RC2: 'Comment on acp-2022-756', Anonymous Referee #2, 31 Jan 2023

This is a nice paper describing the ecosystem surface influence of the ICOS network and the increased coverage with the addition of new sites. I recommend publication with some minor revisions described below.

We thank the reviewer for their assessment of our manuscript. The individual points made are addressed below. Please note that the line numbers in the reviewer comments refer to the first version of the paper and our responses to the latest version of the paper.

Minor comments

The abstract is overly long and not concise enough. Please condense it.

The abstract has been shortened and now reads:

"The ICOS (Integrated Carbon Observation System) network of atmospheric measurement stations produces standardized data on greenhouse gas concentrations at 36 stations in 14 different European countries (November 2022). The placement of instruments on tall towers and mountains makes for large influence regions (concentration footprints). The combined footprints for all the individual stations create a "lens" through which the network sees the European CO2 flux landscape. In this study, we summarize this view using quantitative metrics of the fluxes seen by individual stations, and by the current and future ICOS network. Results are presented both from a country-level and pan-European perspective, using open-source tools that we make available through the ICOS Carbon Portal. We target anthropogenic emissions from various sectors, as well as the land-cover types found over Europe and their spatiotemporally varying fluxes. This recognizes different interests of different ICOS stakeholders. We specifically introduce "monitoring potential maps" to identify which regions have a relative underrepresentation of biospheric fluxes. This potential changes with the introduction of new stations, which we investigate for the planned ICOS expansion with 19 stations over the next few years.

We find that the ICOS network has limited sensitivity to anthropogenic fluxes, as was intended in the current design. Its representation of biospheric fluxes follows the fractional representation of land-cover and is generally well-balanced considering the pan-European view. Exceptions include representation of grass & shrubland and broadleaf forests which is abundant in southeastern European countries, particularly Croatia and Serbia. On country scale the representation shows larger imbalances, even within relatively densely monitored countries. The flexibility to consider both individual ecosystems, countries, or their integrals across Europe demonstrates the usefulness of our analyses and can readily be re-produced for any network configuration within Europe."

line 50: atmospheric needs to be mentioned here. You have mentioned land and ocean but the rest of the co2 is contributing to the atmospheric growth rate.

The reviewer is referring to this section which has been updated (underlined part):

Up until now, about half of the CO_2 humans have emitted has been taken up by land (29% of total CO_2 emissions 2011-2020, Friedlingstein et al., 2022) or stored in the deep ocean (26% of total CO_2 emissions 2011-2020, Friedlingstein et al., 2022). <u>The other half of the anthropogenic CO_2 remains in the atmosphere and contributes to the atmospheric growth rate which is 2.5 ppm for 2022 according to a preliminary estimate by Friedlingstein et al. (2022).</u> On global scale, our common CO_2 trajectory will greatly depend on the capacity for storage in these carbon reservoirs and is important to plan our efforts under the Paris agreement. Furthermore, understanding the natural carbon exchanges between carbon reservoirs is important for our ability to track and verify changes in emissions (Balsamo et al., 2021).

Line 60. Full stop missing.

A full stop has been added.

Line 93. While the exact approach used here is not awfully common, there have been a few previous studies that have examined ecosystem representation of various networks with a slightly different tool (eddy flux) and should be mentioned. Malone et al., 2022 (https://doi.org/10.5194/bg-19-2507-2022) examined the ecological representation of the NEON network of eddy flux towers over the US but for the eddy flux footprints, which are much smaller than the concentration footprints / surface influence of the ICOS network. Pallandt et al., 2022 (https://doi.org/10.5194/bg-19-559-2022) also looked at ecosystem representation in the Arctic ecosystems.

We thank the reviewer for pointing us to these interesting references which indeed should be mentioned in our study. The following was added:

"For ecosystem sites, where fluxes rather than concentrations are measured, the "flux footprints" are small with influence mainly from the site's immediate surrounding. In this context, the idea of representation has been applied in Pallandt et al. (2022) to assess what Arctic ecosystem types are at the site locations compared to what ecosystems are found in the Arctic. Malone et al. (2022) similarly identified gaps in the U.S. NEON network based on representation of different clusters identified based on their ecological properties. In both studies, the evaluation of the network representation was subsequently used to advice on future expansion and how to evaluate the appropriateness of upscaling of the fluxes to larger regions."

Line 116. Do you mean STILT v2 (Fasoli et al.,2018, https://www.geosci-modeldev.net/11/2813/2018/). If not, I'd recommend upgrading. It's much faster to produce the footprints than v1.

We thank the reviewer for the suggestion. However, STILT was set up in the ICOS Carbon Portal in collaboration with C. Gerbig at MPI for Biogeochemistry and we share input data processing. Therefore, we use the STILT version that is supported by MPI-BCG.

Line 124. I don't understand this statement. If you want to combine the footprints with biogenic CO2 estimates, then you need to have at least 3 hourly (hourly would be better) time-step footprints back over the 10 days or you won't be able to interpret the CO2 signals. There is a strong diurnal cycle in CO2 flux from the biosphere with uptake during the day and emission at night. So you can't just take a 10 day footprint and multiply it by the net CO2 from VPRM. That's not the same as combining it in a sub-diurnal way. See Commane et al, 2017, Schiferl et al., 2022 for examples. It sounds like on Line 137 that you are using the time varying footprints for the interpretation so maybe I am just misunderstanding. In that case, maybe a little re-wording/clarification would be good. Did you combine the GPP and Resp from VPRM separately? In that case, did you use a static average number for the previous 10 days? I think that would actually be ok, given what you are doing with this study. But it needs to be explained.

We thank the reviewer for this important point and useful references. We did indeed multiply time-step aggregated footprints back over the ten days with static CO_2 fluxes from VPRM, but from GEE and Respiration rather than the net CO_2. We used the flux maps matching the time the air was modelled to arrive at the receptor, which indeed meant that we missed the strong diurnal cycle of especially GEE. To do better justice to this variation, we have updated our methods:

We have re-created the study with hourly time-step footprint back over the ten days, as pointed out as preferable by the reviewer. It means updated results throughout the study, but it did not change our main conclusions (see comparison below).

Hourly backward footprints required to re-create the study were created and saved specifically for our purpose and are not normally saved when the Carbon Portal Footprint Tool is run. This, in

combination with the computational resources required for the updated approach, means we cannot offer this to the general users of our online tool hosted at the Carbon Portal JupyterHub. Rather, we will update the tool to use a static average number for the previous ten days as suggested as an acceptable alternative by the reviewer.

The different approaches to arrive at network representation of different ecosystem fluxes are compared below for the current network year 2020 (same information as in paper Fig. 5b, and Fig. 8b for Germany, upper bars). The fair agreement between using the static 10-day average compared to the best approach now used for the paper gives confidence that it is feasible to use in the online tool.

To better understand the differences between the approaches, we have further examined the representation of coniferous forests; the higher overrepresentation in the static tool comes mainly from the night-time hours (0:00, 3:00, 6:00, 21:00) with average overrepresentations of the individual time-steps ranging from 12-24% compared to the "equal view". Our explanation for this is that there is essentially no GEE during these hours when backward resolved footprints are used, whereas the static 10-day average GEE mean activity also during these night-hours. Footprints representing the night, where there is less mixing of the air, will generally have more local influence on the measurements. Many of the ICOS stations, such as Hyltemossa, is close to/in coniferous forests which therefore explains the relative over-representation. This again stresses the advantage with the new approach suggested by the reviewer.

Country	Total GEE	Broad leaf forest	Coniferous forest	Mixed forest	Other	Grass & shrub-land	Cropland	Pasture	Urban
Europe GEE "closest match" (preprint, outdated)	3,12	-12,56	8,88	-3,72	56,83	-52,93	8,60	7,21	59,45
Europe GEE "static 10 days" (online tool)	3,51	-16,84	12,64	-4,39	74,09	-53,13	11,54	-1,76	62,70
Europe GEE "backward resolved" (paper)	2,96	-16,51	0,93	-0,35	40,67	-53,66	13,56	7,68	63,89

Table 1. The over- (+) or under (-) representation of the current ICOS network within Europe (see paper Sect. 2.5). Results are given for GEE summer year 2020 with the different approaches to combine footprints with fluxes.

The difference in results presented above will be shared in the online tool to inform users about how the methods are different and what this may mean for their results.

Line 178. Others.

"Other" changed to others.

The Results and discussion could be combined. I think it would read better and there is a lot of discussion in the Results section already. But that's just a suggestion.

We thank the reviewer for this suggestion but have decided to keep the sections separately. we have removed text that appears in both sections in a couple of places to avoid redundancy.