Reviewer report 2:

General comments:

The manuscript conducted model sensitivity analyses to compare a few different plume rise approaches in WRF-CMAQ over the northern peninsular Southeast Asia (nPSEA), and used the best case to study the transport of biomass burning aerosol to Taiwan. While this is an interesting and important topic, the manuscript needs to address the following comments before publication.

Specific comments:

1. Line 13: "The boreal spring biomass burning (BB) in the northern peninsular...". Change it to "plumes from the boreal spring biomass burning" or "trace gases and aerosols emitted from the boreal spring biomass burning".

Revision #1: Changes "The boreal spring biomass burning" to "Plumes from the boral spring biomass burning"

2. Line 16: Provide full name for WRF-CMAQ in the abstract.

Revision #2: Included the full name for WRF-CMAQ in the abstract – "Weather Research and Forecast coupled with Community Multiscale for Air Quality model"

3. Line 23: "The calibrated model greatly improves not only the BB emission prediction over..." Do you mean "improves not only the prediction of BB impact"?

Answer #3: Sorry for the confusion. This sentence is intended to mean the improvement of the BB aerosol concentration prediction.

Revision #3: Such setup greatly improves not only the BB **aerosol concentration** prediction over near-source and receptor ground-based measurement sites but also the aerosol vertical distribution and column aerosol optical depth of the BB aerosol along the transport route."

4. Lines 45-47: change "overpredict the BB emissions" and "exceedance of predicted emission" to "overestimate the BB emissions" and exceedance of estimated emission".

Revision #4: Previous studies have found that the numerical model has prone to **overestimate** the BB emissions including CO, $PM_{2.5}$, and PM_{10} up to three times of the measured amount at the major burning source in northern Thailand (Huang et al., 2013; Pimonsree et al., 2018). The exceedance of **estimated** emission at the near-source burning leads to the incorrect modelled signal at the downwind site (Fu et al., 2012).

5. The temporal and spatial domain of the study is limited. It would be nice to at least include a discussion/implication of broad application outside the time and region of the study domain.

Answer #5: Additional discussion and implication have been included in Section 3.3

Revision #5: The variation of model performance has intrigued the compatibility of emission inventory with the PLMRIM performance. The FINN dataset provides high-resolution data for each fire (1 km2) **compared to the other emission dataset (GFEDv4s: 0.25º; GFASv1.2: 0.1º). As the finest study domain at the burning source is downscaled to 5km, the FINN dataset would have the nearest representation of the emission grid distribution. BB emission in the nPSEA is mainly caused by small fires and prevailing dry conditions over the period (Giglio et al., 2013; Reid et al., 2013), hence the representation of the small fires (usually accounted from 500 m burnt area) in the emission inventory is relatively crucial. This might have been one of the reasons that it fits**

better in the inline calculation with the plume-in-grid concept. When the offline method is adopted (FWrp), the FINN emission dataset in the nPSEA region tends to over-predict by 4-fold (Fig. 3a). Previous literature has to make an adjustment to the fire inventory to bring down the FINN emission amount that was overestimated by up to 2 – 3 times of PM2.5 and PM10 at the source region (Pimonsree et al., 2018), and FLAMBE overestimates up to 3 times for CO and PM_{10} at the LABS site (Chuang et al., 2015; Fu et al., 2012). **From this study, it is seen that the prescribed heights in the offline method have overestimated the plume rise height under the dry weather condition where the atmospheric stratification has no control on the pyro-convection through entrainment. While,** the inline module (IWrp+EC) **considers the variability of atmospheric condition over the mountain region better.**

The inaccuracy of the offline module is likely to be caused by the role of the complex terrain in uplifting the smoke plume and the nature of the fuel loadings. The connecting slopes (0.2–1.8 km as seen in Fig. 1c) causes the complication to boundary layer physics that governs the dynamics to transport the plumes formed in the valley pockets. Due to the unique topographic structure in nPSEA, the lifting and breaking away of burning emission plumes from burning area occurs during the evening-to-night period. **Therefore, mountain meteorology played an important role in the distribution of higher-level plumes. Moreover, the ability of PLMRIM to capture the boundary layer physics becomes essential in the mountainous region.** Through the inline module with the WRAP initial plume profile (**IWrp+EC**), the natural buoyancy of fire together with the convective interaction of the atmosphere can correctly distribute the BB emission. The spatial distribution of PM_{10} over burning regions in nPSEA is shown, with comparison made for scenarios nofire (Fig. 8a), offline (Fig. 8b) and inline (Fig. 8c). Comparison of the figures shows that each sub-grid scale fire hotspots more realistically represents the actual high concentration of emission emitted at the source (Fig. 8c) compared to the grid-following averaged out effect in the offline method (Fig. 8b). Nevertheless, the current setting does not include the two-way aerosol-radiation and aerosol-radiation-cloud feedback. This will be further studied in the future work looking at its importance in the cloud-laden SEA region (Tsay et al., 2016), as seen in the missing data due to the cloud cover in Fig. 6d.

6. Line 83: add full name for ARW.

Revision #6: This work employs Weather Research and Forecast **with Advanced Research core** (WRF-ARW v3.9.1) (Wang et al., 2017) model to hindcast the weather field and predict the corresponding air chemistry field with the chemical transport model CMAQ v5.2.1 (Byun and Schere, 2006).

7. Line 85: “The model domain is dynamically nested down...”. I’m not sure if I understand the term “dynamically nested”. Please rephrase.

Revision #7: The model domain is **dynamically downscaled through nesting** from the majority of Asia (d01 resolution: 45 km) to cover the transport route from nPSEA to Taiwan (d02: 15 km), Taiwan only (d03: 5 km) and nPSEA only (d04: 5 km) as shown in Fig. 1.

8. Line 88: Add a reference for the NCEP dataset.

Revision #8: Added in the reference list:

National Centers for Environmental Prediction/National Weather Service/NOAA/U.S. Department of Commerce: NCEP FNL Operational Model Global Tropospheric Analyses, continuing from July 1999 (ds083.2). Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. https://doi.org/10.5065/D6M043C6. Accessed 27 Sep 2018, 2000, updated daily.

National Centers for Environmental Prediction/National Weather Service/NOAA/U.S. Department of Commerce: NCEP ADP Global Surface Observational Weather Data, October 1999 – continuing (ds461.0). Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. https://doi.org/10.5065/4F4P-E398. Accessed 23 Mar 2019, 2004, updated daily.

Satellite Services Division/Office of Satellite Data Processing and Distribution/NESDIS/NOAA/U.S. Department of Commerce, and National Centers for Environmental Prediction/National Weather Service/NOAA/U.S. Department of Commerce: NCEP ADP Global Upper Air Observational Weather Data, October 1999 – continuing (ds351.0). Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. https://doi.org/10.5065/39C5-Z211. Accessed 23 Mar 2019, 2000, updated daily.

9. Lines 97-104: This part describes observations used in this study, and is not part of sub-section "2.1 Model Physics and Experimental Design". I suggest make it a new sub-section 2.2.

Answer #9: Apology for the confusion. This part is intended as the data used for model verification which is a continual from the discussion before. Additional description is included to ensure the flow of the paragraphs.

Revision #9: On top of the ground-based measurement weather and air quality data, the lidar systems are also used to evaluate the performance of the model ability to estimate the vertical profile of BB aerosols. They are the bottom-up Micro-Pulse Lidar Network (MPLNET) and top-down Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) lidar sensors. The MPLNET is a federated network managed by NASA to measure the aerosol vertical structure (Welton et al., 2000). In line with the 2014 7-SEAS spring campaign conducted in nPSEA, **the MPLNET is located at the Doi Ang Khang Meteorology (DAK) Station to collect the near-source aerosol vertical distribution profile (L1.5a) data.** The gridded extinction, diagnosed from the planetary boundary layer height and vertical aerosol extinction coefficient data collected is used to verify the performance of the model output (Wang et al., 2015a). The CALIOP **sensor mounted** on the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite is used to study the transport pattern over larger spatial coverage to complement the single point cross-extinction profile provided by the MPLNET system. The diagnosed vertical feature mask (VFM) product is used to distinguish the aerosol types with consideration of observed backscatter strength and depolarization (Winker et al., 2011).

10. Table 1: In the row "Emission inventory", also include the BB inventory FINNv1.5.

Revision #10:

Table 1: WRF and CMAQ model settings

	Settings
Weather model	WRF version 3.9.1
Period	1– 31 Mar 2013 (after spin up)
Boundary condition	NCEP FNL lateral boundary condition
Vertical	41 layers up to 50 hPa with 10 layers in the bottom 2km
Weather nudging	Grid and observation nudging
Planetary boundary	Asymmetric Convective Mechanism 2
Surface and land surface model	Pleim-Xiu
Longwave radiation	RRTM scheme
Shortwave radiation	Goddard
Microphysics scheme	Goddard
Cumulus scheme	Kain-Fritsch (1) for d01, d02 only
Chemistry transport model	CMAQ version 5.2.1
Gas-phase chemistry and aerosol mechanism	CB05e51 + AE6 (with aqueous chemistry)
Anthropogenic and biogenic emission inventory	d01, d02, d04: MICS-ASIA 2010, biogenic emission from MEGANv2.1 d03: Taiwan local emission inventory (TEDS v8.1)

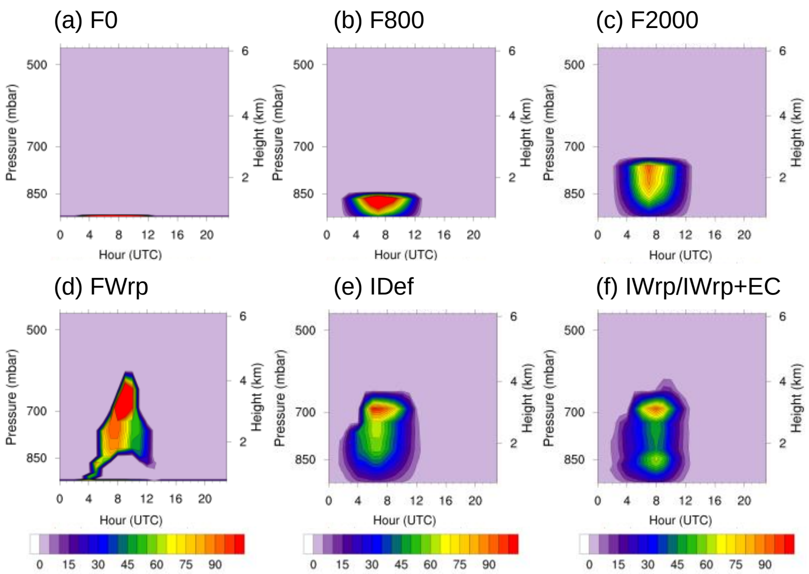
Fire emission inventory	FINNv1.5

11. Since the study uses the version 1.5 of FINN (FINNv1.5), please make sure to use the term "FINNv1.5" instead of "FINN" (for example Line 139) in the text.

Revision #11: The global data set, Fire INventory from NCAR (FINN v1.5**, referred as "FINN" here onwards**) has been applied in several previous works of literature in the region (Lin et al., 2014; Pimonsree and Vongruang, 2018) and is used as the input to the BB emission inventory into the model.

12. Figure 2. Please check if there's any error with Fig 2a and Fig 2b. It seems that F800 has a higher top than F2000.

Revision #12: (Figure 2): Initial CO emission rate (mol/s) profile at Mae Hong Son, Thailand on 13 Mar 2013 (UTC) for each case setup in Table 2 with (a) F0, (b) F800, (c) F2000, (d) FWrp, (e) IDef, (f) IWrp/IWrp+EC.



13. Figure 3: The legend is not clear. For example, obs should be black instead of grey.

Revision #13: Figure 3

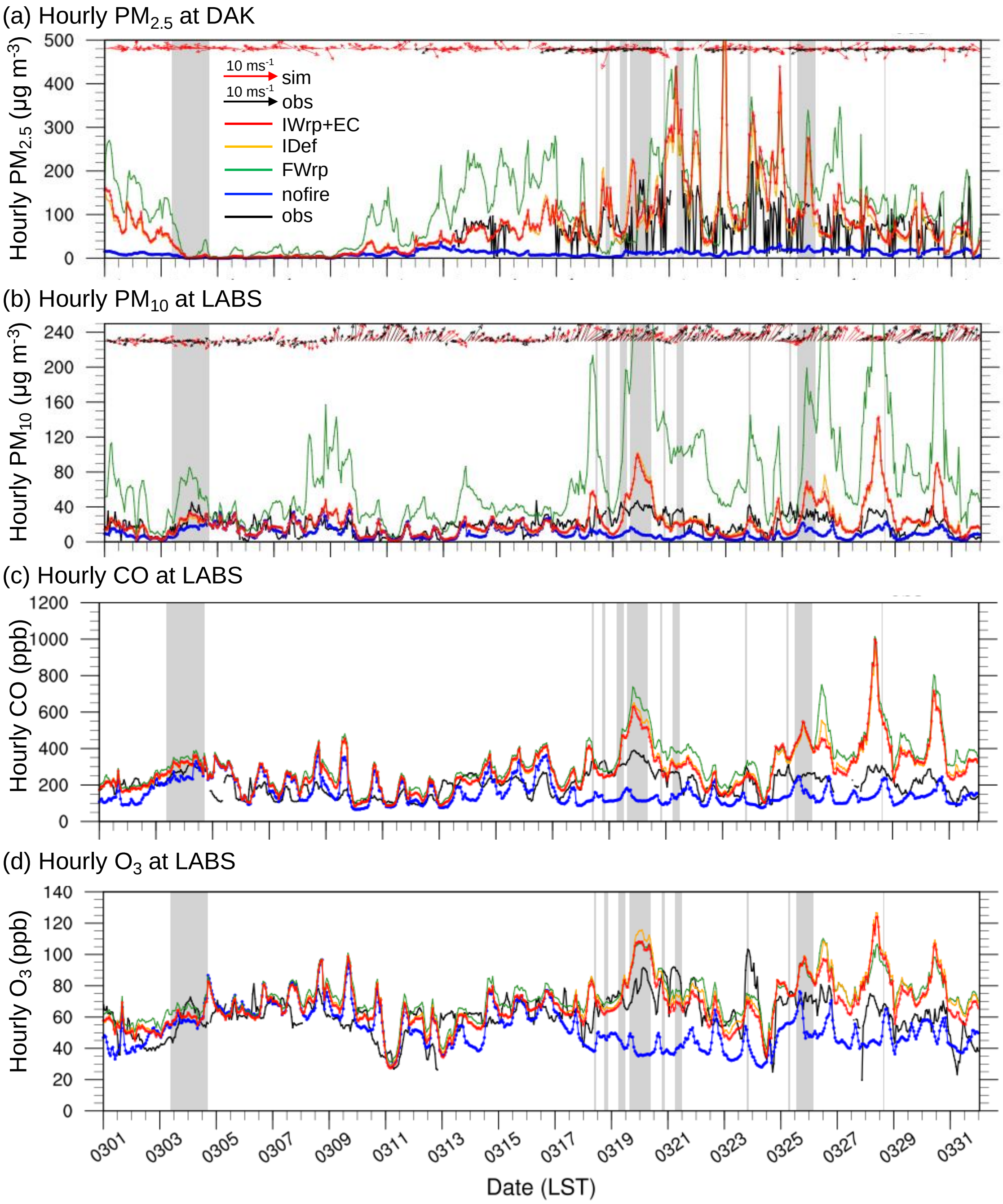


Figure 3: Comparison of PLMRIM (observation (black), nofire (blue), FWrp (green), IDef (orange), IWrp+EC (red) of (a) hourly wind field and $PM_{2.5}$ at DAK, and (b,c,d) hourly wind field and (b) PM_{10} (b), (c) CO, (d) O_3 at LABS in Mar 2013; Grey shade highlights the high pollution hour at LABS (CO > 300 ppb, PM_{10} > 35 μg m^{-3}). Wind field for observation (black) and simulation (red) are shown in vector form.

14. Lines 216-225: Please add more discussion on the reasons of the model biases in addition to the description of the figure details.

Answer #14: The statistical indexes of the ground-based measurement have been discussed thoroughly in the beginning of Section 3.1 to supplement the discussion of time-series. Please see the Section 3.1 for more details.

15. Table 3: Please add in caption why some numbers are bold while others are not.

Revision #15: Table 3 caption - Performance of modelled chemistry field with different settings of PLMRIM at mountain site in western North Pacific (LABS) and nPSEA (DAK). R: correlation coefficient; MFB: Mean Fractional Bias; MFE: Mean Fractional Error; MNB: Mean Normalized Bias; MNE: Mean Normalized Error. **Bold values are model output that satisfied the standard of each index.**

16. Lines 246-259. I'm concerned with comparing the model results of 2013 with obs of 2014. The authors need to justify the reliability of such comparison. The fact that there are a similar number of burning hotspots in model domain 2 in 2013 and 2014 is far from enough. Even if the total number of fires are similar over model domain 2 in 2013 and 2014, their spatial distributions may be different. Meteorology may be different too. I do not think such comparison is valid unless the author further justify this. Alternatively, the author could run the model for 2014 and do the comparisons, or simply compare the obs and model results for 2013 (make sure to exclude model data when obs are not available for comparisons).

Answer #16: After going through previous literature for year 2013 in Pani et al (2016) and year 2014 in Wang et al (2015). We agree that the aerosol extinction profiles are indeed different, hence using data from year 2014 to represent for year 2013 is not sensible. Hence, we have extracted data from year 2013 from MPLNET for the subsequent comparison.
Pani, S. K., Wang, S. H., Lin, N. H., et al.: Radiative effect of springtime biomass-burning aerosols over northern indochina during 7-SEAS/BASELInE 2013 campaign, Aerosol Air Qual. Res., 16(11), 2802–2817, https://doi.org/10.4209/aaqr.2016.03.0130, 2016.
Wang, S.-H., Welton, E. J., Holben, B. N., et al.: Vertical Distribution and Columnar Optical Properties of Springtime Biomass-Burning Aerosols over Northern Indochina during 2014 7-SEAS Campaign, Aerosol Air Qual. Res., 15, 2037–2050, https://doi.org/10.4209/aaqr.2015.05.0310, 2015a.

Revision #16: The 3-hourly average profile of the extinction coefficient from MPLNET v0 L1.5a, **IWrp+EC** and **FWrp** model output during 13 – 28 Mar 2013 at DAK station is illustrated in Fig. 4b-d. In Fig.4b, the MPLNET extinction coefficient is low at the surface and peaks between 2.5–3.2 km. The model output has a lower elevation over DAK station has modelled a higher extinction coefficient, which is likely to be accumulation effect due to lower wind condition. (Please refer to the manuscript for more write-ups)

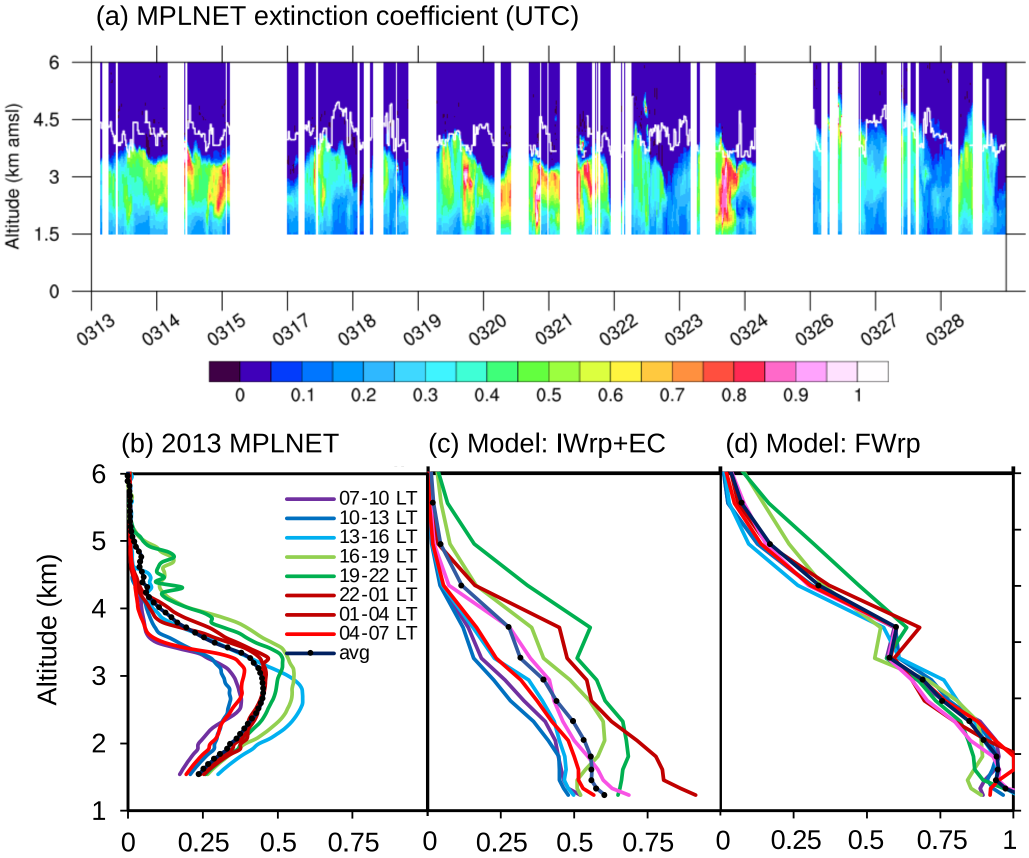


Figure 4: Vertical extinction coefficient profiles between 13 to 28 Mar 2013 at DAK station from (a) MPLNET with boundary layer height (white), (b) MPLNET 3-hourly average extinction coefficient, (c) IWrp+EC 3-hourly averaged model output, (d) FWrp 3-hourly averaged model output.

17. Lines 272-287: Figure 5 shows a very interesting case study with satellite data. However, it would be better to use model results to support some of the statements instead of using the empirical statements. For example, "The aerosol layers are believed to be lifted ...", "It is known that the burning aerosols...”.

Answer #17: Due to the coarse time intervals of the satellite data, it is difficult to provide affirmative statement at this point, however, the model result in subsequent section is able to confirm the observation from the satellite data. The sentence is rephrased to inform the author the subsequent section will prove the statements on satellite data.

Revision #17: The aerosol layers are believed to be lifted to a higher level and also mixed to the surface over the land mask in southeastern China, **which is later confirmed in the model result in Section 4.**

18. Lines 284-285: “Recently, it is proven through brute-force methods that the pollution from clusters arrived at the higher altitude in Taiwan during the winter season.”. I’m not sure I understand this sentence. Please add more details/explanations (for example, what clusters).

Revision #18: Recently, it is proven through brute-force methods that the pollution from the **PRD** cluster arrived at the higher altitude in Taiwan during the winter season (Chuang et al., 2019).

19. Lines 297-298: By “Figure 5”, do you mean “Figure 6”?

Revision #19: Figure 6 shows the model PM_{10} result for FWrp (range: 0-300 µg m-3) and IWrp+EC (range: 0-120 µg m-3) for the corresponding period of CALIPSO swath in Fig. 5.

20. Line 314: "The cross-sectional profile in Fig. 6 shows that the amount of emission produced by the offline method is substantially larger". For the simulations with fires in this study, emissions should be produced by FINNv1.5, instead of the offline method.

Answer #20: The offline method is also using the data from FINNv1.5 to run. Please refer to Table 2 for detailed case setup.

21. Line 314-317: "The cross-sectional profile in Fig. 6 shows that the amount of emission produced by the offline method is substantially larger than the amount produced by the inline method. Therefore, the total columnar AOD data provided by 1o x 1o MODIS Terra Level 3 AOD product (MOD08_D3, Platnick et al, 2015) during the same period (20 Mar 10:30 LST) is used for the verification of the aerosol concentration." I don't see the connection here. Please explain why "total columnar AOD data provided by 1o x 1o MODIS Terra Level 3 AOD is used" because "the amount of emission produced by the offline method is substantially larger than the amount produced by the inline method".

Answer #21: The sentence is rephrased for clarity.

Revision #21: The cross-sectional profile **of PM_{10}** in Fig. 6 shows that the amount of emission produced by the offline method is substantially larger than the amount produced by the inline method. **However, it could not be verified the vertical PM_{10} value due to the lack of measurement of vertical distribution of PM_{10}. The amount of PM_{10} has directly contributed to the columnar AOD value and the latter could serve as a good benchmark for the accuracy of model aerosol concentration.** Hence, the total columnar AOD data provided by 1º × 1º MODIS Terra Level 3 AOD product (MOD08_D3, Platnick et al, 2015) during the same period (20 Mar 10:30 LST) is used for the verification of the aerosol concentration **through the columnar AOD value**.

22. Figure 8: Please add in the Figure caption which model layer/level is shown.

Revision #22: Figure 8: Spatial distribution of **near surface** PM_{10} concentration on 19 Mar 17:00 LST over burning regions of nPSEA for 4th domain (d04)

23: Line 384: "This is the commonly known scenario that is well studied due to the availability 385 of measurement collected at LABS." Add a reference here.

Revision #23: This is the commonly known scenario that is well studied due to the availability of measurement collected at LABS **(Lee et al., 2011; Ou-Yang et al., 2014)**.

Lee, C. Te, Chuang, M. T., Lin, N. H., Wang, J. L., Sheu, G. R., Chang, S. C., Wang, S. H., Huang, H., Chen, H. W., Liu, Y. L., Weng, G. H., Lai, H. Y. and Hsu, S. P.: The enhancement of PM2.5 mass and water-soluble ions of biosmoke transported from Southeast Asia over the Mountain Lulin site in Taiwan, Atmos. Environ., 45(32), 5784–5794, https://doi.org/10.1016/j.atmosenv.2011.07.020, 2011.

Ou-Yang, C. F., Lin, N. H., Lin, C. C., Wang, S. H., Sheu, G. R., Lee, C. Te, Schnell, R. C., Lang, P. M., Kawasato, T. and Wang, J. L.: Characteristics of atmospheric carbon monoxide at a high-mountain background station in East Asia, Atmos. Environ., 89, 613–622, https://doi.org/10.1016/j.atmosenv.2014.02.060, 2014.

24: 393: Change "The interaction of BB with local pollutants" to "The interaction of BB plumes with local pollutants".

Revision #24: The interaction of BB **plumes** with local pollutants depends on the loading of local pollutants present.

25: Some of the statements/conclusions made in the manuscript are not supported by the analysis/figures/tables of the manuscript. There seems to be a mix of data analysis and literature review. For example, in the Conclusion, "impact on surface sites in Taiwan" is mentioned. However, the paper does not provide analysis for surface sites in Taiwan.

Answer #25: The paper has provided thorough analysis for mechanism of biomass burning plumes to arrive at surface sites in Taiwan in Section 4.2: Mixing of BB emission with local pollution on surface.

26: The connection between domain 03 and domain 04 needs to be further justified. While Figure 3 shows that the enhanced pollutants in some period is due to BB, it is not convincing enough that pollutants observed at LABS they are due to BB in domain 03.

Answer #26: The 2nd domain (d02) that cover the transport route is used to show the connection between d03 and d04. The comparison of Fig. 7a and 7c is able to show the difference between fire and nofire cases which is solely contributed by the biomass burning plumes from nPSEA. Additional description for Fig. 7 is included to clarify for it. Besides that, the nofire case is designed to remove only the biomass burning emission within d02, hence the comparison between the fire and nofire case for receptor region (d04) is able to identify the source of the biomass burning plumes from the source (d03).

Revision #26: **Figure 7 shows the 2nd model domain (d02) that covers the transport route between the source (d04) and the receptor (d03) domains. The comparison between Fig. 7a and 7c is able to show the difference between fire and nofire cases which is solely contributed by the biomass burning plumes from nPSEA. The figure also** shows that the total column AOD produced by the inline module gives a closer approximation to the MODIS. FWrp greatly overestimates the aerosol produced by the BB emissions, while the inline module gives a closer agreement on northern Thailand and southern Vietnam.