Review

This paper is an ambitious and very timely study that introduces a novel methodology for in-plume radiosonde profiling during wildfires. The paper offers new insights into fire–atmosphere interactions and pyroconvection dynamics, which is an active area of research that needs further exploring. The indicators of potential transitions to extreme behavior help identify plume top heights and characterize pyroconvection prototypes, which are notable contributions that will help fire management better understand fire behavior. The authors also provide one of the most extensive datasets of simultaneous ambient and in-plume profiles to date. While the paper offers key contributions and advancements, the authors must refine the write-up to be more consistent and coherent, improve the visualization of figures, and clarify ambiguous points in the text to enhance readability. Please find comments and suggestions below:

Clarify/highlight key contributions:

- I suggest restructuring the early stages of the paper to highlight key contributions and advancements more clearly in the beginning. For example, line 466: "Observing the plume top dilution just below the Lifting Condensation Level (LCL) in real-time is a unique and valuable aspect of this methodology."

Thanks for the comment.

Yes, in the revised version, we have proposed a more comprehensive description of the state of the art. We have placed this methodology in a better context, enabling us to determine, using real-time state variables, whether pyroconvection would occur. As such, these new data and its analysis in conserved variables provide reliable information for informed strategic, tactical, and safety decision-making.

In response to the author's comment in line 466, we changed the text:

> ***Old version:***
>
> *Unlike the Rojals fire, this case shows evidence of a potential transition from a convective plume prototype to an overshooting pyroCu prototype, as suggested by MU parcel. Observing the plume top dilution just below the Lifting Condensation Level (LCL) in real-time is a unique and valuable aspect of this methodology. Thanks to these in-situ profiles, crews left for safety zones, and 2 hours later, the formation of an opyroCu worsened the spread of the fire.*
>
> ***New version:***
>
> *In contrast to the Rojals fire, this case provides evidence of a potential transition from a convective plume to an overshooting pyroCu prototype, as indicated by the MU parcel. Real-time observations revealed that the plume top was close to the lifting condensation level (LCL), even though the fireline intensity was moderate at that moment. This observation, along with firefighters' reports of an increasing rate of fire spread, alerted us to a possible sudden and dangerous change in fire behavior, catching the firefighters off guard. There, the in-situ profiles and their analysis using a systematic criteria of pyrcoumulus formation (Castellnou et al., 2022) were key to provide warnings and take decisions to movethe crews to safety zones. Two hours later, the formation of a pyroCu confirmed the expected intensification of the fire. This aspect of the methodology is both unique and valuable, as it enables proactive tactical adjustments to enhance safety.*

Following the comment to address the firefighter safety in the paper, and as proposed in the answer to RC1 comments, we have added a table clarifying how the information has been used for decision-making.

Indeed, to highlight the key safety contributions of the proposed methodology in each case shown in the paper, we have added safety/awareness information to the tables accompanying Figures 3 and 9-12. The new information describes how the in-situ radiosondes confirmed or added new information to the analysis that the numerical model data couldn't provide.

Fire event	*Region*	*Fuel*	*in-plume hour (UTC)*	*Ambient hour (UTC)*	*area (ha), (Total / hour)*	*FLI (kW·m-1)*	*ROS (m·s-1)*	*FRE (TJ)*	*Prototype*
Granja d'Escarp 03-07-2024	*ME*	*TU5*	*16:37*	*16:58*	*118 / 36*	*26741*	*1.05*	*2.1*	*Convective*
	Sonde confirms model proposed no pyroconvection transition.								
La Selva del Camp 03-08-2023	*ME*	*SH5*	*15:33*	*15:50*	*3.2 / 0.09*	*1258*	*0.029*	*n. d.*	*Surface*
	Sonde identified an unexpected (by numerical model) pyroCu potential, prompting monitoring and safety debriefing for firefighters. This change modified tactical priorities.								

● The title and abstract imply that the paper holds important implications for firefighter safety. This is also foreshadowed in Lines 79-80 but not directly addressed in the paper. Currently, it seems that safety is only discussed in terms of data collection. I recommend including a sub-section or paragraph that discusses how the paper's methods and results can be used for firefighter safety.

We value this comment. The paper focuses on providing a safe methodology for gathering detailed and in situ information about the pyroconvection prototype and the transition between prototypes. Awareness of such processes is crucial for ensuring the safety of firefighters and civilians in the fire area.

The current operational analysis processes, although improved from their previous state, are still based on numerical model data that is uncertain in terms of potential changes of the weather due to local phenomena and/or the wildfire-weather interaction (see answer to Pedro Oria and the new proposed Figure S8) or utilize satellite geostationary information that can only provide reactive safety to ongoing processes.

In the text, we have insisted on the use of the proposed methodology in:

a) *Ambient radiosondes complement the numerical models results by adding almost real time and the local meteorological conditions, so the analysis is more robust since it incorporates the local geography and weather-induced change due to the interaction of fire or local meteorology*
b) *In-plume sondes can register the fire-induced changes in ABL and LCL levels. Therefore, we have a more accurate quantification of changes in height and in the time of the fire-atmosphere coupled situation. This information can be contrasted with available numerical results and improve our predictions in a very short time*
c) *Importantly, the information is ready to be used directly on the fireline by the incident management team*

In the previous comment, we have reinforced the safety approach by adding the accompanying tables to Figures 3 and 9-12

Also, as stated in the previous comment, in the answer to RC1 we include a table in the available data signaling the use of every sonde information for decision making, classifying it for safety, strategy, tactics. Together, the new table and the new information in the figures added focus in sondes use for firefighter safety and highlights how sondes in our campaigns have been used for incident management teams. This new information is summarized in new section 3.4, that is renamed from 'Failed profiles' to 'Usability of plume profiling methodology'

In this new text, we also addressed concerns about safety for sonde launching during ongoing pyroCb events and their complex conditions due to downdraft-driven chaotic fire behavior.

Old text:

‘3.4 Failed profiles

It is important to note that during the campaigns, we did not observe detrained sondes from the plume once the sonde entered the plume neck. However, we have had cases of sondes failing to enter the plume or entering the plume at higher altitudes when we launch into weak or intermittent indraft conditions. Those cases have always been reported with launching conditions too far away from the head fire (Figure S4) or when we launch into a decaying head fire, and there are strong surface winds present (>6 m·s-1). ‘

New text:

‘3.4 Usability of Plume Profiling for Incident Management in Extreme Fire Events

During the five years of fire campaigns conducted from 2021 to 2025, we compiled and analyzed data that clearly supported our methodology of using paired ambient-in-plume profiling with radiosondes on active wildfires (see Table 4). The methodology demonstrated a low failure rate of 7.7% and was instrumental in adapting operational tactics in 39.7% of our case studies. Additionally, it enabled us to safely retire all firefighters to the safety zone in 7% of the cases.

It's important to note that during the campaigns, sondes that failed to enter the plume updraft typically did so because they were launched too far from the plume base, landing in weak or intermittent indrafts (see Figure S4), unable to keep them in the indraft flow to the base of the plume and its updraft. This often occurred in the head or flank indrafts. In contrast, rear indraft sondes, which travel in the main indraft into the plume, are normally able to reach the plume updraft and deliver a full plume profiling.

This finding is particularly significant in the context of extreme pyroconvective fires. Deep plumes and fully developed pyroconvective clouds (pyroCbs) create stronger rear indrafts, which facilitate the safe launch of sondes from distances that ensure the safety of the launching team. This phenomenon was observed during rear indraft in-plume launches of sondes in the Santa Coloma Queralt 2021 fire (SCQ21) and the Guissona 2025 fire (Gui25). In both instances, the sondes were launched at 2.2 km (SCQ21) and 9.3 km (Gui25) into a strong rear indraft, successfully entering the plume and reaching altitudes above 8,000 meters.

Table 4.- Summary of success and use in decision making of the sondes launched).

<table>
<tr><td>Type of sonde</td><td>Proportion over total sondes</td><td colspan="2">description</td></tr>
<tr><td rowspan="3">Failed sondes</td><td rowspan="3">7.73%</td><td colspan="2">61.3% too weak indraft, or launching too far away</td></tr>
<tr><td colspan="2">23% pushed to the ground by rear indraft</td></tr>
<tr><td colspan="2">15.3% due to sonde failure</td></tr>
<tr><td rowspan="3">operational</td><td rowspan="3">73.27%</td><td>Awareness</td><td>34.1%</td></tr>
<tr><td>Tactical</td><td>32.7%</td></tr>
<tr><td>Safety</td><td>7%</td></tr>
<tr><td>Research</td><td>19%</td><td colspan="2"></td></tr>
</table>

Improving the visualization of main figures:

● Figure 1: The proportion of the observations are difficult to differentiate. I suggest adding a text label denoting the relative proportion for each country/region (e.g., ME, 44.73%, AE, 3.29%, SA, 51.98%). Also, since the symbols are difficult to see, it would help to see the distribution of observations by fire type and by country/region (e.g., additional stacked bar plots)

Thanks for helping to improve the Figures. Yes, we have added the labels and differentiated fire types. We also added the extra sondes launched during the 2025 European fire season. The new Figure will look:

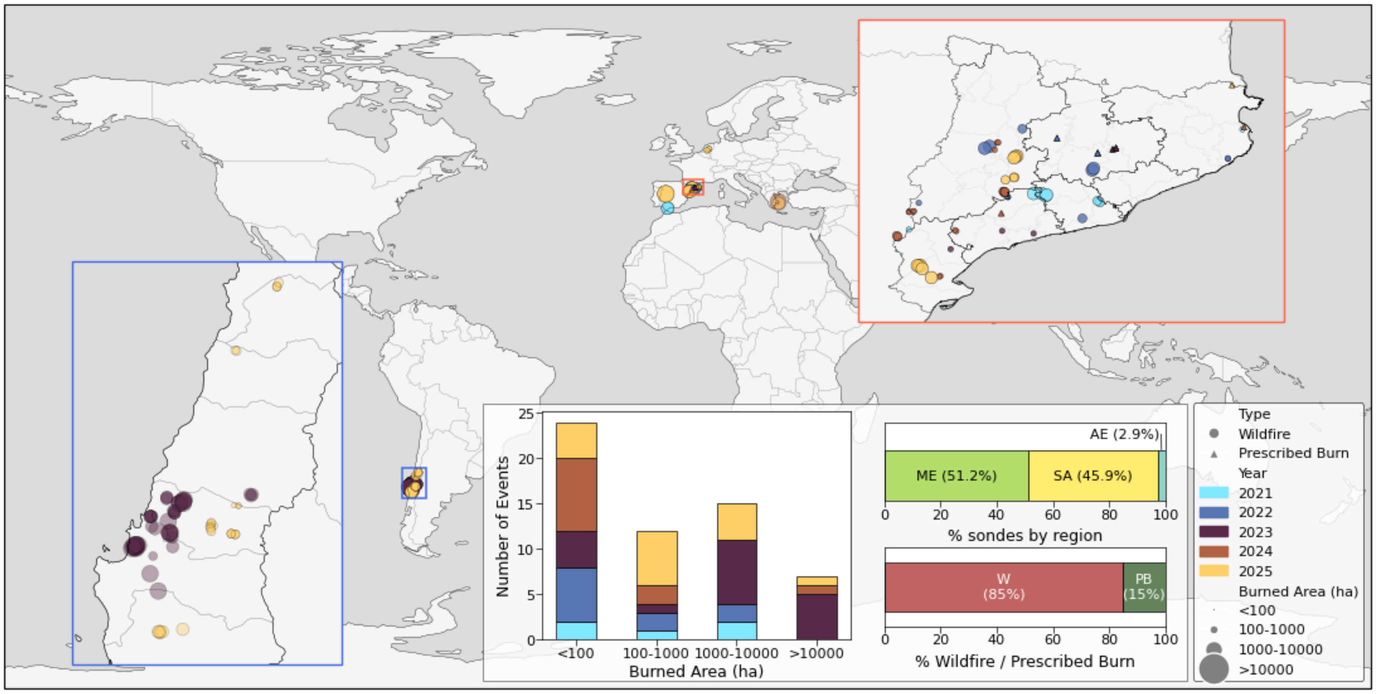
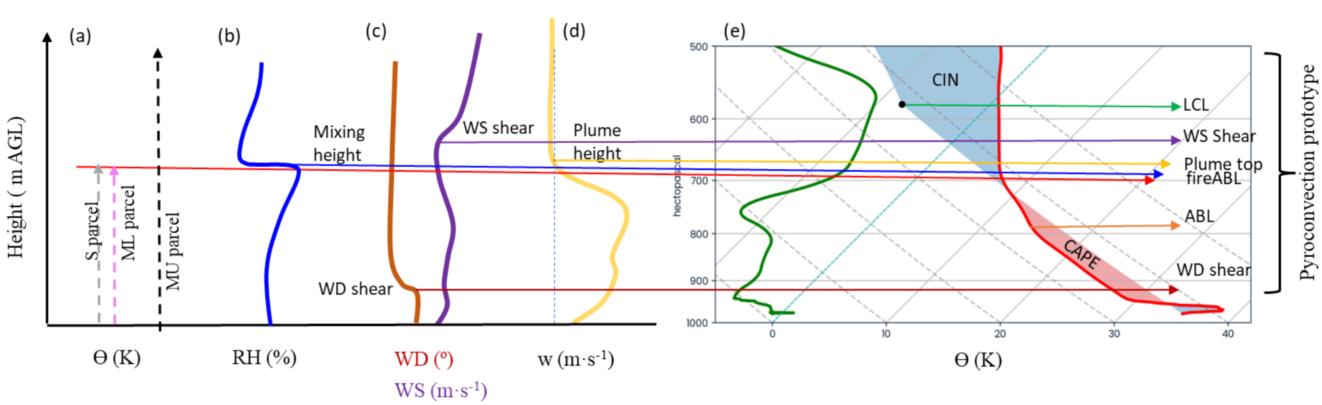


Figure 1: Location of the 173 in-plume profile observations during the radiosonde campaigns conducted between 2021 and 2025. Sondes are identified based on whether they were launched during wildfires (circle) or prescribed fires (triangle). The color of each dot represents the campaign year, while the size of the dot reflects the total fire size (in hectares). The distribution of the sondes by fire sizes, region, and type of fire (wildfire or prescribed fire) is shown in the bar plots to highlight the range in which the methodology has been tested. Last updated: September 15th, 2025.

● Figure 3: Please update the horizontal axis labels so that they are consistent (i.e., Panel a): θ (K) and Panel e): Temperature (oC))

Thanks for spotting the detail. We have solved the issue

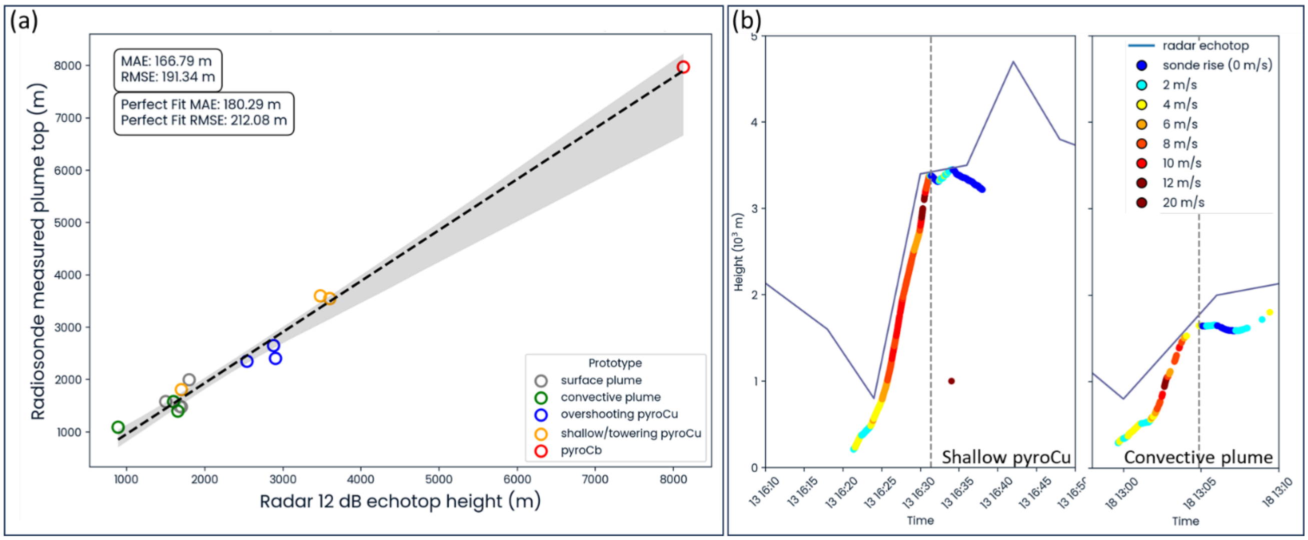


● Figure 4: Please update the bottom table of the figure. I suggest to rename the contents of “Fire event”, expand “Reg” (i.e., region), and write the fuel model code instead of as a number. Also, under “Ambient Hour”, there are two times for Granja d’Escarp.

We have solved the issue and translated the table changes to Figures 9, 10, 11, and 12. Now the figures are consistent. This is shown in the previous comment about the table in the first comment of this reviewer

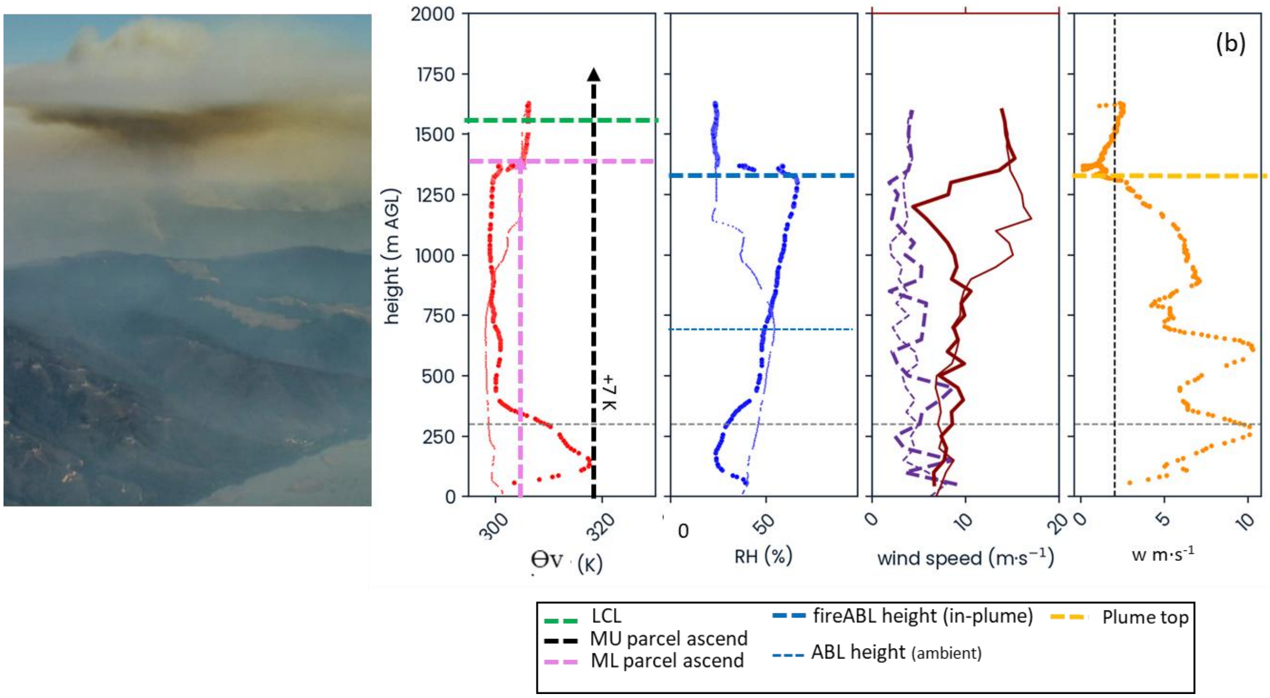
● Figure 8: I suggest updating the legend for plot a). First, I suggest using the full names of the prototypes. Second, I suggest changing the font formatting of the legend and axis labels to be more visible. Please also edit the x-axis label. Third, I suggest re-ordering/modifying the visibility of the symbols (e.g., Re-order so symbols appear on top or change the transparency). Fourth, for plot b), please edit the typo in the legend to "radar echotop"

We solved the issue on the Figure, adding the changes to the proposed modifications of RC1:



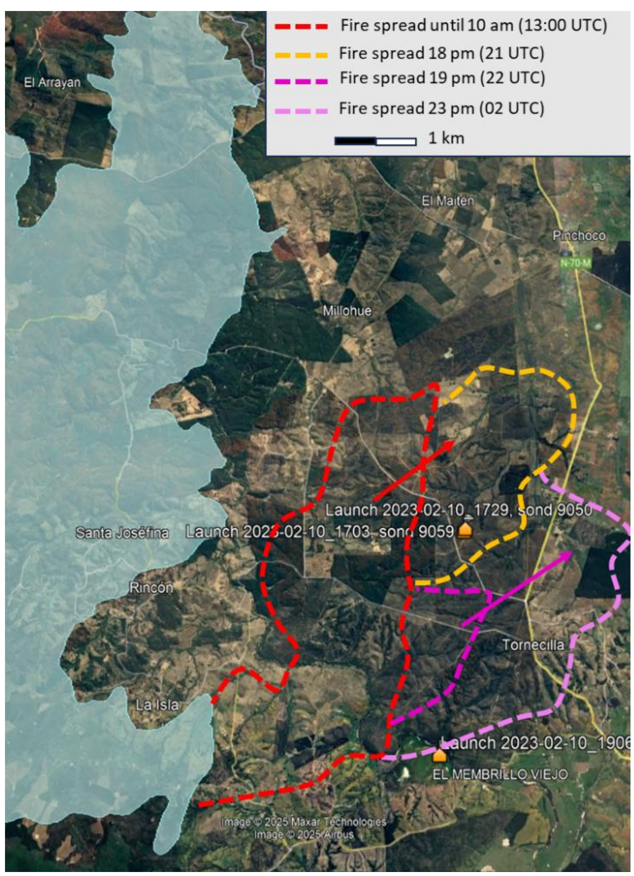
● Figures 9-12: Please edit the spacing of the plots in a) and b). Currently, the x-axis labels are overlapping. Also, please edit the "Fire event" names,

We have solved the issue by incrementing the spacing between subplots and tilting the x-axis labels. We provide an example for the Figure 9b profiles. The rest of the plots in Figure 9-12 have been updated accordingly:



● Figure 12: In the legend, the time formatting is incorrect (Check AM and PM) and the line symbol for “Fire spread 19pm to 2am” is missing.

We have solved the issue, the right figure is:



Clarification

● In Line 171, why should the soundings be taken “no more than 1 hour apart”? Is there any supporting citation or any reasoning?

Thanks for the comment, we updated our text.

Old version:

'Our strategy and primary objective were to systematically obtain (1) an ambient sonde outside the shading of the plume and (2) an in-plume sonde, launched close enough to the plume into the indraft, capturing the fire-induced changes in the atmospheric boundary layer (ABL). Both soundings should be taken no more than 1 hour apart (Figure 2)'.

New version:

'Our strategy and primary objective are to systematically obtain (1) an ambient sonde outside the influence of the wildfire and (2) an in-plume sonde, launched into the updraft, capturing the fire-induced changes in the atmospheric boundary layer (ABL). Soundings should be taken no more than 1 hour apart (Figure 2) due to the ABL's response time of approximately one hour or less (Granados et al. 2012, Liu & Liang 2010, Stull, 1988). This maximum time ensures that the ambient and in-plume soundings remain comparable'.

● Line 424: Why was the estimated plume top defined as the maximum height where radar reflectivity was equal or higher than 12 dBz?

In section 2.5.2 of the methodology, we have clarified the echotop value used to filter the radar data. Our decision was based on the work of Krishna et al. (2024), which suggests that the plume top should be retrieved at an echotop of 10 dBz or higher. To ensure safety, we chose a threshold of 12 dBz.

Krishna, M., Saide, P. E., Ye, X., Turney, F. A., Hair, J. W., Fenn, M., & Shingler, T. (2024). Evaluation of wildfire plume injection heights estimated from operational weather radar observations using airborne Lidar retrievals. Journal of Geophysical Research: Atmospheres, 129(9), e2023JD039926.

Old version:

'2.5.2 Data collection for post-analysis and research

- *Radar measured echotop. It is a proxy measure for the plume top. We analyze the radar echotop height (m) using radar data from the Servei Català de Meteorologia (www.meteo.cat). We filter the radar echotop data and define the estimated plume top as the maximum height where the reflectivity value equals or is higher than 12 dBZ. Unfortunately, the data for all fires is not available. This dataset is utilized to validate the estimates of plume tops collected from in-plume radiosondes during 18 wildfires'.*

New version:

'2.5.2 Data collection for post-analysis and research

- *Radar measured echotop. It is a proxy measure for the plume top. We analyze the radar echotop height (m) using radar data from the Servei Català de Meteorologia (www.meteo.cat). The data treatment is the following. We filter the radar echotop data and define the estimated plume top as the maximum height where the reflectivity value equals or is higher than 12 dBZ (Krishna et al, 2023). Unfortunately, the data for all fires is not available. This dataset is utilized to validate the estimates of plume tops collected from in-plume radiosondes during 18 wildfires'.*

● Line 449: It is difficult to recognize the "excess of 7K". I suggest explaining the surface temperature values or labeling them to make this observation clearer

We have labeled the Tª excess on the plot for clarity (see improved final Figures in previous comment about Figures 3 and 9-12)

● Line 454: The authors claim that "the theoretical undiluted updraft height, estimated using the MU parcel method (black dashed arrow), is located at 980 m AGL". However, Figure 9A shows that the black dashed arrow lies above 1000 m AGL. There are many lines and colors in the plots, which make the figure difficult to understand. While the figure captions seem well-explained, the authors should clearly define each line and color as well as provide ample reasoning for deciding on specific values (e.g., 980m AGL) in the text to enhance readability.

We have reorganized the legend and lines in the plots to clarify its reading. It is shown in previous comments about Figures 3 and 9-12

Minor Comments

● Explicitly refer to ICON-EU as the atmospheric model

*In section 2.4, we complement the text to identify ICON_EU as the atmospheric model when possible. It is not available in South America, where we shift to ICON (13*13 km):*

***Old version**:*

- *Framing the day vertical atmospheric profile conditions:*

  *We utilize the ICON-EU 7*7 km2 resolution simulated atmospheric vertical profile to understand the general conditions we can expect (https://www.dwd.de/EN/ourservices/nwp_forecast_data/nwp_forecast_data.html).*

New version:

- *Framing the day vertical atmospheric profile conditions with atmospheric numerical models:*

  We utilize the ICON (13 km^2 horizontal resolution) global model as a reference. In using the meteorlogical values in Europe with ICON-EU, we use a finer 7 km^2 resolution. The modeled atmospheric profile identifies the general conditions, without local topography or fire-induced changes, we can expect in the fire area (https://www.dwd.de/EN/ourservices/nwp_forecast_data/nwp_forecast_data.html).

Also, in the text, every time we refer to the ICON we make sure we refer to ICON-EU or ICON accordingly

● Please add the short-form abbreviations of each prototype in Table 3. I suggest adding them inside brackets below each prototype under the column "Pyroconvective Prototype"

Done

● Please explain the state variables recorded by the in-plume (updraft) sonde or explicitly refer to Table 2. The authors state that the in-plume sonde is classified based on its position (head, flank, rear). Does this imply that, ideally, users should launch individual sondes at each position to address turbulence experienced near the head direction of the fire?

The estate variables are the same for the ambient as the in-plume sondes. Those are explained in point 2.5.1 and complemented in appendix S3.

In regard to the in-plume (updraft), we recognize that different launch positions around the plume can capture varying induced indrafts at the surface, as discussed in section 2.4 and illustrated in Figure 2. We differentiate

the different launching positions by the type of induced indrafts in the surface that will transport the sonde into the plume updraft, as discussed in section 2.4 and illustrated in Figure 2, to analyze them separately. This will allow us to assess each launching position sensitivity on gathering the information needed for the awareness of the pyroconvection prototypes transition.

Old version:

- *In-plume or updraft sonde:*

  Launched near the flame front into the plumes' indraft, the device measures state variables affected by the fire-atmosphere interaction. However, turbulence around the head of the fire can significantly impact the readings. To address this issue, we classified each updraft sonde based on its position relative to the plume's indraft, using categories: head indraft (downwind from head fire front), flank indraft (on the flanks), or rear indraft (upwind from the head fire front) launching positions (Figure 2). This classification ensures interoperability among sondes of the same kind of indraft.

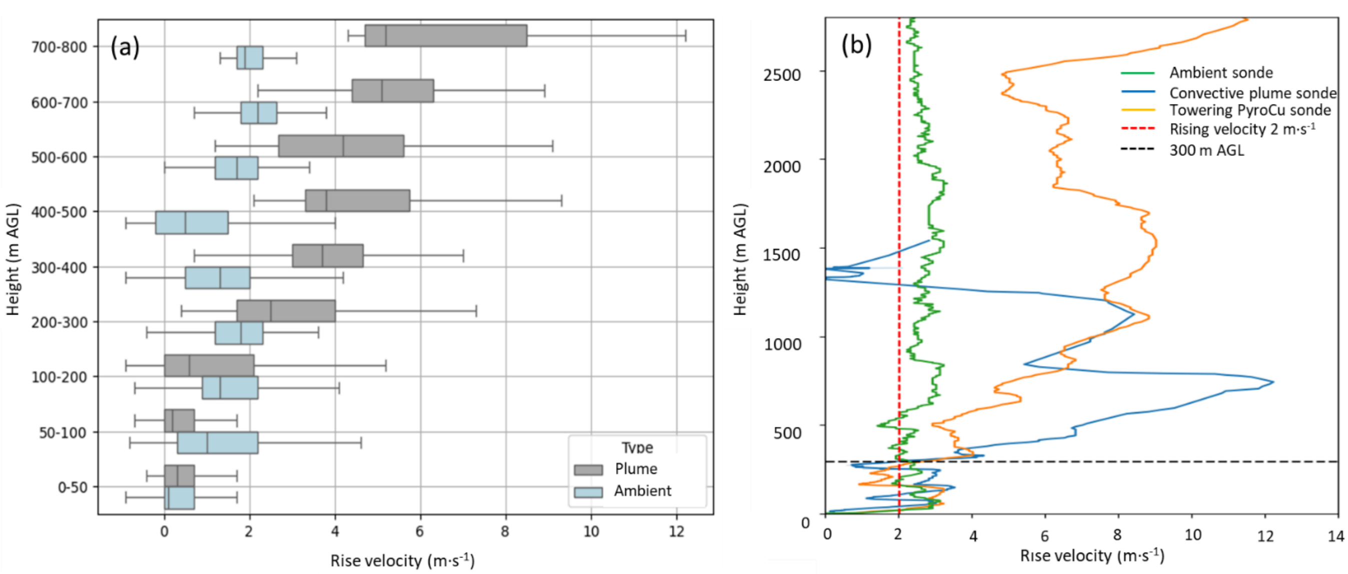
New version:

- *In-plume (updraft) sonde:*

  Launched near the flame front into the indraft of the plume, the device is pulled into the plume and rises with the updraft. It measures the state variables affected by the turbulent interactions between the fire and the atmosphere. The intensity of the indraft and turbulence varies significantly from the head to the rear and flanks of the fire. To analyze the sondes sensitivity on capturing the characteristics of the plume updraft for the different launching positions, we classified each in-plume sonde by its launch type (Figure 2): head indraft (downwind from the fire front), flank indraft (on the flanks), and rear indraft (upwind). This classification ensures the interoperability of sondes within the same indraft.

● Please use consistent terminology in the paper. For instance, in Figure 7, I suggest using "Ambient" and "In-plume" (instead of "Environment").

Solved:



● Please provide a citation or reference to "the previous analysis" on Line 420

Thanks for the observation. We propose changes to clarify the text:

Old version:

‘Based on rising velocities, the previous analysis provided a first-order estimate of the plume's top height’.

New version:

Our analysis of the rise velocity porofiles as presented in Figures 6 and 7 shows us that this variable is a first-order criterion to estimate the top height of the plume the plume’s top height’.

New Bibliography due to this revision

Granados-Muñoz, M. J., Navas-Guzmán, F., Bravo-Aranda, J. A., Guerrero-Rascado, J. L., Lyamani, H., Fernández-Gálvez, J., & Alados-Arboledas, L. (2012). Automatic determination of the planetary boundary layer height using lidar: One-year analysis over southeastern Spain. Journal of Geophysical Research: Atmospheres, 117(D18).

Krishna, M., Saide, P. E., Ye, X., Turney, F. A., Hair, J. W., Fenn, M., & Shingler, T. (2024). Evaluation of wildfire plume injection heights estimated from operational weather radar observations using airborne Lidar retrievals. Journal of Geophysical Research: Atmospheres, 129(9), e2023JD039926.