Author response to referee comments on "Atmospheric gas-phase composition over the Indian Ocean" by Tegtmeier et al.

We thank both referees and the editor for their valuable comments. We have changed the manuscript according to the comments listed below. Most important, we have shortened Section 2.2 by moving Fig. 2 to the supplementary material and have rewritten the section on VSLSs entrainment into the stratosphere.

Comments are reproduced below, followed by our responses in italics.

Anonymous Referee #1

The revised version has taken care of most of the comments and suggestions. Though it is much better now but I still feel that it is too lengthy. I had mentioned this earlier also. As the title says- ' ..over the Indian Ocean', so anything below the surface is not required. Section 2.2 and Fig. 2 may be totally removed. Also, I checked that 'salinity' and 'SST' are not much used in the discussion, may be once.

We have shortened section 2.2 by removing Figure 2 and have also shortened some of the text in 2.3. However, we respectfully disagree with the reviewer that "...anything below the surface is not required." Many of the gases that exchange with the atmosphere are directly influenced by oceanic processes, sometimes through production and sometimes through consumption. These biogeochemical and physical processes are driven by salinity, SST, and productivity in the ocean. Spatial and temporal distributions seen in the gas concentrations and fluxes (discussed in section 4) are therefore a direct result of the here described oceanic processes. We have therefore kept a very short discussion of salinity, SSTs and productivity in section 2.2.

There have been good amount of in-situ measurements after the INDOEX over the BOB, the AS as well as over the IO. This paper summarises very well these findings for various kinds of trace gases. In the first sentence in Section 1.4, it is mentioned that 'Here we will focus on recent progress in the field by giving an overview of results obtained after 2010.' but the data used are from various campaigns before this period also (Table 1 & 4). You may modify the text accordingly.

Thanks for pointing this out. Indeed, we are including all campaigns that have contributed to publications after 2010 as explained in the next paragraph and in Section 3.1. We have changed the sentence to 'Here we will focus on recent progress in the field by giving an overview of results published after 2010.'.

During the ICARB campaign, vertical ozone measurements were also made over BOB and AS (Lal et al., JGR 2013). These results showed differences in ozone distributions over the two marine regions.

Thanks for pointing this out. We have included the main points of the paper and the reference in the new version of the manuscript.

I would have liked to see a summary table giving average values of these species and trends, if any, in the 3 different oceanic regions (BOB, AS and IO).

Based on the large spatial gradients and the large seasonal differences, we think that such average values over the three oceanic regions are difficult to interpret and prefer to stay with the current figures and discussions in the text.

Anonymous Referee #2

I have re-read this manuscript following my initial review and I am satisfied that the authors have addressed the majority of my concerns. Some of the overly long sections have been shortened or removed to the supplement, and the arrangement of the summary and future directions is much improved. I thank the authors for their diligence and am happy to recommend the review for publication in ACP. I have one question for clarification and a few minor corrections.

P49, Section 7.1: In their response to my question regarding the StratoClim project the authors suggested that the contribution of VSLS sources in the IO to the Asian anticyclone is very small. However, the impression given in section 7.1 is that the IO is actually very important as a stratospheric source of VSLS. If the main uplift region and time is the northern Bay of Bengal during summer (?), why was this not seen during StratoClim and why is this not relevant to this review? Could you please explain this apparent contradiction?

Thanks for bringing this up. We have done another literature search and found more papers (in addition to Bucci et al., 2020, ACP mentioned in our earlier response) highlighting that air masses in the anticyclone mostly originate from the planetary boundary and not from the marine boundary layer.
Bergmann et al. (2013): ' … We calculated regional contributions to air within the anticyclone by boundary layer sources from five regions: the Tibetan Plateau, India/SE Asia, eastern China, the Indian Ocean, and the western Pacific. … Boundary layer sources for the anticyclone are primarily from the Tibetan Plateau and India/SE Asia (a combined 70%–80%) at both the 200 mbar and 100 mbar levels, with minor contributions by the western Pacific and Indian Ocean (a combined 15%–20%). …'
Vogel et al. (2018) based on CLAMS backward simulations of the anticyclone state '… High fractions of air from India/China up to 90 % and low fractions below 10 % from the tropical adjacent regions are found in the core of the Asian monsoon anticyclone at 360 K potential temperature. Highest fractions from the tropical adjacent regions of about 40 % are found in a belt around the edge of the anticyclone …'

These results are in agreement with the regional modelling study from Fiehn et al. (2018) and the global modelling study from Tegtmeier et al. (2020). Both papers demonstrate that marine trace gases as short-lived as bromoform are largely transported into the stratosphere by localized convection extending from the Arabian Sea to the Philippines including the Bay of Bengal and the Arabian Sea. These transport patters cause high VSLS entrainment over southern India and adjacent ocean, but no particular maximum over the Asian monsoon region. The apparent contradiction probably results from Fiehn et al. (2017) showing for the OASIS ship campaign measurements that oceanic VSLSs are also entrained into the stratosphere in the south-eastern part of the Asian monsoon anticyclone. Putting these three studies into context suggests that the main entrainment region for VSLS emitted from the Indian Ocean is over the Bay of Bengal and Arabian Sea, while some smaller fractions can be transported via the Asian Monsoon. The second pathway becomes more important for longer lived VSLSs such as CH_2Br_2. This picture is confirmed by results from Adcock et al. (2020, JGR)

who show based on StratoClim measurements that CH_2Br_2 in the UTLS above the Asian Monsoon is very similar to tropical background values (despite the Indian Ocean being a strong source), while chlorinated VSLSs originating from surface industrial emissions in Asian countries are strongly enhanced (their Figure 3).
We agree that the section was written in a confusing way and have reorganized it by first citing the global and regional modelling studies and highlighting the main entrance region and then discussing the special case of the OASIS case study. We have also added results from Adcock et al. (2020). Furthermore, we have checked the papers published in the StratoClim special issue, but to the best of our knowledge none of the publications links any of the StratoClim observations to oceanic source gases.

P14, L3: replace "over previous" with "to previous versions" or something similar.

Done.

P15, L1 "allowed us to study...." (?)

We have changed this to 'facilitating studies of its variations and …'.

P15, L35-36: toxicity is not the only reason why CO is important, and it certainly isn't an issue over the IO. Perhaps list some others?

Further down in the paragraph we are listing other reasons such as 'CO has an indirect radiative effect, since it scavenges the hydroxyl radical (OH), the cleaning agent of the atmosphere that otherwise would destroy the greenhouse gases CH_4 and O_3 (Daniel and Solomon, 1998).'

P32, L12 and elsewhere: what is meant by the term "head"? Is this the same as the "north"?

Yes, this is the northern part of the BoB. We have added this information on page 32.

P47, L24: change "make often" to "often make"

Done.

P52, L20: replace "momentarily" with "currently"

Done.

P53, L37: replace "of" with "in", i.e. Long-term changes in the atmospheric composition…"

Done.

P54, L25: replace "clear" with "clean"

Done.