Reply by the authors to Bryce Kelly's comment on "Quantifying methane emissions from Queensland's coal seam gas producing Surat Basin using inventory data and an efficient regional Bayesian inversion" (#acp-2020-337)

We thank Assoc. Prof. Bryce Kelly for taking the time to read our manuscript and making a number of comments. We appreciate that he found our work 'a valuable scientific contribution.'

We are aware of the measurements and analysis work Prof. Kelly and his team have been doing on methane emissions from the Surat Basin, and it is really useful to get his perspective on our paper.

Virtually all comments by Prof. Kelly concern the construction of the bottom-up methane inventory for the Surat Basin that we have used in the paper.

The 2015 emission inventory for the Surat Basin was prepared by Katestone Environmental Pty. Ltd for us (i.e. CSIRO) (Lisa Smith of Katestone is a co-author on the paper).

We now attach the Katestone report "*Surat Basin Methane Inventory 2015 – Summary Report*" in the Supplement S6. This report fully explains as to how the bottom-up methane inventory was constructed and should answer many of the questions and comments by Prof. Kelly.

We want to emphasise that the main purpose of the paper was the top-down calculation (i.e. inverse Bayesian modelling). For this purpose, the bottom-up methane inventory provided a valuable a priori information. The inverse modelling aims to bring out any significant differences between the top-down and bottom-up estimates for methane emissions by using the long-term, in-situ methane concentration observations that we made at two locations, Ironbark and Burncluith, in the Surat Basin.

Our inverse modelling suggests the top-down emissions are 33% larger in the coal seam gas (CSG) subdomain and 18.5% lower in the non-CSG region (dominated by grazing cattle), than those from the bottom-up inventory. This result is qualitatively consistent with the calculations done by Prof. Kelly which give higher CSG emissions and lower grazing cattle emissions that our bottom-up inventory. We expand Section 7.3 of the paper to include this.

The 2015 bottom-up inventory was prepared by compiling the best information available at the time, and it was not in the scope of the work to go back and reconstruct the bottom-up inventory based on the results from the inverse modelling by re-examining the various source components.

Additional response to Prof. Kelly's is given below.

"As recently presented at EGU 2020 in Lu et al. (2020) UNSW researchers have developed their own bottom-up inventory in the Surat Basin for the year 2018. …"

We are pleased to hear that Kelly et al. have prepared a bottom-up methane inventory for the Surat Basin for the year 2018 which they will shortly submit for review. Note that our inventory was for the year 2015, which partly corresponds the period of methane concentration measurements in the region (i.e. July 2015 – December 2016) used in our paper. We would expect changes in emissions going from 2015 to 2018, and would be keen in following up on Kelly et al.'s bottom-up inventory methodology when it is out in the print.

"Concerns with the lack of details provided on the inventory calculations…"

As mentioned above, we now attach the Katestone report "*Surat Basin Methane Inventory 2015 – Summary Report*" in the Supplement S6, which provides full details of the bottom-up methodology adopted and data used.

"Suggested manuscript revision inventory calculations

In the supporting information a table needs to be presented that lists the base quantity, emission factor used, clear referencing of the document(s) for the emission factor (and for each document clear referencing of the table and row selected for the emission factor), and justification for the selection of the emission factor, …"

Again, most of this information is give in the Katestone report.

"Points of clarity required with the CSG bottom-up inventory estimation of emissions

Because Luhar et al. (2020) does not adequately list the base CSG data …"

Please see the Katestone report in the Supplement S6.

"No listing of Pels covered is provided in Luhar et al. (2020). From the Queensland Government database in the Surat Basin gas was produced from 3519 wells in the period ending 30/06/2015 and 3768 wells in the period ending 31/12/2015. This total well number used in producing gas is actually slightly lower …"

The total well number is lower probably because the database file places the gas fields of Spring Gully and Peat within the Bowen Basin whereas in our bottom-inventory these are part of the Surat Basin. This is because of how the gas field zones and basin boundaries are defined. The gas fields included in our study are based on their geographic locations relative to the square study domain selected. There is a footnote about this in Section 7.4 of the paper.

"It is well documented that there are emissions from the water management ponds in the Surat Basin: refer to Iverach et al. (2015) Figure 3, and Nisbet et al. (2020) Figure 10…"

Methane emissions from produced water from both CSG production and processing are included in our emission inventory. These relate to collection and storage of produced water, and high point vents on produced water pipelines (Table 11 of the Katestone report). These emissions are calculated at 1.63×10^6 kg yr^{-1} (~ 10% of the total CSG emissions). Produced water is a component of both CSG production and processing, and as such was not presented as a separate source category in the inventory but included under venting (now mentioned in the revised paper and Supplement S2.3).

We used an emission factor of 0.036 tonnes CH_4/1000 m3 produced water based on API (2009) "Methane Emission Factors from Produced Water from Shallow Gas Wells" (76 psi (~ 5.2 atmosphere) pressure or less and produced water at a temperature of 50°C) (see API (2009) Table 5-11, page 5-57).

The above emission estimate from produced water is only about 10% of Prof. Kelly's estimate, which uses an emission factor of 0.31955 tonnes CH_4/1000 m3 produced water, which is about 9 times greater that the value we used. This explains the discrepancy between the two estimates.

The emission factor Prof. Kelly used is also based on API (2009), but for "Produced Salt Water Tank Methane Flashing Emission Factors" (see API (2009) Table 5-10, page 5-57) with a separator pressure of 1000 psi (~ 68 standard atmosphere pressure) and a produced salt water content of 10.7%. In this Table, the emission factor value varies greatly, from 1/35th to 1.25 times the value used by Prof. Kelly, depending on the separator pressure and produced water salt content. We are not sure how the emission factors given in Table 5-10 are applicable to the Surat Basin produced water.

Prof. Kelly does a bulk calculation for the total CSG emissions from the Surat Basin by using the total gas produced and Facility Level Average emission factors. The aim of our methodology was to develop a fine resolution (1 km × 1 km) gridded bottom-up inventory needed for forward modelling and inversion, by using information such as location of CSG well and processing facilities based on data available through DNRM, and methane emissions data and calculations provided by operators. There are differences between the two estimates, and as mentioned above, the inversion highlighted the differences between the top-down and bottom up estimates.

Also, please note that the Surat Basin as defined for the present study is the 350 km × 350 km area shown in Figure 1 (which is on Queensland's side) and does not cover the whole Surat Basin.

Reference:

API 2009 Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Natural Gas Industry. See https://www.api.org/~/media/files/ehs/climate-change/2009_ghg_compendium.ashx.

"Suggested manuscript revision CSG bottom-up inventory

In the revised manuscript it is recommended for the CSG inventory portion …"

Again, much of the detail on our inventory emissions from the Surat Basin is given in the Katestone report, which is now included in the Supplement S6.

"Points of clarity required with the cattle bottom-up inventory estimation of emissions

The choice of using Harper et al. (1999) for cattle emission factors needs to be justified…"

Please see the attached Katestone report.

We used the Harper et al. (1999) emission factor for cattle.

We acknowledge that it may be an overestimate, and if that is the case then our top-down emission estimate for the non-CSG area (dominated by grazing cattle) is consistent with this. We add the following new paragraph in Section 7.3

"Conversely, the total bottom-up inventory emissions from the non-CSG area is 125.5 × 10^6 kg yr^{-1} whereas that obtained using the inversion (Case 3c) is 102.2 × 10^6 kg yr^{-1} which is 18.5% lower than the former. The total bottom-up emission for this area is dominated by grazing cattle (62.7%), followed by feedlots (24.8%) and coal mines (8.6%), which together account for 96.1% of the emissions from this area. It is possible that the emission factor of 84 kg CH_4 $animal^{-1}$ yr^{-1} for Australian grazing cattle (Harper et al., 1991) used in the bottom-up inventory (see the Supplement

S6) is an overestimate (cf. 51 kg CH_4 animal^{-1} yr^{-1} for beef cattle (pasture) used by the Australian National Inventory Report (NIR, 2017) or 63 kg CH_4 animal^{-1} yr^{-1} for non-dairy cattle for the Oceania (IPCC, 2019)), and that would be consistent with the lower top-down methane emission from the non-CSG area compared to the inventory. This also means that the CSG component of the top-down emissions in CSG sub-domain could be higher to compensate for the lower grazing cattle emissions if a lower emission factor for grazing cattle is used."

"Closing Comments…"

Thanks again for your comments.