Author's Reply to comments from the referee #1

We would like to thank the referee #1 for his/her interest in our work and helpful comments to improve our manuscript. Listed below are our replies to the referee's comments and suggestions, which we will revise our manuscript according to.

<Referee> I still would like to see more scientific discussion of the data, e.g. seasonal variation, longitudinal and latitudinal gradients. By now a significant amount of data has been collected, and I recommend Section 5 (preliminary results) to be somewhat extended. The Western Pacific region has been studied comparatively well in the past using various platform types, especially in the northern hemisphere, and the new data could for example be compared to data from coastal stations in the region. To my knowledge there exist or have existed similar measurement programs deploying commercial ship in the Pacific that should be referenced.

<Reply> Thanks very much for your suggestions, in particular, keen eyes to past observations in the western Pacific region. In this paper submitted to Atmos. Meas. Technol., we paid great attention to the instrumentation of continuous measurements of atmospheric CO onboard cargo-ships, and tried to focus on technical aspects of this shipboard system in detail. We are currently in the process of finalizing the observed data from both continuous measurements and bottle samples. Detailed analysis of seasonal, latitudinal, and longitudinal characteristics of CO and co-measured species such as CO_2 and O_3 on the basis of several ships will be presented in a separate paper, which we plan to submit to Atmos. Chem. Phys. in a due course. We will refer to previous measurement programs deploying commercial ship in the revised paper for sure.

<Referee> The authors mention that besides CO also O_3 and CO_2 are measured. Why is none of this data shown? It is mentioned that commercially available instruments are used for this. What is the data quality of these measurements? Section 3.4 explains that CO_2 measurements are used for quality control of the data. How about CO/CO_2 correlations? Also, the flask samples seem to be analyzed for a variety of other compounds that could help investigate CO source types.

<Reply> As described above, this paper focuses on the methodology of shipboard CO observations and its field deployment on commercial ships. Hence we briefly mentioned CO_2 and O_3 by referencing to our previous papers. Detailed analysis of CO including relationships with CO_2 and O_3, and other gaseous species from flask samples is currently in preparation and will be submitted to Atmos. Chem. Phys. soon.

Specific comments

<Referee > The expression “over the Pacific Ocean” on first reading implies measurements are performed onboard aircraft. Although it is clearly said, that these are ship based measurements, it should be “in the Pacific” or “in the Pacific region” or “in the Pacific boundary layer”.

<Reply> We will replace “over the Pacific Ocean” with “in the Pacific”.

<Referee > Is the same air intake used for all measurements (flasks, continuous CO, O_3, CO_2)? The position of the intake is mentioned a couple of times. Please make this clear and omit afterwards.

<Reply> We have individual intakes for flasks samplings, and continuous CO, O_3 and CO_2 measurements. We will clarify this description.

<Referee > How much time is in between flask sample collection and GC analysis? What are typical O_3 values encountered? Has CO growth in the cylinders been investigated?

<Reply> This is really an important point for CO analysis in flask samples. The time between sampling and analysis depends on ship's routes (i.e., TF5, FTW, SKB) and sampling locations (i.e., first or second half of the cruise). Flask samples are analyzed immediately after the flasks have returned to laboratories at NIES. This means, all the flask samples are typically analyzed within 1 to 2 month after collection of ambient air. Typical O_3 mixing ratios are different depending on the ship's route. The O_3 mixing ratios are less than 20 ppbv in the open ocean but are more than 40 ppbv in coastal area. We examined the CO growth in the cylinders of gas standards as shown in Fig. 5. Since the growth is significant for ppbv-level standards used for flask analysis, we have applied correction factors before comparison to continuous data.

<Referee > It is not clear to me what the different measurement time scales are.

<Reply> This sentence means that 10-sec data from CO, CO_2, and O_3 instruments are merged into a same electric file on the GPS time, and then 1-min mean data are produced for further data processing.

<Referee > P4507, L23-P4508, L4: To my knowledge CO measurements are also performed as part of the Japanese CONTRAIL program. If so, this should also be mentioned here. Yashiro et al in JGR 2009 also discussed a similar project of ship-based sampling that might be a suitable reference here because similar measurements are carried out in the same region.

<Reply> We will revise the introduction section by adding CONTRAIL program and ship-based flask sampling observation by Yashiro et al. [2009] to the Reference list.

<Referee > P4510, L20/21: “including gases”: Later calibration gases and the use of nitrogen are discussed, presumably only potentially poisonous gases are meant?

<Reply > Yes, it means any hazardous or flammable gases. We will correct the text to make it more understandable.

<Referee> P4512, L22: At which time resolution are the different types of raw data recorded?

<Reply> All the continuous instruments: CO, CO_2, and O_3 analyzer provide 10-sec data.

<Referee> Section 2.2: The title is confusing because the term continuous system has been used before to distinguish between the continuous CO measurement and the flask sampling. The importance and length of this paragraph does not justify the separate treatment. It can be merged into section 3. More details about the analyzers used should be given, e.g. what are the measurement techniques, detection limit, precision, time resolution…

<Reply> We will integrate sections 2.2 and 2.3 to make a new section. Technical details of analyzers are given in references.

<Referee> P4511, L6: the term “air sample” should be used careful to avoid confusion with the flask samples.

<Reply> To avoid confusion, we will use a term “continuous air sample” and “flask air sample” in a revised manuscript.

<Referee> P4511, L16: Why is the number of samples limited to seven? This is a very small number for the large distances traveled.

<Reply> As shown in Fig. 1, 21, 14, and 7 samples are collected in total for CO analysis

along the route of TF5, SKB, and FTW, respectively. Each air sampling equipment contains seven glass (or stainless) flasks. Several air sampling equipments can be set on the automatic air sampler unit depending on the space of the observation room.

<Referee> P4512, L4/5: What is the actual sampling time for one flask?

<Reply> After the flask is rinsed, air sample is collected for 4-5 min with ambient air pressurized up to 1.6 kgf for glass flasks and 2.5 kgf for stainless steel flasks, respectively. We will add this phrase to a revised manuscript.

<Referee> P4513, L5ff: Please mention that continuous measurements are performed in addition to flask sampling.

<Reply> We will update section 3 according to the referee's comments.

<Referee> P4514, L25: In section 2.1, it was mentioned that no gases were used onboard, Please clarify.

<Reply> As mentioned above, only hazardous or flammable gases are unusable.

<Referee> P4516, L22: 20 min zero-air injection time seems rather long. The daily calibration time is only 10 min. How long does the instrument need to stabilize after changing from sample to zero air? Is it ensured that flask sample collection takes place while ambient air is measured?

<Reply> We apply relatively long zeroing period to obtain zero-levels more precisely, especially for low CO mixing ratios typically seen in the southern hemisphere. We believe that this is acceptable for measurements on ships that are moving "relatively" slowly. For comparison of continuous measurements and flask analyses, we only compared concomitant data within 1 hour.

<Referee> P4516, L25: Does that mean that a 40 min averages is taken or is the mean only calculated for the drift correction? At which time resolution are the raw data recorded? This needs to be clarified.

<Reply> For CO, 10-sec instant and 1-min mean data are available. To obtain highly precise CO mixing ratios from GFC measurement, data for a few tens of minutes were averaged. We calculate CO mixing ratios from 40-min data.

<Referee> P4519, L24: How about the fourth route (PX)? How many samples were collected?

<Reply> On board PYXIS, 14 flask samples were collected but continuous CO measurements were not made (Please see Figure 1). Hence we do not describe the onboard observation of PYXIS.

<Referee> Section 4.1: I suggest to skip this section. It does simply state that there is reasonable agreement between flask sampling and continuous measurements, the quantitative details of this are presented in section 4.2. It is no big surprise and does not need to be discussed in such detail that high resolution measurements capture more details than coarse flask sampling, and unsurprisingly this is more relevant in regions with high spatial variability.

<Reply> We believe that this section is one of the most important sections in this paper, because it demonstrates reasonably good agreement between two independent techniques to determine atmospheric CO, in very different environments observed in TF5, FTW, and SKB routes. Technically, it would also be difficult to illustrate the CO variations from Figure 9 only.

<Referee> P4520, L6: It is mentioned in section 2.2 that 10s and 1min data are reported, so why are 40 min mean values used? See also my question on the 40 min averaging above. I was unable to find the exact time resolution of the continuous instrument and I am not sure what the sampling time is, but it should be possible to calculate a well matching integral value from continuous measurements for each flask sample.

<Reply> Please see our reply above.

<Referee > P4522, L2ff: “four distinct regimes” may be a better expression to use here. For better understanding refer to the colors used in Fig. 6. The statement about the Asian monsoon circulation needs be clarified. In the current version the discussion of the FTW route winter cruise (P4521, L25 – P4522, L22) is very difficult to follow.

<Reply > Thanks for this comment. We will revise this sentence accordingly, and add the explanation of Asian monsoon circulation.

<Referee > I suggest to merge Figure 1 and 9 into one figure and to include a table quantifying the number of cruises on each route.

<Reply > We think that flask sampling locations should be provided along with the ship’s route. It is difficult to clearly show the locations in Figure 9 only.