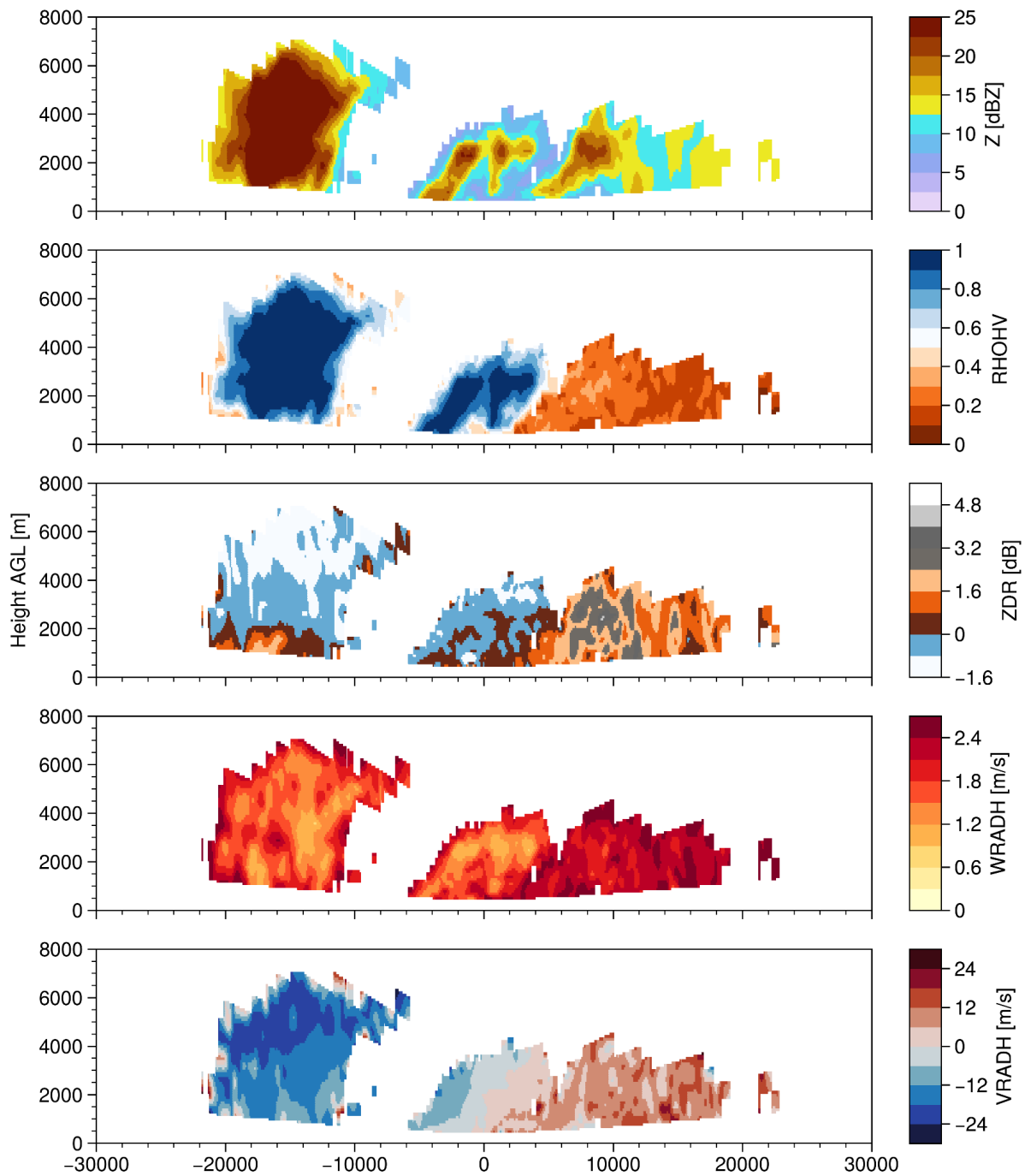
variables, highlighting the need to include texture fields as additional features to help the algorithm segment these echoes. Following this process, all volumes were segmented into these three classes.

After that first segmentation, plume echoes only (pyrometeors) can be extracted for further classification. Echo classification within the plume was performed using a Gaussian Mixture Model (GMM) applied to polarimetric radar variables. Three components were fitted in feature space (DBZH, ZDR, RHOHV and WRADH), allowing separation between background/weak returns and high-intensity, highly anisotropic echoes. Two of these components, both characterized by elevated reflectivity and enhanced differential reflectivity, were subsequently merged into a single pyrometeor class, encompassing dense ash particles and potential firebrands, labelled thereafter “Enhanced Pyrometeors Clusters” or EPC. To better capture the asymmetric distribution of ZDR typical of lofted debris, additional emphasis was placed on the high-ZDR tail during clustering (i.e., by increasing its influence in feature space), ensuring that rare but physically meaningful large-ZDR returns were not diluted by the dominant low-ZDR population. The resulting labels were then used to derive class-specific plume metrics and spatial statistics.

We derive plume geometry metrics from gridded radar reflectivity by first isolating the plume echo and then measuring its dominant orientation and cross-plume structure in a consistent reference frame. For each time step, we extract a 3-D plume mask from the radar grid (reflectivity thresholding with basic cleanup to remove isolated speckle) and compute bulk properties such as plume voxel count and volume (voxel count multiplied by the fixed grid-cell volume), along with intensity metrics (e.g., percentile reflectivity within the mask). The plume main axis is estimated from the 2-D footprint of the masked reflectivity at a fixed analysis height (e.g.,  $z$  index 10  $\approx$  1 km AGL) using a weighted principal-component approach, where reflectivity values provide weights so that high-DBZ cores influence the axis while lower-DBZ plume returns still contribute. The resulting principal direction defines two endpoints ( $p_0$ – $p_1$ ) that are stabilized in time (and, when needed, oriented using a known downwind/source constraint) to avoid sign flips. Once the axis is defined, we project plume voxels onto the along-axis coordinate to estimate plume length, and we sample perpendicular “slabs” normal to the axis to compute cross-sectional metrics such as width (e.g., percentile/threshold-based span), area, and derived shape ratios, alongside time series of bearing, axis stability, and quality flags. The axis ratio is defined as the ratio of the major to minor spatial variance derived from the weighted PCA of the plume mask, providing a measure of plume elongation independent of absolute size.



**Figure S1.** Segmentation of weather radar echoes, showing: (a) all clusters; (b) merged clusters into ground clutter (blue), hydrometeors (black), pyrometeors (orange); (c) histogram of DBZH/ZH [dBZ]; (d) ZDR [dB]; (e) RHOHV [-].



**Figure S2.** Cross section of plume interacting with a precipitating cloud (Congestus F.).