On behalf of all the co-authors, we want to express our sincere gratitude to Reviewer 2 for providing very thoughtful comments and valuable suggestions regarding our manuscript. Following these comments and suggestions, we revised and reorganized the manuscript to improve its quality. Following the Reviewer's comments in black, please find our point-to-point responses in blue. The new texts in the revised manuscript are in blue and italic.

General Comments:
Review of "Two-way coupled meteorology and air quality models in Asia: a systematic review and meta-analysis of impacts of aerosol feedbacks on meteorology and air quality," by Gao et al., submitted to Atmospheric Chemistry and Physics Discussions.

This paper reviews air coupled meteorology-air quality models applied to Asia. It is quite detailed, almost too much in parts of it. It could benefit from more organization, better figure captions, and more specific conclusions. Below are some additional comments.
Response: To improve the paper's organization, we changed the title of Section 3 to "Basic overview", added a new Section 3.3 (Summary of modeling methodologies), and moved Section 5.1.2 and Section 5.2.2 to Appendix C in the revised manuscript. With respect to figure captions as well as table captions, we went through the manuscript and revised them accordingly. All the revisions of captions are listed in our response to the sixth comment. In the conclusion section, we refined several takeaways of our study and strengths and limitations of two-way coupled models, and the corresponding response is detailed in the ninth comment.

All responses to the additional comments are:

1. Introduction. "Online models or coupled models are designed and developed to consider the two-way feedbacks and attempted to accurately simulate both meteorology and air quality." It seems that this would be a good place to identify the origin of such models. According to Zhang (2008), the GATOR-GCMOM model is "the first fully-coupled online model in the history that accounts for all major feedbacks among major atmospheric processes based on first principles (Jacobson, 1994, 1997; Jacobson et al., 1996)."
Response: According to this suggestion, in Introduction section we added "*As Zhang (2008) pointed out, Jacobson (1994, 1997) and Jacobson et al. (1996) pioneered the development of a fully-coupled model named Gas, Aerosol, Transport, Radiation, General Circulation, Mesoscale, and Ocean Model (GATOR-GCMOM) in order to investigate all the processes related to ARI and ACI.*" before "Currently, there are three representative two-way coupled meteorology and air quality models, namely the Weather Research and Forecasting-Chemistry (WRF-Chem) (Grell et al., 2005), WRF coupled with Community Multiscale Air Quality (CMAQ) (Wong et al., 2012) and WRF coupled with a multi-scale chemistry-transport model for atmospheric composition analysis and forecast (WRF-CHIMERE) (Briant et al., 2017)".

2. Introduction. "Currently, there are three representative two-way coupled meteorology and air quality models." What does that mean? There are several more two-way coupled meteorology and air quality models, as cited later in the paragraph.

Response: To be more precise, the sentence is changed to "*Currently, there are three open-sourced two-way coupled meteorology and air quality models.*"

3. Introduction. Another coupled air quality-meteorological model used in Asia is GATOR-GCMOM. Its applications have included a study of the local and global fate of radionuclides from Fukushima (Ten Hoeve and Jacobson, 2012), where the model was run in both nested and global mode, and studies of the impact of urbanization in Beijing (Jacobson et al., 2015) and New Delhi (Jacobson et al., 2019) on air quality and meteorology. It seems that these papers meet the criteria listed.

Response: Thanks for providing this helpful information. We added relevant information into our revised manuscript and the details are listed as follows：

(1). Lines 178-180: "*(1) model-related keywords including "coupled model", "two-way", "WRF", "NU-WRF", "WRF-Chem", "CMAQ", "WRF-CMAQ", "CAMx", "CHIMERE", "WRF-CHIMERE" and "GATOR-GCMOM";*".

(2). Lines 282-283: Adding information of these three papers in Table 1.

(3). Lines 233-236: "*A total of 160 articles were selected according to the inclusion criteria, and their basic information was compiled in Table 1. In Asia, five two-way coupled models are applied to study the ARI and ACI effects. These include GATOR-GCMOM, two commonly used models, i.e., WRF-Chem and WRF-CMAQ, and two locally developed models, i.e., the global-regional assimilation and prediction system coupled with the Chinese Unified Atmospheric Chemistry Environment forecasting system (GRAPES-CUACE) and WRF coupled with nested air-quality prediction modeling system (WRF-NAQPMS).*".

(4). Line 321: Adding information regarding *GATOR-GCMOM* in Figure 1.

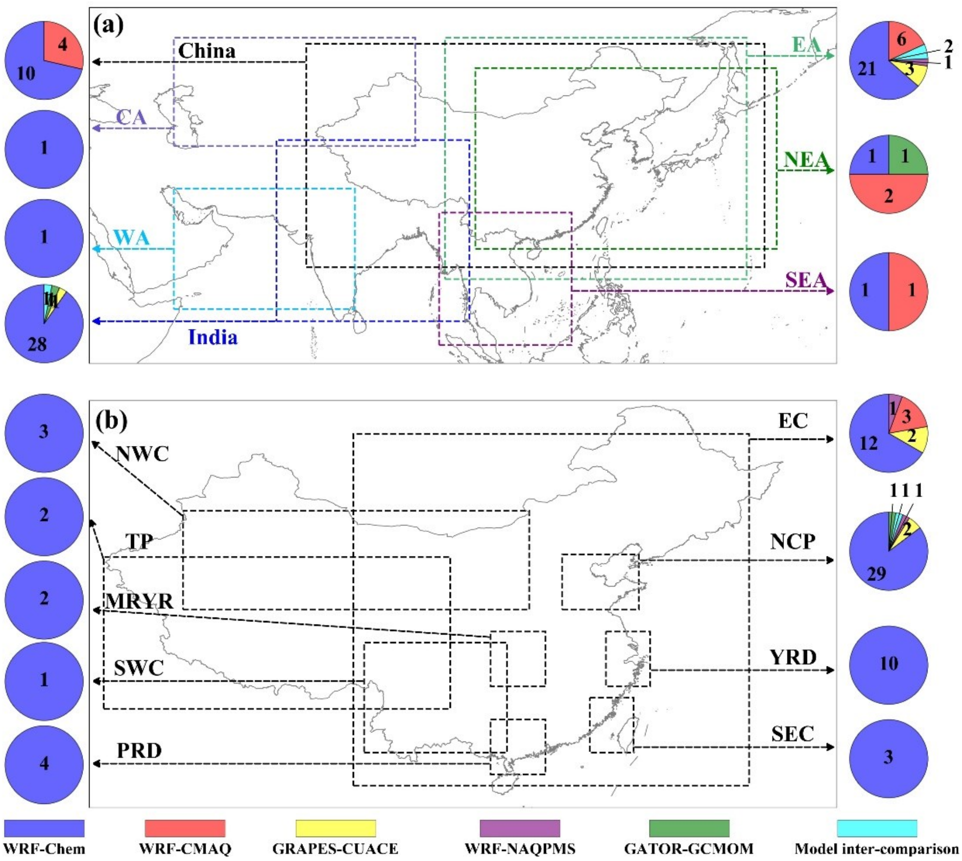

Figure 1. The spatial distributions of study domains as well as the two-way coupled modeling publication numbers in different subregions or countries of Asia (a) and areas of China (b). (EA: East Asia, NEA: Northeast Asia, SEA: Southeast Asia, EC: East China, NCP: North China Plain, YRD: Yangtze River Delta, SEC: Southeast China, NWC: Northwest China, TP: Tibetan Plateau, MRYR: middle reaches of the Yangtze River, SWC: Southwest China; PRD: Pearl River Delta).

(5). Line 329: Adding information of *GATOR-GCMOM* in Figure 2.

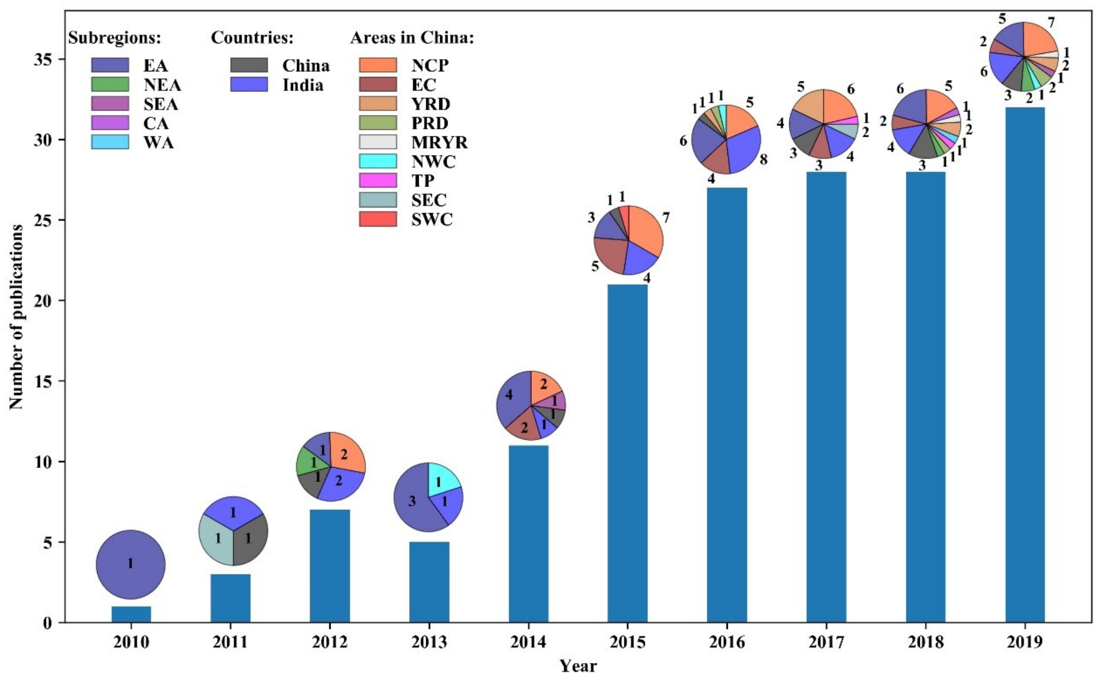

Figure 2. The temporal variations of study activities adopting two-way coupled models in Asia during 2010-2019. (EA: East Asia, NEA: Northeast Asia, SEA: Southeast Asia, EC: East China, NCP: North China Plain, YRD: Yangtze River Delta, SEC: Southeast China, NWC: Northwest China, TP: Tibetan Plateau, MRYR: middle reaches of the Yangtze River, SWC: Southwest China; PRD: Pearl River Delta).

(6). Lines 335-519: A new section named "Summary of modeling methodologies" of our revised manuscript had been added, and related information of GCTOR-GCMOM was inserted into this section.

(7). Lines 973-978 "*Also, to examine how different coupled models (i.e., WRF-Chem, WRF-CMAQ, WRF-NAQPMS, GRAPES-CUACE and GATOR-GCMOM) performed in Asia with respect to meteorological variables, the SI were extracted from PSI in term of these five coupled models and displayed in Fig. 4. The SI for T2, RH2, SH2, and WS10 from WRF-NAQPMS, GRAPES-CUACE and GATOR-GCMOM simulations were missing or with rather limited samples so that the discussions here only focused on the WRF-Chem and WRF-CMAQ simulations.*".

(8). Line 1013: Adding information related to *GATOR-GCMOM* in Figure 4.

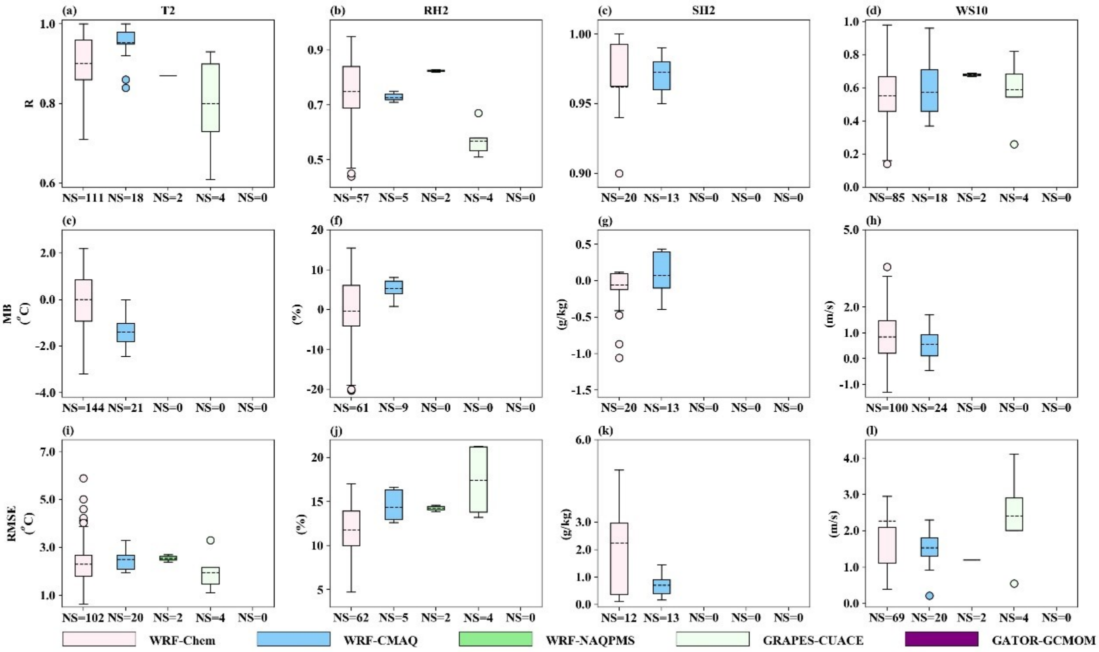

Figure 4. Quantile distributions of the statistical indices for simulated surface meteorological variables by WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM in Asia.

(9). Line 1069: Adding information regarding *GATOR-GCMOM* in Figure 6.

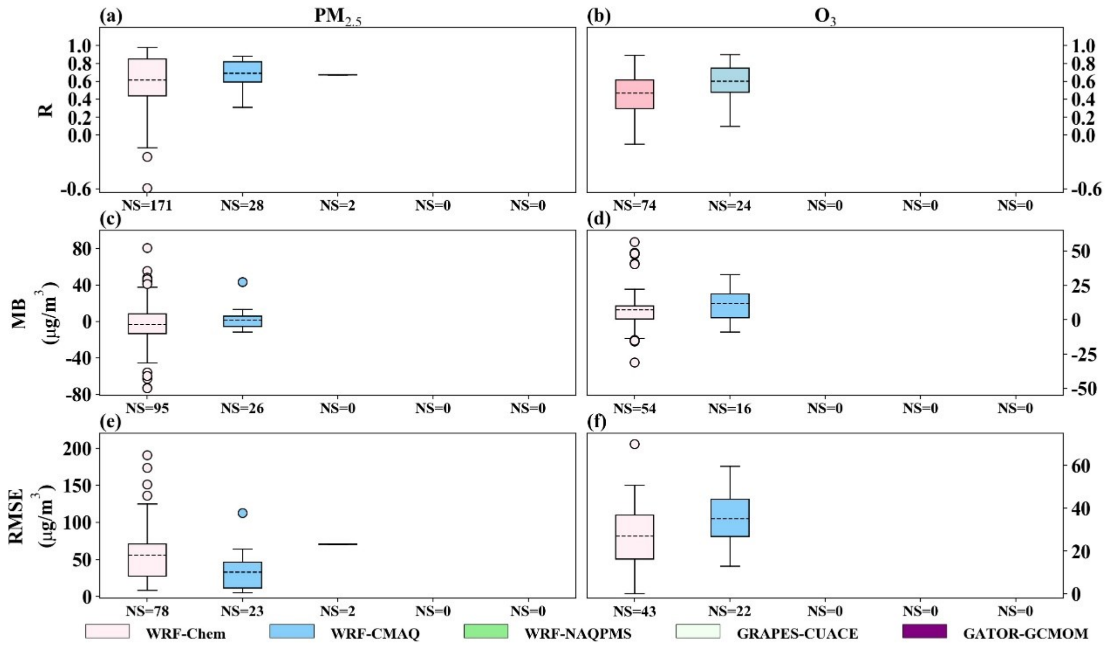

Figure 6. Quantile distributions of R, MB and RMSE of $PM_{2.5}$ and O_3 simulated by WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM in Asia.

(10). Lines 1289-1291: "*Through systematically searching peer-reviewed publications with several scientific-based search engines and a variety of key word combinations and applying certain selection criteria, 160 relevant papers were identified.*".

(11). Lines 1291-1297: "*Our bibliometric analysis results (as schematically illustrated in Fig. 9) showed that in Asia, the research activities with two-way coupled models had increased gradually in the past decade and the five two-way coupled models (WRF-Chem, WRF-CMAQ, WRF-NAQPMS, GRAPES-CUACE and GATOR-GCMOM) were extensively utilized to explore the aerosol effects in Asia focusing on several high aerosol loading areas (e.g., EA, India, China and NCP) during wintertime or/and severe pollution events, but less investigations looking into other areas and seasons with low pollution levels.*".

(12). Lines 1297-1299: "*Among the 160 papers, nearly 89 % of them focused on ARI (79 papers) and both ARI and ACI effects (63 papers), but papers that only considering ACI effects were relatively limited.*"

(13) Lines 1324-1327: *"Besides the five two-way coupled models mentioned in this paper, more models capable of simulating aerosol feedbacks (such as WRF-CHIMERE and WRF-GEOS-Chem) have become available and should be included in future inter-comparisons.*".

(14). Line 1334: Adding information involving *GATOR-GCMOM* in Figure A1.

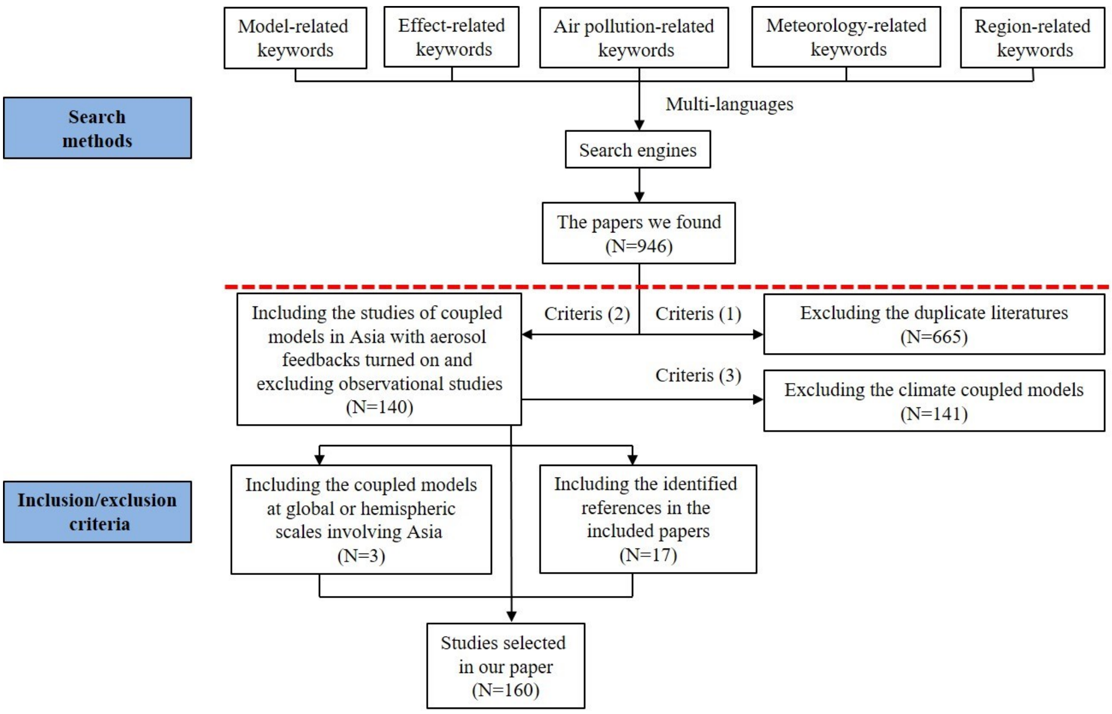

Figure A1. Flowchart of literature search and identification

(15). Lines 1340-1341: Adding information concerning *GATOR-GCMOM* in Table B1.

4. The discussion could be improved by identifying how different models treat aerosol size and composition. Do they use lognormal modes or discrete size sections. How many size distributions in either case are treated? What aerosol physical processes are treated? Coagulation? Condensation/evaporation? Internal-aerosol thermodynamic equilibrium? Hydration?

Response: We absolutely agree that it would improve the scientific quality of our manuscript by adding more detailed information and discussion about how aerosol size and composition are treated in two-way coupled models. In the new added Table 5 of the revised manuscript, we listed the methodologies representing aerosol composition and aerosol size distribution in different aerosol mechanisms. This table is also to response the comment by Reviewer 1 about how ARI and ACI being calculated in two-way coupled models.

Regarding to the questions raised here, we searched relevant papers through Google scholar and Web of Science and found three important review papers. Zhang (2008) and Baklanov et al. (2014) had systematically reviewed how aerosol size and composition were treated in two-way coupled models before 2013. Stevens and Dastoor (2019) outlined representations of aerosol mixing state and size distribution in 39 aerosol modules used in all available atmospheric models. Based on the thorough summary listed in Table 1 of Stevens and Dastoor (2019), we further dug out more detailed numerical settings of aerosol size distribution (namely, geometric diameter and standard deviation for modal approach or bin ranges for sectional method) in the five two-way coupled models used in Asia and compiled them in a new Table 3 in our revised manuscript. Please note that the values were extracted from published papers or/and source codes in different versions of these five models.

We added a new Section 3.3 titled "Summary of modeling methodologies" with the following contents:

"*How accurately ARI and ACI are simulated also rely on the representation of aerosol size distribution and composition in two-way coupled models. Three typical approaches (bulk, modal and sectional methods) are adopted by the five two-way coupled models and WRF-Chem offers all the three approaches, but other models only support one specific option. The Global Ozone Chemistry Aerosol Radiation and Transport (GOCART) model (Ginoux et al., 2001) in WRF-Chem is the only one that is based on a combination of bulk (for water, BC, OC, and sulfate aerosols) and sectional (for dust and sea salt aerosols) approaches. In the five two-way coupled models applied in Asia, modal and sectional approaches are widely used and their detailed numerical settings of aerosol size distribution (namely, geometric diameter and standard deviation for modal approach or bin ranges for sectional method) and the corresponding aerosol compositions are compiled in Table 3. Regarding the modal method, same parameter values for Aitken and accumulation modes and geometric diameters for coarse mode in the latest version of WRF-Chem (v4.3.3) and older version of WRF-CMAQ (before v5.2) are set as default, except the standard deviations for coarse mode are slightly different. In the official version of WRF-CMAQ released after v5.2, there are some modifications to the default setting of geometric diameters in Aitken, accumulation and coarse modes, from 0.010 to 0.015 μm, 0.070 to 0.080 μm and 1.00 to 0.600 μm, respectively. For the GRAPES-CUACE model, the geometric diameters and standard deviations for certain aerosol species in the accumulation mode were updated from its older version (Zhou et al., 2012) to newer one (Zhang et al., 2021). With respect to the sectional approach, 4 or 8 (from 0.039 to 10 μm), 12 (from 0.005 to 20.48 μm) and 14 (from 0.002 to 50 μm) particle size bins are defined in WRF-Chem, CUACE and GATOR-GCMOM, respectively. As shown in Tables 2 and 3, GATOR-GCMOM considered 47 aerosol species, and others coupled models adopted different numbers of species groups (such as 6, 5, 7, 8 aerosol species groups in WRF-Chem, CMAQ, NAQPMS and CUACE, respectively). Recently, more studies with two-way coupled models focused on aerosol feedbacks of light-absorbing aerosols, especially BrC emitted from BB (Jiang et al., 2012; Yao et al., 2017; Simeon et al., 2021). Some observational studies had applied the single particle soot photometer to investigate the optical properties of tarball particles released from BB (Adachi et al., 2019; Corbin et al., 2019; Yuan et al., 2021), but only GATOR-GCMOM had taken tarballs into account as a specific component. In addition, mineralogical compositions of dust aerosols were incorporated in a specific version of WRF-Chem (Li and Sokolik, 2018) to explore their ARI effects (Li and Sokolik, 2018).*"

Table 5. Summary of numerical representations of aerosol size distribution and composition in two-way coupled models applied in Asia.

Model	*Aerosol mechanism*	*Modal approach*						*Compositions*	*Reference*
		Aitken		*Accumulation*		*Coarse*			
		Geometric diameters (μm)	*Standard deviations (μm)*	*Geometric diameters (μm)*	*Standard deviations (μm)*	*Geometric diameters (μm)*	*Standard deviations (μm)*		

WRF-Chem v4.3.3	*MADE/SORGAM*	*0.010*	*1.7*	*0.07*	*2.0*	*1.0*	*2.5*	*Water, BC, OC, and sulfate, dust and sea salt*	*WRF-Chem codes*❁
WRF-Chem	*MAM3*	*0.013 (sulfate and secondary OM)*	*1.6 (sulfate and secondary OM)*	*0.068 (sulfate, secondary OM, primary OM, BC, dust and sea salt)*	*1.8 (sulfate, secondary OM, primary OM, BC, dust and sea salt)*	*2.0 (sea salt), 1.0 (dust)*	*1.8 (sea salt and dust)*	*Sulfate, methane sulfonic acid (MSA), OM, BC, sea salt and dust*	*Easter et al. (2004) Liu et al. (2012)*
	MAM7	*0.013 (sulfate and secondary OM and BC)*	*1.6 (sulfate, OM and BC)*	*0.068 (sulfate and BC) 0.068 (primary OM) 0.2 (sea salt) 0.11 (dust)*	*1.8 (sulfate and BC) 1.6 (primary OM) 1.8 (sea salt) 1.8 (dust)*	*2.0 (sea salt) 1.0 (dust)*	*2.0 (sea salt) 1.8 (dust)*	*Sulfate, methane sulfonic acid (MSA), OM, BC, sea salt and dust*	*Easter et al. (2004) Liu et al. (2012)*
WRF-CMAQ (before CMAQ v5.2)	*AERO5*	*0.010*	*1.7*	*0.07*	*2.0*	*1.0*	*2.2*	*Water, water-soluble BC, insoluble, sea salt*	*CMAQ codes*[*]
WRF-CMAQ (after CMAQ v5.2)	*AERO6, AERO7*	*0.015*	*1.7*	*0.08*	*2.0*	*0.60*	*2.2*	*Water, water-soluble BC, insoluble, sea salt*	*CMAQ codes*[†]
WRF-NAQPMS	*AERO5*	*0.052*	*1.9*	*0.146*	*1.8*	*0.80*	*1.9*	*Nitrate, dust, BC, OC, sea-salt, sulfate, ammonium, other primary particles*	*Wang et al. (2014)*
GRAPES-CUACE	*CUACE*	*BC: 0.10 OC: 0.10*	*1.7*	*Sulfate: 0.25 Nitrate: 0.25*	*1.7*	*Dust: 3.0*	*Dust: 1.7*	*Nitrate, dust, BC, OC, sea-salt, sulfate, ammonium*[ǂ]	*Zhou et al. (2012)*
GRAPES-CUACE	*CUACE*	*Unclear*	*Unclear*	*BC: 0.37 OC: 0.37*	*BC: 0.42 OC: 0.42*	*Unclear*	*Unclear*	*Nitrate, dust, BC, OC, sea-salt, sulfate, ammonium*[ǂ]	*Zhang et al. (2021)*
		Sectional approach							
WRF-Chem v4.3.3	*MOSAIC*	*0.039-0.156, 0.156-0.625, 0.625-2.5, 2.5-10.0 μm (4 bins) 0.039-0.078, 0.078-0.156, 0.156-0.312, 0.312-0.625, 0.625-1.25, 1.25-2.5, 2.5-5.0, 5.0-10.0 μm (8 bins)*						*Water, BC, OC, sulfate, dust and sea salt*	*WRF-Chem codes*◊
WRF-Chem	*MADRID*	*0.0216-10 μm (8 bins)*						*Water, BC, OC, and sulfate, dust and sea salt*	*Zhang et al. (2016)*
WRF-Chem v4.3.3	*GOCART*	*0.1-1.0, 1.0-1.8, 1.8-3.0, 3.0-6.0, 6.0-10.0 (5 bins for dust) 0.1-0.5, 0.5-1.5, 1.5-5.0, 5.0-10.0 (4 bins for sea salt)*						*Dust and sea salt*	*WRF-Chem codes*❁
GRAPES-CUACE	*CUACE*	*0.005-0.01, 0.01-0.02, 0.02-0.04, 0.04-0.08, 0.08-0.16, 0.16-0.32, 0.32-0.64, 0.64-1.28, 1.28-2.56, 2.56-5.12, 5.12-10.24, 10.24-20.48 μm (12 bins)*						*Nitrate, dust, BC, OC, sea-salt, sulfate, ammonium*	*Zhou et al. (2012)*
GATOR-GCMOM	*GATOR 2012*	*0.002-50 μm (14 bins)*						*42 species*[‡]	*Jacobson (2002, 2012)*

❁ *Official released WRF-Chem*

[*] *https://github.com/USEPA/CMAQ/blob/5.1/models/CCTM/aero/aero6/AERO_DATA.F.*

[†] *https://github.com/USEPA/CMAQ/blob/5.2/CCTM/src/aero/aero6/AERO_DATA.F.*

[‡] *More detailed components were presented in the first column of Table 2.*

[ǂ] *Initial size distribution is tri-modal log-normal distribution.*

We added a new Table 2 into revised manuscript and following paragraph into the new Section 3.3:

"*The physiochemical processes involved with ARI and ACI are sophisticated in actual conditions of atmospheric environment but their representations in two-way coupled models can be rather different. Also, simulation results depend on how these models are configured and set up. Therefore, the treatments of aerosol and cloud microphysics, and aerosol-radiation-cloud interactions in WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM applied in Asia, as well as the various aspects of how the modeling studies being set up in the selected papers are summarized in Tables 2-5, respectively, and outlined in this section.*

Aerosol microphysics processes consist of particle nucleation, coagulation, condensation/evaporation, gas/particle mass transfer, inorganic aerosol *thermodynamic equilibrium, aqueous chemistry and formation of secondary organic aerosol (SOA). Their representations in a variety of aerosol mechanisms offered in the five two-way coupled models applied in Asia and relevant references are compiled in Table 2. Note that the GOCART scheme in WRF-Chem is based on a bulk aerosol mechanism that is not able to consider the details of these microphysics processes. The binary homogeneous nucleation schemes with/out hydration developed by different authors are applied in the five coupled models for simulating the new particle formation and GATOR-GCMOM also adopts the ternary nucleation parameterization scheme for H_2SO_4, NH_3 and H_2O vapors. All the five coupled models calculate the aerosol-aerosol coagulation rate coefficients based the Brownian coagulation theory, with certain enhancements in GATO-GCMOM as stated in details by Jacobson (1999). The dynamic condensation/evaporation approaches of inorganic gases (e.g., H_2SO_4, NH_3, HNO_3, and HCl) and organic gases (VOCs) based on the Fuchs-Sutugin expression are implemented in various aerosol mechanisms offered by WRF-Chem, WRF-CMAQ, GRAPES-CUACE, and WRF-NAQPMS, while GATOR-GCMOM deploys the condensation/evaporation approach in which several terms of processes are factored in the 3-D equations of discrete size-resolved aerosol growth (Jacobson, 2012). The mass transfer between gaseous and aerosol particles are treated via two typical methods (i.e., bulk equilibrium and kinetic) in most coupled models, and the hybrid and Henry's law equilibrium methods are also applied in the MADRID (WRF-Chem) and the 6th/7th generation CMAQ aerosol modules (AERO6/AERO7) (WRF-CMAQ), respectively. Different versions of the ISORROPIA module, the Model for an Aerosol Reacting System-version A (MARS-A), the Multicomponent Equilibrium Solver for Aerosols with the Multicomponent Taylor Expansion Method (MESA-MTEM), and the EQUIlibrium SOLVer version 2 (EQUISOLV II) modules are implemented for computing the inorganic aerosol thermodynamic equilibrium in these two-way coupled models. For aqueous chemistry, the bulk aqueous chemistry scheme and variations of the CMAQ's standard aqueous chemistry module (AQCHEM) are the most applied, and the CBM-IV aqueous chemistry scheme, the Regional Acid Deposition Model (RADM) aqueous chemistry module, and the size-resolved aqueous chemistry module are utilized as well. Multiple approaches have been incorporated into the five coupled models for calculating the SOA formation and include the volatility basis set (VBS) approach, approaches considering reversible absorption or combined absorption and dissolution, fixed or bulk two-product yield approaches, and the approach of time-dependent organics condensation/evaporation with considering vapor pressure.*"

Table 2. Treatments of aerosol microphysics processes in two-way coupled models (WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM) applied in Asia.

	WRF-Chem						*WRF-CMAQ*			*GRAPES-CUACE*	*WRF-NAQPMS*	*GATOR-GCMOM*
	GOCART	*MADE/SORGAM*	*AERO5*	*MAM3/MAM7*	*MOSAIC*	*MADRID*	*AERO5*	*AERO6*	*AERO7*	*CUACE*※	*AERO5*	*GATOR2012*[*]
New particle formation/if with hydration	*None*	*H_2SO_4-H_2O binary homogeneous nucleation (Kulmala et al., 1998)/Yes*	*H_2SO_4-H_2O binary homogeneous nucleation (Kulmala et al., 1998)/Yes*	*H_2SO_4-H_2O binary homogeneous nucleation (Vehkamäki et al., 2002)/Yes*	*H_2SO_4-H_2O binary homogeneous nucleation (Wexler, et al., 1994)/Yes*	*H_2SO_4-H_2O binary homogeneous nucleation (McMurry and Friedlander, 1979)/Unclear*	*H_2SO_4-H_2O binary homogeneous nucleation (Kulmala et al., 1998)/Yes*	*H_2SO_4-H_2O binary homogeneous nucleation (Vehkamäki et al., 2002)/Yes*	*H_2SO_4-H_2O binary homogeneous nucleation (Vehkamäki et al., 2002)/Yes*	*H_2SO_4-H_2O binary homogeneous nucleation (Kulmala et al., 1998)/Yes*	*H_2SO_4-H_2O binary homogeneous nucleation (Yu, 2006)/Yes*	*H_2SO_4-H_2O binary homogeneous nucleation (Vehkamäki et al., 2002)/Yes; H_2SO_4-NH_3-H_2O ternary homogeneous nucleation (Napari et al., 2002)/Yes*

Coagulation	*None*	*Brownian motion (Binkowski and Shankar, 1995)*	*Brownian motion (Binkowski and Roselle, 2003)*	*Brownian motion (Whitby, 1978)*	*Brownian motion (Jacobson et al., 1994)*	*Brownian motion (Jacobson et al., 1994)*	*Brownian motion (Binkowski and Roselle, 2003)*	*Brownian motion (Binkowski and Roselle, 2003)*	*Brownian motion (Binkowski and Roselle, 2003)*	*Brownian motion (Jacobson et al., 1994)*	*Brownian motion (Jacobson et al., 1994; Chen et al., 2017)*	*Brownian motion, Brownian diffusion enhancement, turbulent shear, turbulent inertial motion, gravitational setting, Van der Waals forces, viscous forces, fractal geometry (Jacobson, 2003)*
Condensation/ Evaporation	*None*	*Dynamical condensation/ evaporation of H_2SO_4 vapor and VOCs based on Fuchs-Sutugin expression (Binkowski and Shankar, 1995)*	*Dynamical condensation/ evaporation of H_2SO_4 vapor and VOCs based on Fuchs-Sutugin expression (Binkowski and Shankar, 1995); Condensation/ evaporation of volatile inorganic gases to/from the gas-phase concentrations of coarse particle surfaces using ISORROPIA in reverse mode (CMAQ User's Guide)*	*Dynamical condensation of H_2SO_4 vapor, NH_3 (7 modes) and semi-volatile organics; Condensation/ evaporation of SOA gas (Liu et al., 2012)*	*Dynamical condensation/ evaporation of H_2SO_4 vapor, methanesulfonic acid, HNO_3, HCl and NH_3 with adaptive step time-split Euler approach (Zaveri et al., 2008)*	*Dynamical condensation/ evaporation of semi-volatile species for analytical predictor of condensation with moving-center approach (Zhang et al., 2010)*	*Dynamical condensation/ evaporation of H_2SO_4 vapor and VOCs based on Fuchs-Sutugin expression (Binkowski and Shankar, 1995); Condensation/ evaporation of volatile inorganic gases to/from the gas-phase concentrations of coarse particle surfaces using ISORROPIA in reverse mode (CMAQ User's Guide)*	*Same as in AERO5*	*Same as in AERO5*	*Dynamical condensation/ evaporation of H_2SO_4 vapor and gaseous precursors based on modified Fuchs-Sutugin expression (Jacobson, et al., 1994; Gong et al., 2003)*	*Condensation/ evaporation of H_2SO_4 with advanced particle microphysics approach (Li et al., 2018; Yu and Luo, 2009; Chen et al., 2019; Yu, 2006)*	*Dynamical condensation of H_2O and involatile species with Analytical Predictor of Nucleation, Condensation, and Dissolution scheme (Jacobson, 2002); Evaporation of a volatile component over a single particle (Jacobson and Turco, 1995)*
Gas/particle mass transfer	*None*	*1. Bulk equilibrium approach for HNO_3 and NH_3 (Zhang et al., 2005) 2. Kinetic approach for H_2SO_4 (Zhang et al., 2016)*	*Kinetic approach for all species (Foley et al., 2010)*	*Bulk equilibrium approach for $(NH_4)_2SO_4$ (Hu and Zhang, 2014)*	*Kinetic approach for all species (Zaveri et al., 2008)*	*1. Bulk equilibrium approach for HNO_3 and NH_3 (Zhang et al., 2010) 2. Kinetic approach for all species (Zhang et al., 2010) 3. Hybrid approach (Zhang et al., 2010)*	*Kinetic approach for all species (Foley et al., 2010)*	*1. Henry's law equilibrium (Foley et al., 2017) 2. Kinetic approach for all species (Foley et al., 2017)*	*Same as in AERO6*	*Kinetic approach for all species (Zhou et al., 2021)*	*Kinetic for all species (Chen et al., 2021)*	*Kinetic approach for all species (Jacobson, 1999)*
Inorganic aerosol thermodynamic equilibrium	*None*	*MARS-A (Binkowski and Shankar, 1995)*	*ISORROPIA (Byun and Kenneth, 2006)*	*ISORROPIA II (Hu and Zhang, 2014)*	*MESA-MTEM (Zaveri et al., 2008)*	*ISORROPIA (Zhang et al., 2010)*	*ISORROPIA (Byun and Kenneth, 2006)*	*ISORROPIA II (Appel et al., 2013)*	*ISORROPIA II (Appel et al., 2013)*	*ISSOROPIA (Zhou et al., 2012)*	*ISSOROPIA (Li et al., 2011)*	*EQUISOLV II (Jacobson, 1999)*
Aqueous chemistry	*None*	*Bulk cloud-chemistry scheme (Fahey and Pandis, 2001; Zhang et al., 2015)*	*AQCHEM (Fahey et al., 2017)*	*Based on algorithm developed by Barth et al. (2001) (He and Zhang, 2014)*	*Same as in MADE/ SORGAM (Fahey and Pandis, 2001; Chapman et al., 2009)*	*Same as in MADE/ SORGAM (Fahey and Pandis, 2001; Zhang et al., 2004)*	*1. AQCHEM 2. AQCHEM-KMT (Fahey et al., 2017)*	*1. AQCHEM-KMT 2. AQCHEM-KMTI (Fahey et al., 2017)*	*1. AQCHEM-KMT 2. AQCHEM-KMTI (Fahey et al., 2017)*	*Based on aqueous chemistry in CBM-IV mechanism by Gery et al. (1989)*	*Based on the RADM mechanism used in CMAQ v4.6 (AERO5) (Li et al., 2011)*	*Bulk or size-resolved cloud-chemistry module (GATOR2012)*
SOA formation	*None*	*1. Reversible absorption of 8 classes volatile organic compounds (VOCs) based on Caltech smog-chamber data (Odum et al., 1997; Griffin et al., 1999) 2. Based on volatility basis set approach (Ahmadov et al., 2012)*	*Combined absorption and dissolution approaches for 9 parent VOCs and 32 SOA species (Carlton, et al., 2010)*	*Treatment of SOA from fixed mass yields for anthropogenic and biogenic precursor VOCs (Liu et al., 2012)*	*1. Based on ambient ageing measurement of organic aerosols by Hodzic and Jimenez (2011) 2. Based on volatility basis set approach (Knote et al., 2014)*	*1. Absorptive approach for 14 parent VOCs and 38 SOA species 2. Combined absorption and dissolution approaches for 42 hydrophilic and hydrophobic VOCs (Zhang et al., 2004)*	*Combined absorption and dissolution approaches for 9 parent VOCs and 32 SOA species (Carlton, et al., 2010)*	*On the basis of SOA scheme in AERO5, adding parameterization of in-cloud SOA formation from biogenic VOCs (Foley et al., 2017)*	*On the basis of SOA scheme in AERO5/6, updated parametrization of monoterpene SOA yielded from photooxidation (Foley et al., 2021)*	*Reversible absorption of 8 classes VOCs based on Caltech smog-chamber data (Zhou et al., 2012)*	*Bulk two-product yield parametrization (Fu et al., 2016; Odum et al., 1997)*	*Using Henry's Law to determine vapor pressure of organics and perform either time-dependent condensation or evaporation calculations. (Jacobson, 2002)*

※CUACE is the aerosol mechanism implemented in the GRAPES-CUACE model (Zhou et al., 2012).

• GATOR2012 is the aerosol mechanism implemented in the GATOR-GCMOM model (Jacobson et al., 2012).

5. How are clouds treated in the models? Are they treated with lognormal modes or discrete size distributions or without size information? How do clouds interact with aerosol particles?

Response: To address the questions raised here, we added a new Table 3 and a paragraph about how clouds properties and aerosol-cloud interactions are represented in coupled models in Section 3.3 of our revised manuscript as follows:

"*In addition to aerosol microphysics processes, the cloud properties included in cloud microphysics schemes and the treatment of aerosol-cloud processes in the five two-way coupled models are different in terms of hydrometeor classes, cloud droplet* *size distribution, aerosol water uptake, in-/below-cloud scavenging, hydrometeor-aerosol coagulations, and sedimentation of aerosols and cloud droplets (Table 3). Among the microphysics schemes implemented in the five coupled models, mass concentrations of different hydrometeors (including cloud water, rain, ice, snow or graupel) are included but their number concentrations are only considered if the cloud microphysics schemes are two-moment or three-moment. The single modal approach with either lognormal or gamma distribution and the sectional approach with discrete size distributions for cloud droplets are applied in different microphysics schemes. Based on the Mie theory, WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM calculate cloud radiative properties (including extinction/scattering/absorption coefficient, single scattering albedo and asymmetry factor of liquid and ice clouds) in their radiation schemes (e.g., RRTMG, GODDARD, GATOR2012). In atmosphere, the hygroscopic growth of aerosols due to water uptake is parameterized based on the Köhler or Zdanovskii-Stokes-Robinson theory and the hysteresis effects depending on the deliquescence and crystallization RH are taken into account in the five coupled models. The removal processes of aerosol particles include wet removal and sedimentation. Aerosol particles in accumulation and coarse modes can act as CCN or IN via activations in cloud, which can further develop to different types of hydrometeors (cloud water, rain, ice, snow and graupel), and then gradually form precipitations. These processes are named as in-cloud scavenging or rainout. The aerosol particles below cloud base also can be coagulated with the falling hydrometeors, which are known as below-cloud scavenging or wash out. Both representations of in- and below-cloud scavenging processes are based on scavenging rate approach in aerosol mechanisms of WRF-Chem, WRF-CMAQ, GRAPES-CUACE and WRF-NAQPMS except GATOR-GCMOM. Size-resolved sedimentation of aerosols are computed from one model layer to layers below down to the surface layer using setting velocity in most coupled models and the MOSAIC aerosol mechanism in WRF-Chem only considers the sedimentation in the lowest model level (Marelle et al., 2017).*"

Table 3. Compilation of cloud properties and aerosol-cloud processes in two-way coupled models (WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM) applied in Asia.

	WRF-Chem	WRF-CMAQ	GRAPES-CUACE	WRF-NAQPMS	GATOR-GCMOM
Hydrometeor (Cloud microphysics scheme)	Mass concentrations: Cloud water, rain, ice, snow and graupel (Morrison, Lin, Thompson, WSM 6 class and Milbrandt-Yau) Cloud water, rain, ice and snow (WSM 5 class) Number concentrations: Rain, ice, snow and graupel (Morrison and Milbrandt-Yau) Rain and ice (Thompson) None (Lin, WSM 5 class and WSM 6 class)	Mass concentrations: Cloud water, rain, ice, snow and graupel (Morrison) Cloud water, rain, ice and snow (WSM 5 class) Cloud water and rain (WSM 3 class) Number concentrations: Rain, ice, snow and graupel (Morrison) None (WSM 3 class and WSM 5 class)	Mass concentrations: Cloud water, rain, ice, snow and graupel (WSM 6 class) Number concentrations: None (WSM 6 class)	Mass concentrations Cloud water, rain, ice, snow and graupel (Lin) Number concentrations: None (Lin)	Mass concentrations: Cloud water, ice and graupel (GATOR2012) Number concentrations: Cloud water, ice and graupel (GATOR2012)
Cloud droplet size distribution (Cloud microphysics scheme)	1. Single, modal approach with lognormal distribution (Morrison and Lin) 2. Gamma distribution (Thompson, WSM 5 class and WSM 6 class)	1. Single, modal approach with lognormal distribution (Morrison) 2. Gamma distribution (WSM 3 class and WSM 5 class)	Gamma distribution (WSM 6 class)	Single, modal approach with lognormal distribution (Lin)	Sectional approach with multiple size distributions (GATOR2012*) (Jacobson, et al., 2007)
Cloud radiative properties (Radiation scheme)	Extinction coefficient, single scattering albedo and asymmetry factor of liquid and ice clouds based on Mie scattering theory (RRTMG SW) Absorption coefficient of liquid and ice clouds using constant values (RRTMG LW) Extinction coefficient, single scattering albedo and asymmetry factor of liquid and ice clouds from lookup tables (Goddard SW and LW)	Extinction coefficient, single scattering albedo and asymmetry factor of liquid and ice clouds based on Mie scattering theory (RRTMG SW) Absorption coefficient of liquid and ice clouds using constant values (RRTMG LW)	Extinction coefficient, single scattering albedo and asymmetry factor of liquid and ice clouds using lookup tables (Goddard SW) Extinction coefficient, single scattering albedo and asymmetry factor of liquid and ice clouds from lookup tables (Goddard LW)	Extinction coefficient, single scattering albedo and asymmetry factor of liquid and ice clouds using lookup tables (Goddard SW) Clear sky optical depth from lookup table (RRTM LW)	Integrating spectral optical properties over each size bin of each hydrometeor particle size distribution (Toon SW and LW) (Jacobson and Jadhav, 2018)
Aerosol water uptake	Equilibrium with RH based on Köhler theory, and hysteresis is treated (Ghan and Zaveri, 2007)	The empirical equations of deliquescence and crystallization RH developed by Martin et al (2003), and hysteresis is treated (CMAQ source code)	Equilibrium with the mutual deliquescence and crystallization RH using the Zdanovskii-Stokes-Robinson equation, and hysteresis is treated (Personal communication)	Equilibrium with the mutual deliquescence and crystallization RH using the Zdanovskii-Stokes-Robinson equation, and hysteresis is treated (Nenes et al., 1998; Li et al., 2011)	Size-resolved equilibrium with the mutual deliquescence and crystallization RH using the Zdanovskii-Stokes-Robinson equation, and hysteresis is treated (Jacobson et al., 1996)

In-cloud scavenging (Aerosol mechanism)	*Scavenging via nucleation, Brownian diffusion, collection and autoconversion in both grid-scale and sub-grid clouds with a first-order removal rate (MADE/SORGAM, MOSAIC, MAM3 and MAM7) (Easter et al., 2004)*	*Scavenging of interstitial aerosol in the Aitken mode and nucleation scavenging of aerosol in the accumulation and coarse modes by the cloud droplets in both grid-scale and sub-grid clouds (AERO5, AERO6 and AERO7) (Binkowski and Roselle, 2004; Fahey et al., 2017)*	*Algorithm of rainout removal tendency by Giorgi and Chameides (1986)*	*Employing a scavenging coefficient approach based on relationships described by Seinfeld and Pandis (1998), only hydrophilic particles can be scavenged (Chen et al., 2017)*	*Size-resolved aerosol activation; nucleation scavenging and autoconversion for size-resolved cloud droplets (GATOR2012) (Jacobson, 2003)*
Below-cloud scavenging (Aerosol mechanism)	*Scavenged aerosols are instantly removed by interception and impaction but not resuspended by evaporating rain (MADE/SORGAM, MOSAIC, MAM3 and MAM7) (Slinn, 1984; Easter et al., 2004)*	*All aqueous species are scavenged from the cloud top to the ground in both grid-scale and sub-grid clouds (AERO5, AERO6 and AERO7) (CMAQ User's Guide; Fahey et al., 2017)*	*Aerosol particles between sizes ranging from 0.5 to 1 μm radius are instantly removed with considering cloud fraction, and scavenged rate depends on aerosol and hydrometeor sizes (Slinn, 1984; Gong et al., 2003)*	*Employing a scavenging coefficient approach based on relationships described by Seinfeld and Pandis (1998), considering accretion of in-cloud droplets particles into precipitation and impaction of ambient particles into precipitation*	*Discrete size-resolved coagulation between hydrometeors and aerosol particles (aerosol-liquid, aerosol-ice and aerosol-graupel) (GATOR2012) (Jacobson, 2003)*
Sedimentation of aerosols (Aerosol mechanism)	*Sedimentation with considering mass and number concentrations of aerosols at surface (MOSAIC) (Marelle et al., 2017)*	*Only considering gravitational sedimentation for aerosols (AERO5, AERO6 and AERO7)*	*Size-resolved sedimentation of aerosol particles above surface layer is computed with the setting velocity (CUACE) (Gong et al., 2003)*	*Using size-resolved sedimentation velocity to simulate sedimentation of aerosols (AERO5)*	*Sedimentation of size-resolved aerosols is computed from one model layer to layers below down to the surface, and the sedimentation velocities are calculated by two-step iterative method (GATOR2012) (Bear, 1976; Jacobson, 1997, 2003)*

* *GATOR2012 refers to either the aerosol or cloud microphysics scheme used in Jacobson (2012).*

6. Figure 6, caption. "…using two-way coupled models in Asia from literature." Please identify exactly which models are included and where the results are applicable to in the figure caption. Same with other captions.

Response: Thank you for your suggestion and we rewrote the captions of Figure 3, Figure 4, Figure 5, Figure 6, Figure 7, Figure 8, Table 6, Table 7, Table 8, Table B2, Table B3, Table B4 and Table B5 in the revised manuscript as follows:

Caption of Figure 3 is revised as "*Figure 3. Quantile distributions of R, MB and RMSE for simulated surface meteorological variables by the five coupled models (WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM) (a-d) and comparisons of statistical indices with/out ARI (e-h) in Asia.*"

Caption of Figure 4 is revised as "*Figure 4. Quantile distributions of the statistical indices for simulated surface meteorological variables by WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM in Asia.*"

Caption of Figure 5 is revised as "*Figure 5. Quantile distributions of statistical indices for simulated $PM_{2.5}$ and O_3 (a-b) by the five two-way coupled models (WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM) and comparisons of statistical indices with/out ARI (c-d) in Asia.*"

Caption of Figure 6 is revised as "*Figure 6. Quantile distributions of R, MB and RMSE of $PM_{2.5}$ and O_3 simulated by WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM in Asia.*"

Caption of Figure 7 is revised as "*Figure 7. Variations of shortwave and longwave radiative forcing (SWRF and LWRF) simulated by two-way coupled models (WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM) with aerosol feedbacks at the bottom and top of atmosphere (BOT and TOA), and in the atmosphere (ATM) in Asia.*"

Caption of Figure 8 is revised as "*Figure 8. Responses of shortwave radiation forcing to aerosol feedbacks in different areas/periods in Asia (a) and the inter-regional comparisons of its variations in Asia, Europe and North America (b).*"

Caption of Table 6 is revised as "*Table 4. Summary of variations of surface meteorological variables and planetary boundary layer height (PBLH) caused by aerosol feedbacks simulated by two-way coupled models (WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM) in different regions of Asia and at different temporal scales.*"

Caption of Table 7 is revised as "*Table 5. Summary of changes of cloud properties and precipitation characteristics due to aerosol feedbacks simulated by two-way* *coupled models (WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM) in Asia.*"

Caption of Table 8 is revised as "*Table 6. Compilation of aerosol-induced variations of $PM_{2.5}$ and gaseous pollutants simulated by two-way coupled models (WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM) in different regions of Asia and at different temporal scales.*"

Caption of Table B2 is revised as "*Table B2. The compiled number of publications (NP) and number of samples (NS) for papers that providing statistical indices (SI) of meteorological variables.*"

Caption of Table B3 is revised as "*Table B3. The compiled number of publications (NP) and number of samples (NS) for papers that providing statistical indices (SI) of air quality variables.*"

Caption of Table B4 was revised as "*Table B4. The compiled number of publications (NP) and number of samples (NS) for papers that simultaneously providing the statistical indices (SI) of meteorological variables simulated by coupled models (WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM) with/out ARI.*"

Caption of Table B5 was revised as "*Table B5. The compiled number of publications (NP) and number of samples (NS) for papers that simultaneously providing the statistical indices (SI) of air quality variables simulated by coupled models (WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM) with/out ARI.*"

7. In the figures, it would be useful to know what the overall mean percent error is in addition to the absolute errors

Response: We agree that it would be useful to add the overall mean percent errors in our figures depicting statistical indices, but we can only find very limited studies reporting this kind of information. According to our compiled data, there were only 13 studies reporting normalized mean error (NME) (%) of surface meteorological and air quality variables simulated by two-way coupled models (WRF-Chem and WRF-CMAQ) in Asia, which is summarized in Table B7 of our revised manuscript. It should be noted that no NME of meteorological variables simulated by two-way coupled models with and without enabling the ARI effects was mentioned in these studies. To reflect this additional information towards the meta-analysis, we also add two new paragraphs in Section 5.1.1 and Section 5.2.1 of the revised manuscript, respectively, as follows:

For meteorological variables in Section 5.1.1: "*Besides the SI discussed above, very limited papers reported the normalized mean error (NME) (%) of surface meteorological variables (T2, SH2, RH2 and WS10) simulated by two-way coupled* models (WRF-Chem and WRF-CMAQ) *in Asia, which is summarized in Table B7 of Appendix B. The evaluations with two-way coupled models in Asia showed that the overall mean percent errors of T2, SH2, RH2 and WS10 were 22.71%, 10.32%, 13.94%, and 51.28%, respectively. The ranges of NME (%) values were quite wide for T2 (from -0.48 to 270.20 %) and WS10 (from 0.33 to 112.28%) reported by the limited studies.*

Note that no NME of surface meteorological variables simulated by two-way coupled models simultaneously with and without enabling the ARI effects was mentioned in these studies."

For air quality variables in Section 5.2.1: "*In addition to the SI analyzed above and similar to the surface meteorological variables, the NME (%) of $PM_{2.5}$ and O_3 is listed in Table B7. The limited studies with WRF-Chem and WRF-CMAQ indicated that the overall mean percent errors of $PM_{2.5}$ and O_3 were 47.63% (from 29.55 to 104.70 %) and 43.03% (from 21.10 to 127.00 %), respectively. With the ARI effects enabled in WRF-Chem in different seasons over the China domain, the NME (%) of $PM_{2.5}$ increased slightly during most seasons, except during a spring month with little change (Zhang et al., 2018). Another study by Nguyen et al. (2019b) revealed that the NME (%) of $PM_{2.5}$ and O_3 simulated by WRF-CMAQ became a little worse in SEA comparing to the simulations without ARI.*"

Table B7. Summary of normalized mean error (NME) (%) of surface meteorological and air quality variables using two-way coupled models (WRF-Chem and WRF-CMAQ).

T2	SH2	RH2	WS10	$PM_{2.5}$	O_3	$PM_{2.5}$ with ARI (ARI) or without ARI (NO)	O_3 with ARI (ARI) or without ARI (NO)	Model	Region	Reference
					23.60, 38.50, 55.70, 39.80			WRF-Chem	EA	Liu X. et al. (2016)
0.80, 0.60, 0.60, 0.60		19.10, 16.50, 10.00, 10.10	58.90, 41.60, 44.90, 49.50	37.31, 37.61, 35.77, 34.69, 35.34, 35.41, 45.22, 44.33, 43.09, 39.29, 39.49, 39.07		37.61, 35.34, 44.33, 39.49 (ARI) 35.77, 35.41, 43.09, 39.07 (NO)		WRF-Chem	China	Zhang et al. (2018)
270.20, 22.30, 12.50, 17.60								WRF-Chem	EA	Zhang Yang et al. (2016a)
				44.99, 29.55, 37.28				WRF-Chem	NCP	Yang et al. (2015)
15.50, 15.80, 13.90, 9.90	10.40, 10.40, 9.90, 9.90		31.30, 31.30, 32.50, 32.50	49.80, 65.30, 49.80, 65.60, 88.30, 56.90, 88.40, 57.00	127.00, 32.20, 25.40, 126.10, 32.10, 25.00, 79.90, 25.80, 21.40, 45.80, 77.90, 25.60, 21.10, 39.50			WRF-Chem	EA	Zhang Y. et al. (2015a)
14	11		32	52.70, 58.00, 104.70, 62.00	87.50, 28.60, 23.30, 52.90, 32.40, 28.20			WRF-Chem	EA	Chen Y. et al. (2015)
-0.48, 0.19, 0.21, 0.05, 0.08, 0.13, 0.05, 0.04, 0.04, 0.05, 0.02, 0.02, 0.06, 0.05, 0.04, 0.02			0.33, 1.92, 0.71, 0.78, 0.28, 1.72, 0.61, 0.64, 0.24, 1.76, 0.00, 0.45, 0.34, 1.29, 0.44, 0.56					WRF-Chem	NCP	Chen D. et al. (2015)
16.60, 10.50, 8.90, 12.90, 10.50, 10.20								WRF-Chem	EA	Wang K. et al. (2018)
6.52, 6.58		15.76, 12.15	112.28, 97.26					WRF-Chem	NEA	Park et al. (2018)
				36.00, 33.00	31.00, 22.00			WRF-Chem	China	Zhao et al. (2017)
				44.00, 44.60, 40.10, 54.30				WRF-Chem	NCP	Gao M. et al. (2015)
				41.48, 41.00, 51.77, 55.70	26.68, 26.71, 34.43, 34.64	41.00, 55.70 (ARI) 41.48, 51.77 (NO)	26.71, 34.64 (ARI) 26.68, 34.43 (NO)	WRF-CMAQ	SEA	Nguyen et al. (2019b)
				37.99, 35.06, 38.59, 35.44, 34.39				WRF-CMAQ	China	Chang (2018)

8. Figure 9. Please provide details of the models used and the region covered.

Response: In the revised manuscript, Figure 9 becomes Figure 7. The caption of Figure 7 is revised to "*Figure 7. Variations of shortwave and longwave radiative forcing (SWRF and LWRF) simulated by two-way coupled models (WRF-Chem, WRF-CMAQ, GRAPES-CUACE, WRF-NAQPMS and GATOR-GCMOM) with aerosol feedbacks at the bottom and top of atmosphere (BOT and TOA), and in the atmosphere (ATM) in Asia.*" As per the reviewer's suggestion, a new table is added in Supplement as Table S5 in our revised manuscript and organized in the same order as Table 1, to illustrate the detailed information about the variations of SWRF and LWRF generated by which model and in which region/area in Asia. In addition, we revise the sentence in Lines 1087-1089 of the revised manuscript to "*Figure 7 presents the variations of simulated SWRF and LWRF at the bottom (BOT) and TOA and in the ATM due to aerosol feedbacks, and detailed information of these variations are compiled in Table S5 of Supplement.*"

Table S5. Summary of aerosol-induced variations of simulated shortwave and longwave radiative forcing (SWRF and LWRF) at the bottom and top of atmosphere (BOT and TOA) and in the atmosphere (ATM) in Asia.

No.	ΔSWRF at BOT (W/m^2)	ΔLWRF at BOT (W/m^2)	ΔSWRF in ATM (W/m^2)	ΔLWRF in ATM (W/m^2)	ΔSWRF at TOA (W/m^2)	ΔLWRF at TOA (W/m^2)	Model	Region	Reference
1	-8.05, -6.07, -0.45, -1.34	-0.28, -0.1, -0.02, -0.06	†	†	†	-1.91, -0.52, -0.48, -0.50	WRF-Chem	India	Singh et al. (2020)*
2	†	†	†	†	†	†	WRF-Chem	India	Bharali et al. (2019)
3	†	†	†	†	†	†	WRF-Chem	India	Shahid et al. (2019)
4	-73.71	†	†	†	†	†	WRF-Chem	NCP	Wang et al. (2019)
5	†	†	†	†	†	†	WRF-Chem	NCP	Wu et al. (2019a)
6	†	†	†	†	†	†	WRF-Chem	NCP	Wu et al. (2019b)
7	†	†	†	†	†	†	WRF-Chem	NWC	Yuan et al. (2019)
8	-40.6, -82.2, -38.4, -49.9	†	†	†	†	†	WRF-Chem	NCP	Zhang et al. (2019)
9	-38	†	†	†	†	†	WRF-Chem	NCP	Zhou et al. (2019)
10	-19.3	†	†	†	-14.2	†	WRF-Chem	WA	Bran et al. (2018)
11	†	†	†	+0.86, +1.21	-3.07, -4.39	†	WRF-Chem	China & India	Gao et al. (2018b)
12	-8.4	†	†	†	†	†	WRF-Chem	CA	Li M. M. et al. (2018)
13	-83.4, -91.4, -116.3, -82.9, -95.6, -139.1	+39, +45, +26.8, +38.6, +39.1, +26.8	+68.9, +82.3, +127.5, +67.8, +88.9, +164.8	-32.5, -36.4, -21.2, -32.2, -31.5, -21	-14.5, -9.1, +11.2, -15, -6.7, +25.7	+6.5, +8.6, +5.5, +6.4, +7.6, +5.7	WRF-Chem	YRD	Li and Sokolik (2018)
14	-69	†	†	†	†	†	WRF-Chem	NCP	Liu et al. (2018)
15	†	†	†	†	†	†	WRF-Chem	NCP	Miao et al. (2018)
16	-16.20, -14.86, -13.25, -12.74	+5.78, +5.29, +2.45, +2.52	+20.20, +21.00, +17.06, +19.07	-1.84, -4.26, +0.36, -1.80	+4.00, +6.14, +3.80, +6.34	+3.94, +1.03, +2.82, +0.72	WRF-Chem	India	Soni et al. (2018)
17	†	†	†	†	†	†	WRF-Chem	NCP	Wang L. T. et al. (2018)
18	-5.9	†	†	†	†	†	WRF-Chem	EC	Wang Z. L. et al. (2018)
19	†	†	-2, +2	†	†	†	WRF-Chem	TP	Yang et al. (2018)
20	†	†	†	†	†	†	WRF-Chem	EA	Zhou et al. (2018)
21	†	†	†	†	†	†	WRF-Chem	EC	Gao et al. (2017c)
22	-52.3	†	†	†	†	†	WRF-Chem	YRD	Li et al. (2017a)
23	-130	†	†	†	†	†	WRF-Chem	YRD	Li et al. (2017b)
24	-54.6, -18, -36.1	†	†	†	†	†	WRF-Chem	NCP	Qiu et al. (2017)
25	†	†	†	†	†	†	WRF-Chem	NCP	Yang and Liu (2017a)
26	†	†	†	†	†	†	WRF-Chem	NCP	Yang and Liu (2017b)
27	†	†	†	†	+0.79	†	WRF-Chem	EC	Yao et al. (2013)
28	†	†	†	†	†	†	WRF-Chem	SEC	Zhan et al. (2017)
29	-9.3, -14.2, -11.7	†	+6.3, +9.3, +6.3	†	-3, -4.9, -5.4	†	WRF-Chem	India	Feng et al. (2016)
30	†	†	†	†	†	†	WRF-Chem	NCP	Gao et al. (2016b)
31	-6.5, -8.3, -12.1, -8.5	†	†	†	†	†	WRF-Chem	EA	Liu et al. (2016)
32	-21.1, -13.1	†	+12.7, +4.8	†	†	†	WRF-Chem	NCP	Liu et al. (2016)
33	†	†	†	†	†	†	WRF-Chem	NCP	Miao et al. (2016)

34	-20, -30.8, -27.1, -25.8, -22.8	†	†	†	†	†	WRF-Chem	EA	Wang et al. (2016)
35	†	†	†	†	†	†	WRF-Chem	NWC	Yang et al. (2016)
36	†	†	†	†	†	†	WRF-Chem	EA	Zhong et al. (2016)
37	†	†	†	†	†	†	WRF-Chem	India	Govardhan et al. (2015)
38	-10.2, -12.6, -7.5, -3.3, -4.8	†	†	†	†	†	WRF-Chem	China	Huang et al. (2015)
39	†	†	†	†	†	†	WRF-Chem	EA	Wang et al. (2015)
40	-14, -10	†	+2, +9	†	-5, -8	†	WRF-Chem	EA	Chen et al. (2014)
41	-10.6, -2.9, -3.2	†	+4.2, +4.6, +0.4	†	-6.5, +1.7, -2.8	†	WRF-Chem	SEA	Gao et al. (2014)
42	†	†	†	†	+20	†	WRF-Chem	India	Ge et al. (2014)
43	-8	†	+5.1	†	-2.9	†	WRF-Chem	NCP	Kumar et al. (2014)
44	†	†	†	†	†	†	WRF-Chem	EA	Li et al. (2014)
45	-30.93	+4.08	+25.45	-3.34	-5.48	+0.74	WRF-Chem	NWC	Lin et al. (2014)
46	-5.58	†	+1.61	†	-3.97	†	WRF-Chem	India	Chen et al. (2013)
47	†	†	†	†	†	†	WRF-Chem	India	Dipu et al. (2013)
48	†	†	†	†	†	†	WRF-Chem	India	Kumar et al. (2012a)
49	†	†	†	†	†	†	WRF-Chem	India	Kumar et al. (2012b)
50	-30	†	†	†	†	†	WRF-Chem	China	Seethala et al. (2011)
51	†	†	†	†	+0.75, +1.024, +5.5, +7	†	WRF-Chem	PRD	Zhuang et al. (2011)
52	†	†	†	†	†	†	WRF-Chem	NCP	Liu et al. (2020)*
53	†	†	†	†	†	†	WRF-Chem	EC	Jia et al. (2019)
54	†	†	†	†	†	†	WRF-Chem	China	Wang et al. (2019)
55	†	†	†	†	+0.45, +1.04, +0.89, +1.77, -0.13, +0.05	+0.04, +0.18, +0.05, +0.20, +0.04, +0.15	WRF-Chem	YRD	Nicholls et al. (2019)
56	†	†	†	†	†	†	WRF-Chem	India	Li et al. (2019)
57	†	†	†	†	†	†	WRF-Chem	India	Kedia et al. (2019a)
58	†	†	†	†	†	†	WRF-Chem	PRD	Kedia et al. (2019b)
59	†	†	†	†	†	†	WRF-Chem	EC	Huang et al. (2019)
60	-25, -75	†	†	†	†	†	WRF-Chem	NCP	Ding et al. (2019)
61	†	†	†	†	†	†	WRF-Chem	EA	An et al. (2019)
62	-7.74	†	†	†	†	†	WRF-Chem	MRYR	Liu et al. (2018)
63	†	†	†	†	-5.38	†	WRF-Chem	PRD	Liu et al. (2018)
64	†	†	†	†	†	†	WRF-Chem	China	Zhang et al. (2018)
65	†	†	†	†	†	†	WRF-Chem	YRD	Gao et al. (2018)
66	-6.8	†	†	†	†	†	WRF-Chem	EA	Zhang et al. (2017)
67	†	†	†	†	†	†	WRF-Chem	EC	Wu et al. (2017)
68	-88	†	†	†	†	†	WRF-Chem	YRD	Sun et al. (2017)
69	†	†	†	†	†	†	WRF-Chem	YRD	Zhong et al. (2017)
70	-29.9	†	+27.0	†	-2.9	†	WRF-Chem	NCP	Gao et al. (2017a)
71	†	†	†	†	†	†	WRF-Chem	NCP	Gao et al. (2017b)
72	-21.9, -29.1, -14.6, -12.1, -14.8, -21.5, -10.6	†	†	†	†	†	WRF-Chem	China	Ma et al. (2017)
73	†	†	†	†	†	†	WRF-Chem	India	Lau et al. (2017)
74	†	†	†	†	†	†	WRF-Chem	NCP	Kajino et al. (2017)
75	†	†	†	†	†	†	WRF-Chem	TP & India	Yang et al. (2017)
76	†	†	†	†	†	†	WRF-Chem	EA	He et al. (2017)

77	†	†	†	†	†	†	WRF-Chem	YRD	Campbell et al. (2017)
78	†	†	†	†	†	†	WRF-Chem	EC	Zhang et al. (2016)
79	-9.12, -8.53, -10.94, -11.23	†	†	†	†	†	WRF-Chem	China	Ma et al. (2016)
80	†	†	†	†	†	†	WRF-Chem	EC	Zhang et al. (2016a)
81	-7.1, -9.8, -11.7, -7.8	†	†	†	†	†	WRF-Chem	EC	Zhang et al. (2016b)
82	-45.5	†	†	†	+14.9	†	WRF-Chem	EC	Huang et al. (2016)
83	†	†	†	†	†	†	WRF-Chem	YRD	Xie et al. (2016)
84	†	†	†	†	†	†	WRF-Chem	India	Srinivas et al. (2016)
85	†	†	†	†	†	†	WRF-Chem	India	Kedia et al. (2016)
86	†	†	†	†	†	†	WRF-Chem	India	Jin et al. (2016a)
87	†	†	†	†	†	†	WRF-Chem	India	Jin et al. (2016b)
88	†	†	†	†	†	†	WRF-Chem	NCP	Gao et al. (2016a)
89	-58, -115	-10	†	†	†	†	WRF-Chem	NCP	Gao et al. (2016)
90	†	†	†	†	†	†	WRF-Chem	EC	Ding et al. (2016)
91	-26.51	†	†	†	†	†	WRF-Chem	NCP	Yang et al. (2015)
92	-18.15, -18.50, -17.64, -23.15	†	†	†	†	†	WRF-Chem	NCP	Shen et al. (2015)
93	†	†	†	†	†	†	WRF-Chem	EA	Zhang et al. (2015a)
94	†	†	†	†	†	†	WRF-Chem	EA	Chen et al. (2015)
95	†	†	†	†	†	†	WRF-Chem	NCP	Zhong et al. (2015)
96	†	†	†	†	†	†	WRF-Chem	India	Jin et al. (2015)
97	†	†	†	†	†	†	WRF-Chem	India	Jena et al. (2015)
98	-20, -140	†	+20, +120	†	†	†	WRF-Chem	NCP	Gao Y. et al. (2015)
99	†	†	†	†	†	†	WRF-Chem	SWC	Fan et al. (2015)
100	-11.03, -9.84, -5.84, -12.37	†	†	†	†	†	WRF-Chem	NCP	Chen et al. (2015)
101	†	†	†	†	†	†	WRF-Chem	EC	Zhang et al. (2015)
102	†	†	†	†	†	†	WRF-Chem	EA	Wu et al. (2013)
103	†	†	†	†	†	†	WRF-Chem	India	Beig et al. (2013)
104	†	†	†	†	†	†	WRF-Chem	NCP	Jia et al. (2012)
105	†	†	†	†	†	†	WRF-Chem	EA	Zhang et al. (2012)
106	†	†	†	†	†	†	WRF-Chem	China	Gao et al. (2012)
107	†	†	†	†	†	†	WRF-Chem	MRYR	Bai et al. (2020)†
108	†	†	†	†	†	†	WRF-Chem	YRD	Liu et al. (2019)
109	-7.5	†	†	†	†	†	WRF-Chem	EA	Wang K. et al. (2018)
110	†	†	†	†	†	†	WRF-Chem	EA	Su et al. (2018a)
111	-2.19, -1.94	+1.44, +1.19	+1.56, +1.44	-1.26, -0.88	-0.63, -0.49	+0.18, +0.31	WRF-Chem	EA	Su et al. (2018b)
112	-86, -94.5	†	†	†	†	†	WRF-Chem	NEA	Park et al. (2018)
113	†	†	†	†	†	†	WRF-Chem	EC	Gao and Zhang (2018)
114	†	†	†	†	†	†	WRF-Chem	SEC	Shen et al. (2017)
115	†	†	†	†	†	†	WRF-Chem	China	Zhao et al. (2017)
116	†	†	†	†	†	†	WRF-Chem	India	Bhattacharya et al. (2017)
117	†	†	†	†	†	†	WRF-Chem	PRD	Jiang et al. (2016)
118	-5.4	+0.9, +20.1	†	†	†	†	WRF-Chem	EA	Zhang et al. (2015b)
119	†	†	†	†	†	†	WRF-Chem	India	Sarangi et al. (2015)
120	-12	†	†	†	†	†	WRF-Chem	EA	Zhang et al. (2014)
121	†	†	†	†	†	†	WRF-Chem	EC	Lin et al. (2014)
122	†	†	†	†	†	†	WRF-Chem	SEC	Bennartz et al. (2011)
123	†	†	†	†	†	†	WRF-Chem	China	Zhong et al. (2019)

124	†	†	†	†	†	†	WRF-Chem	India	Conibear et al. (2018a)
125	†	†	†	†	†	†	WRF-Chem	India	Conibear et al. (2018b)
126	†	†	†	†	†	†	WRF-Chem	India	Ghude et al. (2016)
127	†	†	†	†	†	†	WRF-Chem	NCP	Gao M. et al. (2015)
128	†	†	†	†	-5, -9, -10, -20	†	WRF-CMAQ	EA	Dong et al. (2019)
129	†	†	†	†	†	†	WRF-CMAQ	NEA	Jung et al. (2019)
130	-10.98, -17.8, -4.31	†	†	†	†	†	WRF-CMAQ	EA	Nguyen et al. (2019a)
131	-16.47, -22.54, -15.63, -12.99, -14.71	†	†	†	†	†	WRF-CMAQ	SEA	Nguyen et al. (2019b)
132	-50	†	†	†	†	†	WRF-CMAQ	NEA	Yoo et al. (2019)
133	†	†	†	†	†	†	WRF-CMAQ	EA	Sekiguchi et al. (2018)
134	-7.5, -7, -21.8	†	†	†	†	†	WRF-CMAQ	EA	Hong et al. (2017)
135	†	†	†	†	†	†	WRF-CMAQ	China	Xing et al. (2017)
136	†	†	†	†	†	†	WRF-CMAQ	EA	Xing et al. (2016)
137	†	†	†	†	†	†	WRF-CMAQ	EC	Xing et al. (2015a)
138	†	†	†	†	†	†	WRF-CMAQ	EC	Xing et al. (2015b)
139	-9.9, -13	†	†	†	-4.9, -6.5	†	WRF-CMAQ	EC	Xing et al. (2015c)
140	-32.41, -37.04	†	†	†	†	†	WRF-CMAQ	China	Wang et al. (2014)
141	-23.9, -16.6, -19.9	†	+19.1, +10.8, +14.7	†	†	†	WRF-CMAQ	China	Chen et al. (2019b)
142	†	†	†	†	†	†	WRF-CMAQ	China	Chang et al. (2018)
143	†	†	†	†	†	†	WRF-CMAQ	EA & India	Hong et al. (2019)
144	†	†	†	†	†	†	GRAPES-CUACE	NCP	Wang et al. (2017)
145	†	†	†	†	†	†	GRAPES-CUACE	EC	Wang H. et al. (2018)
146	†	†	†	†	†	†	GRAPES-CUACE	EA	Wang et al. (2013a)
147	-45.1	+12.2	†	†	-23.9	+6	GRAPES-CUACE	EA	Wang et al. (2013b)
148	†	†	†	†	†	†	GRAPES-CUACE	NCP	Zhou et al. (2012)
149	-10, -80, -200, -233	†	†	†	-120, -140, -20, -60	†	GRAPES-CUACE	EA	Wang et al. (2010)
150	†	†	†	†	†	†	GRAPES-CUACE	EC	Zhou et al. (2016)
151	†	†	†	†	†	†	WRF-NAQPMS	EA	Li J. et al. (2018)
152	-23.9	†	†	†	†	†	WRF-NAQPMS	NCP	Wang et al. (2014)
153	†	†	†	†	†	†	WRF-NAQPMS	EC	Wang et al. (2014)
154	†	†	†	†	†	†	GATOR-GCMOM	NEA	Ten Hoeve and Jacobson, 2012
155	†	†	†	†	†	†	GATOR-GCMOM	India	Jacobson et al. (2019)
156	†	†	†	†	†	†	GATOR-GCMOM	NCP	Jacobson et al. (2015)
157	†	†	†	†	†	†	Multi-model comparison	EA	Chen et al. (2019a)
158	†	†	†	†	†	†	Multi-model comparison	EA	Li et al., (2019)
159	†	†	†	†	†	†	Multi-model comparison	NCP	Gao et al. (2018a)
160	†	†	†	†	†	†	Multi-model comparison	India	Govardhan et al. (2016)

*†: Unclear. *: A preprint version of this study was available online on October 31, 2019, and was formally published on January 1, 2020. (EA: East Asia, NEA: Northeast Asia, SEA: Southeast Asia, EC: East China, NCP: North China Plain, YRD: Yangtze River Delta, SEC: Southeast China, NWC: Northwest China, TP: Tibetan Plateau, MRYR: middle reaches of the Yangtze River, SWC: Southwest China; PRD: Pearl River Delta).*

9. Overall, it is difficult to determine what the main scientific takeaways from the paper are. Are the existing models sufficient to provide reliable estimates going forward?

What are the main limitations and strengths of the models?

Response: According to your suggestion, we further discussed with other co-authors and here concisely summarized three takeaways as follows:

(1) Enabling aerosol feedbacks in two-way coupled models could improve their simulation/forecast capabilities of meteorology and air quality in Asia.

(2) Meta-analysis results showed that a wide range of differences exist among the previous studies due to various model configurations (selections of model versions and parameterization schemes). Projects covering more comprehensive intercomparisons of two-way coupled models need to be conducted in Asia.

(3) Large uncertainties mainly exist in ACI processes, and more investigations should be conducted by the modeling community in the future.

The two-way coupled models serve as a powerful tool for investigating how aerosols interacting with meteorology and the associated physiochemical processes, which is not possible with offline models. Our bibliometric and meta- analysis results revealed that the current two-way coupled models can sufficiently simulate surface meteorological and chemical variables but may not be able to accurately simulate variables affected by ACI effects. For numerical representations of ACI processes in coupled models, large uncertainties exist in cloud microphysics, cumulus cloud and ice nucleation parameterizations, and recent advances of observational studies have not been implemented into coupled models. At the same time, turning on aerosol feedbacks could lead to higher computational cost compared to offline models, but this shortcoming can be overcome with the new developments of cluster computing technology (i.e., GPU-accelerated computing and cloud computing). All of above assessments are reflected in the revised Conclusion section:

"*Two-way coupled models have been applied in US and Europe extensively and then in Asia due to frequent occurrences of severe air pollution events accompanied with rapid economic growth in the region. Until now, no comprehensive study is conducted to elucidate the recent advances in two-way coupled models' applications in Asia. This paper provides a critical overview of current status and research focuses of related modeling studies using two-way coupled models in Asia between 2010 and 2019, and summarizes the effects of aerosol feedbacks on meteorological and air quality variables from these studies.*

Through systematically searching peer-reviewed publications with several scientific-based search engines and a variety of key word combinations and applying certain selection criteria, 160 relevant papers were identified. Our bibliometric analysis results (as schematically illustrated in Fig. 9) showed that in Asia, the research activities with two-way coupled models had increased gradually in the past decade and the five two-way coupled models (WRF-Chem, WRF-CMAQ, WRF-NAQPMS, GRAPES-CUACE and GATOR-GCMOM) were extensively utilized to explore the ARI or/and ACI effects in Asia with focusing on several high aerosol loading areas (e.g., EA, India, China and NCP) during wintertime or/and severe pollution events, with less investigations looking into other areas and seasons with low pollution levels. Among the 160 papers, nearly 82 % of them focused on ARI (72 papers) and both ARI and ACI effects (60 papers), but papers that only considering ACI effects were relatively limited.

The ARI or/and ACI effects of natural mineral dust, BC and BrC from anthropogenic sources and BC from ARB were mostly investigated, while a few studies quantitatively assessed the health impacts induced by aerosol effects.

Meta-analysis results revealed that enabling aerosol effects in two-way coupled models could improve their simulation/forecast capabilities of meteorology and air quality in Asia, but a wide range of differences occurred among the previous studies perhaps due to various model configurations (selections of model versions and parameterization schemes) and largest uncertainties related to ACI processes and their treatments in models. Compared to US and Europe, the aerosol-induced decrease of the shortwave radiative forcing was larger because of higher air pollution levels in Asia. The overall decrease (increase) of T2, WS10, PBLH and O_3 (RH2, $PM_{2.5}$ and other gaseous pollutant concentrations) caused by ARI or/and ACI effects were reported from the modeling studies using two-way coupled models in Asia. The ranges of aerosol-induced variations of T2, PBLH, $PM_{2.5}$ and O_3 concentrations were larger than other meteorological and air quality variables. For variables of CO, SO_2, NO_2, and NH_3, reliable estimates could not be obtained due to insufficient numbers of samples in past studies.

Even though noticeable progresses toward the application of two-way coupled meteorology and air quality models have been made in Asia and the world during the last decade, several limitations are still presented. Enabling aerosol feedbacks lead to higher computational cost compared to offline models, but this shortcoming can be overcome with the new developments of cluster computing technology (i.e., Graphics Processing Unit (GPU)-accelerated computing and cloud computing). The latest advances in the measurements and research of cloud properties, precipitation characteristics, and physiochemical characteristics of aerosols that play pivotal roles in CCN or IN activation mechanisms can guide the improvements and enhancements in two-way coupled models, especially to abate the uncertainties in simulating ACI effects. Special attention needs to be paid to assess the accuracies of different methodologies in terms of ARI and ACI calculations in two-way coupled models in Asia and other regions. Besides the five two-way coupled models mentioned in this paper, more models capable of simulating aerosol feedbacks (such as WRF-CHIMERE and WRF-GEOS-Chem) have become available and projects covering more comprehensive intercomparisons of these coupled models should be conducted in Asia. Future assessments of the ARI or/and ACI effects should pay extra attention to their impacts on dry and wet depositions simulated by two-way coupled models. So far, the majority of two-way coupled models' simulations and evaluations focuses on episodic air pollution events occurring in certain areas, therefore their long-term applications and evaluations are necessary and their real-time forecasting capabilities should be explored as well."