#### Author's response to Reviewer#1 (anonymous)

General comments:

The goal of the paper is of interest for the scientific community and the approach seems interesting but because the paper is not easy to understand doubt remain on the approach. For instant, some 5 details are missing in sections 2 and 3 that are explained later in the results or discussion sections and reduce the clarity of these sections. For example, in section 3 maps resolutions are provided but not explanation is given on how maps are rescaled or not to be employed for the simulations at various resolution. Then the results description in section 4 is fine but is structured with too many subsections. The content of the result section can stand with no subsections. I believe. While results are 10 consistent with the previous section 1 to 3, the discussion section 5 is disappointing. There is a discussion on the wetland map resolutions and a reanalysis of wetland extend of models employed in

- the WetChimp model intercomparison paper of Melton et al. (2013) and a very small discuss on methane emissions and on the actual simulation results of the paper. It is also disappointing not to have some discussion on the complexity of methane emissions models for example for models
- 15 employed in the WetChimp model intercomparison versus the simple model employed here. The main conclusions of the paper is that wetland distribution is the main uncertainty for methane emissions and it has been demonstrated using a simplified model and conceptual framework. However, this uncertainty has already be addressed and demonstrated in a different manner in the paper of the global methane budget by Saunois et al. (2020) by comparing methane emissions 20 estimated by 13 land surface models using the same wetland map.

We thank reviewer #1 for her/his positive comments, their detailed review and for the constructive recommendations. We respond thereafter to each of their comments.

#### **Specific comments:**

- Abstract: Line 13 the rang of resolution, from 0.005° to 1° resolution, indicates in the abstract is 25 different than the one in table 3 that range from 0.001° to 1° resolution. Could you explain why? You show results at 0.001°, even though it is employed as a reference, it is still compared to the other runs.

Response: We meant to say that we aggregate from the reference resolution (0.001°) to six resolutions starting from 0.005°. However, the sentence will be revised as "This is done using a high-resolution wetland map (100x100 m<sup>2</sup>) and soil carbon map (250x250 m<sup>2</sup>) in combination with a highly simplified CH<sub>4</sub> emission model that is coarsened in six steps from 0.001° to 1°.

- Units: Sometimes the resolutions are given in different units than degree such as in line 147, 191 and 256; please make sure that all the units are the same for each variable.

Response: The native PCRG model resolution is in arcmin units. The units of PCRG resolution will be revised as (5 arcmin  $\sim 0.083^{\circ}$ 35

Also, some numbers in the text are formatted using scientific notation, others are not, such as in lines 298-303. It will ease the reading of the paper to have the same format of numbers.

Response: all numbers will be reformatted using scientific notation.

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- Although, the author sometimes qualifies the methane model by "highly simplified model" I think the model is a "simple model".

Response: "Highly simplified model" is replaced by "simple model".

## 45 **Figures and Tables:**

- I believe that Figure 1 and 2 can be merged into one single figure and by adding case 1 next to the content of Figure 1, case 2 next to the content of figure 2 and adjusting the figure caption.

Response: Done.

50 - Figure 3 can be removed, it is not useful to understand the paper. Possibly it can be placed in the appendix or supplementary document.

# Response: Done.

- Figure 4: My understanding is that you also run Sn 1 at 0.001° resolution which is also you 55 "reference resolution" why does it not appear in Figure 4?

Response: We agree with the reviewer at this point. The reason we choose not to include it because the reader won't see the difference between  $0.001^{\circ}$  and  $0.005^{\circ}$  since both are at very high resolution. We will replace the  $0.005^{\circ}$  figure with  $0.001^{\circ}$  to keep figure 4 in the shape of 4x2 (rows, columns)

Figure 5: the axis labels are not clear what is the right y axis, methane concentration? methane emissions? and the left y axis which ratio is it? Figure captions should describe more the figures. Also, I would advise to modify Sn.1-Sn.3 to Sn.1 to Sn.3 to avoid any misunderstanding such as the difference between Sn.1 and Sn.3

Response: We agree with the reviewer on this point. The figure and caption are modified as below:



Figure 5: Resolution dependence of CH<sub>4</sub> emissions for Sn.1 to Sn.3. The right y-axis represents the ratio of the emissions between emissions of the reference resolution (0.001°) to the coarsened resolution step as described in section 2.2. The left y-axis represents the domain integrated annual methane emission.

-Figure 6: please add the resolution for each box diagram in larger characters. Also, axis need labels that describe each axis in addition of the units. In each box diagrams all text should be enlarged except for the boxes with  $K_{CH4}$ .

Response: The resolution of each plot is now mentioned in the title of the plot. The figure is modified as follows:

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# **Figure 1:** Degero-Sweden (left) and Siikaneva-Finland (right) CH<sub>4</sub> flux measurements and calibrated model estimates at 0.1°, 0.5° and 1° resolution.



Response: Done as shown below.



Figure 7: CH<sub>4</sub> emissions for wetlands over the study area using PCRG soil moisture inputs at 0.1° (top) and 0.5° (middle) and 1° (bottom) for Sn.4.



**Figure 8:** Wetland extent maps used by the WetChimp intercomparison models (from b to i) in comparison to the CLC2018 wetland extent map (a).



Figure 9: Total wetland extent for the Fennoscandinavian peninsula.

- Figure 10: It is the correlation matrix of wetland extent? Please add this detail in the caption



# Figure 10: Correlation matrix for the tested wetland extent datasets used by WETCHIMP models and the current study wetland map extracted from CLC2018.

-Table 1: The table caption needs to provide all details for the reader to understand the table. All acronyms need to be defined in the caption.

**Response:** We added footnotes to the table.

|           | Wetlands             |                                      | Uplands              |                                      |                |
|-----------|----------------------|--------------------------------------|----------------------|--------------------------------------|----------------|
| Scenarios | SC*                  | SM**                                 | SC                   | SM                                   | Temperature*** |
|           | [g.m <sup>-2</sup> ] | [cm <sup>3</sup> .cm <sup>-3</sup> ] | [g.m <sup>-2</sup> ] | [cm <sup>3</sup> .cm <sup>-3</sup> ] | [K]            |
| Sn.1      | 110                  | 0.70                                 | 0                    | 0                                    | ERA-5          |
| Sn.2      | 0                    | 0                                    | 10                   | 0.10                                 | ERA-5          |
| Sn.3      | 110                  | 0.70                                 | 10                   | 0.10                                 | ERA-5          |
| Sn.4      | ISRIC2017            | PCRG                                 | 0                    | 0                                    | ERA-5          |

#### Table 1: List of Scenarios used in this study.

\* SC: Soil carbon values obtained from ISRIC2017 dataset (see sec.3.2)

\*\* SM: Soil moisture values. Wetland and uplands representative values where chosen based on previous studies (see sec.3.2).

105 **\*\*\*** ERA5: ECMWF Soil surface temperature (see sec.3.2)

- The title can possibly be modified to:" Spatial resolution significance in methane emissions modelling of natural wetlands"

**Response:** The reason for this suggestion is not clear for the authors. It mostly replaces 'importance' by 'significance'.

110 -I think a better suited subtitle for section 2.1 could be "conceptual framework"

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**Response:** subtitle changed from hypothetical case to conceptual framework.

- In this section the author explains the conceptual framework that they employed to evaluate wetland, soil organic carbon and soil moisture maps resolution on methane emissions. They use two cases: (1) an area entirely covered with wetlands and (2) the same area with one half cover with wetland and the other half with uplands. Both cases are well described however the aim of this section is not obvious.

**Response:** The aim is to explain the resolution dependence that we are studying using a very simple hypothetical case as explained in the first sentence of this subsection.

It is unclear to me the transition between the calculation of methane emissions over the all-domain area (up to line 105) and the calculation of methane emissions only for wetland areas (after line 105). Indeed, for case (2) the authors make the hypothesis that for uplands soil organic carbon and soil moisture are null then resume equation 2 and 3. Because of this hypothesis both equations serve to estimate methane emitted only by wetlands. This suggests that uplands are not emitting methane whereas simulation protocols defined for scenario 2 and 3 suggest otherwise which is confusing.

- 125 Response: We assume that the answer of this question is fulfilled from line 136 to 141. "In Sn.2 uplands are treated as the wetlands in Sn.1. CH<sub>4</sub> oxidation in upland soils may show a resolution-dependence following the logic of section 2.1 also. However, since the upland fraction is generally substantially larger than the wetland fraction at spatial resolutions that are common in global wetland modelling, the sensitivity of the sink to resolution is expected to be less important (see equation 4).
- 130 The setup of Sn.2 is meant to isolate the impact of the difference between wetland and upland fraction on the resolution dependence, which explains why the method to compute the flux is kept the same"

- In addition, I do not understand how the average of the SC or SM of the wetlands and the uplands over A<sub>HR</sub> (which for me is  $(n_{Wl} SC_{Wl} + n_{uplands} SC_{uplands})/(n_{Wl} + n_{uplands}))$  is equivalent to the average of SC or SM of only wetlands over A<sub>HR</sub> (which is for me n<sub>Wl</sub> SC<sub>Wl</sub>/n<sub>Wl</sub>)?

Because it is SC or SM that is equal to zero and not  $n_{uplands}$  (which gives after simplification  $(n_{wl} SC_{wl}) / (n_{wl} + n_{uplands})$ ). Then, if I am not mistaking, in equation 3 :

 $E_{HR} = [n_{Wl} SC_{Wl} / (n_{Wl} + n_{uplands})] \times [n_{Wl} SM_{Wl} / (n_{Wl} + n_{uplands})] \times A_{HR} = [n_{Wl} / (n_{Wl} + n_{uplands})]^2 \times SC_{Wl} \times SM_{Wl} \times A_{HR}$ 

140 and equation 4:  $E_{HR}/E_{LR} = [1/(n_{Wl} + n_{uplands})^2] \times A_{LR}/A_{HR}$ 

If I am mistaking, I need some explanations to understand the equations in the manuscript.

#### **Response:**

Since  $A_{HR}$  is the area of a high-resolution grid box, the following holds:

145  $A_{LR} = (n_{upland} + n_{wl}) A_{HR}$ 

Else  $SC_{uplands} = SM_{uplands} = 0$  in the hypothetical case

SC<sub>wl</sub> and SM<sub>wl</sub> are the soil carbon and soil moisture contents at high resolution (i.e.

150  $SC_{wl} = SC_{wl,HR}$  and  $SM_{wl} = SM_{wl,HR}$ 

So;

 $SC_{LR} = (n_{wl} A_{HR}SC_{wl} + n_{uplands} A_{HR}SC_{uplands}) / ((n_{wl} + n_{uplands}) A_{HR}) = n_{wl}SC_{wl}A_{HR}/A_{LR}$ 155  $SM_{LR} = (n_{wl} A_{HR}SM_{wl} + n_{uplands} A_{HR}SM_{uplands}) / ((n_{wl} + n_{uplands}) A_{HR}) = n_{wl}SM_{wl}A_{HR}/A_{LR}$ 

At high resolution the high-resolution versions SC<sub>wl</sub> and SM<sub>wl</sub> apply.

So  $E_{HR} = (n_{wl} SC_{wl} SM_{wl} + n_{upland} SC_{upland} SM_{upland})A_{HR} = n_{wl} SC_{wl} SM_{wl} A_{HR}$ 

- It is also unclear to me, at this stage of the paper, what the wetland fraction  $F_{wl}$  represents? In equation 4  $F_{wl}$  is defined as the proportional ratio of methane emissions estimated using LR map over the HR map. Therefore, to me  $F_{wl}$  is a ratio of methane emissions and not a fraction of wetland area. It is only because of the hypothesis that uplands are emitting no methane that the emission ratio is directly proportional to the wetlands fraction but it not clearly explained in the text.
- 165 **Response:** Equation 4 shows that the emission ratio is equal to the wetland fraction in this case. We modified the text to define wetland fraction as the areal fraction.

- In section 2.2, the authors define the wetlands methane model and scenarios that are simulated. It is not clear which model/method there are using to simulate these scenarios, equation 2-3 or equation 1?

170 **Response:** We amended the text and refer to eq. 1.

-Line 132-133: It is explained that it is considered that upland does not emit methane but in the next sentence methane emissions are still simulated for uplands? Then lines 135 - 137 seem to be some results or results discussion rather than method description.

**Response:** Lines 135-137 are moved to discussion secton.

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-Line 178-179: "The underlying assumption is that soil carbon in the ISRIC map is limited by the peat fraction at 250x250m resolution, and that the highest values represent grid boxes that are fully covered by peat." Finally, how much peatland area is estimated for the total area domain considered?

Response: The total peatland area estimation is mentioned in line 297 to 303, which is 53x10<sup>3</sup> km<sup>2</sup>.

- Line 200-201: "This gives rise to variations in soil surface temperature that we are unable to account for but are assumed to be second order in importance compared to variations in soil carbon and soil moisture." In the present study, authors may considered soil temperature as secondary however in sensitivity analysis of more complex methane models that represent methane production, oxidation and transport in global land surface models show that soil temperature is the first variable controlling methane emissions before soil carbon content and soil moisture (van Huissteden et al. 2009)
- 185 methane emissions before soil carbon content and soil moisture (van Huissteden et al., 2009, https://doi.org/10.5194/bg-6-3035-2009; Riley et al., 2011, https://doi.org/10.5194/bg-8-1925-2011; Salmon et al., 2022, https://doi.org/10.5194/gmd-15-2813-2022)

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Response: We agree with the referee about the importance of temperature for methane emissions which is indeed not second order. However, in first order, we account for this influence using ERA5 temperature at 7x7km2. The second order referred to any deviation of the local soil temperature from the 7x7km2 mean.

- At the end of section 3, it is unclear which map resolution is employed for the SC, SM average soil temperature and wetland maps for each scenario?

- Response: The results of the first three scenarios cover the full range of resolutions (0.001° 1°).
  Here typical averaged values from literature are used for SC and SM in wetlands and uplands, rather than maps. This can be found in Table 1 and also mentioned in section 3. These average values were assigned for every 100x100m box in the fine-resolution map based on the land cover type (mainly wetlands and uplands). For Sn4 and Sn5, maps have been used as indicated. We believe that Table 1 summarize this.
- 200 Line 222: "Significant differences are seen across the wide range of scales from the reference resolution to the coarsest resolution of 1°x1°" why does the reference resolution is not displayed in Figure 4?

Response: We admit that we should have made the point clearer. The reference resolution figure will be included in Figure 4. The 0.005° is removed due to visual similarities to the 0.001° and to keep the figure plots aligned evenly.



Figure 4: CH<sub>4</sub> emissions of Sn.1, spanning the full range of resolutions from  $0.001^{\circ}$  (top left) to  $1^{\circ}$  (bottom right). Because of visual similarities, the  $0.005^{\circ}$  is not shown.

Line 224 "the reference resolution integrated CH<sub>4</sub> emissions is ~1.68 Tg CH<sub>4</sub> yr-1" please add Table
 3 in the text such as "the reference resolution integrated CH<sub>4</sub> emissions (Table 3) is ~1.68 Tg CH<sub>4</sub> yr-1"

#### Response: Done.

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-Line 237 "Figure A.1 compares total CH<sub>4</sub> emission for the study area obtained using prescribed values for SC and SM in Table 2." How do you obtain uplands emissions since in lines 132-134 you explain that equation (5) does not apply?

Response: The reviewer referred to lines 132-134 which are part of the paragraph that describe the procedure of simulating methane emissions at Sn.1. Figures A1 is showing the results of Sn.2. In line 137 we mentioned the reason of simulating methane emissions from uplands.

- Line258 : "This is done in two ways;" what is the second way?

Response: The text is amended as follows: "Second, we calibrate the results of each resolution used in this scenario with site measurements, so that each modelled resolution agrees with the measured annual total, this results in different  $K_{CH4}$  values for each of the tested resolutions (Figure 6).

- Line 292 : "Secondly, the representation of wetland area in models is associated with large uncertainties." Please explain further the large uncertainties?

Response: The text is amended as follows: "However, a few problems remain. The first is that the wetland fraction is determined from a hydrological model or satellite data with a limited horizontal resolution, compromising the ability to determine the wetland fraction. Secondly, the representation of wetland area in models is associated with large uncertainties. These uncertainties mainly related to the accuracy of the hydrological models and how well satellite can represent wetlands.

-From line 294 to 311, I believe that the figure numbers do not correspond to the right figures. Please check the figure numbers in the text.

#### 235 **Response:** Done.

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#### **Technical corrections:**

Line 13: replace "that is coarsened in six steps from  $0.005^{\circ}$  to  $1^{\circ}$ ." To "at resolution from  $0.005^{\circ}$  to 240 1°.

#### Response: Done.

Line 24: replace "improve the accuracy of models, the main message of this study" to "improve the accuracy of models. The main message of this study"

#### Response: Done.

Line 90: "the availability of soil carbon" do you mean soil **organic** carbon or soil carbon that include organic and inorganic carbon?

Response: Changed to "soil organic carbon".

Line 91: "that we will use in the remainder of this study" this could be modified to "that we will use in this study"

#### 250 **Response:** Done.

Equation 2 is right only if SC and SM of each High-resolution grid box are equal and if SC and SM for uplands are nul.

**Response:** That is right. The equation refers to the hypothetical experiment.

I do not understand what the wetland fraction corresponds to? For me it is the proportional ratio of CH<sub>4</sub> emissions at Low resolution over high resolution.

**Response:** The wetland fraction is the areal fraction of a grid box that is covered by wetlands.

Line 110: Are "the grid boxes that covered by wetland" entirely covered by wetlands?

Response: Yes, entirely covered by wetlands at the high-resolution dataset.

Line 121:"the number of model parameters is only small" please modify to "the number of model parameters is small"

#### Response: Done.

Line 122: "the basic CH<sub>4</sub> controls of soil temperature" please modify to "soil temperature"

#### Response: Done.

Line128-130 "K<sub>CH4</sub> is a calibration constant relating the driving variables to a CH4 flux in units of [g
CH<sub>4</sub> m-2 yr-1]. We want to note here that The input data used in Eq.5 are for year 2015 as will be and are described in section 3.2." please modifies to "K<sub>CH4</sub> is a calibration constant relating the driving variables to a CH4 flux in [g CH<sub>4</sub> m-2 yr-1]. The input data used in Eq.5 are for year 2015 and are described in section 3.2."

## Response: Done.

270 Line 145: "For the remained scenario" please modify to "For the last scenario (Sn.4)"

#### Response: Done.

Line 146: "(5arcmin)" please confer to resolution degree.

#### Response: Done.

Line 156:"that are reporting" please modify to "that are reported"

275 **Response:** Done.