Response to referee comments on "Technical note: 12-km resolution capability for the global GEOS-Chem model of atmospheric composition"

Response to Anonymous Referee #1:

The authors extend the existing GEOS-Chem Classic modelling framework to double the spatial resolution relative to previous implementations, yielding a regional simulation with a resolution of 0.125°×0.15625° (roughly 12×12 km2). They show that the effects of some processes manifest differently in this new configuration, most notably a strengthening in vertical transport.

The central advance is incremental, but useful. Being able to perform higher-resolution regional simulations with GEOS-Chem provides a new and relevant capability for the user community. The announcement of new data archives is particularly welcome, and the authors provide some excellent insights into the new results which can be developed. However, I have one concern which I would argue is not well addressed by the current manuscript but which is important to interpreting its results. I have also listed some minor errors.

We sincerely thank the reviewer for the constructive and insightful comments. Our replies are shown in blue and *revised text is shown in italic blue*. Line numbers in our responses refer to the revised manuscript version with marked revisions.

My major concern is the question of whether the results the authors are seeing are specifically because of better resolving the meteorology, or just that an increase in resolution allows for gradients to be better preserved. This concern is raised in part due to the question below regarding "native" resolution, and I recognize that this may be beyond the scope that the authors intended for a technical note. However, the abstract specifically argues that the different results are due to better resolution of transport variables (line 21), but do not provide evidence of this. I would recommend that the authors consider running a simulation in which their input meteorology is degraded to 25 km resolution, but their simulation grid remains at 12 km. This would allow them to directly assess how much of the benefit comes from the meteorology being better resolved compared to from the ability to better resolve emissions and chemical gradients.

Thank you for this insightful comment. We added a sensitivity TransportTracers simulation at 12-km resolution driven by the 25-km advection archive. The differences between this sensitivity simulation and the standard 12-km simulation are shown in the newly added right columns of Figures 1–3. We find that both better resolved horizontal convergence and finer resolution of concentration gradients at 12-km contribute to the differences between resolutions. We have added a discussion of this sensitivity test in the main text.

[Lines 199–204]: *"Differences between the 12-km and 25-km simulations could reflect stronger vertical winds at 12-km due to better resolved horizontal convergence (Yu et al., 2018) and better resolution of concentration gradients leading to stronger tracer convergence for the same winds.*

To separate these two effects, we conducted a 12-km sensitivity simulation driven by the 3-hourly 25-km advection archive regridded to 12-km resolution during runtime (right columns of Figures 1-3). We find that both effects contribute."

My more minor issue concerns the way that the grids are described. The authors state that GC-Classic can operate on native GEOS grid resolutions (line 63), but this is not true. To my knowledge, GC-Classic cannot directly ingest cubed-sphere data and it does not use a cubed sphere grid. As it stands, the paper risks misleading the reader by implying that there has been no regridding (i.e. information loss) between the GEOS and GC-Classic grids, which is not true. Based on section 2 (specifically lines 91-92) it appears that the data has already been regridded from C720 to 0.125°×0.15625°; such an operation will have introduced spurious resolution at the poles, and will have greatly degraded the resolution at the equator where the C720 grid is actually finer. Furthermore the misalignment of grid edges likely means that, even where the C720 and 0.125°×0.15625° grids are roughly the same size, the data will have been "smoothed out" by the regridding process. This is inevitable in a cubed sphere to rectilinear regrid, and does not detract from the idea that the use of a higher resolution rectilinear grid should still yield benefit. However, the manuscript currently flips between describing the GC-Classic simulation as being at 0.125°×0.15625° (presumably correct), "native" (likely incorrect unless the architecture has changed to allow C720 simulation), and 12-km (definitely incorrect as even C720 has some variation in grid cell area - albeit much less than at 0.125°×0.15625). I would recommend that the authors revise the manuscript to precisely describe exactly what grid resolution is being used where (e.g. are the pre-calculated archives, listed as "12 km", actually at C720 or at 0.125°×0.15625?), and to be clear about where lossy regridding is or is not being applied. I would also request that claims such as "[t]he 12-km simulation has no spatial averaging of winds relative to the parent GEOS ESM" (lines 166-167) be removed, as this is not true unless GC-Classic is now running on a cubed sphere at C720.

Thank you for pointing out this lack of clarity. We have revised the manuscript throughout to use consistent terminology for the different grids and to clarify where regridding is applied and its effects. We now use "native" to refer only to the GEOS-FP cubed-sphere C720 archive, while "0.125° × 0.15625°" refers to the GC-Classic nested grid simulation. For convenience, we continue to refer to GC-Classic simulation at 0.125° × 0.15625° as the 12-km capability and have revised the text to clearly define this. Relevant revisions are now included in the Abstract, Sections1 and 2, and Table 1, including the following:

[Abstract, lines 14–19]: *"This capability can be applied to simulations for any user-selected domain worldwide from March 2021 onward by accessing a new hourly cubed-sphere C720 (approximately 12 km ×12 km resolution) global wind archive from the NASA GEOS-FP meteorological data assimilation system. We regridded the archive to support rectilinear GEOS-Chem Classic nested grid simulations worldwide at 0.125° × 0.15625° resolution and denote this as the 12-km GEOS-Chem capability."*

[Section 1, lines 41–47]: *"Here we introduce the capability to conduct GEOS-Chem simulations at 0.125° × 0.15625° (≈12 km × 12 km) resolution by… In what follows we will refer to it as the 12-km capability in GEOS-Chem."*

[Section 1, lines 62–64]: *"GEOS-FP operates at native C720 resolution (approximately 12km × 12km) but the data archive was previously made available only at 0.25°×0.3125° resolution."*

[Introduction, lines 83–84]: *"The one-way nested GC-Classic capability at GEOS-FP 0.25° ×0.3125° (referred to as 25-km) resolution is widely used for…"*

We have clarified that the 12-km advection archive is generated by regridding the hourly global C720 GEOS-FP archive to the rectilinear 0.125° × 0.15625° grid, which can introduce information loss.

[Section 2, lines 102–112]: *"Here we use the new global C720 GEOS-FP hourly advection archive, regridded to 0.125° × 0.15625°, to produce the 12-km advection archive that enables GC-Classic nested-grid simulations at 0.125° × 0.15625° resolution. … The regridding from cubed-sphere C720 to the rectilinear 0.125° × 0.15625° grid yields an approximately 12 km × 12 km horizontal scale over midlatitudes, slightly coarser toward the equator and finer toward the poles."*

We have removed the misleading discussion that "the 12-km simulation has no spatial averaging of winds relative to the parent GEOS ESM" as suggested.

Finally, my understanding is that GEOS-Chem is usually referred to as "GEOS-Chem X.Y.Z" rather than "GEOS-Chem version X.Y.Z" (line 79), although I would defer to the senior authors on this manuscript in that regard given their leadership in the community."

Thank you for catching this. We have revised it to "GEOS-Chem 14.6.0".