First of all, we appreciate the reviewer's comments and suggestions. In response to the reviewer's comments, we have made relevant revisions to the manuscript. Listed below are our answers and the changes made to the manuscript according to the questions and suggestions given by the reviewer. Each comment of the reviewer (in black) is listed and followed by our responses (in blue).

Referee Report

Lee et al., Examination of effects of aerosol on a pyroCb and their dependence on fire intensity and aerosol perturbation using a cloud-system resolving model, submitted to Atmos. Chem. Phys., 2019

General comments

The paper addresses the important question of aerosol effects on pyroCb impacts on UTLS water vapor and cirrus cloud area, both of which have substantial, but uncertain, radiative impacts. The authors conclude that microphysical processes (e.g. autoconversion) in pyroCbs associated with weak fires / surface heat fluxes are sensitive to smoke aerosol enhancements, and that such aerosols intensify convection, affecting UTLS water vapor and cirrus. On the other hand, pyroCbs from more intense fires are not very sensitive to smoke effects. Such understanding of UTLS water vapor and cirrus response to smoke is critical to better predicting future atmospheric response to fires, whose frequency and intensity continue to increase.

The contribution of the paper is that it extends a previous modeling study (Kablick et al., 2018) by testing the effects of a range of aerosol concentrations and surface heat fluxes in a cloud-system resolving model and thus is able to show the variation in sensitivity to aerosols of pyroCb UTLS impacts. The authors find that UTLS and cirrus clouds are increased by the presence of smoke for weak fires but not strong fires, and explain the causal mechanisms. In the future, these sensitivities / processes could be parameterized in climate models.

The simulation methodology and analysis are rigorous, and the introduction and conclusions are well-organized and logical. However, the results section is very wordy/lengthy and often unclear, so substantial efforts should be made to improve clarity/efficiency of the text, and some figures should be removed or moved to the SI. I recommend publication in ACP after major revisions.

Based on the reviewer's comments below and through authors' efforts, the result section is condensed by removing unnecessary text as a way of improving the readability of text. Some figures are removed, following the reviewer's and the other reviewer's comments. For details, see authors' responses below.

Specific comments

Main Text

I'm not familiar with the terminology "basic updrafts." Perhaps it should be "maximum" or "typical" "updraft speed"?

"Basic" is replaced with "typical". Also, the following is added:

(LL110-111 on p4)

For the simplicity of the term, in this study, “typical updraft speeds” are referred to as “typical updrafts”.

Line 80 “makes individual droplet smaller.” Please include references.

References are added.

Line 84 “the efficiency is proportional to the sizes.” Please include references.

References are added.

Line 87 “invigorates updrafts and associated convection.” Please include references.

A reference is added.

Line 114 Replace “confident information” with “more confident information than from a microphysics-parameterizing model.” There are no in-situ observations used in the study for model validation and the conclusions are drawn purely from model representations of microphysical processes. Additionally, the pyroCb case is idealized (no temporal variation in heat flux or interactions with the atmosphere). Therefore, the sensitivity tests provide useful but limited information.

The corresponding text is revised as follows:

(LL120-128 on p5)

These simulations are for a case of a pyroCb which is identical to that in Kablick et al. (2018), and performed by using a cloud-system resolving model (CSRM) which is able to resolve cloud-scale dynamic and thermodynamic processes. By resolving these processes that play a critical role in the development of clouds and their interactions with aerosols, we are able to obtain information on aerosol effects on the pyroCb development and its impacts the UTLS water vapor and cirrus clouds, and on associated dynamic and thermodynamic mechanisms. This information is likely to be more confident than that from a model that does not resolve but parameterize those cloud-scale processes.

Line 119 After “used by Kablick et al. (2018),” please add a brief explanation of the benefit of using a more sophisticated microphysical scheme.

The following is added:

(LL131-140 on p5)

Through extensive comparisons between various types of bin schemes and bulk schemes, Fan et al. (2012) and Khain et al. (2015) have concluded that the use of bin schemes is desirable for reasonable simulations of clouds, precipitation, and their interactions with aerosols. This is because the bin scheme explicitly predicts cloud-particle size distributions, while the bulk scheme prescribes those size distributions. The bin scheme also uses collection efficiencies and terminal velocities varying with varying cloud-particle sizes to emulate this variation in reality, while the bulk scheme in general uses fixed efficiencies and terminal velocities, which are not able to consider the variation of collection efficiencies and terminal velocities in reality. This makes the bin scheme more sophisticated than the bulk scheme.

Line 139 I suggest changing “CSRM” to “Modeling Framework.” Remember that ACP has a broader audience than the cloud modeling community.

Done.

Lines 197-199 Why were these CCN concentrations chosen? Please include references that they are typical values, e.g. for smoke plumes and background or urban areas.

The following is added:

(LL229-232 on p8)

These prescribed concentrations of aerosols are typically observed in fire spots and their background (Pruppacher and Klett, 1997; Seinfeld and Pandis, 1998; Reid et al., 1999; Andreae et al., 2004; Reid et al., 2005; Luderer et al., 2009).

Line 228 To shorten the paper, I suggest eliminating sentences that describe the contents of the figures, which is already contained in the figure legends, and replacing “in Figure X” etc. with “(Fig. X)” after the result is described. Change “In Figure 1, the observed cirrus cloud at the top of the pyroCb” to “The observed cirrus cloud at the top of the pyroCb (Fig. 1)”

We followed this suggestion except for situations where some description of figures and “in Figure x” are needed for the flow of text.

Line 238 Remove sentences on lines 238-240, and add “(Fig. 4)” at the end of line 241 after “cloud reflectivity fields.”

Done.

Lines 266-271 Condense to “Hence, the variation of fire intensity can be represented by variation of fire-induced surface latent and sensible heat fluxes. As a first step, the control run is repeated by reducing fire-induced surface latent and sensible heat fluxes by factors of 2 and 4. The first repeated run represents a case with medium fire intensity, while the second represents a case with weak fire intensity.”

Done.

Line 289 Redundant. Alter to: “can also be dependent on the magnitude of fire-induced increases in aerosol concentrations.”

Done.

Lines 294-302 What real-world situations do aerosol concentrations of 30000, 7500, 2000, and 1000 cm-3 represent? Please provide some context in the text.

The following is added:

(LL361-366 on p12-13)

The aerosol concentration of 30000 cm^{-3} over the fire spot corresponds to a situation when fire produces a larger concentration of aerosols than a typically observed range between 10000 and 20000 cm^{-3}, while the aerosol concentrations of 7500, 2000 and 1000 cm^{-3} over the fire spot corresponds to a situation when fire produces a lower concentration of aerosols than the typically observed range (Reid et al, 1999; Andreae et al, 2004; Reid et al, 2005; Luderer et al., 2009).

Results section: Lengthy and hard to follow. Please make an effort to condense the text, and summarize key results at the end of each section.

Done.

Line 307: Change to “Results from the control and low-aerosol runs”

Section “Results” itself includes sections for all the simulations. So, we created a new subsection 4.1 which is named “the control run and the low-aerosol run”

Lines 313-316 Change to “In this study, we expand upon the results of Kablick et al. (2018) by focusing on aerosol effects on pyroCb development and subsequent impacts on UTLS water vapor and cirrus clouds.”

Done.

Move sentence on lines 327-328 to the beginning of the paragraph starting on line 317.

Done.

Lines 330-332 Remove description of Table 2

Done.

Lines 332-333 Remove “In Figure 5 and Table 2”, and add “(Fig. 5 and Table 2)” at end of sentence

Done

Lines 336-340 Delete first three sentences of this paragraph.

Done.

Lines 345-350 Delete last two sentences of this paragraph.

Done.

Line 351 In what regions does 16 km correspond to the

UTLS? Please provide some context in the text.

We defined the UTLS as follows:

(LL384-393 on p13)

Regarding the UTLS, in this study, the upper troposphere is defined to be between ~ 9 km in altitude and the tropopause that is ~ 13 km in altitude; the equilibrium level where the buoyancy of a rising air parcel becomes zero above the level of free convection is considered to be the tropopause (Emanuel, 1994). Hence, the defined upper troposphere occupies around a quarter of the total vertical extent of the troposphere. The lower stratosphere is defined to be between the tropopause and an altitude which is 10 km above the tropopause. Hence, the UTLS is between ~9 km and ~23 km in this study. Considering that the stratosphere is between the tropopause and its top that is generally ~ 50 km in altitude, the defined lower stratosphere occupies around a quarter of the total vertical extent of the stratosphere.

Lines 367-369 What is the significance of increasing the vertical extent of water vapor from 14 to 16 km? Please explain in the text.

The following is added:

(LL415-424 on p14)

This means that air parcels that include water vapor and rise from below the tropopause overshoot the tropopause by ~ 3 km in the pyroCb, while those parcels in the background do so by ~ 1 km. This in turn implies that air parcels and associated updrafts in the pyroCb are stronger to reach higher altitudes before their demise in the stratosphere than those in the background. Those stronger air parcels enable water-vapor layers to be deepened in the lower stratosphere, which in turn enable the interception of longwave radiation by water vapor to occur over longer paths in the lower stratosphere. These longer paths and greater water-vapor mass over the paths both contribute to more interception of longwave radiation by water vapor in the UTLS over the pyroCb than in the background.

Lines 370-372 How is UTLS defined here? Please explain in the text.

The following is added:

(LL384-393 on p13)

Regarding the UTLS, in this study, the upper troposphere is defined to be between ~ 9 km in altitude and the tropopause that is ~ 13 km in altitude; the equilibrium level where the buoyancy of a rising air parcel becomes zero above the level of free convection is considered to be the tropopause (Emanuel, 1994). Hence, the defined upper troposphere occupies around a quarter of the total vertical extent of the troposphere. The lower stratosphere is defined to be between the tropopause and an altitude which is 10 km above the tropopause. Hence, the UTLS is between ~9 km and ~23 km in this study. Considering that the stratosphere is between the tropopause and its top that is generally ~ 50 km in altitude, the defined lower stratosphere occupies around a quarter of the total vertical extent of the stratosphere.

(LL402-403 on p14)

Henceforth, the UTLS water vapor means water vapor in a part of the UTLS at and above the tropopause.

(LL443-444 on p15)

Henceforth, the UTLS cirrus clouds mean those clouds in a part of the UTLS below the tropopause.

Line 375 How is tropopause defined here? Please explain in the text.

The following is added:

(LL385-387 on p13)

the equilibrium level where the buoyancy of a rising air parcel becomes zero above the level of free convection is considered to be the tropopause (Emanuel, 1994).

Lines 379-381 Alter to: “In addition to water vapor in the UTLS, ice crystals comprising cirrus clouds around the tropopause play an important role in the global radiation budget. To identify the impact of the pyroCb on cirrus clouds…”

This sentence is considered redundant and is removed, since this important role by cirrus clouds is already mentioned in introduction.

Line 409 Alter to: “The sensitivity of updrafts, water vapor, and cirrus clouds to aerosol loading in the pyroCb may be affected by fire intensity.”

Done.

Line 414 Change “In other words” to “Thus”.

Done.

Line 422 Change “just based on” to “to evaluate the”.

Done.

Line 426 Change “Updrafts and the UTLS water vapor and cirrus cloud” to “Effects of updrafts on UTLS water vapor and cirrus cloud”.

Done.

Lines 438-443 Condense/clarify to “Of interest is that the greatest percentage increase in updraft mass flux is in the case of weak fire (weak-low to weak runs), smallest in the case of strong fire (low-aerosol to control runs), and intermediate in the case of medium fire (medium-low to medium runs) (Figure 9 and Table 2).”

Done.

Lines 452-453 Alter to: “The percentage difference for medium (weak) fire intensity is obtained by replacing the control run with the medium (weak) run and the low-aerosol run with the medium-low (weak-low) run in Equation (1).”

Done.

Lines 454-456 Delete “The percentage difference… Equation (1).”

Done.

Lines 456-459 Alter to: “Associated with the greatest (smallest) increases in updraft mass fluxes, the percentage increases in water vapor and cloud-ice mass in the UTLS (Equation 1), are the greatest (smallest) in the case of weak (strong) fire (Figures 10 and 11 and Table 2).”

We changed text pointed out here as follows:

(LL512-514 on p17)

Associated with the greater increases in updraft mass fluxes, the percentage increases in the UTLS water vapor and cloud-ice mass (Equation 1) are greater in the case of weaker fire (Figures 5 and 6 and Table 2).

Lines 459-464 Delete “Figures 10 and 11 … intensity.”

Done.

Lines 473-476 Alter to: “The simulation period is divided into four sub-periods for this next analysis: period 1 (initial formation of the pyroCb) between 17:00 and 19:00 GMT on August 5th, period 2 between 19:00 and 21:00 GMT on August 5th and period 3 between 21:00 GMT and 23:00 GMT on August 5th (initial stages of cloud development), and period 4 between 23:00 GMT on August 5th and 12:00 GMT on August 6th (mature and decaying stages).”

Done.

Lines 476-479 Delete “The initial formation” to “the decaying stages.”

Done.

Lines 481-485 Combine/condense these two sentences

Done.

Line 505 Alter “weakens” to “decreases”

A phrase including “weakens” is considered redundant and is removed.

Lines 525-529 Change “reduces” to “decreases”

Done.

Lines 545-558 Move this discussion and accompanying figure to SI. Summarize the section.

The discussion part pointed out here is removed following the other reviewer’s comment. This section is summarized at its end.

Lines 598-601 Alter “aerosol chemical composition and aerosol” to “aerosol chemical composition. Aerosol …”

Following the other reviewer’s comment, the section including text pointed out here is shortened a lot. Associated with this, text pointed out here is removed.

Line 602 Alter to “aerosol composition (Rogers and Yau (1991))”

Text including this part pointed out here is removed during the process of shortening corresponding section following the other reviewer’s comment.

Line 607-655 This is a very long paragraph. Please divide it into multiple ones.

The corresponding paragraph is shortened a lot following this comment here and the other reviewer's comment.

Lines 663-666 Confusing. Delete "The concentration of … Figures 3 and 14;"

Done.

Line 668 Delete "Stated differently"

Done. Also, the following sentence is considered redundant and is removed.

Lines 676-681 Alter to "This contributes to a situation where the increment (the average minimum size with weak fire intensity minus that with strong fire intensity, 0.03 μm), among the low-aerosol, medium-low, and weak-low runs is similar to that among the control, medium, and weak runs during period 1 (Figure 14)."

Text pointed out here is removed during the process of shortening the corresponding section, following the other reviewer's comment.

Lines 683-685 Accordingly, the increase in the average minimum size with decreasing fire intensity reduces the number of aerosol particles that can be activated to droplets (Figure 14)."

Text pointed out here is removed during the process of shortening the corresponding section, following the other reviewer's comment.

Lines 698 and 700 Alter "varies" to "decreases"

Done.

Lines 741-742 Redundant. Remove "Autoconversion … proportional."

Done.

Lines 770-779 Remove "Remember … (Figure 15a)."

We removed text between line 770 and 775. However, we did not remove text between line 776 and 779, since information in this text was not given before.

Line 848 Alter to "establishing a positive feedback"

Done.

Line 876-877 Clarify to state what the effects are

We clarified that these effects are about effect of fire-produced aerosols as follows:

(LL717-718 on p24)

This leads to the greater overall effects of fire-produced aerosols on the UTLS water vapor and ice with weaker fire intensity.

930 Alter to “conclusions”

Done.

Lines 942-973 Divide this paragraph in two, one for each conclusion. (1) “This means that the role of fire-produced aerosols in water-vapor transport to the UTLS and the production of cirrus cloud in the pyroCb becomes more significant as fire intensity weakens.” (2) “This more significant role with weaker fire intensity is also robust to the variation of the fire-induced aerosol perturbation with the varying fire intensity unless the variation is very high.”

Done.

Figures and Tables

Which figures are essential to the main text and which could be moved to the SI? I suggest moving Figs. 3 and 13 to the SI. I also suggest eliminating Figs. 5-7, since the same information is contained in Figs. 9-11.

Done. Following the comment by the other reviewer, Figures 3 and 13 are also removed.

Figures w/ multiple lines (4-11): Use multiple line styles (e.g. dashed, dotted, solid). Current lines are difficult to distinguish when printed in grayscale.

There is no additional cost for color printing in ACP. Hence, all the figures will be published in colored form.

Change “over cloudy areas” to “in cloudy areas” and state altitude ranges first, e.g. “at all altitudes in cloudy areas”

Done.

Table 2: Remove sentence lines 1255-1260 “Note…”
Put equation in parentheses after “for each fire intensity ((polluted – clean)/clean x 100 (%))”

Done.

Table 3: “cirrus-cloud mass density between 9 and 13 km in cloudy areas, over the simulation period between 17:00 GMT on August 5th and 12:00 GMT on August 6th The numbers in parentheses are the percentage differences: ($control-30000$ (or $control-7500$) - $low-aerosol$)/ $low-aerosol$)” (etc. for other equations)

Done.

Fig. 1: Bright white represents cirrus (anvil) at the top of the pyroCb, while the red circle marks the fire spot. Dark white represents smoke produced by the fire.

Done.

Fig. 2: The simulated fire spot (red circle) …
Eliminate “The red circle… “

Done.

Fig. 5: “Vertical distributions of the averaged updraft mass fluxes over cloudy areas (where the sum of liquid-water content (LWC) and ice-water content (IWC) is non-zero) over the simulation period between 17:00 GMT on August 5th and 12:00 GMT on August 6th in the control and low-aerosol runs.”

Done.

Fig. 6: Specify line colors

“Vertical distributions of average water-vapor mass density in the control and low-aerosol runs at altitudes above 13 km and over the simulation period between 17:00 GMT on August 5th and 12:00 GMT on August 6th. Colored lines represent the average values in cloudy grid columns (non-zero sum of liquid-water path (LWP) and ice-water path (IWP)) in the control and low-aerosol runs, while the black line represents those values in non-cloudy columns (zero sum of LWP and IWP) in the control run.”

Done.

Fig. 7: “Vertical distributions of averaged cloud-ice mass density in cloudy areas (non- zero sum of liquid-water content (LWC) and ice-water content (IWC)) over the simulation period between 17:00 GMT on August 5th and 12:00 GMT on August 6th in the control and low-aerosol runs.”

Done.

Fig. 8: “Same as Fig. 7, for averaged deposition rate.”

Done.

Fig. 12: “the averaged CDNC, Rv, and LWC at all altitudes in cloudy areas, over the period between 17:00 and 19:00 GMT on August 5th.”

Done.

Fig. 14: “Diagrammatic depiction of the varying minimum size of aerosol activation (see Section 4.1.2 for details) with varying fire intensity in the unimodal aerosol size distribution which is assumed in this study.“

Figure 14 in the old manuscript is removed by following the comment by the other reviewer.

Eliminate: “The details of the varying minimum size are described in Section 4.1.2”

Figure 14 in the old manuscript is removed by following the comment by the other reviewer.

Eliminate or move to main text: “Here, the variation of the minimum size from Dcs to Dcw is identical to that from Dps to Dpw.”

Figure 14 in the old manuscript is removed by following the comment by the other reviewer.

Fig. 15: “The average rates of condensation, deposition and cloud-liquid freezing at all altitudes in cloudy areas and over periods (a) 2, (b) 3 and (c) 4. In panel (a), the average autoconversion rates are additionally shown.”

Done.

Fig. 16: “Time series of differences in the average values of variables related to aerosol-induced invigoration of convection, at all altitudes in cloudy areas between the (a) control and low-aerosol runs for strong fire intensity, (b) medium and medium-low runs for medium fire intensity and (c) weak and weak-low runs for weak fire intensity.”

Done.