Reviewer 1

General comments:

This article examines the sensitivities of two cloud microphysics schemes—a single-moment bulk scheme and a double-moment bulk scheme—implemented in the regional configuration of ICON, as well as the sensitivities associated with two domain configurations: a regional model and a global model. The target region selected by the authors is the Amazon over land, and the simulations are conducted for a one-week period.

The motivations for examining these sensitivities are well justified, and similar sensitivity studies can be found throughout the existing literature. However, the conclusions drawn in this study may depend on the specific implementations of the cloud microphysics schemes, as well as on the choice of domain and simulation period. Consequently, it is unclear to what extent these conclusions can be generalized to other cases.

Despite these limitations, the authors clearly describe the simulation results, and the article can serve as a useful reference for understanding such dependencies. Therefore, the reviewer recommends that this article be considered for publication, provided that the authors address the comments raised below adequately.

Response:
We thank Reviewer 1 for their constructive comments, which have helped us substantially improve the manuscript.

Following these suggestions, we have revised the manuscript to clarify the generalisability of our conclusions. We have now refined the language in the Conclusions and Abstract to demonstrate this (L15 and 471-475).

In addition to the cloud microphysics profiles, the authors analyze the characteristics of fog. However, in this article, the simulated fog is not compared with observations, making it unclear which results are more realistic. The reviewer therefore requests that the authors include an evaluation of the simulated fog against observational data. Fog formation is generally controlled by thermodynamic conditions rather than by the detailed formulation of cloud microphysics, with surface temperature and humidity near the surface being the most influential factors. The dynamic and thermodynamic representations in the model should be examined in detail.

Response:
We agree that fog should be evaluated against observations. Since observations over the Amazon are limited during the experimental period, we apply two complementary observational constraints from the Amazon Tall Tower Observatory (ATTO) and SYNOP.

1. Since ATTO ceilometer data are only available from March 2021 onwards, we use observations from the first week of February during 2022–2025 to construct a climatological fog-occurrence signal and compare it with the simulated diurnal

cycle of fog mass mixing ratio (Fig. AC1.1), showing that ICON reproduces the observed fog diurnal cycle reasonably well. This figure is now included in the manuscript as Fig. 7c.

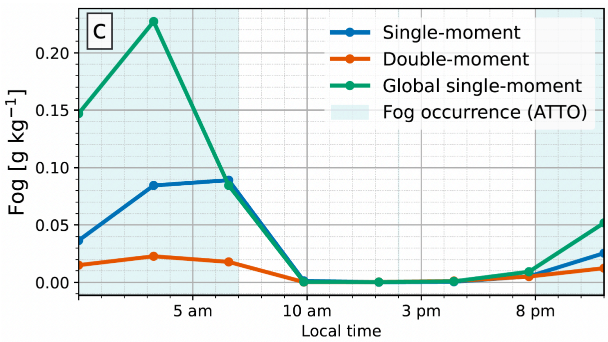

Fig. AC1.1 *Diurnal cycle of fog (defined as the cloud water present within the lowest atmospheric layer) for the regional single-moment (blue) and double-moment (red) simulations, shown alongside the global single-moment run (green), averaged over the entire Amazon region and experiment duration. The blue shading indicates periods when fog was observed by the ATTO ceilometer at least twice during the first week of February between 2022 and 2025.*

2. SYNOP stations provide surface meteorological observations, including horizontal visibility, at standard synoptic times. Due to the sparse spatio-temporal coverage, we calculate SYNOP fog frequency as the normalised count of occurrences with visibility below 1.5 km. We compare SYNOP to the simulated fog occurrence frequency, defined using a threshold of 0.01 g kg^{-1} at the corresponding SYNOP times (see Fig. AC1.2). This comparison now replaces Fig. 6 in the manuscript.

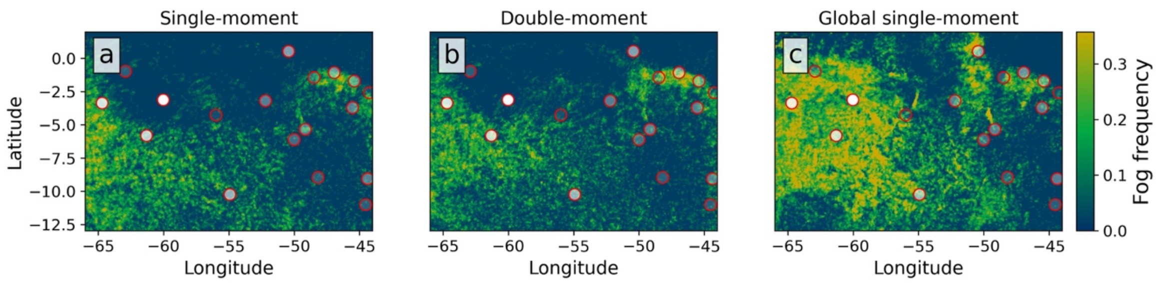

Fig. AC1.2 *Fog occurrence frequency for (a) the single-moment and (b) double-moment simulations, shown alongside (c) the global single-moment run. Fog occurrence is defined as the fraction of analysed timesteps with fog mass mixing ratio exceeding 0.01 g kg^{-1}. Overlaid circles (red) represent SYNOP stations, with their filling opacity indicating the normalised observed frequency of fog events (visibility < 1.5 km) during the study period. Higher opacity corresponds to a greater frequency of fog reports.*

We agree that near-surface thermodynamic conditions are a primary control on fog formation. To place the simulated fog differences in context, we compared surface temperature, pressure, humidity, and wind fields across the simulations (Fig. AC1.3). The two regional runs remain in close agreement throughout the simulation period despite the large domain size, whereas larger deviations occur in the global simulation. The similarity of the regional thermodynamic evolution, together with the pronounced differences in simulated fog characteristics, indicates that the microphysics scheme strongly modulates the fog response under comparable large-scale conditions. We have revised the manuscript accordingly to better reflect the coupled thermodynamic and microphysical controls on fog formation while retaining the focus on microphysical sensitivity.

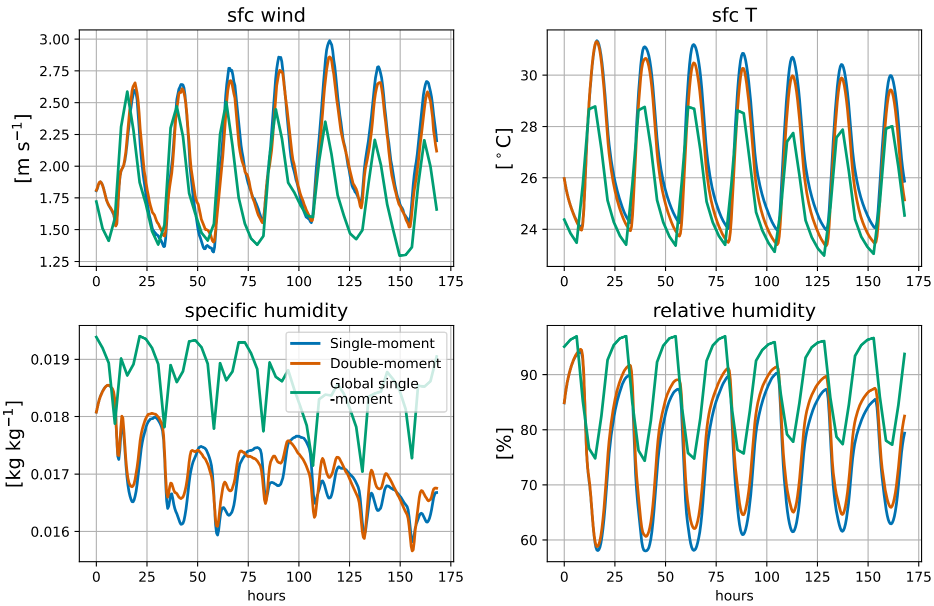

Fig. AC1.3 *Time series of surface (a) wind, (b) temperature, (c) specific humidity, and (d) relative humidity, for the regional single-moment (blue) and double-moment (red) simulations, shown alongside the global single-moment run (green), averaged over the entire Amazon region.*

We now include a clarification at the beginning of Section 3.1:

> "Fog formation is fundamentally governed by thermodynamic and dynamic conditions, including surface temperature, near-surface humidity, and boundary-layer structure. In this study, we do not aim to evaluate the absolute realism of simulated fog, but rather to characterise how fog responds to the two controlled differences between runs: the choice of microphysics scheme and the domain configuration. Although the regional simulations evolve freely within the domain interior, their large-scale thermodynamic evolution remains similar throughout the analysis period (not shown). Differences in fog characteristics between the regional runs can therefore be largely interpreted in terms of the differing microphysical representation, while differences between the regional and global runs additionally reflect the influence of large-scale dynamics."

And a discussion on the potential biases from dynamics/thermodynamics in Section 4.2:

“To assess whether thermodynamic biases underpin the fog differences, we compared domain-mean diurnal cycles of surface temperature, pressure, relative humidity, and wind between the runs (not shown). The two regional simulations exhibit nearly identical thermodynamic evolutions, consistent with their shared lateral boundary conditions, whereas the global run diverges. Crucially, fog characteristics differ strongly between the two regional runs despite their thermodynamic similarity, which supports the interpretation that differences in microphysical representation are a major contributor to the inter-simulation fog variability, beyond the relatively small thermodynamic difference. The global run's enhanced fog is therefore attributable to both its distinct thermodynamic environment and its unconstrained dynamics, acting on top of the microphysical differences. We note that microphysical and thermodynamic processes are inherently coupled, and a complete separation of their effects is not possible; however, the similarity of thermodynamic conditions between the regional runs provides a useful natural control that isolates the microphysical contribution in this case."

The differences between the regional and global model results appear to arise primarily from how large-scale (synoptic-scale) circulations are represented in the global model. In the regional model, these circulations are constrained by the lateral boundary conditions. Therefore, it is important for the authors to examine how the large-scale fields are simulated in the global model and how they may deviate from reality. To this end, the reviewer requests that the authors analyze the large-scale evolution over a domain broader than the target Amazon region. Equatorial waves might represent the modulation of the large-scale fields. A Hovmöller diagram along a representative latitude would likely be sufficient for this purpose.

Response:
We thank the reviewer for this important suggestion. Following this comment, we examined Hovmöller diagrams of OLR over several tropical latitude bands extending beyond the Amazon region for both ERA5 and the global simulation. However, over the relatively short analysis period considered here, the variability is dominated by the strong diurnal cycle, and no robust large-scale propagating structure could be identified consistently across the diagnostics. We therefore chose not to include these diagrams in the manuscript to avoid overinterpreting the large-scale variability.

Instead, we analysed low-frequency variability using a low-pass filtered domain-mean surface pressure diagnostic (Fig. AC1.4), which suppresses the dominant diurnal and semi-diurnal oscillations. This analysis shows that the two regional simulations remain closely aligned, whereas the global simulation evolves differently on longer timescales, supporting the interpretation that the global configuration develops a distinct large-scale state during the analysis period.

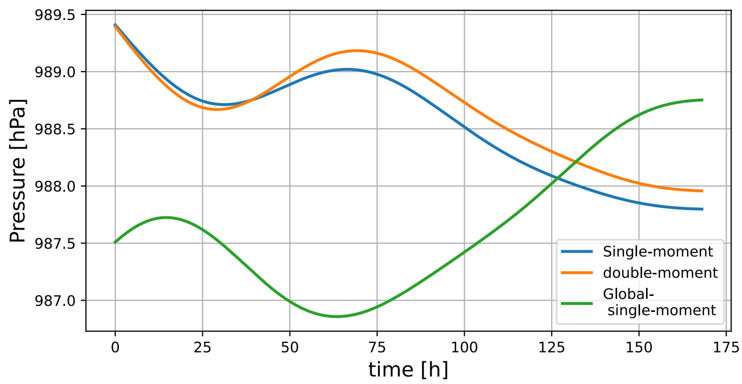

Fig. AC1.4 *Low-pass filtered domain-mean surface pressure time series for the regional single-moment (blue), regional double-moment (red), and global single-moment (green) simulations. The filter suppresses diurnal and semi-diurnal variability, highlighting low-frequency pressure modulation on timescales longer than approximately 3 days.*

We have added a discussion of this point to the manuscript (Section 2.2) to ensure that the connection between large-scale state divergence and global–regional differences is clear to the reader:

> …" and differences in the temporal evolution of surface pressure. Additional filtering tests (not shown) indicate that these differences persist beyond the dominant diurnal variability, suggesting that the global simulation evolves toward a distinct large-scale state during the analysis period. This behaviour is absent in the regional simulations, which remain continuously relaxed toward ERA5 at their lateral boundaries.

And a reference in the Discussion:

> "This behaviour is consistent with the large-scale boundary discrepancies identified in Fig. 3, which indicate that the global simulation progressively evolves towards a distinct large-scale state relative to the ERA5-constrained regional simulations. Such divergence likely contributes to the increasing differences in cloud structure between the global and regional configurations over time."

Specific comments:

Introduction:

Although the references cited in the introduction are extensive, the reviewer suggests the following additional references, which would help enrich the evidence presented in the article.

Performance of single vs double moment bulk microphysics schemes in different configuration of the models (L35-42):

- Satoh, M., Matsugishi, S., Roh, W., Ikuta, Y., Kuba, N., Seiki, T., Hashino, T., Okamoto, H. (2022) Evaluation of cloud and precipitation processes in regional and global models with ULTIMATE (ULTra-sIte for Measuring Atmosphere of Tokyo metropolitan Environment): A case study using the dual-polarization Doppler weather radars. Progress in Earth and Planetary Science, 9, 41.https://doi.org/10.1186/s40645-022-00511-5

For uncertainties of cloud microphysics profiles across global storm-resolving models (L68-78):

- Roh, W., Satoh, M., Hohenegger, C. (2021) Intercomparison of cloud properties in DYAMOND simulations over the Atlantic Ocean. J. Meteorol. Soc. Japan, 99, https://doi.org/10.2151/jmsj.2021-070

Response:
We now include both citations in the manuscript.

L59: "Regional CRMs" are the central part of the operational short-range forecast. This aspect of the operational model activities should be described here.

Response:
To keep the technical argument of this paragraph intact, we add a nuance to the limitation of using lateral boundary conditions while mentioning the regional CRMs' central part:

> "This dependency is especially consequential in operational short-range forecasting, where regional CRMs serve as the primary tool for convective-scale prediction (e.g., Clark et al., 2016), and errors introduced at the lateral boundaries can rapidly propagate into the forecast."

L75: "a steady state" should be "a statistically steady state" or "a quasi-steady state".

Response:
We now use "statistically steady state".

L139: It is unclear why different time steps are used for the regional and global models, and in particular why the time step for the regional model is shorter than that of the global model. In general, one would expect the time step of a global model to be shorter than that of a regional model, because the global model is subject to a wider range of topographic and meteorological conditions.

Response:
The time steps were chosen based on stable configurations commonly used in the respective global and regional ICON configurations, while also accounting for computational constraints.

Although all simulations use the same horizontal resolution, the global configuration was run with a comparatively aggressive but stable time step, whereas the regional simulations employed a more conservative temporal discretisation, consistent with standard limited-area modelling practice.

To assess whether this difference in time step influences the results, we ran a lighter regional single-moment simulation using the same time step as the global configuration. The field distributions exhibit consistent histogram shapes, and their statistics show only negligible differences (see Table AC1.1). This indicates that the selected time steps have only a minor quantitative influence on the results and do not affect our main conclusions.

Table. AC1.1 *Comparison of domain-mean statistics between the original regional single-moment configuration (Standard timestep) and a sensitivity simulation using the same timestep and radiation frequency as the global configuration (Global timestep). Values are shown as mean ± standard deviation over the analysis period.*

Variable	Unit	Standard timestep	Global timestep
Surface pressure	hPa	988.87 ± 19.11	988.86 ± 19.11
Sea-level pressure	hPa	1011.81 ± 1.92	1011.79 ± 2.01
Surface temperature	K	300.25 ± 3.57	300.37 ± 3.55
2 m air temperature	K	285.20 ± 65.22	285.34 ± 65.26
2 m dew-point temperature	K	280.47 ± 64.11	280.50 ± 64.12
Surface wind speed	m s^{-1}	1.96 ± 1.64	1.99 ± 1.68
Surface zonal wind	m s^{-1}	-0.62 ± 1.50	-0.62 ± 1.52
Surface meridional wind	m s^{-1}	-1.03 ± 1.68	-1.04 ± 1.73
Total cloud fraction	–	0.736 ± 0.441	0.734 ± 0.442
Precipitable water	kg m^{-2}	47.69 ± 13.06	48.20 ± 13.25
Liquid water path	g m^{-2}	132.29 ± 453.67	135.75 ± 457.86
Ice water path	g m^{-2}	15.28 ± 45.94	13.91 ± 42.11
Graupel water path	g m^{-2}	36.97 ± 467.19	32.22 ± 389.07
Rain water path	g m^{-2}	58.37 ± 638.22	57.53 ± 585.83
Snow water path	g m^{-2}	69.19 ± 333.43	74.21 ± 360.91
Total precipitation	mm day^{-1}	8.11 ± 97.41	8.04 ± 93.26
Large-scale rain precipitation	mm day^{-1}	8.11 ± 97.41	8.04 ± 93.26
Surface latent heat flux	W m^{-2}	-102.43 ± 152.30	-101.94 ± 150.54
Surface sensible heat flux	W m^{-2}	-60.07 ± 126.04	-57.54 ± 123.56
Surface downwelling shortwave radiation	W m^{-2}	239.05 ± 342.43	235.60 ± 339.23
Surface downwelling longwave radiation	W m^{-2}	402.20 ± 94.03	403.22 ± 94.14
TOA outgoing shortwave radiation	W m^{-2}	117.56 ± 175.70	120.36 ± 180.19
TOA outgoing longwave radiation	W m^{-2}	228.26 ± 66.93	229.23 ± 66.40

Figures 2 and 3: The authors are requested to add the corresponding figures for the regional model using the two different cloud microphysics schemes. In particular, the representation of surface temperature warrants further examination.

Response:
We have now updated Fig. 2 to include the corresponding figures for the regional model. Since the regional runs are identical to each other and to ERA5 at the boundary zone, Fig. 3 is left unchanged.

Figure 2 presents a single instantaneous snapshot and therefore does not adequately illustrate the overall agreement or discrepancies between the global model and observations. A more focused analysis over a broader temporal and spatial range is needed to demonstrate how the global model simulates the evolution of large-scale fields. One possible approach would be to include a Hovmöller diagram of convective systems, as requested in the general comments above.

Response:
Fig. 2 is intended primarily to illustrate the initial differences between the ERA5-constrained regional simulations and the freely evolving global configuration following

spin-up. As discussed in our response to the general comments above and in the associated Fig. AC1.4, this experiment is too short to consistently identify a robust, large-scale propagating structure across the diagnostics. We therefore decided not to include these diagrams in the manuscript to avoid overinterpreting the large-scale variability.

L173-174: As for the limitation of IMERG, it is generally less sensitive to weaker precipitation, including drizzle. The authors must mention this limitation and should be cautious when evaluating the PDF of weaker precipitation (Fig. 10b).

Response:
We now discuss the limitations of IMERG in detecting weaker precipitation (see response to comment 4 from Reviewer 2).

L186, "All simulations predict more clouds": It is unclear what "clouds" mean here.

Response:
We now state that: "All simulations predict increased LWP and IWP values over and near the coastline"

3.1 Fog: It is unclear why the authors chose fog as a primary metric for evaluating the model results. Fog formation is more strongly constrained by thermodynamic conditions than by cloud microphysical processes, with surface temperature and humidity near the surface being key controlling factors. Moreover, the manuscript does not demonstrate how the simulated fog is compared with observations.

The reviewer therefore requests that the authors first provide observational evidence of fog characteristics during the simulation period. Subsequently, the simulations of surface temperature and low-level moisture—both critical factors for fog formation—should be evaluated in detail.

Response:
The primary focus of this study is the impact of cloud microphysics on cloud structure and precipitation. Fog is not treated as an isolated evaluation metric, but rather as one component of the simulated vertical cloud structure that exhibited pronounced sensitivity to both the microphysics scheme and the domain configuration. It is therefore analysed alongside differences in mid-level and anvil clouds. We agree that fog formation is strongly controlled by near-surface thermodynamic conditions, and have therefore analysed surface temperature, humidity, and wind fields (Fig. AC1.3), along with observational constraints (Figs. AC1.1-2).

As these additional analyses do not alter the main conclusions, only Figs. AC1.1–2 are included in the revised manuscript (Fig. AC1.1 is added, while Fig. AC1.2 replaces Fig. 6), alongside an expanded discussion of the thermodynamic and dynamical context (L235–240, 258–262, 271–273).

L206-207, "...fog is more sensitive to microphysics choice": Instead of this, fog is more sensitive to surface temperature and humidity near the surface. The choice of microphysics is of secondary importance.

Response:
We agree that this choice of wording may be confusing, and hence we have changed the framing:

> " While this contrast suggests that fog is strongly affected by the microphysics scheme"...

L243, Figure 8c vs Figure 10a: Please explain the relation between Fig. 8c "rain" and Fig. 10a "precipitation". Does Figure 8c show the column integral of the mixing ratio of rain particles? Why does it evolve differently with precipitation? Figure 8 shows that the double moment scheme is an outlier, while Figure 10 shows the global model outstands with the regional model.

Response:
Rain water path is the vertically integrated column mass of raindrops, sourced from autoconversion, accretion, and melting of frozen hydrometeors, and reflects the instantaneous in-cloud rain burden. Surface precipitation rate, by contrast, measures the flux of all hydrometeors reaching the surface, and is therefore additionally shaped by sub-cloud evaporation, hail and graupel fallout, and scheme-specific tuning parameters governing collection and sedimentation efficiency.

We now clarify these differences in Section 3.2:

> "Unlike rain water path, which represents the vertically integrated rainwater content, precipitation refers to the flux of falling hydrometeors reaching the surface."

And discuss the differences between Fig. 8c and Fig. 10a:

> "Notably, the relative ordering of simulations differs between rain water path (Fig.,8c) and surface precipitation rate (Fig.,10a). This discrepancy is particularly pronounced in the double-moment scheme, which sustains the highest rain water path despite similar domain-averaged precipitation rates. This apparent decoupling indicates that a larger in-column rainwater burden does not translate directly into enhanced surface precipitation, which likely reflects differences in the partitioning of rainwater within the column and in processes affecting its conversion to surface precipitation, such as evaporation or recycling into mixed-phase cloud processes."

L252, "indicating that simulations overestimate light precipitation": This may also be because IMERGI is less sensitive to weak precipitation.

Response:
We now include this bias explicitly in the interpretation (L316-318).

L300: Please refer to the following literature:

- Rehbein, A., Ambrizzi, T. (2023) Mesoscale convective systems over the Amazon basin in a changing climate under global warming. Clim. Dyn. https://doi.org/10.1007/s00382-022-06657-8

Response:
We now cite Rehbein et al. (2023).

L316: Please refer to Fig. 5 in addition to Figs. 7, 8, 11.

Response:
We also refer to Fig. 5 now.

L336-339, "This conclusion is consistent with Dagan et al. (2019), which demonstrated that at large spatial scales (where precipitation approximates evaporation), changes in precipitation are constrained by water and energy budgets."; The present results cover only a short time range (within one week), for which precipitation does not approximate evaporation. Therefore, it is not appropriate to suggest consistency based on these budgets.

Response:
We thank the reviewer for pointing this out. Despite the short experiment duration, a similar scale-dependent logic still applies. While microphysical differences may dictate local cloud characteristics, these effects tend to average out at the domain scale. At this larger scale, the total moisture convergence, driven by the regional dynamics, becomes the primary constraint on integrated outputs like total precipitation and OLR. Hence, we revised this paragraph as follows:

> "Despite this, the two schemes yield similar levels of domain-averaged precipitation, OLR, and water vapour (Figs. 10, 13, and 8). This behaviour is consistent with the differing evolution of rain water path and surface precipitation (Section 3.2), highlighting that microphysical changes can redistribute rainwater within the column without proportionally altering surface fluxes. This suggests that while microphysical processes strongly influence the distribution and characteristics of hydrometeors, the domain-integrated outputs appear less sensitive to the specific microphysical parameterisation over these scales. This finding aligns with the conceptual framework of Dagan et al. (2019), which posits that at large spatial scales, atmospheric moisture and energy constraints can limit the impact of microphysical perturbations. While our simulation period is too short to assume a balance between precipitation and evaporation, the results support the idea that at broader scales, the divergence of water vapour (i.e., atmospheric dynamics) acts as a primary driver of precipitation variability,

> potentially dampening the signature of individual microphysical pathways on larger scales."

L367-368, "Although fog is mainly influenced by the microphysics scheme": Fog is controlled by thermodynamic processes near the surface. The microphysics scheme is of secondary importance.

Response:
As discussed above, we now include a more nuanced discussion of the thermodynamic, dynamic, and microphysical controls on fog formation in the manuscript, clarifying that this study focuses on how microphysical representation modulates cloud characteristics (and fog) under comparable large-scale conditions.

L373-374, "The simultaneous increase in IWP and decrease in OLR during the latter part of the global simulation further suggests the onset of deeper convection": Throughout this article, the onset of deeper convection is not clearly demonstrated for any cases considered, making this statement inappropriate.

Response:
We agree that such an onset wasn't demonstrated, hence we have changed the wording in this sentence to align better with the evidence we show in the manuscript:

> "The simultaneous increase in IWP and decrease in OLR during the latter part of the global simulation is consistent with a transition toward deeper, more organised convection, which may contribute to enhanced vapour removal and the subsequent reduction in fog."

Reviewer 2

This manuscript reports a sensitivity study in ICON at about 5 km resolution over the Amazon, comparing two regional simulations with single-moment and double-moment microphysics and one global simulation with single-moment microphysics. The topic is relevant and timely, especially given the current limitations and interests in convection and clouds in GSRMs. The paper is generally well organized, and the focus on vertical hydrometeor structure is useful. At the same time, several aspects of the design and interpretation can be further enhanced.

Response:
We thank Reviewer 2 and believe their comments have helped us substantially improve the manuscript.

Specific Comments:

1. The regional and global simulations differ not only in domain configuration but also in time step and radiation frequency. This is an important issue because differences in cloud water, warm rain, and near-surface condensate can be sensitive to these numerical choices. At present this point is mentioned, but it may need to be further acknowledged when interpreting fog and low-level cloud differences.

Response:
As discussed in our response to Reviewer 1, the differences in time step and radiation frequency between the regional and global configurations reflect the standard stable settings for the respective ICON configurations rather than an intentional experimental design choice. We agree, however, that these numerical differences could in principle introduce a bias in fog and low-level cloud quantities.

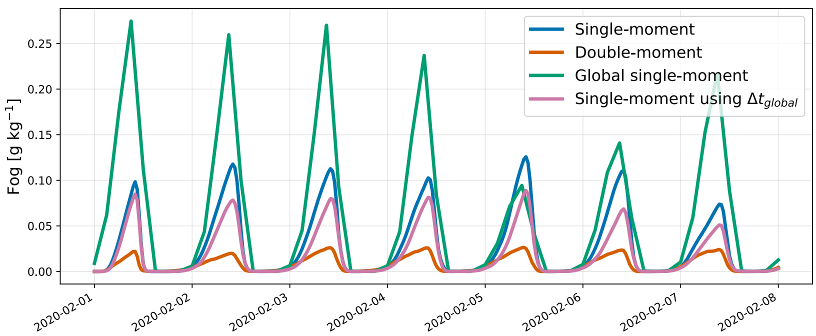

Fig. AC2.1 *Time series of cloud liquid water mixing ratio at the lowest model level (fog) for the regional single-moment (blue) and double-moment (red) simulations, shown alongside the global single-moment run (green) and the regional single-moment run conducted with timesteps used for the global run (purple). The time series are averaged over the entire Amazon region and experiment duration.*

To assess this directly, we repeated the regional single-moment simulation using the same time-step configuration as the global run. A comparison of the resulting 2D fields (Table AC1.5) and a direct comparison of the domain-mean fog mixing ratio (Fig. AC2.1) are included in this response. The repeated run (purple curve) shows a modest quantitative reduction in domain-mean fog, but remains clearly distinct from both the global and double-moment simulations. We therefore conclude that the time-step choice has only a minor quantitative influence and does not affect the main conclusions regarding sensitivity to domain configuration and microphysics scheme. We have added the following clarifications.

In the Methods:

> …" consistent with stable configurations commonly used within the respective ICON configurations and compatible with available computational resources. Additional sensitivity tests using a regional configuration with the same atmospheric time step as the global simulation showed negligible differences in the analysed fields, indicating that the selected time steps do not materially affect the results presented here."

In the Discussion:

> "However, sensitivity tests (not shown) with the global time step applied within the regional configuration show only modest quantitative reductions in domain-mean fog, without altering the qualitative differences between the configurations. This suggests that the time-step choice contributes to the magnitude of the divergence, and does not affect the primary sensitivities to domain configuration and microphysics identified here."

In the summary:

> "Although fog and warm-cloud formation may be further influenced by the longer time step used in the global run, we find that these differences are smaller than the impact of the microphysics scheme and domain size."

2. The single-moment setup uses a fixed cloud droplet number concentration of Nc = 500 cm-3, and this choice needs more justification for the Amazon case. Some of the reported differences between the single- and double-moment runs may be partly associated with this assumption and model setup, rather than only with the moment framework itself. This point would benefit from further clarification.

Response:
We thank the reviewer for raising this point. We note that the value of 500 cm^{-3} stated in the original manuscript was a typo; the correct value is 200 cm^{-3}, the standard ICON default for continental clouds, representative of light-to-moderately polluted conditions and suitable for the Amazonian wet season. This has been corrected in the revised manuscript.

Regarding the concern that differences between the single- and double-moment runs may be partly attributable to the prescribed CDNC rather than to the moment framework itself, we point to White et al. (2021), who demonstrate that differences in simulated cloud morphology and precipitation between microphysics schemes are significantly greater than the sensitivity to CDNC perturbations within a given scheme. This suggests that the moment-framework comparison presented here is unlikely to be substantially confounded by the choice of CDNC.

3. The discussion of fog would benefit from a more careful treatment. In the present manuscript, fog is defined from cloud water in the lowest model level, but its realism is not evaluated with observations. Since low-level fog or near-surface liquid cloud is strongly affected by surface temperature, humidity, and boundary-layer structure, it would be helpful to assess these fields more directly, or at least to acknowledge more clearly that the reported fog differences may also reflect thermodynamic biases rather than microphysics alone.

Response:
We refer the reviewer to Figs. AC1.1–3 and to our detailed responses to Reviewer 1 above, which address both the observational evaluation and the role of thermodynamic conditions in modulating fog differences. We now include such a discussion in the manuscript as well.

4. The observational evaluation is somewhat limited for the level of process interpretation in the discussion. IMERG is useful, but it has known scale-dependent uncertainty, including common biases in light rain and in the tails of the distribution (e.g., Derin et al., 2021). This matters because several statements in the paper focus on PDF behavior and light-precipitation bias. I would recommend making those claims more cautious and acknowledging more clearly that the evaluation at fine temporal and spatial scales is only approximate.

Derin, Y., Kirstetter, P. E., and Gourley, J. J. (2021). Evaluation of IMERG satellite precipitation over the land–coast–ocean continuum. Part I: Detection. Journal of Hydrometeorology, 22(11), 2843–2859.

Response:
We agree that IMERG's underdetection of weak precipitation is an important caveat. The manuscript already notes IMERG's general limitations in the Methods and Discussion; we have now added an explicit statement in the Results section:

> "At low rates, IMERG data decrease more gradually than the simulations, which could reflect genuine model overestimation of light rainfall, but may equally arise from IMERG's known underdetection of weak precipitation due to limitations of passive microwave retrieval (e.g., Derin et al., 2021)."

And clarify the limitations in the Discussion:

> "Given these observational uncertainties, especially the reduced sensitivity of IMERG to weak precipitation, inferred model biases at the low-intensity end of the distribution should be treated with caution. Similarly, discrepancies at the high-intensity tail reflect a combination of model biases and IMERG's reduced reliability

> at sub-daily timescales and fine spatial scales (Huffman et al., 2022; Bulovic et al., 2020; Tan et al., 2017), such that the observed differences represent an upper bound on true model error."

5. The OLR comparison is based on an indirect retrieval from window-channel brightness temperature and is therefore subject to retrieval uncertainty. The authors may discuss the limitations of this proxy more clearly when comparing anvil structure and deep convection between the model and GOES-16 retrievals.

Response:

We agree that OLR derived from a window-channel brightness temperature is subject to retrieval uncertainty and does not represent the full longwave spectrum. In this study, the OLR proxy is primarily used to identify the spatial distribution and temporal evolution of deep convective cloud tops and anvil structures, rather than to evaluate absolute radiative fluxes.

The 11.2 µm window channel is most sensitive to cloud-top temperature and is therefore well suited for detecting deep convection and high-level anvils, but it is less reliable for low- and mid-level clouds due to absorption by overlying water vapour and its limited spectral coverage.

To address this, we have clarified the definition of the retrieved OLR in the Methods section:

> "For deep-convection spatial distribution and occurrence, we use brightness temperature (BT) observations from the Advanced Baseline Imager (ABI) of the first satellite of the Geostationary Operational Environmental Satellites (GOES-16) series (Schmit and Gunshor, 2020) as a proxy for outgoing longwave radiation (OLR). We estimate OLR from ABI level 2 in the cloud and moisture imagery product (MCMIP) channel 11.2 micron using the relationship from Ohring et al. (1984) between the observed longwave window BT and the flux equivalent BT. This provides an estimate of OLR that is most representative of high cloud tops but does not capture the full longwave spectrum."

And now explicitly caution that comparisons should be interpreted qualitatively, particularly for low- and mid-level cloud regimes and for absolute flux magnitudes, added a mention of its limitations in the Results section:

> "As noted in Section 2.3, the window-channel OLR proxy should be interpreted with caution for low- and mid-level clouds."