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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Evolution of an extreme Pyrocumulonimbus-driven wildfire event in Tasmania, Australia" *by* Mercy N. Ndalila et al.

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RC: This article by Ndalila et al. presents the concomitant analysis of a wildfire plume, which produced a pyroCb, and surface fire behaviour. I quite enjoyed reading the paper, and I am quite familiar with the area where the fire took place. My research interests include the use of weather radar to monitor fire plumes, therefore I felt it useful to provide some comments that might help improve the paper.

Overall, I feel that the radar data, possibly making half of the paper content (the other half being fire behaviour observations) are well under-utilised by the authors. For instance, I am surprised that the authors did not show and discuss radar observations of the Doppler velocity? We have shown in Terrasson et al. (2019) that these can provide

great insights into the dynamics of the PyroCb, including convection, shear, vortices etc. Its derivative, i.e. the spectrum width as we showed in Terrasson et al. (2019) and McCarthy et al. (2017; 2018) can also give great insights. Here, the radar data is only presented as a time-series of integrated variables in one figure of the article, which gives limited information. The Figure S3 in the supplementary material shows only cross sections of the Reflectivity, without colour scale, which is really limited. Recent work by McCarthy et al. (2019) and number of papers from Lareau and Clements show that radar observations can be utilised to draw multiple quantitative and qualitative information: this richness must be utilised.

AC: We greatly appreciate the reviewer's comments about making further use of the radar data. However, we feel that including all of the work suggested by the reviewer would go well beyond the intended scope of the manuscript, which was to provide a qualitative description of the evolution of the Forcett-Dunalley fire and pyroCb, and their relation to coincident surface weather and lower atmospheric conditions. Indeed, we feel that it would be more appropriate to pursue the work suggested by the reviewer in a separate and more detailed quantitative analysis, drawing upon the work of Terrasson et al. (2019) and McCarthy et al. (2019). We have amended the discussion to specifically note this as a natural extension of the qualitative analysis presented in the manuscript.

Additionally, an aspect of the Sir Ivan fire in Terrasson et al. (2019) was that the pyroCb was a supercell, which is a more organised type of thunderstorm, with more to investigate in the radar data. There's no evidence of that in Dunalley, but this might make a similar analysis more interesting as a complement to that study.

The section in the discussion now reads: "... radars remain a reliable data source that can provide near-real time monitoring of strong pyroconvection, as evidenced by previous pyroCb studies in Australia and globally (Rosenfeld et al., 2007; Fromm et al., 2012; Lareau and Clements, 2016; Dowdy et al., 2017; Peace et al., 2017; Lareau et al., 2018; Terrasson et al., 2019). This study did not analyse radial velocity from the Doppler radar; therefore future research on the Forcett-Dunalley fire and other fires should consider using that information to provide a more quantitative analysis of the thunderstorm, drawing upon previous work in Australia (McCarthy et al., 2019; Terrasson et al., 2019). A feature of our study was linking plume evolution to fire severity mapping - an approach that has received limited attention".

RC: Specific comments below: RC: 1. Title: " . . .Pyrocumulonimbus-driven . . .." We know of the feedback loop between surface fire behaviour and pyroCb, but it reads as if the fire was influenced by the PyroCb and not the other way around. What do you mean by "Extreme PyroCb", how does it differ from a standard PyroCb? The use of more scientific rather than emotive language should be preferred.

AC: Noted. Actually, extreme in this case describes the wildfire event, not the pyroCb. Regarding the statement that the title supposes that the pyroCb caused the extreme fire, that is also true, although we meant, as you correctly put, that the extreme fire caused the pyroCb.

A new title now reads: "Evolution of a pyrocumulonimbus event associated with an extreme wildfire in Tasmania, Australia".

RC: 2. L34 and other occurrences in the article. Shouldn't references listed in brackets be in chronological order?

AC: Noted. All the references are now in chronological order.

RC: 3. L36: this seems somehow restrictive, as not only atmospheric instability but wind shear and mesoscale conditions can drive fire behaviour.

AC: We have rephrased the sentence to read: "While fire weather is most often understood as a surface phenomenon (for example, through surface temperature, wind speed and relative humidity), atmospheric processes such as instability, wind shear and mesoscale conditions can also drive extreme fire development".

RC: 4. L44; Chronological order

AC: Noted. The references are now in chronological order.

RC: 5. Melnikov et al. (2008) does not present observations of PyroCb so the reference should not be cited here. Authors should also cite Terrasson et al. (2009) in which we report detailed radar observations of a PyroCb in NSW. Terrasson, A., McCarthy, N., Dowdy, A., Richter, H., McGowan, H., & Guyot, A. (2019). Weather radar insights into the turbulent dynamics of a wildfire- triggered supercell thunderstorm. Journal of Geophysical Research: Atmospheres, 124, 8645–8658.https://doi.org/10.1029/2018JD029986

AC: We have replaced Melnikov et al. (2008) reference with Terrasson et al. (2009).

RC: 6. L57 and 58: This sentence would probably benefit from the use of a more scientific description of the radar capabilities, e.g. . . ."they are "tuned" to identify" is actually incorrect. The frequency of the radar will determine which particles the radar is likely to receive a backscatter from. Post-processing analysis can be improved possibly, but it won't modify the frequency of the radar, which is a fixed hardware choice. More details on the scatterers as observed by the radar and reference to pyrometeors as described by McCarthy et al. (2019) would be appropriate here.

McCarthy, N. F., Guyot, A., Protat, A., Dowdy, A., & McGowan, H. (2019). Tracking Pyrometeors with Meteorological Radar Using Unsupervised Machine Learning. Geophysical Research Letters, 46. https://doi.org/10.1029/2019GL084305

AC: We respectfully disagree that the statement is incorrect. We however agree with you that the frequency of radar determines what kind of particles it receives backscatter from. In line 104 of our original submission, we noted that weather radars do not detect smoke components smaller than 100 μm. Therefore, we believe that the above statement is correct.

For clarity, we have replaced 'tuned to' with 'sensitive' as follows: "Weather radars . . ... do not accurately detect the exact extent of entrained gaseous and fine particulate emissions because they are sensitive to larger particles such as rain and ice crystals, and can therefore fortuitously detect pyrometeors such as ash, scorched debris and embers (McCarthy et al., 2019). We checked the reference you provided, whose authors agree with us by suggesting that there is “increasing evidence that weather radar does not have the sensitivity to detect aerosol-sized smoke targets. Instead it detects ash and larger debris, characterized as generally horizontal, plate-like targets with high (low) ZDR (hv)”.

Additionally, the below reference states: “The consensus with such polarimetric radar results is now that the scatterers within fire plumes are dominantly ash”. The article goes on to list all scatterers such as “coarse mode particle emissions, ash, firebrands, and extinguished and scorched debris.”

McCarthy, N., Guyot, A., Dowdy, A., and McGowan, H.: Wildfire and Weather Radar: A Review, J. Geophys. Res. Atmos., 124, 266-286, doi:10.1029/2018jd029285, 2019.

RC: 7. L69: the authors might want to discuss here the V-shape profile as described by Peterson et al.?

AC: We have now added the following section: “The role of tropospheric temperature and moisture in pyroCb dynamics is exemplified in the inverted-V thermodynamic profile (Peterson et al., 2017). The profile shows a dry and warm near-surface environment in which temperature decreases dry adiabatically with altitude to the top of the mixed layer ($\sim$ 3 km) where relative humidity is higher. Altitudes immediately above the mixed layer are usually drier, and this dry air can mix to the surface in strong convective downdrafts, increasing surface fire behaviour (McRae et al., 2015). Further, higher mid-troposphere moisture can also interact with weaker wind shear and high temperature lapse rate to produce strong updrafts (Peterson et al., 2017)”.

RC: 8. L71: it would be useful to give here the frequency of the radar (C-band) and state that this is a Doppler radar. The reader might also want to know if this is an operational radar (thus with a given scan strategy) and by whom it is operated (BoM).

AC: We have now included the word ‘Doppler’ in the sentence. The other suggested information has been provided in the description of the weather radar in section 2.2.1 (in the Methods section).

RC: 9. L83: space between “600” and “m”

AC: It has now been corrected.

RC: 10. Can you give here the time at which the pyroCb started to form?

AC: It is difficult to know the exact time, but likely between 15:24 and 15:30. A malfunction in radar between 15:30 and 15:36 resulted in plume information to be only available at the lowest elevation angle of the radar scan, and was therefore not useful.

The sentence now reads: “On 4 January, southeast Tasmania recorded dangerous fire weather conditions, resulting in a large uncontrollable fire that led to the development of a pyrocumulonimbus (Fig. 1Sb) from around 15:24 and caused the near-complete destruction of Dunalley township (Fig. 1d)”.

RC: 11. Figure 1(d), the location of the weather radar is hard to see . . . could you possibly use another colour or/and larger font?

AC: The colour of the symbol has been changed and the size increased. See the figure attachment for details.

RC: 12. L108: This is likely to be case but how did McRae validate this? What do you mean by “violent convection”? i.e. did you compute vertical velocities?

AC: We did not compute vertical velocities, but the occurrence of the pyroCb (that rapidly rose from 9 km at 15:24 to 15 km at 15:48) is evidence of violent convection. The term ‘violent convection’ is used in the NWCG Glossary of Wildland Fire (dating back to 1949, most recent version is 2018) and has been adopted in the 2012 AFAC Bushfire Glossary. It entails a combination of strong (i.e. enough uplift to carry large particles that show up in radar data), highly turbulent and deep convection.

NWCG Glossary: https://www.nwcg.gov/glossary/a-z AFAC Glossary: https://www.afac.com.au/docs/default-source/doctrine/bushfire-terminology.pdf

For clarity, we have, in the introduction defined 'violent convection as 'strong, highly turbulent and deep convection', and maintained the term 'violent convection' thereafter in the manuscript.

RC: 13. L111: there is no consistency with the spelling of "Mt" and "Mt." in the paper. I think it should be "Mt"?

AC: Noted. They have been revised to "Mt" throughout the manuscript.

RC: 14. L119: Why is that threshold of 11 dBZ being used? The paper would benefit here from more explanation on the processing of radar data (clutter removal, attenuation correction if any etc.) We used the 11 dBZ threshold as it clearly demarcated the boundary of the plume better than lower values. We did not do detailed pre-processing such as what you have suggested. There is a degree of pre-processing of radar images prior to operational use (e.g. to remove clutter and permanent echoes), but we didn't further process the data. We contend that the effect of not conducting further processing would be negligible.

RC: 15. L119 and 120: "in this paper" repeated twice

AC: This has now been revised.

RC: 16. L162 and elsewhere: it might be good to use the terminology "air temperature" instead of "temperature".

AC: Noted. These have been revised.

RC: 17. L165: section title seems wrong here.

AC: The title has now been replaced by 'Vorticity-driven Lateral fire spread'.

RC: 18. Figure2: Wind direction? This is an important factor for fire behaviour and

could help discuss the VLS aspects presented by the authors as one of the main mechanism for the increase in fire intensity? I personally prefer multiple subpanels as there is a bit of clutter on that figure with all the variables.

AC: Wind direction has now been included, and plots separated into two: one for wind variables, the other one for the other weather variables. See figure supplement for details.

RC: 19. L224: "1km" above sea level?

AC: Yes. It now reads: "plume height from radar scans gradually increased from around 1 km above sea level at 13:00 to 8 km at around 15:00 and rapidly rose to the maximum injection height of 15 km. . .."

RC: 20. Figure 3: "Smoke on subpanel (a)" is not technically correct; rather "smoke plume" should be used. That is because radar at C-Band can't get good returns from smoke as such, as the authors correctly mentioned earlier in the draft; see McCarthy et al. (2018).

AC: The legend in the subpanel (a) has now been corrected to reflect that it is a smoke plume. See the figure attachment for details.

RC: 21. L249 How is plume length defined?

AC: We have included the description as follows: "Plume length is the horizontal distance between the origin of the plume and the farthest extent of the plume".

RC: 22. Figure 5, nice.

AC: Thanks. However, other reviewers have suggested changes regarding stratifying the fires into different fire size classes, to which we have slightly modified. See figure supplement.

RC: 23. Maybe recall for readers unfamiliar with Tasmanian seasons when that is?

AC: The months in the fire season have now been included in the text. That information (including for non-fire season) is repeated in Fig. 6 captioning.

RC: 24. L315 The authors should cite Terrasson et al. here

AC: The article has now been cited.

RC: 25. L322 325 The authors should cite Terrasson et al. here as well

AC: The article has now been cited.

RC: 26. L338. The authors should discuss the findings of Terrasson et al. – the change of moisture in the lower and upper levels as brought by the cold front on the development of PyroCb and fire behaviour.

AC: It has now been included as follows: "... a number of Australian pyroCb events exhibit a distinct lack of midlevel moisture in their associated atmospheric profiles (e.g. the 2003 Canberra fire (Fromm et al., 2006) and the 2013 Wambelong fire (Wagga Wagga sounding for 13 January 2013 on http://weather.uwyo.edu/upperair/sounding.html). However, in this study, the mid- to upper-level moisture was higher during the time preceding pyroCb formation on 4 January (Fig. S2a), with a total precipitable water of 23 mm indicating a moist lower atmosphere (Webb and Fox-Hughes, 2015). Terrasson et al. (2019) report on the effect of a change in moisture between the low- and upper-levels (brought by a cold front) on the development of a pyroCb and enhancement of fire behaviour in the Sir Ivan fire in eastern Australia. Further research is required to properly understand the potential influence of mid-tropospheric moisture in driving pyroCb development in Australia".

RC: 27. L348: The authors should cite Terrasson et al. here

AC: The article has now been cited.

RC: 28. L392, 394: The effect of the potential VLS on plume development is too speculative. Overall, I think that there is no justification based on the observations as

shown in the current paper, for any effect of VLS.

AC: We agree that the VLS-prone areas seem small, and their influence on pyroCb occurrence likely negligible based on these results, but we also caution that VLS likely occurred, but the effect may have been undermined by the limitations of the input data (DEM and wind direction layer).

We have now rephrased the sentence in both the results and discussion sections to read: In section 3.1.3 (Results): "Evidence of an effect of Vorticity-driven Lateral Spread on the fire behaviour was not strong. Analysis of the precursor terrain conditions only revealed small patches of VLS-prone areas near Dunalley township (Fig. S4). However, we are not able to rule out VLS occurrence on parts of the terrain that were not resolved by the DEM, and which may have played a part in the evolution of the plume. Indeed, the lateral development of the upwind edge of the plume in Fig. S4 suggests lateral development of the fire, similar to that associated with VLS in other fires (McRae et al. 2015)."

In the discussion: "this study did not find strong evidence of the effect of VLS on fire behaviour, as indicated by small patches of VLS-prone areas near Dunalley township (Figure S4). It is therefore possible that the pyroCb attained its maximum height without VLS. However, this interpretation should be taken with caution as VLS possibly occurred but data constraints (especially the spatial resolution of the DEM and wind direction) may have precluded accurate determination of VLS".

RC: 29. The authors should cite Terrasson et al. here

AC: The article has now been cited.

RC: 30. In Terrasson et al. (2019) we did exactly that, e.g. linking fire behaviour to plume development. The authors could also cite McCarthy et al. (2018) where fire behaviour is studied against plume development for a PyroCu in Victoria (Mt Bolton fire). McCarthy, N., H. McGowan, A. Guyot, and A. Dowdy, 2018: Mobile X-Pol Radar :

A New Tool for Investigating Pyroconvection and Associated Wildfire Meteorology. Bull. Amer. Meteor. Soc., 99, 1177–1195, https://doi.org/10.1175/BAMS-D-16-0118.1

AC: We have included the below sentence in the weather radar paragraph of the discussion: "A feature of our study was linking plume evolution to fire severity mapping - an approach that has received limited attention. Duff et al. (2018) conducted one of the few studies, using statistical models to link the radar-detected plume volume to fire growth, and found that radar return volume (above a threshold of 10 dBZ) was a robust predictor of fire-area change. . . . [sentence removed] . . .. Other Australian studies linking fire behaviour to radar-detected plume development include McCarthy et al. (2018) and Terrasson et al. (2019)".

RC: 31. Fig.S3: "the orange colour represents the most intense parts of the PyroCb": it would be appropriate to use a more scientific and precise language, i.e. provide the values or range of values for the equivalent reflectivity in dBZ (colour bar), and refer to the text of the article to describe how these have to be interpreted.

AC: The colour bar has now been included in the maps, and the figure captioning updated to reflect the reflectivity values for the intense parts of the plume. We have moved the map from the supplement to to the main article in Section 3.1.3 in response to another reviewer. We have now added a sentence that describes pyroCb development in the atmosphere.

It reads: "The period of the pyroCb in Fig. 4 is defined by very high radar returns, with reflectivity values of 48-88 dBZ, representing the most intense parts of the pyroCb. This strong reflectivity is indicative of high quantities of ash, and larger-sized hydrometeors such as ice crystals in the higher elevations".

RC: Thanks and again I enjoyed reading your study. Kind regards.

AC: Thanks.

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2019-354, 2019.

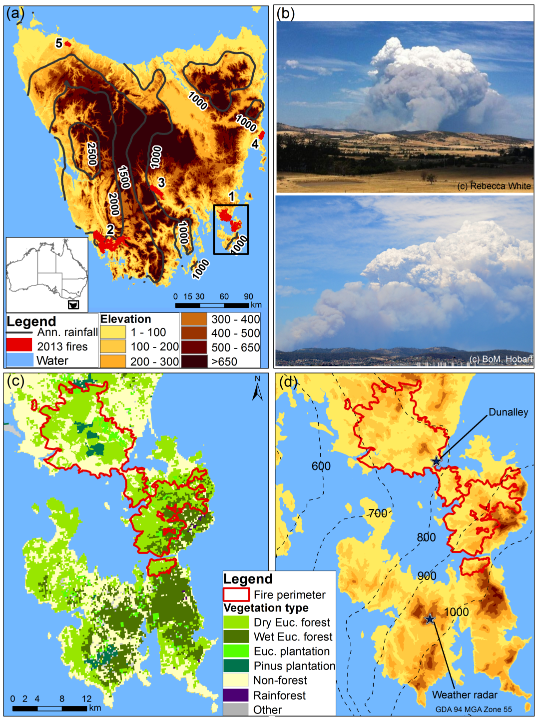

(a)
(b)
(c)
(d)
Legend
Ann. rainfall
2013 fires
Water
Elevation
1 - 100
100 - 200
200 - 300
300 - 400
400 - 500
500 - 650
>650
(c) Rebecca White
(c) BoM, Hobart
Dunalley
Weather radar
Fire perimeter
Vegetation type
Dry Euc. forest
Wet Euc. forest
Euc. plantation
Pinus plantation
Non-forest
Rainforest
Other
GDA 94 MGA Zone 55

Fig. 1.

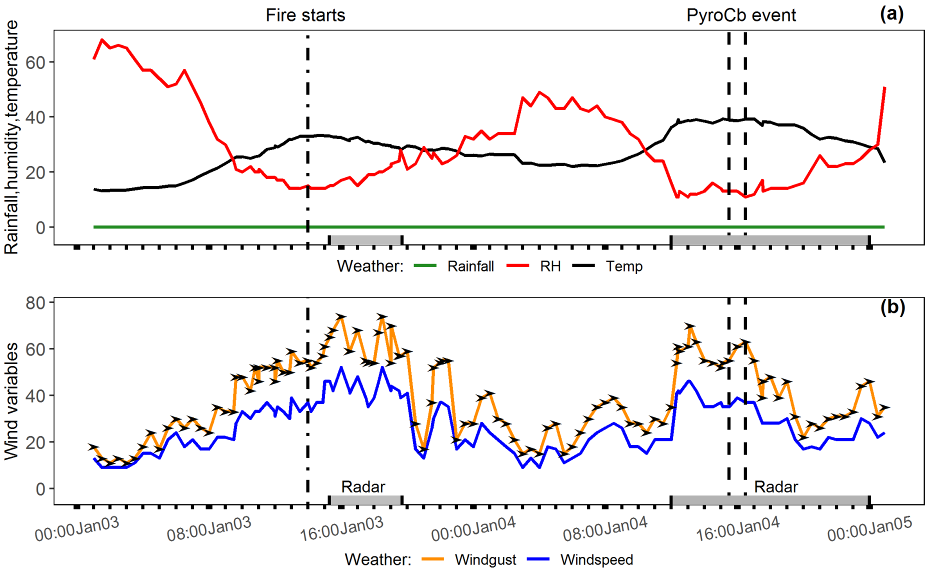

Fire starts
PyroCb event
(a)
Rainfall,humidity,temperature
Weather: Rainfall RH Temp
(b)
Wind variables
Radar
Radar
00:00Jan03
08:00Jan03
16:00Jan03
00:00Jan04
08:00Jan04
16:00Jan04
00:00Jan05
Weather: Windgust Windspeed

Fig. 2.

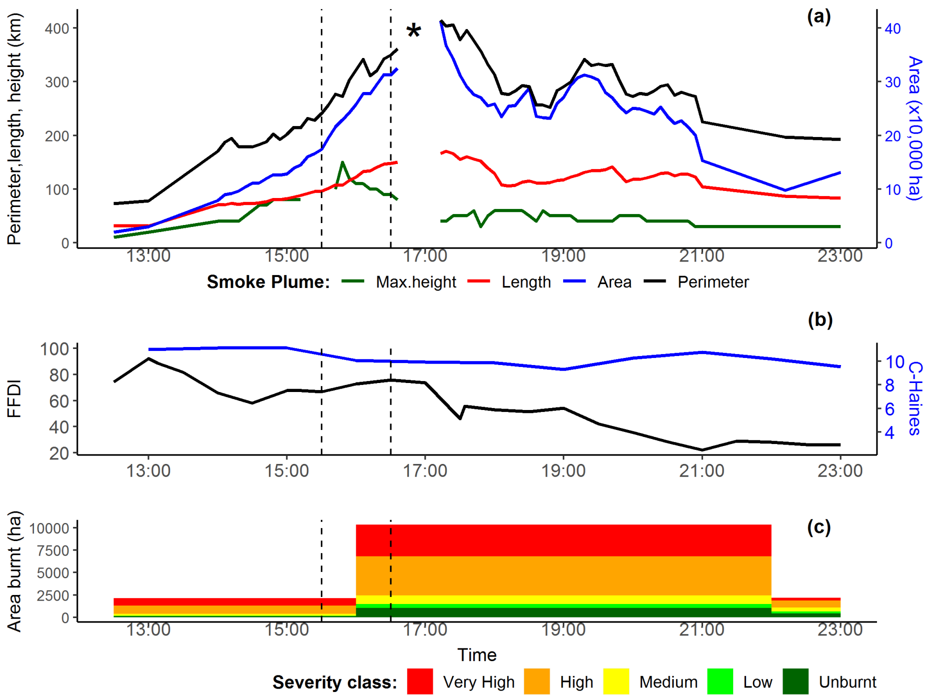

(a)
Perimeter,length, height (km)
Area (x10,000 ha)
*
Smoke Plume: Max.height Length Area Perimeter
(b)
FFDI
C-Haines
(c)
Area burnt (ha)
Time
Severity class: Very High High Medium Low Unburnt

Fig. 3.

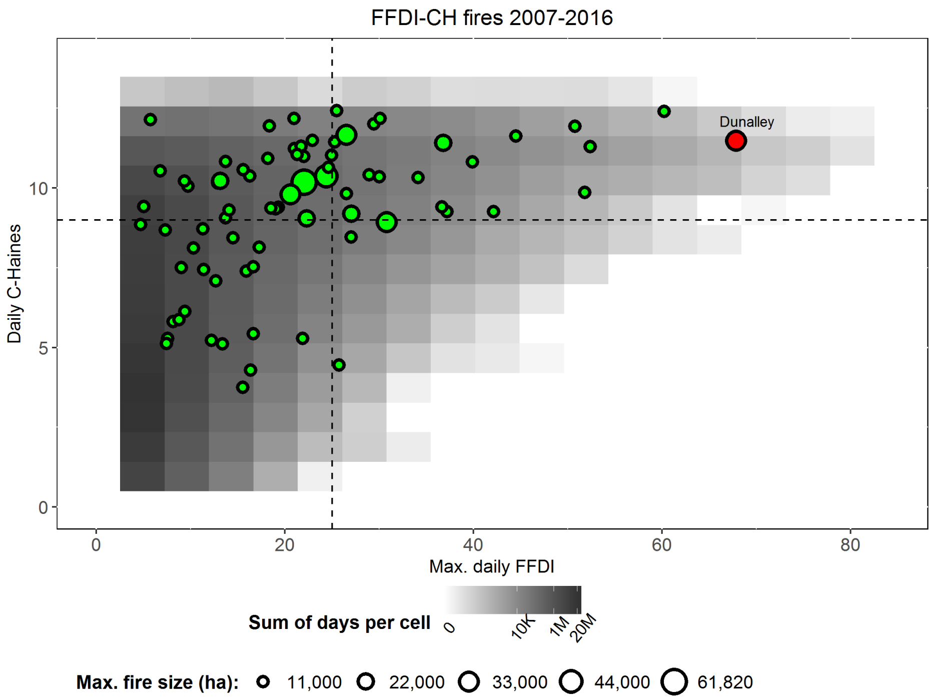
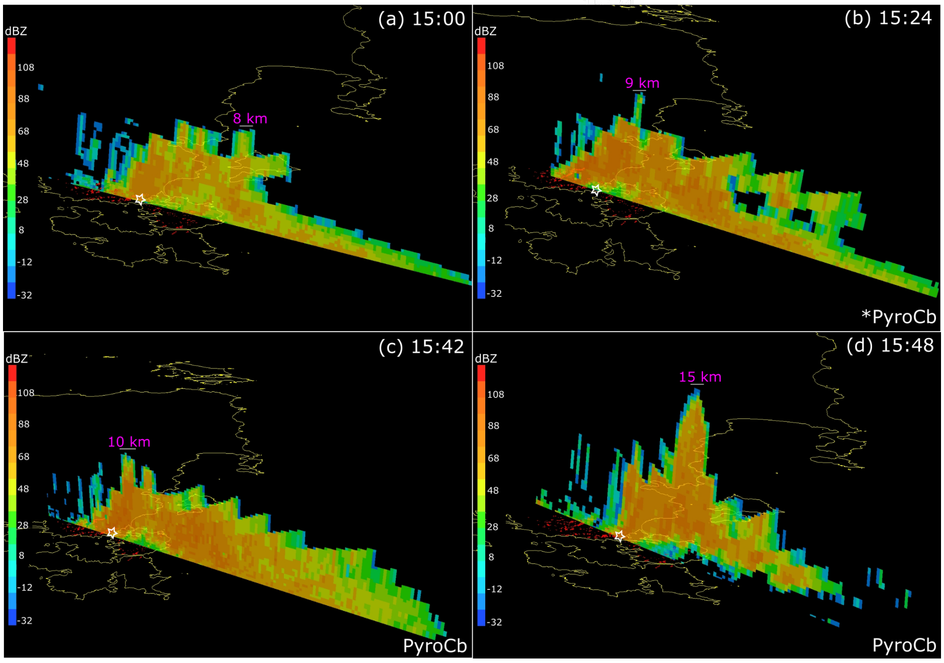

FFDI-CH fires 2007-2016
Dunalley
Daily C-Haines
Max. daily FFDI
Sum of days per cell
Max. fire size (ha): 11,000 22,000 33,000 44,000 61,820

Fig. 4.



(a) 15:00
dBZ
108
88
68
48
28
8
-12
-32
8 km
(b) 15:24
9 km
*PyroCb
(c) 15:42
10 km
PyroCb
(d) 15:48
15 km
PyroCb

Fig. 5.