Response to Comments of Reviewer 2

The authors thank all reviewers for their constructive comments and suggestions, which have helped us improve this paper's quality in sciences and writing. All comments are carefully considered and responded to. The response in blue italic letters follows each comment in black.

The paper, "Determination of the Chemical Equator from GEOS-Chem Model Simulation: A Focus on the Tropical Western Pacific Region" by Xiaoyu Sun et al., proposes a method to identify the hemispheric boundary of air mass transport known as the chemical equator, which has not been extensively studied. The study concentrates on the Tropical West Pacific region and utilizes artificial tracers simulated by the GEOS-Chem model to determine the chemical equator's location. The authors investigate the chemical equator's vertical structure and compare it to the tropical rain belt and wind field convergence. The article fits within the scope of ACP, but significant revisions are necessary before it can be published. To improve the manuscript, the following revisions are suggested. Clarify the vertical level of the chemical equator's results to better understand the location of air mass transport between the hemispheres. Strengthen the justification for the chemical equator determination method by providing a more detailed explanation of the reasoning behind the methodology used. Provide additional evidence to support the interpretation of some results. This can be achieved through the inclusion of further analysis or data that reinforces the conclusions drawn from the results. Apply the chemical equator concept to gain a better understanding of inter-hemispheric air transport. This could include investigating how the chemical equator affects atmospheric composition or analyzing how it may influence global climate patterns.

The following revisions are proposed:

1. To better understand the inter-hemispheric transport of pollutants/tracers, the manuscript should investigate the relationship between the chemical equator's location and atmospheric compositions such as CO, CH_4, and SF_6. This analysis could utilize satellite observations or model output to provide a comprehensive understanding of the differences in tracer distribution between the northern and southern hemispheres. Including a TransCom simulation analysis (i.e. Krol et al., GMD, 2018) in the discussion would be a valuable addition to the manuscript.

Response: Thanks for the suggestion. We added the following discussion to the future revised manuscript in the Sect. 1:

"Methane (CH_4) and Carbon dioxide (CO_2) have a relatively long lifetime and clear latitudinal gradient which has the potential as tracers to investigate the interhemispheric transport. The model output such as TransCom of CO_2 provide a comprehensive understanding of the differences in tracer distribution between the northern and southern hemispheres and study the IHT (Krol et al., GMD, 2018)."

We added the comparison of the CE with the global distribution of vertical columns of CH_4 from TROPOMI and the surface concentration of SF_6 from the GEOS-Chem simulation.

We added Sect. 3.2 to describe the connection between the CE and the distribution of CH_4 and SF_6:

"Section 3.2 The Chemical Equator and the distribution of atmospheric compositions

To better understand the implication of the CE position, satellite measurements of CH_4 and model simulation of SF_6 are presented together with the CE in Fig. 2 . CH_4 used in this study is retrieved from TROPOMI measurements aboard in Sentinel-5 Precursor satellite mission (Veefkind et al., 2012) in the SWIR wavelengths (2300-2389 nm). Here we use the latest release of the WFMD (Weighting Function Modified Differential Optical Absorption Spectroscopy) product (v1.8) (Schneising et al., 2023) and *process it onto a 5° x 5° grid. The details of the satellite data product is described in the Appendix C. We used GEOS-Chem v13.0.0 to obtain the simulation of SF_6. The model set-up of SF_6 is described in details in Appendix D. The CE and the global distribution of CH_4 and SF_6 averaged for January and July 2019 are shown in Fig. 2. The CE and the north-south gradient of CH_4 in the Indian Ocean in January 2019 are well consistent with each other. This indicates the CE has good potential to illustrate the IHT inferred by the satellite measurements of CH_4. However, due to the lack of data coverage, it is relatively difficult to see the distribution of CH_4 in SH from the satellite measurement in July. The CH_4 distribution is also affected by 1) sources in the SH and b) removal due to OH. This means the CH_4 concentration is not monotonically rising like the inert artificial tracer used in our study and does not show a clear distinction between NH and SH. SF_6 has this property and has been used for similar purposes (e.g., Geller et al., 1997; Waugh et al., 2013; Yang et al., 2019), but there are large emissions in South East Asia, which may be emitted into the CE area."*

And we added Appendix to describe the satellite products of CH_4 we use and the GEOS-Chem model set-up of the SF_6.

"Appendix C

The Sentinel-5 Precursor satellite mission (Veefkind et al., 2012) was launched on 13 October 2017 carrying a single scientific instrument, TROPOMI, which is a nadir viewing passive grating imaging spectrometer. The satellite is positioned in a near-polar, sun-synchronous orbit and has a swath width of 2600 km, allowing for daily Earth coverage. The retrieval is however dependent on sun-lit, cloud-free scenes which limits the daily coverage. The instrument consists of four spectrometers measuring radiances in the ultraviolet, ultraviolet-visible, near-infrared, and short-wave infrared bands. CH_4 used in this study is retrieved from TROPOMI measurements of sunlight reflected by Earth's surface and the atmosphere in the SWIR wavelengths (2300-2389 nm). The spatial resolution is 5.5x7 km^2. The Weighting Function Modified Differential Optical Absorption Spectroscopy (WFMD) TROPOMI data product (Schneising et al., 2019) provides vertical columns of both methane CH_4 and CO. Here we use the latest release of the WFMD product (v1.8) (Schneising et al., 2023) and process it onto a 5° x 5° grid. For this, each measurement is assigned to a single grid cell and the weighted average of all measurements per cell is calculated. The measurements are weighted using the inverse standard deviation to disadvantage measurements with high uncertainty. Additionally, only measurements with a quality flag (qf) qf=0 (good) are included. Data coverage is therefore limited over regions with many clouds (e.g. tropics) or challenging measurement conditions.

Appendix D

The meteorological fields used in the model are from MERRA-2 reanalysis as described in Sec. 2.1. We performed the simulation of SF_6 from 2014 to 2019 in the horizontal grid resolution of 2° x 2.5° and vertical grid resolution of 72 levels. The emission database of SF_6 is annually spatially- girded and taken from the Emission Database for Global Atmospheric Research (EDGAR version 4.2) inventory (Muntean et al., 2018), available at 0.1° x 0.1° global resolution for 1970-2008.

"

And we added the following Figure 1 in the future revised manuscript:

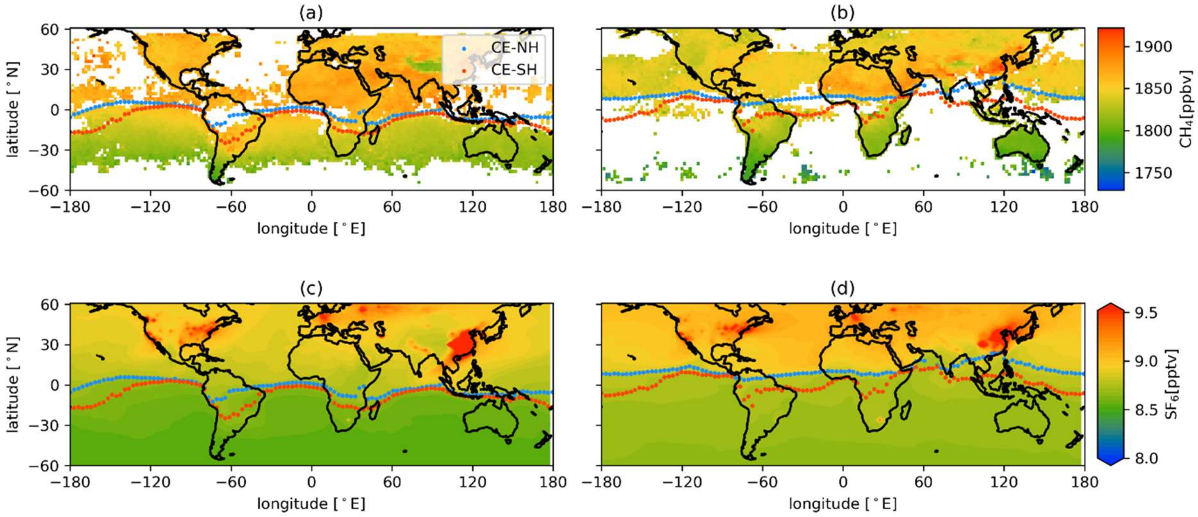

Figure 1. CE with Sentinel-5 Precursor satellite CH_4 vertical columns (ppbv) averaged for (a) January 2019 and (b) July 2019. CE with SF_6 surface concentration (ppbv) simulated by GEOS-Chem averaged for (c) January 2019 and (d) July 2019. The blue dots show the NH boundary (CE-NH) and the red dots show the SH boundary (CE-SH).

2. The manuscript should discuss the unique features of the chemical equator over the Tropical Western Pacific region compared to other regions. This could include a detailed analysis of the chemical equator's behavior and characteristics in the context of the Western Pacific Monsoon and other regional circulations.

Response: The CE is a tool to determine the boundary for air mass transport on a global scale. So the boundary determined by the CE basically has no unique feature in the TWP region compared to other regions over the tropics, despite the complicated circulation pattern. This is the reason why the use of the ITCZ fails to clearly separate the hemispheres in the TWP. But our study and others using models (Hamilton et al., 2008) show that such a separation exists.

However, the reason we choose to focus on the TWP region is that this region is considered as the major transport pathway from the troposphere into the stratosphere during the NH winter. So the air mass transport and the origins in this region need to be studied in detail, and the main application of the CE in this study is to investigate the air mass transport in the TWP. But the method of the CE can also be used for similar studies in other parts of the world, i.e. Africa or South America, which also show a complicated circulation due to the orography.

3. To better understand air mass transport, the manuscript should include the distribution of artificial tracers from 30◦ N - 90◦ N and 30◦ S - 90◦ S. This will provide insight into the relative contributions from source domains and air mass inter-hemispheric transport.

Response: We added the following Fig. 2 in the future revised manuscript to show a direct model output of the basic experiment 1 and 2 with CE-NH and CE-SH:

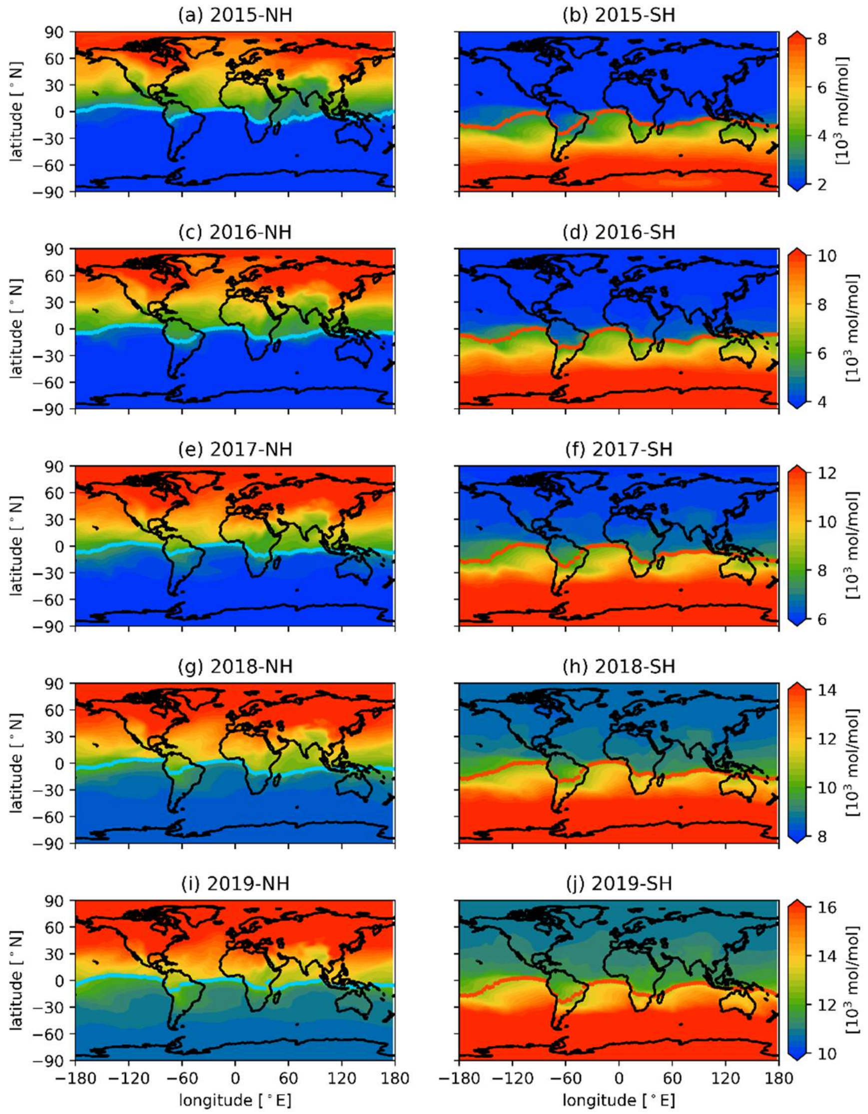

Figure 2. The surface concentration (mol/mol) of the passive tracer averaged in January at each year of the simulation from 2015 to 2019. The subplots in the left column (a), (c), (e), (g), (i) show the passive tracer released from the NH in Experiment 1 and subplots in the right column (b), (d), (f), (h), (j) show the passive tracer released from the SH in Experiment 2. The blue lines and the red lines show the CE-NH and CE-SH respectively.

And we added the following sentences in the future revised manuscript to describe the distribution of the passive tracer: "The global distribution of the passive tracer averaged in January at each year of the simulation time from 2015 to 2019 are shown in Fig. 2. The concentration of the passive tracer gradually increases after the releasing time in both experiment cases, where in the E1 the passive tracer is released in the NH and in the E2 the passive tracer is released in the SH. This latitudinal gradient can be clearly seen in the distribution of the passive tracer and is well determined by the CE-NH and CE-SH. The continuous release of the artificial tracer has been inspired by SF_6, which is also continuously released in the NH."

4. The manuscript should clarify the vertical level on which the results are based to obtain the chemical equator. This information should be provided in both the methods and results sections to ensure that the reader can understand the study's findings.

Response: The results in the paper are based on the vertical grids of GEOS-Chem which are 72 layers from the surface up to 10 hPa / 80 km. We checked the whole manuscript and made the following changes:

- *We added the sentence:*

"The simulation results used in this study are based on the vertical and horizontal grids which are 72 levels and 0.5°x0.625°, respectively."

- *And we corrected the sentence:*

"We calculate CE at each vertical grid of the model output of the passive tracer. When the level goes up, it becomes hard to find an actual boundary between the two hemispheres due to the fast horizontal mixing by high-speed winds in the upper troposphere and lower stratosphere. So, we only take the level of the model grids under 8 km into consideration."

- *And we corrected the caption of Figure 9 in the original manuscript like this:*

"Figure 9. Monthly averaged (2015-2019) CE at the layers from the model vertical grids from surface to 8 km. The CE-NH / CE-SH are zonally (100° E-180°) averaged over the TWP region see Fig. 6. The blue lines show the CE-NH and the red lines show the CE-SH. 1-σ of the CE-NH and CE-SH are given in the plots. "

5. To improve the manuscript's clarity, it is recommended to conduct a thorough review to identify inaccuracies, misprints, and errors. These revisions will enhance the text's readability and improve the manuscript's overall quality.

Response: Thank you. We read the entire text and made some edits to improve the article's accuracy and clarity.

We add the following reference:

Krol, M., de Bruine, M., Killaars, L., Ouwersloot, H., Pozzer, A., Yin, Y., Chevallier, F., Bousquet, P., Patra, P., Belikov, D., Maksyutov, S., Dhomse, S., Feng, W., and Chipperfield, M. P.: Age of air as a diagnostic for transport timescales in global models, Geoscientific Model Development, 11, 3109–3130, https://doi.org/10.5194/gmd-11-3109-2018, 2018.

Veefkind, J. P., Aben, I., McMullan, K., Förster, H., Vries, J. d., Otter, G., Claas, J., Eskes, H. J., Haan, J. F. d., Kleipool, Q., Weele, M. v., Hasekamp, O., Hoogeveen, R., Landgraf, J., Snel, R., Tol, P., Ingmann, P., Voors, R., Kruizinga, B., Vink, R., Visser, H., and Levelt, P. F.: TROPOMI on the ESA Sentinel-5 Precursor: A GMES mission for global observations of the atmospheric composition for climate, air quality and ozone layer applications, Remote Sensing of Environment, 120, 70–83, https://doi.org/10.1016/j.rse.2011.09.027, 2012.

Schneising, O., Buchwitz, M., Reuter, M., Bovensmann, H., Burrows, J. P., Borsdorff, T., Deutscher, N. M., Feist, D. G., Griffith, D. W. T., Hase, F., Hermans, C., Iraci, L. T., Kivi, R., Landgraf, J., Morino, I., Notholt, J., Petri, C., Pollard, D. F., Roche, S., Shiomi, K., Strong, K., Sussmann, R., Velazco, V. A., Warneke, T., and Wunch, D.: A scientific algorithm to simultaneously retrieve carbon monoxide and methane from TROPOMI onboard Sentinel-5 Precursor, Atmospheric Measurement Techniques, 12, 6771–6802, https://doi.org/10.5194/amt-12-6771-2019, 2019.

Schneising, O., Buchwitz, M., Hachmeister, J., Vanselow, S., Reuter, M., Buschmann, M., Bovensmann, H., and Burrows, J. P.: Advances in retrieving XCH4 and XCO from Sentinel-5 Precursor: improvements in the scientific TROPOMI/WFMD algorithm, Atmospheric Measurement Techniques, 16, 669–694, https://doi.org/10.5194/amt-16-669-2023, publisher: Copernicus GmbH, 2023.