We thank the Referee #1 for his/her comments and suggestions. They will help improve the manuscript. We will address comments in the order discussed by the Referee starting with "General comments". In the following, the Referee's comments are in black, our replies in blue and the options that we considered to change the manuscript in green. New phrases added to text are underlined.

GENERAL COMMENTS

Comment 1: "While Sect. 2 is termed "Methods and data", it mostly presents datasets and Sect. 3 presents most of the methodology. I would suggest to move Sect. 2.6 to Sect. 3 and rename Sect. 2 "Datasets" or "Data".

Reply: We agree with the referee. We will restructure Sect. 2 and Sect. 3 in order to enhance the coherence of the paper. The paragraphs listed below and sections will be moved to Sect.3 and the names of subsections, changed accordingly for more clarity.

Modifications:

- 2. Methods and data → *2. Datasets*
- 2.1 Wetland definition and general mapping strategy → *2.1 Mapping strategy and requirements*
  The first two paragraphs of 2.1 will be moved to the new *Sect. 3.1.1 Wetland definition.*
  P4L20-L25: *"In this process, many layers were developed and are summarized in Table 2 and detailed in Sect. 3. The map and methods to exclude lakes from all layers is explained in Sect. 2.2. Input datasets to RFWs and GDWs are presented in Sect. 2.3 and 2.4 respectively, and several independent validation datasets, global and regional, are presented in Sect. 2.5. It should be noted that in the remainder of this paper, the wetland percentages of the land surface area always exclude lakes (Sect. 2.2), the Caspian Sea, the Greenland ice sheet and Antarctica (unless otherwise mentioned). For this reason, these percentages and areas might be different from those shown in Table 1, which are indicated in each original paper or data description.*
- 2.6 Data Processing → *3.1.2 Data processing*

- *3.1 Definitions and layer preparations*
- *3.1.1 Wetland definition*

Comment 2: "Several times in text, the authors highlight the dispersion existing between the three datasets of regularly flooded wetlands (RFW) they use. For example, in P9L7 they show that their overlap is only 5% of the summed RFW area coverage. This intuitively raises questions about the accuracy of each of these RFW datasets. Section 3.1.2 somewhat describe some reasons why some features are specifically captured by each one of them, but do not discuss why they do not overlap. It seems to me that such a short discussion would be desirable, given that these datasets are merged to produce the RFW part of the new composite wetland (CW) estimates presented in this study."

Reply: It is true that we emphasized more on the disparities between the inundation datasets and we do not discuss them in 3.1.2 (now 3.2.2). We will modify the mentioned section, adding a short discussion on the reasons of disagreement between RFW datasets. But generally, the input datasets to RFW are selected to combine different data acquisition methods. In places where they do not agree (like over Western

Europe and the Ob river basin: Fig R1 and R2) it is because the vegetation cover does not allow to access the soil surface for remote sensing techniques. Globally, RFWs cover 9.7% of the Earth surface while the area where two datasets agree covers only 1.8% of the Earth. The small size of intersection between the three dataset however is attributed mainly to JRC surface water extent which is very small (1.5% of the Earth surface area).

We will also add a subsection (5.1) to discuss the uncertainty of the CW maps underlying layers.

Modifications: Underlined parts are the added phrases

- Sect. 3.1.2 (now 3.2.2) first paragraph: "*Overall, the RFW map covers 9.7% of the land surface area (12.9 million km2) including river channels, deltas, coastal wetlands and flooded lake margins (Fig. 1e). Areal coverage of the RFWs is by definition larger than the area of wetlands in all three input datasets (Fig. 1b-d), which were selected to be representative of different types of data acquisition (sensors and wavelengths). Therefore, they correspond to different definitions of inundated areas, and their contribution to the RFW map is fairly different. In particular, the shared fraction of the three input maps is minuscule (5% of the total RFW land surface area coverage), and is mostly composed of the large river corridors and ponds which are detectable by satellite visible range imaging techniques in the JRC dataset. The latter misses most understorey inundations, which are better identified by the ESA-CCI dataset owing to specific vegetation classification. Finally, owing to the use of microwave sensors, GIEMS-D15 extends over larger areas since it captures flooded areas and wet soils, below most vegetation canopies unless the densest ones (Prigent et al., 2007). Besides, the distribution of wetlands in GIEMS-D15 involves downscaling as a function of topography, and can be very different from the other datasets. Hence, 58% of RFWs are solely sourced from GIEMS-D15, mostly in the South-east Asian floodplains, North-east Indian wet plains and rice paddies, and in the Prairie Pothole Region (in Northern US and Canada). The ESA-CCI contribution is mainly found in the Ob River basin where wetland vegetation exists but wet soils are not easily detected by visible (JRC) or microwave (GIEMS-D15) observation. Due to its high resolution, JRC surface water adds small-scale wetlands such as patchy wetlands, small ponds and oases (0.4% of the land surface area).*"
- "*5.1 Uncertainty of the underlying layers (First paragraph)*

It must be stressed that the uncertainty of the proposed CW maps is high, owing to several factors impeding the accuracy of the RFW and GDW maps. The uncertainty of the RFW map comes from the three input layers (ESA land cover, GIEMS-D15, and JRC surface water), and the lack of accuracy of the remote sensing products they rely on (shown by their large range of global flooded extents, from 1.5 to 7.7% excluding lakes). Of particular relevance is the uncertainty of GIEMS-D15, which contributes a lot to the high fraction of RFWs, and exhibits a small overlap with the other two datasets (less than 10% of inundated areas in GIEMS-D15 are confirmed by either ESA land cover or JRC surface water). Taking GLWD as a reference, Adam et al. (2010) concluded that inundation extents are overestimated in GIEMS (0.25° product of Papa et al., 2010) over parts of Northern Europe and India "because very wet soils may be wrongly identified as inundated", but this kind of error is not a major issue to identify wetlands, instead of inundated areas, as targeted by the CW maps. In India and South-East Asia, GIEMS-D15 also includes areas with flooded irrigation, including large rice-paddies, which correspond to artificial wetlands, not recognized in GLWD. Eventually, it is plausible that the RFW contribution from GIEMS-D15 is overestimated, but it must also be underlined that GLWD is not an exhaustive reference as it likely lacks some wetlands, as reported by Adam et al. (2010) and in section 4.2.

Comment 3: "It would be helpful for the reader to draw rectangles corresponding to the sub-regional foci where the authors discuss some of the features of the datasets, e.g. in Fig. 6 (P13L20-21), Fig. 7 (P14L5-6), and in Fig. 10 (L15P22)."

Reply: These figures are corrected with rectangles showing regions of importance or disagreement. These figures are inserted at the end of this reply.

Modification:

- In figures 6, 7 and 10, rectangles are drawn around Negro river basin, Llanos de Moxos, upstream Mekong River and upstream White Nile River.

Comment 4: "The conclusion is quite long and sometimes feels like a discussion. In addition, it tends to reformulate the main results (e.g. P18L22-27) instead of providing conclusive remarks and outlook. Please consider avoiding too much repetition from Sect. 3, and passing elements of the conclusion over to the discussion."

Reply: We agree with the Referee#1 that some parts of the conclusion are almost repetitions of Sect.3 and we will revise the conclusion section in order to better represent the outlooks and concluding remarks. Many modifications are made. Some elements from the conclusion are moved to 5.1 (inserted to previous comments).Suggestions for summarizing the conclusion are explained below:

Modifications:

- In the conclusion, the first four paragraphs are summarized as follows: (in place of P17L36:P18L37)

In an effort to develop a comprehensive global wetland description, we merged regularly flooded wetlands (RFWs) and groundwater-driven wetlands (GDWs) to develop composite wetland (CW) maps, under the assumption that both RFWs and GDWs are relevant although not exhaustive. The corresponding maps were produced globally at high resolution and two CW maps were selected based on comparisons with global and regional evaluation datasets. Their validity is particularly supported by the good match with the MPHFM dataset developed by Berthier et al. (2014) over France, because it was tailored to comprehensively include flooded and non-flooded wetlands with calibration against hydromorphic soils and validation against local surveys. With a total wetland fraction around 21% of the global land area, these CW maps are in the high-end of the literature, together with recent estimates also recognizing the contribution of groundwater-driven wetlands (Fan et al., 2013; Hu et al., 2017). It must be stressed that these high-end estimates, including ours, correspond to potential wetlands, as they neglect most wetland losses due to human activities, which may reach 30 to 50% of undisturbed or potential wetlands (Finlayson et al., 1999; Sterling and Ducharne, 2008; Hu et al., 2017). Overall, many uncertainties prevent from conclusively demonstrating that the CW maps are correct, in terms of patterns and extent, but it is also the case for any wetland mapping effort at the global scale that extends the definition of wetlands beyond inundated zones.

- The rest of the conclusion remains similar with slight changes
- *Most of the* Second, third and fourth paragraph: (in the place of P18L6-L36): is modified and moved to *5.1 uncertainties of the underlying layers*
- Fifth paragraph: (in the place of P19L8-L13) is moved to : *5.1 uncertainties of the underlying layers*

- *"5. Discussion*

  5.1 Uncertainty of the underlying layers" (rest of the subsection)

…

- **Parts of paragraph two of conclusion, now paragraph two of 5.1 with modifications:** *"Regarding the GDW maps, two major sources of uncertainty can be identified, related to modelling and thresholding. Whatever the involved GW modelling (simplified based on wetness indices, or direct like in Fan et al., 2013), a major challenge is to define thresholds on TI or WTD to separate the wet and non-wet pixels. Following the existing literature, we defined wetlands as areas where the mean WTD is less than 20 cm, and this WTD threshold was translated into the TI threshold defining the same global wetland extent (15%). Any error on this extent because of modelling errors will propagate to TI-based wetland mapping. In particular, the steady state assumption and 1-km resolution used by Fan et al. (2013), as well as their imperfect input data, only leads to a "first-order estimate of global land area likely affected by shallow groundwater", according to the authors. Nevertheless, the threshold choices remain subjective in the absence of consensual global wetland map and definition, and the related uncertainty in wetland extent was shown to amount to a few percent of the total land area based on sensitivity analyses for reasonable values of the different thresholds (supplementary section S2, Fig. S3 and S4).*
- **Parts of paragraph two of conclusion, now paragraph three of 5.1 with modifications:** *We also considered several classic variants of the TI to conclude that the TCI (topography-climate wetness index), also* favoured *by Hu et al. (2017) with a modified formula, offers the best correspondence with the validation datasets. The original TI did not capture the wetland density contrasts between arid and wet areas, and the inclusion of sub-surface transmissivity in TCTrI induced overly sharp density contrasts that did not always match the recognized patterns of large wetlands. This does not question the role of transmissivity in forming wetlands, but calls for improved global transmissivity datasets or new methods to supply a more continuous description of transmissivity than those currently proposed based on discrete classes of lithology (Hartmann and Moosdorf, 2012; Gleeson et al., 2014) or soil texture (Fan et al., 2013). A particular attention needs also to be devoted to the effect of permafrost on wetland formation, but simple maps are probably not sufficient to describe the complexity of hydrology-permafrost feedbacks, especially under global warming (Walvoord and Kurylyk, 2016).*
- **Paragraph six of conclusion, now paragraph four of 5.1 with modifications: "***The resolution of the input data sets is also prone to errors if coarser than the target wetlands. It is the case for transmissivity, as discussed above, and for climate input, at the 0.5° resolution for both GDW-TCI and GDW-WTD, which may lead to anomalous discontinuities, although they are not discernible in Fig. 2a,c,f. More relevant is the resolution of topography, at 15 and 30 arc-sec for the TI calculation (Marthews et al., 2015) and WTD modelling (Fan et al., 2013) respectively. An important consequence is that the pixels of our 15-arc wetland maps are either fully wet or fully non-wet, which is obviously wrong in many places with patchy wetlands in small depressions or along headwater streams. A finer delineation can be expected from higher resolution DEMs, such as HydroSHEDS or the MERIT (Multi-Error-Removed Improved-Terrain) DEM of Yamazaki et al. (2017), both offering a worldwide 3-arc resolution.*
- **Paragraph four of conclusion, now paragraph five of 5.1 with modification:** *"Finally, it must be underlined that the RFW, GDW and CW maps largely overlook the loss of wetlands induced by anthropogenic pressures, estimated to affect 30 to 50% of undisturbed or potential wetlands (Finlayson et*

al., 1999; Sterling and Ducharne, 2008; Hu et al., 2017), mostly due to urbanization and agricultural drainage. This feature is especially true for GDWs because most human influences were neglected in the input datasets (climate, topography, transmissivity, and sea level) for global WTD modelling. In contrast, the RFW map was derived by overlapping satellite imagery for the contemporary period (past 5 to 34 years), thus showing most human-induced changes on the surface water, including artificial wetlands linked to flooded irrigation (Adam et al., 2010) or the way in which damming shifts wetlands to lakes or drylands (Pekel et al., 2016). Nevertheless, the overlap of several inundation datasets with different historical depths was intended to minimize these disturbances, as justified by the higher spatial correlation between the inundation datasets and the CW maps than between themselves. Therefore, by construction, the proposed CW largely correspond to potential wetland. Considering that the loss of natural wetlands exceeds by far the extent of artificial ones, they have a larger extent than actual wetlands, making validation all the more complicated."

SPECIFIC COMMENTS

P6, L34: "Can the authors explain why they decided not to consider the permafrost effect for Ks estimates? Especially given the likely influence on the performance of TCTrI"

Reply: As shortly explained in the original manuscript, Gleeson et al. (2014) used a permafrost zonation index (PZI) from Gruber (2012) and defined all pixels with a PZI larger than a constant threshold as permafrost. They then assigned the hydraulic conductivity of all permafrost zones homogenously ($K_s = 10^{-13}\ m/s$). This ignores the diversity of different permafrost zones such as discontinuous and sporadic permafrost and instead considers all of them as continuous with constant active layer depths. Additionally, using this constant value leads to concentration of wetlands (derived from TCTrI) only over Siberian tundra and taiga forests, large parts of the Canadian Arctic Archipelago, Greenland and over well-known arid/semi-arid areas like the Kazakh uplands. In this way, many important wetland areas over equatorial and mid-latitudes like those in Amazon River basin, Congo basin and wet plains of Indian subcontinent are overlooked in these maps.

This is shortly pointed out in 2.4.4. We will modify 2.4.4 to better convey this message.

Modification: Underlined parts are the added phrases

- P6,L34: "*To consider the permafrost effect, Gleeson et al. (2014) used maps of the permafrost zonation index (PZI) from Gruber (2012) and homogenously assigned a rather low hydraulic conductivity ($K_S = 10^{-13}$ m/s) for areas with PZI>0.99. These areas with minimum hydraulic conductivity are limited to Siberian taiga forests and tundra, large parts of the Canadian Arctic Archipelago and Greenland. There is, as a result, a very large contrast in the hydraulic conductivity values between permafrost and non-permafrost zones leading to huge spatial discontinuities in the transmissivity map (considering constant depth for the permeable layer). For our calculations, we rasterized the vector polygons of K_S without the permafrost effect to 15 arc-sec resolution.*"

P10, L16: "The transmissivity (Tr) map used here using GLHYMPS is at a much coarser resolution (1°) than the TI map (15 arc-sec). This mismatch is in addition likely to have a larger impact on dataset accuracy of TCTrI than the mismatch present in TCI (P_e is at 0.5°), since intra-grid Transmissivity variability, from fine-scale heterogeneities, is likely higher than that of P_e. In a way, the lesser performance of TCTrI (or at least its little added value as compared to TCI) was thus somewhat predictable? "

Reply: This is a very good point raised by the Referee#1. But we first should correct that the resolution of the transmissivity maps is not constant in different parts of the world and as noted in 2.4.4, the GLHYMPS hydraulic conductivity map (base map for transmissivity) is formed of polygons of different sizes with an average of 100 km^2 (~0.1° at equator). So, the average resolution of the transmissivity map is higher than that of the climate forcings (P_e). The performance of the TCTrI is therefore not necessarily worse than TCI because of resolution. However, at zones where the spatial accuracy of the transmissivity map can be assumed too low by comparison to regional geological or soil maps for instance (Siberia, most of African continent, Indian peninsula, central Asia and upland Amazon basin), there is indeed a large mismatch between GDW-TCTrI maps and existing pattern of wetland distribution (Sect. 3.2.3).

Modification: There was no modification necessary for this comment.

P13, L10: "*"covered above" is vague, can the authors specify which datasets they are mentioning?* "

Reply: "This is right, and to make the sentence clearer, we revised the phrase giving an example of a study (Saunois et al., 2016) in which the overlap of GLWD (Lehner and Döll, 2004) and SWAMPS (Schroeder et al., 2015) is used to represent the wetland extent to calculate the methane emission from natural wetlands.

Modification: Underlined parts are the added phrases

- P13L5L10: *"The larger wetland fraction in MPHFM and CW maps is consistent with the work of Pison et al. (2018), who found that (wetland-driven) methane emissions over France deduced from atmospheric inversion were almost a third higher than those simulated by state-of-the-art climate models <u>driven by global wetland datasets like the overlap of GLWD and SWAMPS used in Saunois et al. (2016)</u>."*

P13, L25: "*in line with recent estimates of wetlands and peatlands*": references to published works would be needed here.

Reply and modification: The intended literature is the map of Hess et al. (2015). The reference will be mentioned.

TECHNICAL COMMENTS

P6, L34: The symbol or notation after "polygon of" is not properly rendered

Reply and modification: the symbol is K_s, which will be corrected in the new manuscript.

P13, L4: “Fig. 5j”, instead of “Fig. 5”

Reply and modification: Fig. 5 is changed to Fig. 5i,j since it is pointing at both CW maps.

P15, L17: Instead of “CW-TCI(15%)” , “CW-TCI(6.6%)”, “CW-TI(6%)”, dropping the “%” in the name (CW-TCI15, CW-TCI6.6, etc.) could help avoiding confusion when these names are used to describe wetland extent.

Reply and modifications: It’s a very good idea. We will modify the names of the generated maps in the text, tables and figures accordingly.

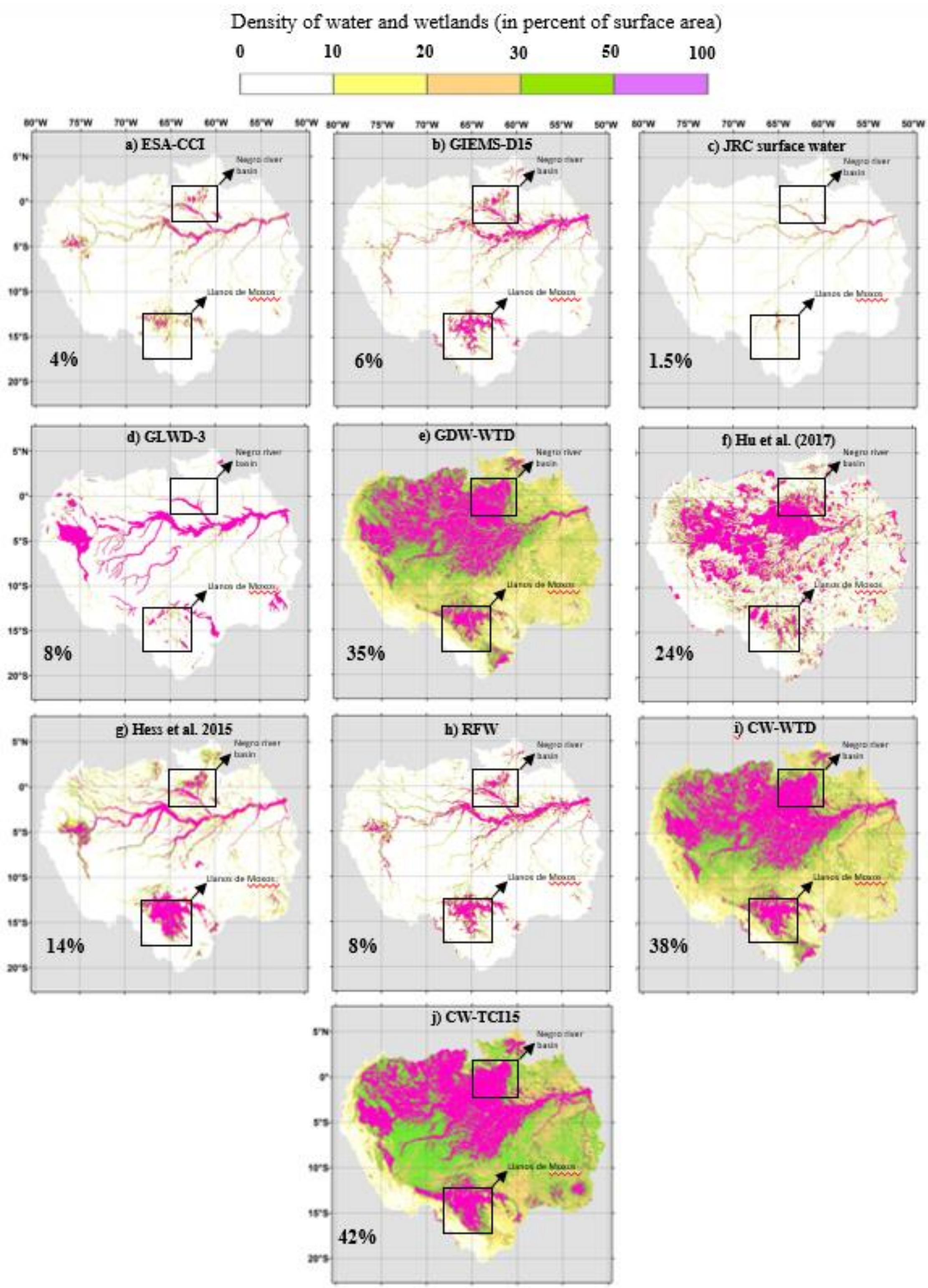

Figure 6: Maps of the Amazon River basin wetlands according to different water and wetland datasets: (a, b, c) components of RFW, (d, e, f, g) evaluation datasets, (h, i, j) datasets generated in this study. The panels also give the mean areal wetland fraction of each dataset in the study area (using the mean fraction of each fractional wetland class of GLWD-3, cf. Sect. 2.5.1). The bounds of the basin are taken from Hess et al. (2015).

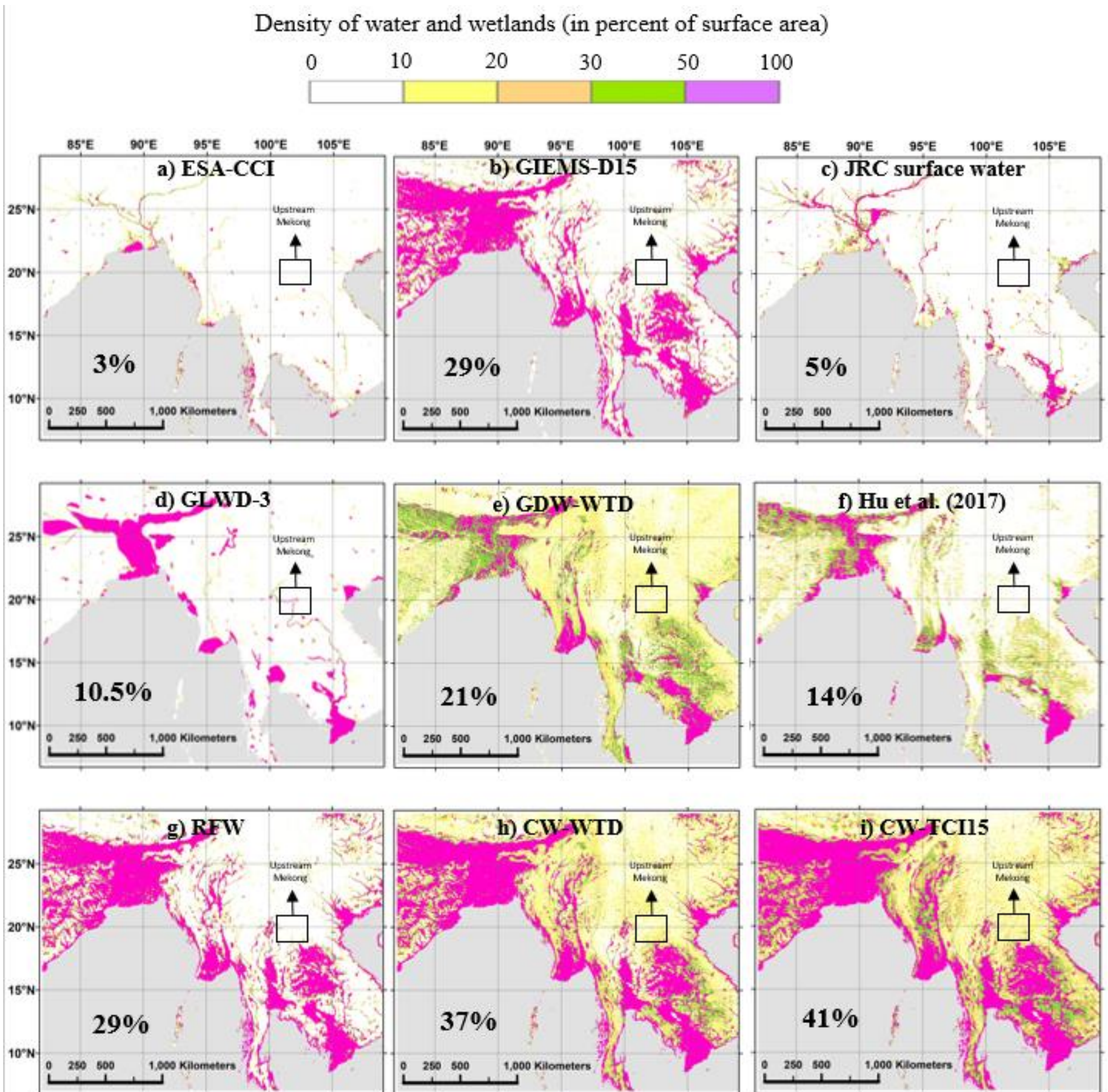

Figure 7: Maps of the South-East Asian wetlands according to different water and wetland datasets: (a, b, c) components of RFW, (d, e, f) evaluation datasets, (g, h, i) datasets generated in this study. The panels also give the mean areal wetland fraction of each dataset in the study area (using the mean fraction of each fractional wetland class of GLWD-3, cf. Sect. 2.5.1). The bounds of the study window are (5°-28°N, 82°30'-108°E).

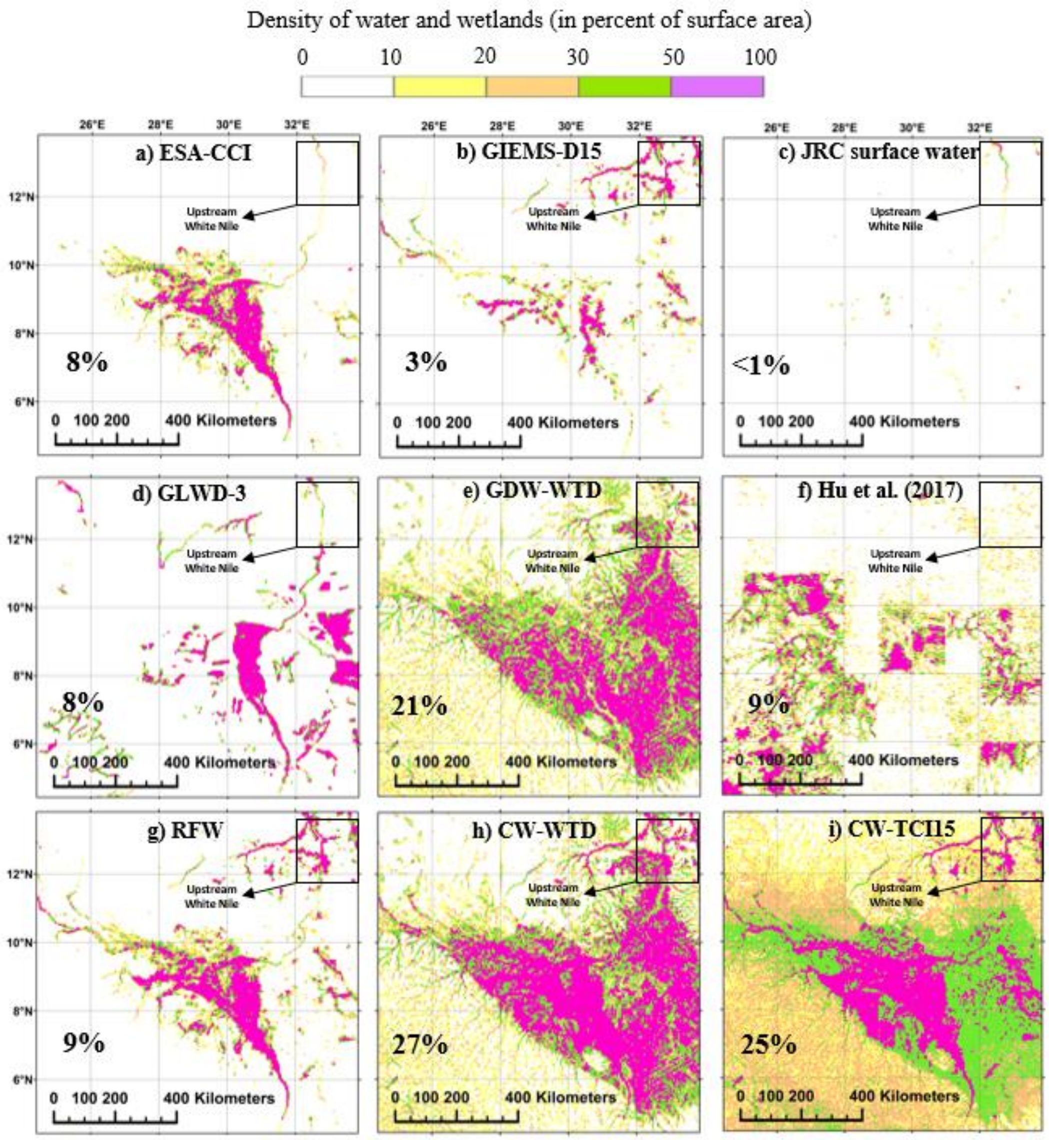

Figure 10: Maps of the Sudd swamp wetlands according to different water and wetland datasets: (a, b, c) components of RFW, (d, e, f) evaluation datasets, (g, h, i) datasets generated in this study. The panels also give the mean areal wetland fraction of each dataset in the study area (using the mean fraction of each fractional wetland class of GLWD-3, cf. Sect. 2.5.1). The bounds of the study area are (4°30'-14°N, 24° 30'-34°E).

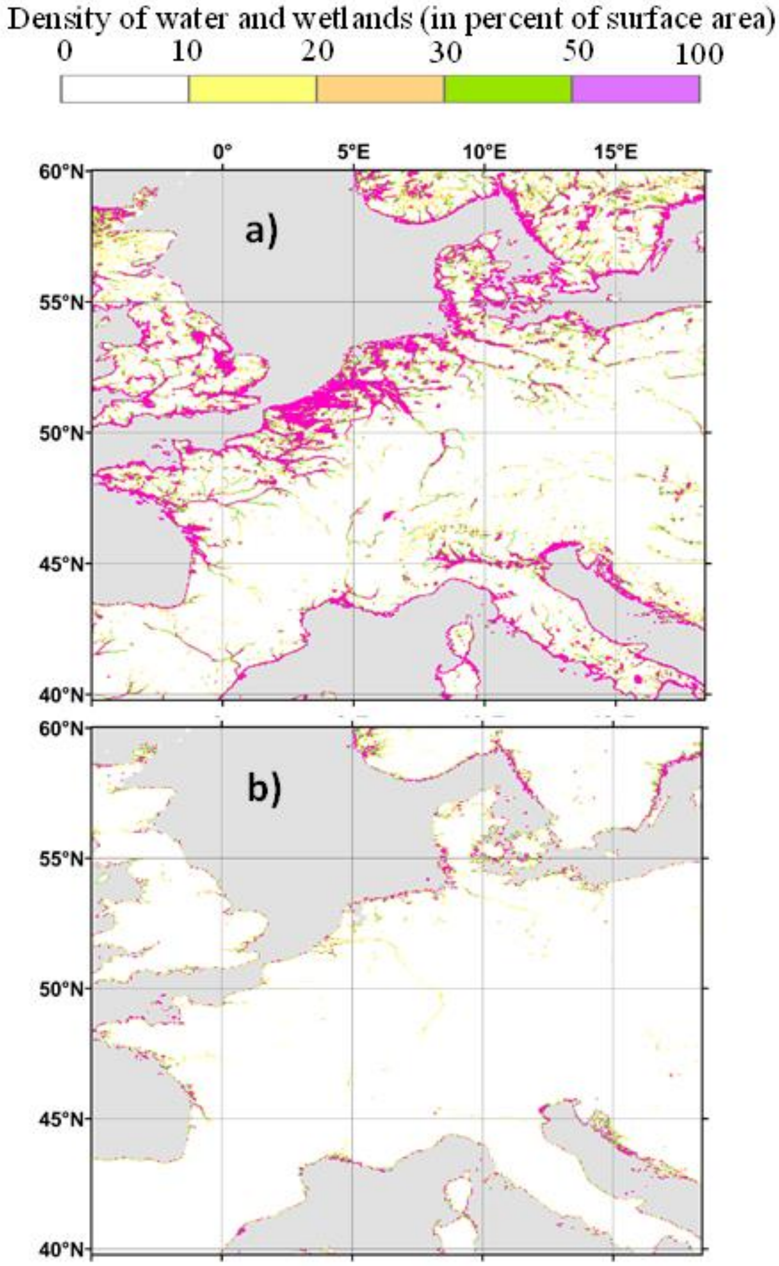

Figure R1: a) RFWs and b) zones where at least two of the inundation datasets agree over western Europe

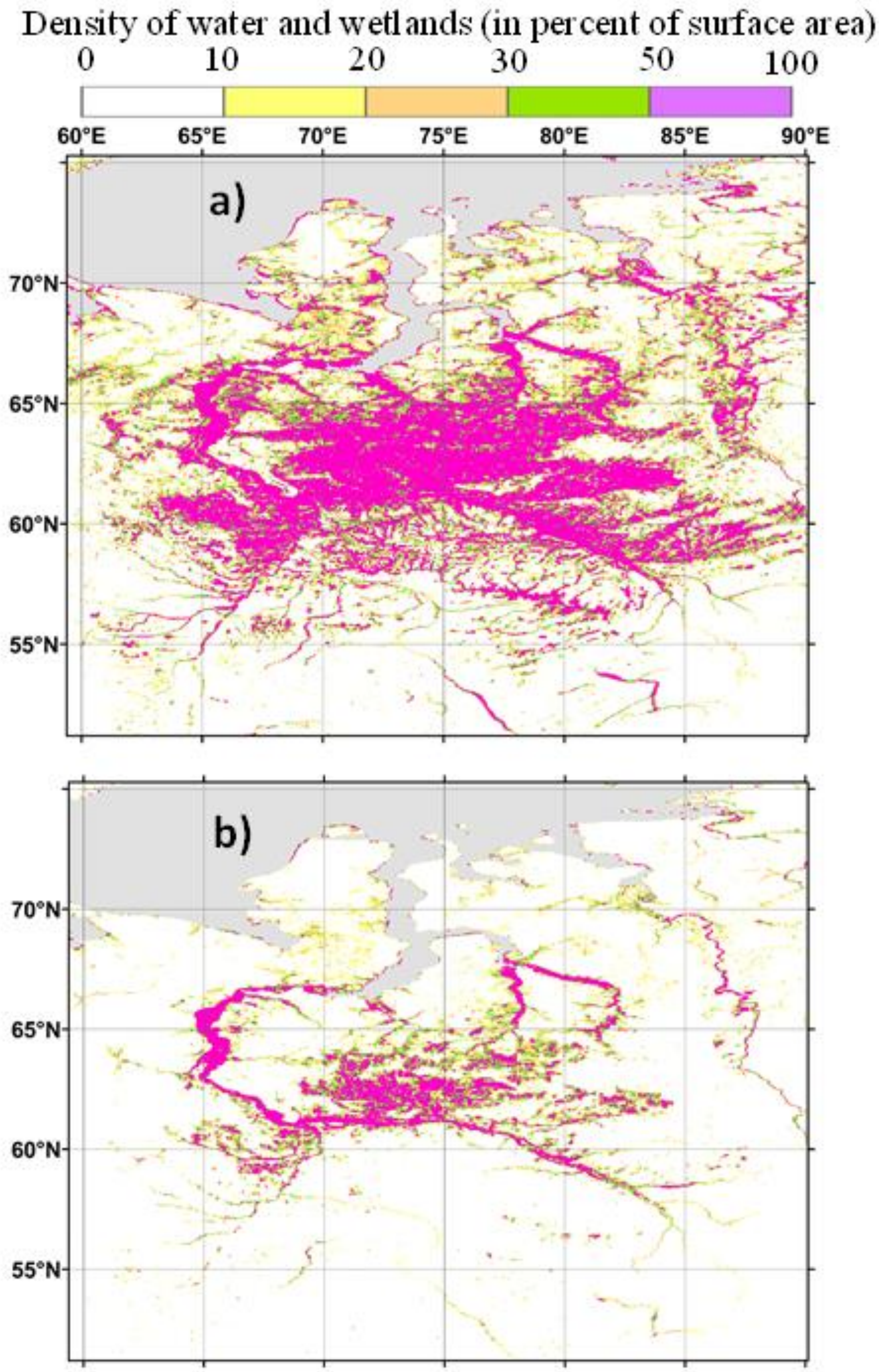

Figure R2: a) RFWs and b) zones where at least two of the inundation datasets agree over Ob river basin