Reply to Anonymous Referee #2

Review for Liao et al., "Widespread stratospheric intrusion influence on summer ozone pollution over China revealed by multi-site ozonesonde, ground-based measurement and fully-validated reanalysis"

This study investigates a stratospheric intrusion (SI) event over China from June 10 to 13, 2013, using a combination of ozonesonde measurements, ground-based observations, and reanalysis data. The authors aim to characterize the SI event, quantify its contribution to surface ozone pollution, and elucidate the underlying dynamical transport mechanisms. The research effectively highlights the importance of ozonesonde observations in validating reanalysis data and improving our understanding of SI impacts on ozone pollution.

Overall, this is good study that combines ozonesonde data from multiple locations (Beijing, Changchun, and Hong Kong) with nationwide ground-based measurements and the EAC4 reanalysis product. This multi-pronged approach provides a comprehensive view of the SI event and its impact.

Additionally, the use of ozonesondes provides valuable vertical ozone profile information, which is crucial for characterizing SI events. The ozonesonde data also significantly aids in the evaluation of the EAC4 reanalysis data. While it's not entirely clear if these observations are directly assimilated into EAC4, they do provide important and independent constraints on the reanalysis results, adding confidence to the study's conclusions.

Reply: So glad to receive your positive comments. We have carefully considered your suggestions and comments, and made corresponding modifications and explanations.

Hence, I suggest the following modifications:

The authors should check with the EAC4 team and add information about the assimilation of Chinese ozonesonde data in EAC4. Providing more information about the ozone-related chemistry in EAC4 (e.g., emission of ozone precursor gases, and whether surface observations from China are included in their assimilation) would help the reader.

Reply: Thank you for this constructive comment. Surface O_3 measurements and ozonesonde O_3 profile data in China are not assimilated into the EAC4 reanalysis. We clarified this in the revised manuscript. The assimilated O_3 retrievals in EAC4 consist of multiple satellite data (SCIAMACHY, MIPAS, MLS, OMI, GOME-2 and SBUV/2). The emission datasets in EAC4 are composed of anthropogenic emissions from the MACCity inventory (Granier et al., 2011), biogenic emissions from MEGAN2.1 model (Guenther et al., 2006), and biomass burning emissions from the Global Fire Assimilation System (Kaiser et al., 2012). In the revised manuscript, we added the abovementioned information and highlighted that other details of the EAC4 can be found in Inness et al. (2019). The following Table from Inness et al. (2019) shows the basic information of the EAC4 model system (i.e., CAMSRA).

	MACCRA	CIRA	CAMSRA
Period covered	2003–2012	2003–2018	2003–2016 (will be extended)
Assimilation system	IFS Cycle 36r1 4D-Var	IFS Cycle 40r2 (2003–2015) 4D-Var IFS Cycle 41r1 (2016–2018) 4D-Var	IFS Cycle 42r1 4D-Var
Horizontal resolution	80 km globally (T255)	110 km globally (T159)	80 km globally (T255)
Temporal resolution (output frequency)	6-hourly analysis fields 3-hourly forecast fields from 00:00 UTC up to 24 h	6-hourly analysis fields 3-hourly forecast fields from 06:00 and 18:00 UTC up to 12 h	3-hourly analysis fields 3-hourly forecast fields from 00:00 UTC up to 48 h 1-hourly surface forecast fields from 00:00 UTC up to 48 h
Anthropogenic emissions	Chemistry species: MACCity (trend: ACCMIP + RCP8.5), Aerosols: AEROCOM	MACCity (trend: ACCMIP + RCP8.5) and CO emission upgrade from Stein et al. (2014) for chemistry and aerosols	MACCity (trend: ACCMIP + RCP8.5) and CO emission upgrade from Stein et al. (2014)
Biomass burning emissions	GFED (2003–2008) and GFASv0 (2009–2012)	GFASv1.2	GFASv1.2
Biogenic emissions	Monthly mean VOC emissions for the year 2003 calculated by the MEGAN2.1 model (Guenther et al., 2006) used for the whole period. No interannual variability.	Monthly mean VOC emissions calculated by the MEGAN2.1 model (Guenther et al., 2006) using MERRA reanalysed meteorology (Sindelarova et al., 2014) for the period 2003–2010. For the remaining years a climatology of the MEGAN–MACC data was used.	Monthly mean VOC emissions calculated by the MEGAN model using MERRA reanalysed meteorology (Sindelarova et al., 2014) for 2003–2016.
Chemistry modules	CTM MOZART3 coupled to the IFS (see Flemming et al., 2009)	IFS(CB05) (Flemming et al., 2015) and Cariolle ozone parametrisation in stratosphere, CHEM_VER=ver14wd	IFS(CB05) (Flemming et al., 2015, with updates documented in Sect. 2.1.2) and Cariolle ozone parametrisation in stratosphere, CHEM_VER=ver15
Aerosol modules	Morcrette et al. (2009)	Morcrette et al. (2009) plus changes described in Flemming et al. (2017b)	Morcrette et al. (2009) with changes documented in Sect. 2.1.1.
Input meteorological observations	ECMWF NWP (stream = DA)	ECMWF NWP (stream = DCDA)	As in ERA5 (2003–2016)
Assimilated O_3 retrievals	GOME, SCIAMACHY, MIPAS, MLS, OMI and SBUV/2	GOME, SCIAMACHY, MIPAS, MLS, OMI, GOME-2 and SBUV/2	SCIAMACHY, MIPAS, MLS, OMI, GOME-2 and SBUV/2
Assimilated CO retrievals	MOPITT, IASI	MOPITT	MOPITT
Assimilated NO_2 retrievals	SCIAMACHY	–	SCIAMACHY, OMI and GOME-2
Aerosol used in radiation scheme	Tegen climatology	Tegen climatology	Interactive aerosols, i.e. aerosol fields from CAMSRA used in radiation scheme
Ozone used in radiation scheme	GEMS climatology	GEMS climatology (2003–2015) MACCRA climatology (2016–2018)	Interactive ozone, i.e. ozone field from CAMSRA used in radiation scheme
Stratospheric chemistry	Yes	No, but Cariolle ozone parametrisation in stratosphere and stratospheric O_3 available.	No, but Cariolle ozone parametrisation in stratosphere and stratospheric O_3 available.

Granier, C., Bessagnet, B., Bond, T., D'Angiola, A., Denier van der Gon, H., Frost, G. J., Heil, A., Kaiser, J. W., Kinne, S., Klimont, Z., Kloster, S., Lamarque, J.-F., Liousse, C., Masui, T., Meleux, F., Mieville, A., Ohara, R., Raut, J.-C., Riahi, K., Schultz, M. G., Smith, S. G., Thompson, A., van Aardenne, J., van der Werf, G. R., and van Vuuren, D. P.: Evolution of anthropogenic and biomass burning emissions of air pollutants at global and regional scales during the 1980–2010 period, Climatic Change, 109, 163–190, https://doi.org/10.1007/s10584-011-0154-1, 2011.

Guenther, A., Karl, T., Harley, P., Wiedinmyer, C., Palmer, P. I., and Geron, C.: Estimates of global terrestrial isoprene emissions using MEGAN (Model of Emissions of Gases and Aerosols from Nature), Atmos. Chem. Phys., 6, 3181–3210, https://doi.org/10.5194/acp-6-3181-2006, 2006.

Inness, A., Ades, M., Agusti-Panareda, A., Barré, J., Benedictow, A., Blechschmidt, A. M., Dominguez, J. J., Engelen, R., Eskes, H., Flemming, J., Huijnen, V., Jones, L., Kipling, Z., Massart, S., Parrington, M., Pench, V. H., Razinger, M., Remy, S., Schulz, M., and Suttie, M.: The CAMS reanalysis of atmospheric composition, Atmos Chem Phys, 19, 3515-3556, 10.5194/acp-19-3515-2019, 2019.

Kaiser, J. W., Heil, A., Andreae, M. O., Benedetti, A., Chubarova, N., Jones, L., Morcrette, J.-J., Razinger, M., Schultz, M. G., Suttie, M., and van der Werf, G. R.: Biomass burning emissions estimated with a global fire assimilation system based on observed fire radiative power, Biogeosciences, 9, 527–554, https://doi.org/10.5194/bg-9-527-2012, 2012.

Please clarify the use of AIRS Level 3 data. For these type of studies you should use level 2 data. Add more information detailing what specific product was used, and how was it processed. Also, how sensitive AIRS is to the surface ozone levels.

Reply: Thanks for this comment. We are confused about your suggestion to use the AIRS Level 2 data, rather than the Level 3 data, which is a more advanced version produced by the AIRS Science Team/Joao Texeira (2013). The AIRS Level-3 ozone retrievals have been commonly used to estimate vertical structure of ozone in stratospheric intrusion events (Knowland et al., 2017; Zhang et al., 2022; Jaeglé et al., 2017). We listed these references and added the spatial resolution ($1^{o} \times 1^{o}$) information of AIRS in the revised manuscript. Our previous evaluation based on long-term ozonesondes in Beijing (Zhang et al., 2024) indicated that AIRS widely retrieves lower ozone values near the surface, and, upward from 700 hPa, larger values are consistently presented by AIRS in the troposphere below 300 hPa. Additionally, AIRS seems to frequently underestimate the ozone between 300 and 100 hPa; however, at numerous pressure levels above 100 hPa, AIRS tends to detect higher ozone concentrations. In this study, we actually further demonstrated that ARIS ozone product had a relatively lower accuracy when compared to EAC4 and MERRA2 reanalysis.

AIRS Science Team/Joao Texeira (2013). AIRS/Aqua L3 Daily Standard Physical Retrieval (AIRS+AMSU) 1 degree × 1 degree V006. Greenbelt, MD, USA: Goddard Earth Sciences Data and Information Services Center (GES DISC).

Knowland, K. E., Ott, L. E., Duncan, B. N., and Wargan, K.: Stratospheric Intrusion-Influenced Ozone Air Quality Exceedances Investigated in the NASA MERRA-2 Reanalysis, Geophys Res Lett, 44, 10691-10701, 10.1002/2017GL074532, 2017.

Zhang, Y. J., Li, J., Yang, W. Y., Du, H. Y., Tang, X., Ye, Q., Wang, Z. X., Sun, Y. L., Pan, X. L., Zhu, L. L., and Wang, Z. F.: Influences of stratospheric intrusions to high summer surface ozone over a heavily industrialized region in northern China, Environ Res Lett, 17, Artn 094023 10.1088/1748-9326/Ac8b24, 2022.

Jaeglé, L., Wood, R., and Wargan, K.: Multiyear Composite View of Ozone Enhancements and Stratosphere-to-Troposphere Transport in Dry Intrusions of Northern Hemisphere Extratropical Cyclones, Journal of Geophysical Research: Atmospheres, 122, 13,436-413,457, https://doi.org/10.1002/2017JD027656, 2017.

Zhang J., Xuan Y., Bian J., Vömel H., Zeng Y., Bai Z., Li D., Chen H., 2024. Comparison between ozonesonde measurements and satellite retrievals over Beijing, China. Atmospheric and Oceanic Science Letters, 17 (2024), 100378.

If feasible, include a broader discussion about SI events. Placing the June 2013 event in a broader climatological context would be beneficial. Given the availability of the EAC4 reanalysis data, the authors should consider including climatological statistics to illustrate the typical influence of SI events on surface ozone on annual and monthly timescales. This analysis would provide valuable perspective on the typical impact of SI on surface ozone in China and contextualize the significance of the specific 2013 event analyzed in this study.

Reply: Thank you for this excellent comment. To be candid, our initial plan was to incorporate climatic statistical characterization after this case analysis. We preliminarily identified 90 summertime upper-level trough cases from 2003 to 2022 using a subjective identification method, and each case persisted 1-7 days. However, we faced a large challenge in composite analysis of these identified cases due to the irregular trough structure. We thought that the "reversed Ω-shaped" trough-induced SI cases can be compositely characterized through a cyclone-centric composite method proposed by Jaeglé et al. (2017). However, the "V-shaped" trough-induced SI cases can not be composited through the cyclone-centric composite method (no cyclonic center can be found for some cases). Beside, as shown in the 2013 case, the locations of deep trough determine the SI influencing areas over the China (Tibetan Plateau or Eastern Plain). Due to the extremely contrasting altitudes between the western and eastern China, the magnitude of SI contribution is also very different between these two areas, implying that the composite analysis should take into account of the locations of SI to avoid the substantial smooth of stratospheric influences at the difference surface areas. The above challenges have forced us to temporarily abandon our initial plan. Still, the climatological statistical characterization is on our schedule, but it needs more time and effort to address the abovementioned challenges (mainly in composite analysis of "V-shaped" trough cases). Once we complete the climatological statistical characterization, we will write another paper to present the results.

Given that this reply will be openly presented in the interactive discussion process, here we show three additional SI cases (2005-08-03, 2019-08-15, and 2022-06-14) in the following figure to enhance the significance of the specific 2013 event analyzed in this study.

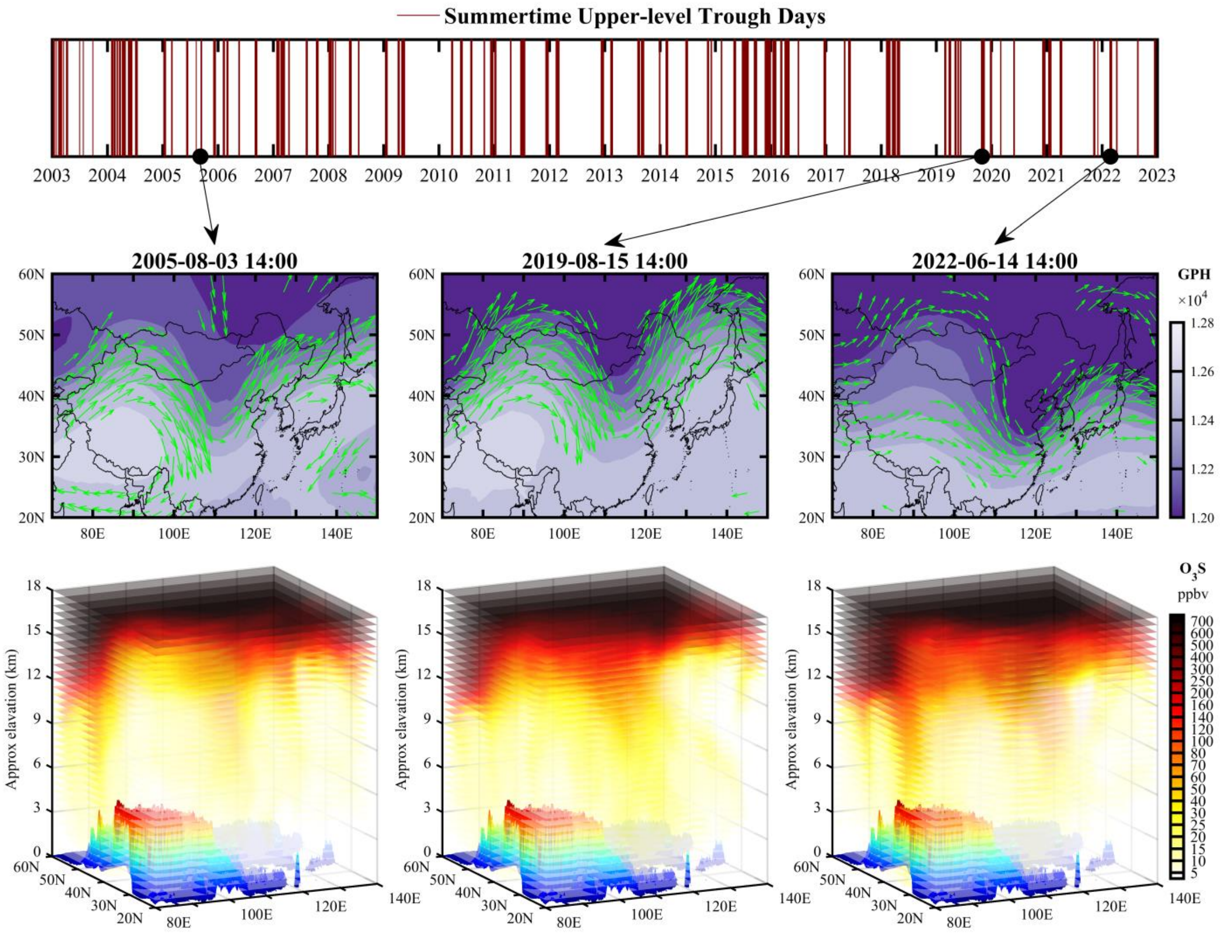

Fig. R1 The identified upper-level trough days in summer of 2003-2022 and three cases of trough-induced stratospheric intrusion.

Jaeglé, L., Wood, R., and Wargan, K.: Multiyear Composite View of Ozone Enhancements and Stratosphere-to-Troposphere Transport in Dry Intrusions of Northern Hemisphere Extratropical Cyclones, Journal of Geophysical Research: Atmospheres, 122, 13,436-413,457, https://doi.org/10.1002/2017JD027656, 2017.

If the authors can modify the manuscript accordingly, I recommend it for publication.

Reply: Thanks for your excellent comments again. We have carefully considered your suggestions and comments, and made corresponding modifications and explanations. Regarding to the climatological statistical characterization, we explain the reasons why it was not presented in this study.