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Atmospheric Measurement Techniques Discussions

Interactive comment on "Spatial estimation of air $PM_{2.5}$ emissions using activity data, local emission factors and land cover derived from satellite imagery" *by* Hezron P. Gibe and Mylene G. Cayetano

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IMPORTANT NOTE: The full text of the author's comment and the revised marked up manuscript reflecting the changes suggested by the referees can be found in the attached supplement (in .pdf and .docx files respectively). The following is a plain text version of the full author's comment:

Journal: AMTD/AMT Title: Spatial estimation of air PM2.5 emissions using activity

Printer-friendly version

Discussion paper

data, local emission factors and land cover derived from satellite imagery Author(s): Hezron Gibe and Mylene Cayetano MS No.: amt-2017-14

Subject: Point-by-point reply to comments (discussion papers stage) We thank the anonymous reviewers for taking time to review this discussion paper. Since many major edits were suggested, the entire paper was edited for clearer wording and the clarification/addition of some points presented by the referees. The structure of some sections was also changed. We believe that these suggestions are important in increasing the quality of the text for recommendation for this paper to be published to AMT.

Kindly refer to the following point-by-point replies to the reviewer comments, and we appreciate your kind consideration and highly detailed comments, for improving the content and preparing this discussion paper for publication to the journal.

I. Author's comment:

An entry in page 1, line 4 has been corrected to show the full name of the Institute of Environmental Science and Meteorology, University of the Philippines-Diliman, where the researchers are affiliated.

II. Evaluation and response to interactive comment by anonymous referee #1:

General comments

I think there are some major concerns with this manuscript that have to be taken in consideration before it can be accepted for AMT. The main problem is the language that is not clear, which means that it is difïňĄcult to fully validate the scientiïňĄc content in this study. However, I think relevant scientiïňĄc questions are addressed that are in the scope of AMT, but they have to better emphasise. I think the authors present a novel idea that deserve to be taken in consideration. The present method is interesting, which can also be used in the developing countries dealing with small budgets and limitation in resources.

Major concerns

1. Due to limitation in time the review of the language has only been performed for the four ïňĄrst pages. Even so, it is obvious that the language has to be improved, and suggestions to improve the text are given below for these four pages. However, English is not my native language, which means that all my suggestions are probably not the best ones in an attempt to make the text more readable. The main criticism is that too much of redundant words and phrases are used in the text. However, the selection of words are also not always correct, which makes it difïňĄcult to understand the text at several places. In addition, I think the structure of the text could be improved by reducing the many paragraphs introduced. This is purely a scientiïňĄc text and not a popular scientiïňĄc text. At some places also very long sentences are found, which should be avoided: for example at the lines 4 – 7 on page 10. I suggest that the authors take contact with someone that is able to improve the text and/or ask AMT if they could support with this work.

Response: In general, effort was taken to improve the wording of all sentences in the text. This is especially edited with the goal of reducing redundancies in some explanations found in the manuscript itself. Paragraph lengths were shortened in general, as well as splitting long sentences, found in almost all the newly edited sections of the manuscript. Specific details as to what changed can be found in later comments.

2. Paragraph at lines 10 – 19: equation 3 and the corresponding text in this paragraph is very confusing. I suggest to present, where it is missing, units for the different factors included in the equations. Should the three ïňĄrst factors in the bracket actually be multiplied with each other? The factor SDF is not deïňĄned. Among other, the following phrase is confusing “PM2.5 per year per square kilometer per kilometer traveled”. For this paragraph I will also give here an example when redundant words are used. Line start with “Emissions for motorcycles. . ...”, which means that you do not need to repeat this in the following sentence after the equation. The same for equations 1&4.

Response: The authors have reworded the section in question. Several major edits were made, the most obvious one the splitting of the former equation (3) to equations (3) and (4). Wording was changed to reflect a focus on “vehicular sources” of PM2.5. Most of the ambiguous factors in question were those intended to serve as the activity data factors for tricycles. NAF in the previous version was renamed to AVF (association vehicles factor) for clarity. Units were added to the explanation of all emission factor estimation equations (1-5). The new explanation hopefully makes it clear as to why the first three factors (Nu, DF, AVF) should be multiplied. The definition for factor SDF (distance/kilometers traveled) was also added. Similar edits were also used for sections containing equations (1) and (4) (now (1) and (5))

Page 6, Lines 11-20: PM2.5 emissions for vehicular sources were estimated with the formula shown in Eq. (3) and Eq. (4). E_(MC/TC)=ãĂŰ(NãĂŮ_u×DF×AVF) ×(EF×KT×SDF)×0.01 , (3) E_PUV=ãĂŰ(NãĂŮ_u×DF) ×EF×0.01 , (4)

Factors that are the same for both equations include: Nu, the estimated number of vehicle units, DF, the density factor (amount of vehicles per km2), and EF, the emission factor. The in-house emission factor for MC/TCs is measured as PM2.5 per kilometer traveled (per vehicle). Due to this non-standard EF unit, additional factors are required in Eq. (3). These include the association vehicles factor (AVF), the percentage of vehicles which are officially registered and properly accounted for by the city. To scale the EF to its proper units, it is multiplied by factor KT (kilometers traveled per day) and SDF (days in service per year). Similar to the previous example, the total is also multiplied by 0.01 to scale to each 0.01 km2 cell. The DF and NAF was verified using sensitivity analysis by ground surveys as detailed in section 2.4.

Page 4, Lines 17-26: All calculations that have been used to estimate PM2.5 emissions are based on a general formula used by the US EPA in the AP 42 Compilation of Air Pollutant Emission Factors (EPA, 1995), as shown in Eq. (1)

E=A ×EF×(1-ER/100) , (1)

where: E is equal to PM2.5 emissions, A is the activity rate/data (e.g. quantity of fuel used, percentage of households using fuel), EF represents the emission factor, and ER is the overall emission reduction factor/efficiency in percent, if applicable. In the present method, E is estimated as being the quantity of PM2.5 per unit cell: micrograms per 0.01 km2 (1 hectare) per year. ER refers to other factors affecting the total amount of PM2.5 emissions (such as factors not directly accounting towards the quantity of fuel used; ER factors also incorporate the activity of those using quantities of fuel lower than average). This comprises the various factors that are also part of activity data (as in, factors that modify the amount of emissions generated) as used in this study.

Page 6, Lines 20-27: Emissions for agricultural waste burning were estimated with the formula shown in Eq. (5):

$E\_agricultural=((RS)/RA)\times EF\times SF$, (5)

where: RS is the amount of rice straw produced per year, divided by RA, which is the total area in hectares (0.01 km2) used for growing of rice. EF is the in-house obtained emission factor for rice straw burning PM2.5 per year per square kilometer. SF is the survey factor, representing the percentage of farming area where burning of rice straw as agricultural waste is used. This reduction factor is taken from the study of Launio, et al. (2013).

3. Lines 18 – 21. Concerning the low percentage values 1%, 5% and 2%, does this means that it was so few respondents that answered the survey? If so, how useful and solid is this information for the present study? You should at least make a comments on this in the manuscript.

Response: Edited paragraph starting in page 7, line 19 to comment on this. Also, an edit was made to the paragraph starting in page 10, line 4 as an additional comment:

Page 7, Line 19 – Page 8, Line 2: The respondents that were surveyed were taken from specific areas, termed emission hotspots. These are locations where the amount of es-

timated PM2.5 emissions are expected to be high. From the total estimated maximum respondents per type (households, vehicles (MC/TCs, PUVs)), the sample group for this study accounts for around 1% of the total for respondents for households, around 5% for total respondents for MC/TCs, and around 2% for the total for respondents for PUVs. This proportion of the sample size is very low, so the proponents have implemented stratified sampling intended to make the small sample as representative of the entire study area as possible. Page 10, Lines 4-10: The validation of specific activity data factors is effective at adapting them closer to the specific conditions present in Cabanatuan City. While the more general original in-house values are more appropriate in areas like Metro Manila, the validation procedure has made them more appropriate for smaller cities in general. An issue during the ground survey activity involves its small sample size compared to the possible maximum number of respondents in the investigation area. However, the benefits of fine-tuning the activity data with this analysis outweigh its disadvantages. Also, in future researches, the ground survey and sensitivity analysis validation will highly be improved if the sample size is greatly increased.

Minor concerns

1. For E and the corresponding equations 2-4 write out the units somewhere in the text. It is not logical to name the emissions with “fuels, vehicles and straw”. Maybe “households, vehicles and agricultural” instead.

Response: Relevant sections were edited to include units for all factors. The names of the E factors (i.e. Ehouseholds) for all equations were also changed to reflect this.

Page 6, Lines 2-27: Emissions for household fuel (charcoal) were estimated with the formula shown in Eq. (2):

E_households=ãĂŰ(NãĂŮ_h×HF)×Q_fuel×EF×0.01 , (2)

where: Nh is the estimated number of households (generated from city government

data), and HF is the percentage of all households using charcoal as fuel, obtained from the HECS. Qfuel is the quantity of fuel in kilograms used per year by each household, sourced from the HECS and verified using sensitivity analysis by ground surveys (see section 2.4). EF corresponds to the emission factor for charcoal fuel PM2.5 per square kilometer per year; this is then multiplied by 0.01 to scale to each 0.01 km2 cell.

PM2.5 emissions for vehicular sources were estimated with the formula shown in Eq. (3) and Eq. (4).

E_(MC/TC)=ãĂŰ(NãĂŮ_u×DF×AVF) ×(EF×KT×SDF)×0.01 , (3)
E_PUV=ãĂŰ(NãĂŮ_u×DF) ×EF×0.01 , (4)

Factors that are the same for both equations include: Nu, the estimated number of vehicle units, DF, the density factor (amount of vehicles per km2), and EF, the emission factor. The in-house emission factor for MC/TCs is measured as PM2.5 per kilometer traveled (per vehicle). Due to this non-standard EF unit, additional factors are required in Eq. (3). These include the association vehicles factor (AVF), the percentage of vehicles which are officially registered and properly accounted for by the city. To scale the EF to its proper units, it is multiplied by factor KT (kilometers traveled per day) and SDF (days in service per year). Similar to the previous example, the total is also multiplied by 0.01 to scale to each 0.01 km2 cell. The DF and NAF was verified using sensitivity analysis by ground surveys as detailed in section 2.4.

Emissions for agricultural waste burning were estimated with the formula shown in Eq. (5):

E_agricultural=((RS)/RA)×EF×SF , (5)

where: RS is the amount of rice straw produced per year, divided by RA, which is the total area in hectares (0.01 km2) used for growing of rice. EF is the in-house obtained emission factor for rice straw burning PM2.5 per year per square kilometer. SF is the survey factor, representing the percentage of farming area where burning of rice straw

as agricultural waste is used. This reduction factor is taken from the study of Launio, et al. (2013).

Authors' comment: The following corrections suggested by anonymous referee #1 were made in various capacities, taking into account our intent for the study methods, and acknowledging our own writing style and use of the English language. Corrections suggested by anonymous referee #1: 2. "Figure 2. The 2.4 x 4.0 km2 study. . .. . ."

Response: Caption edited for technical purposes

Page 14, Line 2 (caption): Figure 2: The 2.4 x 4.0 km study area in Cabanatuan City containing the "city center" (poblacion, highlighted).

Technical/language corrections

Page 1 Line 6, "Exposure to particulate matter (PM) is a serious environmental problem in many urban areas on earth." Line 8, ". . .. . .involving human exposures to particulate pollutants is rare." Line 9, "ïňĄne particulate (PM2.5) emissions" Line 10, "Nueva Ecija in the Philippines," Line 11, "The emissions estimated" Line 11, "geographic information system (GIS)" Line 12, "The present results suggest that emissions from" Line 14, I think this is better "applied to any urban area, as long"

Response: Abstract section mostly edited as suggested, see full changes below:

Page 1, Lines 6-15: Exposure to air particulate matter (APM) is a serious environmental problem in many urban areas on Earth. In the Philippines, most existing studies and emission inventories have mainly focused on point and mobile sources, while research involving human exposures to particulate pollutants is rare. This paper presents a method for estimating the amount fine particulate (PM2.5) emissions in a test study site in Cabanatuan City, Nueva Ecija in the Philippines, by utilizing local emission factors, regionally procured data and land cover/land use (activity data) interpreted from satellite imagery. Geographic information system (GIS) software was used to map the estimated emissions in the study area. The present results suggest that vehicular emis-

sions from motorcycles and tricycles, as well as fuels used by households (charcoal) and burning of agricultural waste largely contribute to PM2.5 emissions in Cabanatuan City. Overall, the method used in this study can be applied in other small urbanizing cities, as long as on-site specific activity data, emission factor and satellite-imaged land cover are available.

Line 21, “Particulate matter, especially. . .. .haze phenomena, local and regional air quality, and climate.” Line 22, “Exposure to pollutants is a risk for many people leaving in urban areas, since the level of pollution frequently exceeds WHO guidelines (Mage et al., 1996).” Line 24, “The presence of high PM2.5 is linked to increased morbidity. . .. .”

Response: Introduction section (paragraph beginning in page 1, line 21) was edited as suggested.

Page 1, Line 21 – Page 2, Line 2: Exposure to air particulate matter, especially fine particles smaller than 2.5 micrometers in size (PM2.5), can reduce air quality, affect visibility through smog and other haze phenomena, and introduce lasting effects on climate on a local and regional scale. Exposure to pollutants is a risk for many people living in urban areas, since the level of pollution frequently exceeds WHO guideline values (Mage, et al., 1996).The presence of PM2.5 is linked to increased morbidity and mortality risk, especially in incidences of various cardio-pulmonary diseases (Chen, et al., 2008; Lin, et al., 2016; Wu, et al., 2013), birth defects (Goto, et al., 2016), and cancer (Cassidy, et al., 2007). PM2.5 pollution is also considered carcinogenic, especially exposure to the finest fractions (ultrafine particles) (Bocchi, et al., 2016). This can be attributed to particles acting as carriers of mutagenic and genotoxic compounds (Chen, et al., 2016).

Page 2 Line 1, “carcinogenic, especially exposed for the ïňĄnest fraction. . ..” I think “for” instead of “at”. Line 2. “attributed to particles acting as” Line 4 “Sources of PM2.5 are caused by many man-made activities.” Line 4, “A common source of. . .. . ..areas

is related to mobile sources, directly. . .. . .” Line 7, Connect this paragraph to the previous one. Line 7, This sentence has to be improved. Line 9, Suggestion “However, PM2.5 emissions from other activities such as burning of agricultural waste occurs as well in Philippines cities. . .. .”

Response: Various edits for wording, clarity, and content were made to the paragraph beginning in page 2, line 4 as suggested (some edits are not exactly the same as suggested by anonymous referee #1)

Page 2, Lines 4-9: Sources of PM2.5 are caused by many man-made activities. A common source of PM2.5, in urban areas is related to mobile sources, directly emitted by internal combustion processes inside vehicles of all types (Andrade, et al., 2012; Ahanchian and Biona, 2014; Chen, et al., 2016). In most of the reports from Philippine cities, vehicular emissions reported in inventories use foreign emission factors (such as CORINAIR and AP 42). However, PM2.5 emissions from other activities such as burning of agricultural waste occurs as well in cities with a mixture of rural and urban land uses (Sarigiannis, et al., 2014; Kim Oanh, et al., 2011; Gadde, et al., 2009). Line 14, “At present, air quality monitoring and management are based on. . .. . ..” Line 15, “Standards for PM2.5 have however not been fully developed and implemented in small cities. Emissions inventories in general have likewise. . .. . ..in many cities.” Line 17. “In addition, previous investigations are rare and limited in time, which means that temporally resolved long-term air quality monitoring data are not available.”

Response: Various edits for wording, clarity, and content were made to the paragraph beginning in page 2, line 11 as suggested.

Page 2, Lines 11-14: At present, air quality monitoring and management are based on PM10 and total suspended particles (TSP) as an indicator. Standards for PM2.5 have however not been fully developed and implemented in small cities. Emission inventories in general have likewise not been conducted in many cities. In addition, previous investigations are rare and limited in time, which means that temporally resolved long-

term air quality monitoring data are not available.

Line 20, “This study present a method to estimate PM2,5 by utilising emission factors, satellite imagery and activity data. The latter is obtained from interpretation of geographic information system (GIS) data and by identifying and localising all sources in a city, taking into account the type of emissions (. . .. .) and activities that produces the emissions. This includes factors such as local population, density of households, number of emission-generating. . .. . ..” Line 27, “A limitation with this study. . .. .sources, since this is required in the mapping process.”

Response: Various edits for wording, clarity, and content were made to the paragraph beginning in page 2, line 16 as suggested (spelling differences reflect local usage of English).

Page 2, Lines 16-22: This study presents a method to estimate PM2.5 by utilizing locally sourced emission factors, satellite imagery, and activity data. The latter is obtained from interpretation of geographic information system (GIS) data and by identifying and localizing all sources in the city, taking into account the type of emission (point, area, mobile), and activities which produces the emissions. This includes factors such as local population, density of households, number of emission-generating events, and the type and amount of various fuels used. This, in conjunction with various local emission factors, will be used to estimate total PM2.5 emissions. A limitation of this study is that all emission sources are treated as being area sources, since this is required in the mapping process.

Line 30, “This study aims to determine. . .. . ..PM2.5, caused by individual and several aerosol sources. The present method can speciïňĄcally be used for similar mixture of man-made activities as in the Philippines cities: open burning of agricultural waste and charcoal (rural activity or population) as well as usage of mobile sources (urban activity or population).” Page 3 Line 1, Connect this paragraph with the previous one. Line 1, “Another application of this study is planning aids for local governments, as the

present method can be used in emission inventories for small cities. The method was developed to be used with minimal required training and effort by stakeholders, in order to create emission inventories of aerosol sources in the cities."

Response: Various edits for wording, clarity, and content were made to the paragraph beginning in page 2, line 24 as suggested (some edits are not exactly the same as suggested by anonymous referee #1)

Page 2, Lines 24-32: From the resulting maps, the study aims to determine areas of high concentration of PM2.5, caused by individual and several aerosol sources. The present method can specifically be used for similar mixtures of man-made activities present in Philippine cities. This method is specifically meant to explore this method for use in relatively small regional urban centers and cities in the Philippines; especially due to these cities being situated in locations where there is a mixture of rural and urban activities. Sources corresponding to rural activity include open burning of agricultural waste and the usage of household cooking fuels such as charcoal. Sources corresponding to urban activity include vehicular mobile sources such as tricycles, jeepneys, and PUVs (buses and vans). Another application for this study is planning aids for local governments; as the present method can be used in emission inventories for small cities. The method was developed to be used with minimal required training and effort by stakeholders, in order to create emission inventories of aerosol sources in the cities.

Line 8, "Philippines (Fig. 1)." Line 9, "and an estimated population of 296,584 in 2012." Line 10, "around half each of the total population (Cabanatuan City SEP, 2015)." Line 13, "A 2.4 by 4.0 kilometre area including the city centre and its nearest environs was selected as the study area." Line 14, "of the study area shown in Fig. 2." Line 15, As it is written, marked with grey is not shown in Fig. 2 and what is meant with "point of reference"? I have difĩňĄcult to understand this sentence. Line 17, "The investigation area includes residential and commercial quarter, and even agricultural areas with less than two kilometres to a main road." Line 19, "A commercial zone and the main industrial district in Cabanatuan City located south and about 8 km from the

eastern border of the investigation area, respectively, are not taken in consideration in the study."

Response: Various edits for wording, clarity, and content were made to the paragraph beginning in page 3, line 3 as suggested (some edits are not exactly the same as suggested by anonymous referee #1, some spelling differences reflecting local usage of English)

Page 3, Lines 3-14: The test study was conducted in Cabanatuan City, Philippines (Fig. 1). It is the former capital and largest city of the province of Nueva Ecija, with a land area of 190.67 square kilometers and an estimated population of 296,584 in 2012. On average, the population density is around 1,516 persons per square kilometer. The urban and rural population take up around half each of the total population (Cabanatuan City SEP, 2015).

A 2.4 by 4.0 kilometer area including the city center and its nearest environs was selected as the main study area. The town proper, (locally known as the poblacion) is highlighted in the map of the study area shown in Fig. 2. Grey lines indicate boundaries of barangays (the smallest administrative division of a local government, a similar concept to town wards or districts), and the constituent barangays of the poblacion are marked using thicker grey outlines. The investigation area includes residential and commercial zones, and even agricultural areas less than two kilometers away from a main road. A commercial zone and the planned main industrial district in Cabanatuan City located south and about 8-10 km southeast of the investigation area, respectively, are not taken into consideration in the study.

Line 22, "The investigation area was divided with 24 x 40 grid cells (100 x 100 m or 1 ha / 0.01 km2). For each cell, the type of man-made activity. . .. . ..Detailed images over the ground, taken by Google Street View (examples are shown in Fig. 3), were also. . .. .(residential/commercial)." Line 26. "Satellite images were dated 3 March 2016, while street view images. . .. . ..September 2015. Additionally,

maps from OpenStreetMap were also used for identifying special landmarks or since it occasionally present more updated information than Google Street View."

Response: Various edits for wording, clarity, and content were made to the paragraph beginning in page 3, line 16 as suggested. Some technical edits are also present (some edits are not exactly the same as suggested by anonymous referee #1)

Page 3, Lines 16-24: The investigation area was divided with 24 x 40 grid cells (100 x 100 m or 1 ha / 0.01 km2 each). For each cell, the type of man-made activity was interpreted from satellite images taken from Google Earth software. The classification process is similar to what is done for methods of supervised classification of land cover. The image of the surface feature is compared to a reference area of known land cover. Due to the size of each cell, the detail of each ground feature can be clearly seen. Detailed images over the ground, taken by Google Street View (examples are shown in Fig. 3) was used to verify building types (residential/commercial). Satellite images were dated 3 March, 2016, while ground level (Street View) images were dated September 2015. Additionally, maps from OpenStreetMap were also used for identifying special landmarks or as an additional resource since it occasionally presents more updated information on surface features than Google Earth/Google Street View.

Line 30, "Google Earth Images have been used here instead of raw image data from example the Landsat satellite. This is because the method developed in this study is intended. . .. . ..familiar with processing of satellite raw imagery data. The Google Earth images have been processed to exclude the presence of clouds and corrected for aberrations from the camera taken the satellite images." If the images really show some clouds sometimes please modify the latter sentence suggested.

Page 4 Line 2, "These images are not representative for the most current features on the ground, minor . . ..coordinates. It is also difiňĄcult to get access to the metadata of the original images. Even so, the Google product is useful enough and then also for the uninitiated considering the present purpose. In addition, other programs such as

the Google Street View or OpenStreetMap (community-based initiative) for mapping can be used." Line 6, Sentence starting with "Actual veriïňĄcation. . .." is hard to understand.

Response: Various edits for wording, clarity, and content were made to the paragraph beginning in page 3, line 26 as suggested (some edits are not exactly the same as suggested by anonymous referee #1)

Page 3, Line 26 – Page 4, Line 6: Google Earth images have been used here instead of raw image data from, for example, the Landsat satellite (The collaged image used in Google Earth is sourced from processed images from Landsat and the European Space Agency (ESA)'s Copernicus program). This is because the method developed in this study is intended to be used by personnel not necessarily familiar with processing of satellite raw imagery data. The Google Earth images have been processed to minimize the presence of clouds and corrected for aberrations from the camera taking the satellite images. These images are not representative of the most current features on the ground. There is also a slight deviation of the actual coordinates representing the location of the area due to the orthographic projection of the satellite image. This is consistent with geolocation deviations present in most consumer-grade satellite/GPS products. It is also difficult to get access to the metadata of the original images. Even so, the Google satellite image product is useful enough for the uninitiated considering the present purpose. In addition, other data products such as Google Street View or OpenStreetMap (community-based initiative) can be used. The usage of supporting documents such as existing local government land use plans and land cover maps, as well as actual verification of features at the ground level (ground truth, that is, information on surface features in the study area), is necessary, and was used in this study to verify land cover and land use features at the surface level.

Line 10, "PM2.5 emissions in the Cabanatuan city highly depend on local activity. Therefore, each grid cell (100 x 100 m) within the study area has been classiïňĄed with respect to the land cover features, i.e. residential/commercial quarter, agricul-

tural areas or other surface characteristics. Figure 4 shows that residential land use (households using liqueïňĄed petroleum gas as a fuel) are spread widely, although with noticeable commercial districts and open ïňĄelds (not settled) located within this area. Two large agricultural areas are found in the northwest and east, occupied by small households likely using fuels." Improve the latter with just writing "fuels". Line 19, The Pampa River is marked with blue color in the ïňĄgure, and in southeast a new residential area near open ïňĄelds and agricultural areas has been built-up." Line 23, Connect this paragraph to the previous one. Line 23, "Note that some of the grid cells are marked as land uses directly: cemetery and terminal. The latter corresponding to the central transport terminal of Cabanatuan city, where high vehicular emissions are expected."

Response: Various edits for wording, clarity, and content were made to the paragraph beginning in page 4, line 8 as suggested (some edits are not exactly the same as suggested by anonymous referee #1). The usage of the wording "household fuels" was fixed overall in this section and in some other parts of the paper to now read "households" or "fuels" depending on context instead.

Page 4, Lines 8-15: PM2.5 emissions in Cabanatuan City highly depend on local activity. Therefore, each grid cell (100 x 100 m) within the study area has been classified with respect to the land cover features, i.e. residential/commercial zones, agricultural areas, or other surface characteristics. Figure 4 shows that residential land use (households using liquefied petroleum gas as a fuel) are spread widely, although with noticeable commercial districts and open fields (not settled or occupied) located within this area. Two large agricultural areas are found in the northwest and east, occupied by small households likely using fuels. The Pampanga River is marked in blue in the figure, and in the southeast, a new residential area near open fields and agricultural areas has been built-up. Note that some of the grid cells are marked as land uses directly: cemetery and terminal, the latter corresponding to the central transport terminal of Cabanatuan City, where high vehicular emissions are expected.

Line 27, “Estimation of PM2,5 emission Line 28, “All calculations that have been used here to estimate PM2.5 emissions are based on. . .. . .(EPA, 1995): Lines 28 and 31, Emissions of what? Line 31, “where E is equal to emissions, A is the activity rate/data (e.g. quantity of fuel, percentage of households using fuel), EF represents the. . .. .”

Response: Various edits for wording, clarity, and content were made to the section beginning in page 4, line 17 as suggested (some edits are not exactly the same as suggested by anonymous referee #1)

Page 4, Lines 17-26: All calculations that have been used to estimate PM2.5 emissions are based on a general formula used by the US EPA in the AP 42 Compilation of Air Pollutant Emission Factors (EPA, 1995), as shown in Eq. (1)

$E=A \times EF \times (1-ER/100)$, (1)

where: E is equal to PM2.5 emissions, A is the activity rate/data (e.g. quantity of fuel used, percentage of households using fuel), EF represents the emission factor, and ER is the overall emission reduction factor/efficiency in percent, if applicable. In the present method, E is estimated as being the quantity of PM2.5 per unit cell: micrograms per 0.01 km2 (1 hectare) per year. ER refers to other factors affecting the total amount of PM2.5 emissions (such as factors not directly accounting towards the quantity of fuel used; ER factors also incorporate the activity of those using quantities of fuel lower than average). This comprises the various factors that are also part of activity data (as in, factors that modify the amount of emissions generated) as used in this study.

III. Evaluation and response to interactive comment by anonymous referee #2:

This is an interesting paper for those researchers interested in PM2.5 emissions and learns about approaches to estimate the spatial distribution of emissions using activity data, local emission factors and land cover derived from satellite imagery. That would be of interest to the Atmospheric Measurement Techniques readership. However, the

manuscript needs to be considerably improved before publication, both from the point of view of its presentation and from the amount of details provided on the data. I think the paper should be accepted after the comments and suggestions below and those from the other reviewer have been addressed.

Major issues

If the paper is to be published in AMT, I advise a signiïňĄcant revision and restructuring of the manuscript. It was at times difïňĄcult to read. The largest issue for me is that the methods section is extremely difïňĄcult to follow. The used methods of the paper must be written clearly and explicitly. I would suggest restructuring the article to better streamline the material. There is a wide combination of methods, calculations and data products used. For example, the description of the study area and Google satellite image are ïňĄrst introduced in Section 2.1. And additionally, the used methods have been mentioned in the same Section 2.1. Then, all details of the activity data and emission estimations are given throughout Section 2.2. My suggestion to improve readability and clarity would be to reorganize all the methods and results into the following Sections: 2. Materials and methods 2.1 Study area 2.2 Activity data (with used data and methods) 2.3 Local emission factors (with used data and methods) 2.4 Land cover classiïňĄcations by using satellite imagery (with used data and methods) 2.5 Validation of emission estimation factors, ground surveys, and sensitivity analysis 3 Results and discussion 3.1 The utilizing of activity data (with the discussions) 2.3 The utilizing of local emission factors (with the discussions) 2.4 The utilizing of Land cover classiïňĄcations (with the discussions) 4 Summary and conclusion The Section “4.1 Recommendations” just stand there or there are other sessions such as 4.2, 4.3? If not, it must be done with the Section 4.

Response: The entire manuscript from section 2 onwards has been restructured using the following headers:

2 Materials and methods Study area Land cover classification using satellite imagery

PM2.5 emission estimation Local emission factors Activity data Emission estimation equations Validation of activity data factors (ground surveys and sensitivity analysis) 3 Results and discussion 4 Summary and conclusion 5 Recommendations

Response (continued): This was done to help streamline section 2 in particular. New sections were added to sections 2.2, 2.3/2.3.1/2.3.2/2.3.3, and 2.4 to give more detail as to the methods used in the study. The other prominent issue I have is the not precise deïňĄnition of "activity data" throughout the manuscript. In page 5 (line 5-6), the "activity data" is written as follows: "this study uses "activity data" to describe this and other relevant factors pertaining to the quantity of fuel used and percentage of households using fuel". Are the activity data estimated? And what are the signiïňĄcant inïňĆuencing factors of the on-site speciïňĄc activity data? An important concern is the emission factor. It is not clear, what is the dependence of emission factors on the fuel types. Another problem I have is that there is a little-to-no mention about the used method of land cover classiïňĄcation.

Response: The definition of "activity data" is now worded to follow more closely with how it is used in the general EPA equation as explained in the section starting in page 4, line 17, and used as the basis for equation (1). All mentions of "emission estimation factors" or "EEF" used in the previous iteration of the manuscript were removed in favor of wording that includes the factors that make up ER in equation (1) under the definition of "activity data" as well.

Page 4, Lines 17-26: All calculations that have been used to estimate PM2.5 emissions are based on a general formula used by the US EPA in the AP 42 Compilation of Air Pollutant Emission Factors (EPA, 1995), as shown in Eq. (1)

$E=A \times EF \times (1-ER/100)$, (1)

where: E is equal to PM2.5 emissions, A is the activity rate/data (e.g. quantity of fuel used, percentage of households using fuel), EF represents the emission factor, and ER is the overall emission reduction factor/efficiency in percent, if applicable. In the present

method, E is estimated as being the quantity of PM2.5 per unit cell: micrograms per 0.01 km2 (1 hectare) per year. ER refers to other factors affecting the total amount of PM2.5 emissions (such as factors not directly accounting towards the quantity of fuel used; ER factors also incorporate the activity of those using quantities of fuel lower than average). This comprises the various factors that are also part of activity data (as in, factors that modify the amount of emissions generated) as used in this study.

In my opinion, the authors not clearly discussed the limitation of Google Earth. It is not clear to me whether there was used any classiïňĄcation method for the land cover classiïňĄcations. If not, then I think a more signiïňĄcant treatment of the uncertainty in the classiïňĄcation is required. Is there the coordinate transformation considered?

Response: The new section 2.2 was created, structured, and edited to address this issue. An additional few sentences were added to the paragraph starting in page 3, line 16 to address the method used in the land cover classification.

Page 3, Lines 16-24: The investigation area was divided with 24 x 40 grid cells (100 x 100 m or 1 ha / 0.01 km2 each). For each cell, the type of man-made activity was interpreted from satellite images taken from Google Earth software. The classification process is similar to what is done for methods of supervised classification of land cover. The image of the surface feature is compared to a reference area of known land cover. Due to the size of each cell, the detail of each ground feature can be clearly seen. Detailed images over the ground, taken by Google Street View (examples are shown in Fig. 3) was used to verify building types (residential/commercial). Satellite images were dated 3 March, 2016, while ground level (Street View) images were dated September 2015. Additionally, maps from OpenStreetMap were also used for identifying special landmarks or as an additional resource since it occasionally presents more updated information on surface features than Google Earth/Google Street View.

Response (continued): Issues regarding the usage of Google Earth images were laid out in the paragraph starting in page 3, line 26.

Page 3, Line 26 – Page 4, Line 6: Google Earth images have been used here instead of raw image data from, for example, the Landsat satellite (The collaged image used in Google Earth is sourced from processed images from Landsat and the European Space Agency (ESA)'s Copernicus program). This is because the method developed in this study is intended to be used by personnel not necessarily familiar with processing of satellite raw imagery data. The Google Earth images have been processed to minimize the presence of clouds and corrected for aberrations from the camera taking the satellite images. These images are not representative of the most current features on the ground. There is also a slight deviation of the actual coordinates representing the location of the area due to the orthographic projection of the satellite image. This is consistent with geolocation deviations present in most consumer-grade satellite/GPS products. It is also difficult to get access to the metadata of the original images. Even so, the Google satellite image product is useful enough for the uninitiated considering the present purpose. In addition, other data products such as Google Street View or OpenStreetMap (community-based initiative) can be used. The usage of supporting documents such as existing local government land use plans and land cover maps, as well as actual verification of features at the ground level (ground truth, that is, information on surface features in the study area), is necessary, and was used in this study to verify land cover and land use features at the surface level.

SpeciïňĄc comments: The other reviewer provides excellent comments related to the technical correction that should be taken into account in the revision of the manuscript.

Response: The suggestions by anonymous referee #1 were largely taken into account (see previous section) for the editing of this manuscript.

(Attached is a copy of the revised manuscript using the .docx template: all references to line numbers in this document reflect the view of the attached MS Word file using "Simple Markup" instead of "All Markup").

Please also note the supplement to this comment:

http://www.atmos-meas-tech-discuss.net/amt-2017-14/amt-2017-14-AC1-supplement.zip

Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2017-14, 2017.