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## Comment on acp-2022-505

Anonymous Referee #1

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Referee comment on "Vertical structure of the lower-stratospheric moist bias in the ERA5 reanalysis and its connection to mixing processes" by Konstantin Krüger et al., Atmos. Chem. Phys. Discuss., <https://doi.org/10.5194/acp-2022-505-RC1>, 2022

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Review of "Vertical structure of the lower-stratospheric moist bias in the ERA5 reanalysis and its connection to mixing processes" by Kruger et al.

This paper evaluates the lower-stratospheric moist bias in a NWP reanalysis. A moist bias is a common problem in NWP and climate models in both the analysis and forecasts, as documented by others, but the novelty of this paper lies in the use of a large dataset of lidar data from aircraft observational campaigns covering several seasons and different years, and characterising well the vertical profile of the error in the latest reanalysis from ECMWF (ERA5). This is very relevant as the lower-stratospheric moist bias leads to a significant temperature error through radiative cooling, which has potential impact on the atmospheric circulation. Importantly, the paper largely confirms the results of other studies on the ECMWF (re)analysis that use other data sources, showing a significant bias in the lowermost stratosphere (LS) but additionally it quantifies the reducing bias in the upper part of the LS, and uses ozone and water vapour to show the largest error is in the mixed tropospheric-stratospheric air layer suggesting the source of the problem is too much mixing of water vapour across the tropopause.

It is a very well written paper and excellent analysis of the DIAL data and evaluation of the ERA5 moist bias. I just have a few points to investigate and a few minor suggestions for text edits that need to be considered before publication.

### SPECIFIC COMMENTS

#### 1. Observational errors

Although the precision of the high quality observational data is discussed in Section 2.1 and various studies referenced, a quantitative description of the measurement uncertainty in this paper is missing, either in percentage terms or absolute specific humidities, as well as a discussion of any possible sources of bias in the observations. Although this

information may be adequately described in other papers, it is important to review the estimated observational error here to be confident about the evaluation.

## 2. Moist bias in the troposphere - Figure 5 and elsewhere

Could the small positive bias in the troposphere be due (or partly due) to a systematic shift between the observed and ERA5 tropopause? Bland et al. (2022) shows the height of the thermal tropopause in the operational ECMWF analyses is on average 200m higher than in the radiosonde observations and this might also apply to the ERA5 reanalyses? In tropopause relative coordinates (using the ERA5 derived tropopause), this would then lead to an apparent moist bias given the significant vertical gradient in the troposphere. Is it negligible? Can you quantify this? Is there possibility of a bias in the DIAL data? These need to be discounted to be sure that the error is in the re-analysis.

## 3. Section 3.2.2 "Synoptic and seasonal variability".

Figure 9 shows the synoptic variability of the vertical profile (by binning the whole dataset by tropopause altitude) and I was expecting to see a similar figure for the vertical profile binned by season. Instead Figure 8 shows the vertical profile separated by observational campaign, and then seasonal biases then has to be inferred from the specific months of each campaign. As two of the campaigns have only a small amount of data, we are also asked to disregard these profiles. Would it not be better to include a figure (or replace Fig 8) for the whole dataset binned by season to more robustly and clearly make the point about the seasonal variation of the bias? [I note that there is a sentence in lines 509-510 that refers to the similarity of two campaigns in Fig 8]

## TECHNICAL CORRECTIONS

Abstract, lines 24 and 26-27 say essentially the same thing.

Line 115-116

Wording with the use of "respectively" not quite clear to say the different trace gas concentrations represent different altitude levels.

Line 193

"method used on a horizontally" -> "method used a horizontally"

Line 210

Again, unusual use of the word "respectively". In this case you could use "(i.e. the lapse rate)"

Line 237

You could just state this is a logarithmic formulation with base 2, just to be clear.

Line 238

Something odd here with the typesetting for the equation number.

Table 2

As there is negative humidity bias in various later figures, you could add a few negative numbers in the table as well?

Figure 4 caption

Presumably all the derived tropopause, pot temp and wind speed is also from ERA5? State in the caption.

Line 312

"compared the observations" -> "compared to the observations"

Line 380

"Tracer-trace" -> "tracer-tracer"

Lines 383, 385 and Figure 11 caption

Figure 11 looks like the VMR H<sub>2</sub>O limit is 6.5ppm as the caption states, but this is inconsistent with the text on p19

Could you also say why this particular value is chosen?

Lines 416-417

Although the average vertical profile from the WISE flights (Fig 13b) is similar to the full dataset (Fig 5b) in the stratosphere, the tropospheric profile looks a bit different, i.e. fairly constant in the full dataset (0.2-0.25), but decreasing with increasing altitude in the WISE data (0.4-0.1). Please reword.

Line 473

"This supported" -> "This is supported"

Line 493 and Line 94

Research question 1 has slightly different wording here compared to the Introduction, but should be the same. Perhaps a more succinct sentence to consider is:

"1. Can the mutli-campaign DIAL data set robustly quantify the LS moisture bias in ERA5"

Line 498

"The flights that were performed in different times of the year can reproduce seasonal differences in the observed humidity distributions"

They rather "show" or "highlight" the seasonal differences than "reproduce" them.

Line 501

"What is of the vertical" -> "What is the vertical"

Line 502

"moist bias is also contained in"

Suggest, "moist bias is present in"

Line 523

"In future" -> "In the future"