Anonymous Referee #1

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This manuscript describes a detailed sensitivity simulation of CH_4/CO_2 in Asia with respect to horizontal resolution employing two different versions of the LMDzINCA model. This kind of study can be expected to contribute significantly to improving performance of data assimilation and accuracy of inverse modeling as the authors emphasize. The overall text is well written, and the authors very carefully discuss the results. However, most of the descriptions in this paper appear to be too detailed and sometime tedious although they may be needed to convey useful information to the data assimilation procedure. The subject of this paper seems to be appropriate to the ACP. However, I would like the authors to consider my questions and revise the manuscript before I recommend the publication of this paper. Details of my comments will be found in the following.

[Response] Thank you very much for your careful review and comments. Following your suggestions, we launched new simulations with 39 vertical layers (L39) for both standard and zoom models, as compared to the previous simulations with only 19 vertical layers (L19). We updated the biomass burning emissions to the latest GFEDv4.1 for both CH_4 and CO_2 simulations. For CH_4, we also ran sensitivity test simulations, in which anthropogenic and wetland emissions are prescribed with the latest EDGARv4.3.2 and model outputs from ORCHIDEE. For CO_2, sensitivity test simulations are also performed with daily and 3-hourly biomass burning emissions from GFEDv4.1 (Table R1). Detailed results and discussions are presented in Section 3 in the revised manuscript. We also replied to your major and minor comments in the following, and hopefully our responses and revision adequately address all your comments and questions.

Major Comments:

M1: For "abstract" and "conclusions" section, I'm not convinced about conclusions of this manuscript. The authors state that the finer horizontal resolution version improves Asian CH_4/CO_2 simulation only moderately. Are you saying that enhancing horizontal resolution is not that useful (not beneficial)? I think you could more clearly express the message/implication of this study at least in abstract and conclusions parts.

[Response] Not really. The model's capability to represent the CH_4 or CO_2 variability at stations does not only rely on model resolution (in both horizontal and vertical direction). In this paper we would like to more emphasize that, with finer model resolution, the model performance is more sensitive to accuracy of the prescribed surface fluxes, particularly distribution of sources/sinks at fine scales and their short-term variabilities. The sensitivity test simulations we launched for the revised paper also show importance of the flux data quality in model performance and thus benefits of improved model resolution. Following your suggestion, we revised the manuscript and clarify it in Abstract and Conclusion.

M2: This study just showed that a finer horizontal resolution more or less contributes to improvement of CH_4/CO_2 simulation for Asia. But it is very unclear whether this improvement is really significant or meaningful in terms of regional budget and flux estimate. I think the authors should check the impacts of other factors (at least vertical resolution or NEE) on the simulation as well as horizontal resolution for more clearly appealing the advantages of your zoomed method in the LMDzINCA modeling framework.

[Response] As we stated in Introduction, the number of regional ground stations in South and East Asia has increased during the recent decades. Observations from these stations will provide useful constraints on regional flux estimates, if gradients between stations and their variabilities can be well represented in transport models. Compared to the global transport model with rather coarse model resolution, the zoomed transport model used in our study has the potential to better capture the observed spatial and temporal variations at regional stations due to the reduced representation errors. The impact of model resolution on regional budget and flux estimate should be addressed by inverse modeling, which is beyond the scope of this study. Following your suggestion, we launched new simulations with 39 vertical layers (L39) for both standard and zoom models, as compared to the previous simulations with only 19 vertical layers (L19). For CH_4, we also ran sensitivity test simulations, in which anthropogenic and wetland emissions are prescribed with the latest EDGARv4.3.2 and model outputs from ORCHIDEE (Table R1). Results show that L39 tends to amplify the simulated magnitude of synoptic and diurnal variabilities. The combination of L39 and the zoomed model grids can substantially improve representation of diurnal cycles in several cases, although sometimes with underestimated amplitudes (which points to further model improvements on PBL physics). In brief, models with finer resolution are more sensitive to flux errors, therefore improvement (or degradation) of model performance really depends on accuracy of the prescribed surface fluxes, especially distribution of local or reginal sources/sinks and their short-term variabilities. Detailed results and discussions are presented in Section 3 in the revised manuscript.

M3: For the moderate improvement with ZASIA, I do not yet understand the reason for it. The authors give several potential candidates like matching between the model's grid and observation site, different transport, etc. But how much do they contribute? Or what is the most possible reason for the improvement?

[Response] With the zoomed model, the explanation for the improved model performance on CH_4 mean annual gradients really depends on different stations. As mentioned in Section 3.1.1, the better performance at SDZ (117.12°E, 40.65°N, 293m a.s.l.) is more related to the detailed description of source distribution around the station; for the two coastal stations PON (79.86°E, 12.01°N, 30m a.s.l.) and CRI (73.83°E, 15.08°N, 66m a.s.l.), the improved model performance is related to the better characterization of the complex terrain (coastal environment) as well as the fluxes (continental flux dominated or ocean flux dominated).

M4: The authors stated that the ZASIA version does not deteriorate the performance of CH_4/CO_2 outside the zoomed area (L383). But they seem to be looking only at the sites displayed in Figure 1 (mostly in Japan). How about the impacts on performance for other sites like in EU, US, Africa, and the southern hemisphere? This point should be clarified in the main text with an additional figure as supplementary material.

[Response] Following your suggestions, we further included several global/regional stations in Europe (the stations JFJ and MHD), North America (the stations ALT, BRW, NWR and MLO), and the southern hemisphere (the stations AMS, CGO, and SPO) in this study (Table 2). Analyses show that the zoom versions do not deteriorate model performance outside the zoomed region compared to the standard versions. For example, the CH_4 and CO_2 annual gradients between HLE and these added stations can be well captured by both standard and zoom model versions (see open circles in Figure 2). Detailed results and discussions are presented in Section 3 and the supplementary material.

Minor Comments:

L158 to L173: How do you represent diurnal variation in OH?

[**Response**] As described in Section 2.1.1, we used climatological monthly OH concentration fields in this study and didn't consider the diurnal variation in OH fields. According to Patra et al. (2009), the CH_4 chemical lifetime in the troposphere is much longer than the dynamical residence time due to atmospheric transport, and accounting for OH diurnal cycle is not crucial for simulating seasonal, synoptic, and diurnal variations in CH_4 concentration fields.

L177 "The spin-up time of 6 years": Don't you have any trend or drift of global mean CH_4 concentration during these 6 years?

[Response] Take the global background station Mauna Loa as an example, Figure R1 presents time series of the simulated and observed CH_4 concentrations over the period 2000–2013, as well as the corresponding long term trends extracted from the data using the CCGVU curve fitting routine (Thoning et al., 1989). During the 6-year spin-up period (2000–2005), the simulated CH_4 concentrations decreased for the first three years and then levelled off. Drift of the global mean is found for both standard and zoom models, equivalent to around -12 ppb over this period. The model-observation disagreement in trend and global mean CH_4 concentrations results from the imperfect surface emissions and OH fields prescribed in the simulations. As we reply to the Reviewer #2 (Specific comments, Line 163), in this paper we are more focusing on the improvement gained from refinement of model grids rather than accurately reproducing the observed CH_4 concentrations and their interannual variations. Furthermore, all the traits and metrics we have considered to evaluate the model performance (i.e., annual mean gradient, seasonal cycle, synoptic variability, diurnal cycle and vertical gradient) give "relative" values that are not affected by the absolute CH_4 concentrations. Therefore the trend and drift of global mean CH_4 during the spin-up period will not have significant impact on comparison of performance between the standard and zoom models.

L179 “already realistic”: What do you mean by “realistic”? You should explain more about the initial conditions for CH_4.

[Response] In the revised paper, the initial CH_4 concentration field we used for the updated simulations is defined based on the optimized initial state from a CH_4 inversion that assimilates observations from 50+ global background stations over the period 2006–2012 (Locatelli, 2014; Locatelli et al., 2015). The optimized initial CH_4 concentration field for the year 2006 was rescaled to the levels of the year 2000 and used as the initial state in our simulations. As the initial condition for CH_4 is optimized with observations, we assume it to be “realistic”. Following your suggestion, we revised Section 2.1.1 accordingly to clarify the setup of initial condition for CH_4.

L395 “better description of the surface fluxes and/or transport”: Given the fact that CO_2 simulation is not improved by ZASIA, the improvement seen in CH_4 seems to be resulting from non-transport process (surface fluxes?).

[**Response**] Here we mean that, with ZASIA, the model improvement on the CH_4 annual gradient <u>at the stations SDZ, PON and CRI</u> may “result from a reduction in representation error with a higher model horizontal resolution in the zoomed region, through a better description of the surface fluxes and/or transport around these stations”. In fact, we also found improved model performance on the CO_2 annual gradients at the three stations, although not as significant as it is for CH_4 (Table R2). Therefore the model improvement may result from better characterization of either surface fluxes or transport processes or both.

L435: There appears no explanation for the abbreviation of “NEE”.

[**Response**] Following your suggestions, we provide the full name (net ecosystem exchange) when the abbreviation is used for the first time.

L500 “rather coarse (19 layers)”: How do you get the model concentrations at the elevation of the observational site? The model layers are linearly interpolated?

[**Response**] As described in Section 2.3, the modelled concentrations are sampled at the nearest gridpoint and vertical level to each station.

Tables

Table R1 Model setups for different simulations.

Simulation Code	Version	Anthrop. Emis.	Wetland Emis.
ST19_ED42	144×142 Standard, 19 layers	EDGAR4.2FT2010	KAPLAN climatology
ZA19_ED42	144×142 Asian Zoom, 19 layers		
ST39_ED42	144×142 Standard, 19 layers		
ZA39_ED42	144×142 Asian Zoom, 19 layers		
ST39_ED432	144×142 Standard, 19 layers	EDGAR4.3.2	
ZA39_ED432	144×142 Asian Zoom, 19 layers		
ST39_ED432ORC	144×142 Standard, 19 layers		ORCHIDEE climatology
ZA39_ED432ORC	144×142 Asian Zoom, 19 layers		

Table R2 The observed and simulated mean annual gradient of CH_4 **(a)** and CO_2 **(b)** between HLE and three stations (CRI, PON and SDZ) within the zoomed region. The bias reduction rates (in percentage) by using ZA compared to ST are also given for both 19- and 39-layer simulations.

a)

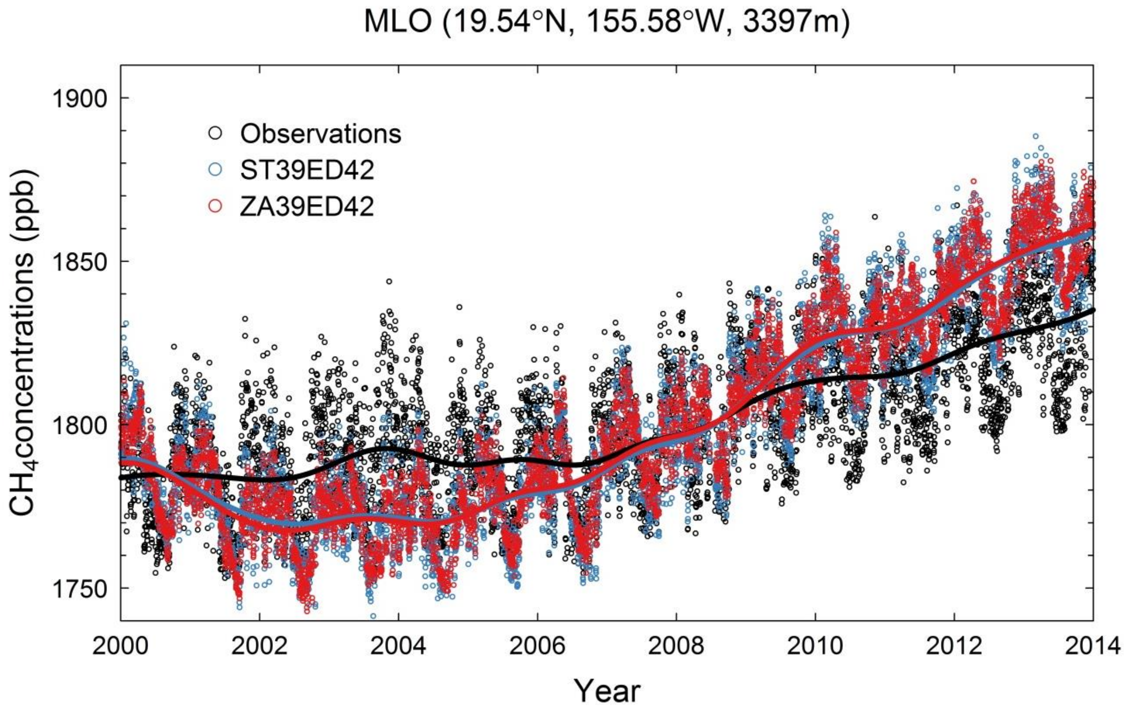
CH_4	OBS (ppb)	ST19 (ppb)	ZA19 (ppb)	Bias reduction	ST39 (ppb)	ZA39 (ppb)	Bias reduction
CRI	17.5±12.7	9.3±4.1	20.2±7.1	66.6%	8.6±3.0	23.0±6.7	38.8%
PON	32.4±12.4	2.5±11.6	31.1±7.7	95.6%	0.4±11.9	34.1±7.8	94.7%
SDZ	90.0±15.4	125.1±18.8	86.8±16.0	91.0%	128.5±19.3	100.4±22.4	73.0%

b)

CO_2	OBS (ppm)	ST19 (ppm)	ZA19 (ppm)	Bias reduction	ST39 (ppm)	ZA39 (ppm)	Bias reduction
CRI	4.6±0.9	1.2±0.1	2.0±0.3	25.5%	1.4±0.1	2.2±0.2	25.2%
PON	2.7±1.6	1.3±0.3	1.8±0.5	35.2%	1.5±0.3	1.9±0.5	37.0%
SDZ	6.8±0.5	8.8±1.3	7.7±1.9	57.9%	9.3±1.5	8.1±2.3	48.1%

Figures

Figure R1 Time series of observed and simulated CH_4 concentrations at Mauna Loa (MLO, 19.54°N, 155.58°W, 3397) during the period 2000–2013. The simulated CH_4 concentrations are based on outputs from both standard (ST39ED42, blue circles) and zoom models (ZA39ED42, red circles). The solid lines indicate the corresponding long-term trends extracted from the data using the CCGVU curve-fitting routine (Thoning et al., 1989).



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