

PARAMETERS TO ESTIMATE CO₂ EMISSION IN PEATLAND AREA BASED ON CARBON CONTENT AND SUBSIDENCE RATE FROM SAR INTERFEROMETRY

Noorlaila Hayati^{1,*}, Noorkomala Sari², Rahmat Arief³, Maulida Annisa Uzzulfa¹

¹Institut Teknologi Sepuluh Nopember, Department of Geomatics Engineering, Indonesia (noorlaila@geodesy.its.ac.id)

²Universitas Lambung Mangkurat, Department of Agroecotechnology, Indonesia

³National Research and Innovation Agency, Research Organization of Aeronautics and Space,
Research Center of Remote Sensing, Indonesia

Commission III, WG III/03

KEY WORDS: subsidence, peatland, InSAR, persistent scatterer, carbon content, CO₂ emission

ABSTRACT:

Peatlands are one of the important parameters to determine environmental quality because peatlands can store carbon stocks in their biomass. Based on the official page pantaugambut.id, Kalimantan Island is the second largest area that has peatlands. Land subsidence (subsidence) on peatland is one of the physical environmental impacts due to the shrinking volume of peat due to the drought process at a certain level in peatland processing, but also due to the decomposition process, erosion, and peat fires. This subsidence phenomenon will be measured using the InSAR technique, which is one of the existing methods in active remote sensing technology to measure changes in the earth's surface which is calculated based on changes in the phase difference between two SAR image acquisitions. Our research used the time series InSAR technique with the incorporation of Persistent Scatterer (PS) and small baseline approach to accurately calculate the value of soil subsidence rate to the cm-mm level. Furthermore, the estimation of CO₂ emission was calculated from the carbon parameters observed by the in-situ measurement, the affected peatland area, and its subsidence obtained by satellite remote sensing. We found that the highest CO₂ emission was located in the southern part of the study area. Since years ago, the region has been affected by deforestation and land expansion due to the need for fiscal revenues from palm oil and urbanization.

1. INTRODUCTION

Peatlands are one of the important parameters to determine environmental quality because peatlands can store carbon stocks in their biomass. Based on the official page pantaugambut.id, Kalimantan Island is the second largest area that has peatlands. Land subsidence (subsidence) on peatland is one of the physical environmental impacts due to the shrinking volume of peat due to the drought process at a certain level in peatland processing, but also due to the decomposition process, erosion, and peat fires. Dradjat et al. (1986) and Rina and Noorinayuwati (2007) reported a subsidence rate of 0.36 cm/month in the sapric peat soil of Barambai (South Borneo) for 12-21 months after reclamation, while for the sapric peat in Talio (Central Borneo) the rate was 0.178 cm/month and 0,9 cm/month for the hemic peat. Land subsidence in Babat Raya and Kolam Kanan Villages, Barambai District, South Borneo suffered from subsidence about 75-100 cm for 18 years (April 1978- September 1996) (Widyati, 2011).

Carbon storage in peatlands has been found in organic materials that make up peat, plant tissue, and litter (Widyati, 2011). Based on previous research, Indonesia has around 21 million ha of peatland with the below-ground carbon storage of approximately 37 gigatonnes (Gt) (Wahyunto et al., 2000). Peatlands are a huge store of carbon. Stored carbon could be released into the atmosphere due to land clearing activities. Logging accompanied by fire will accelerate the process of biomass emission. Thus, the carbon contained in peat soil is unstable. When peat forest is cleared and drained, the carbon stored will easily decompose and produce CO₂. In addition, excessive peat-

land drainage will make peatlands vulnerable to fires. Fires can reduce carbon storage in plant tissue and in peat. CO₂ emissions are a product of the oxidation-reduction process of organic matter from peat and are the largest contributor to greenhouse gas emissions. The decomposition, consolidation (compacting), and fires cause peat will experience subsidence and loss of various functions in supporting the surrounding land from flooding and drought. Namely, the conversion of peatlands due to land clearing activities causes an increased rate of C emissions. According to Hooijer et al. (2010), it is estimated that emissions associated with changes in peatland use and peatland management give 50% of Indonesia's national emissions.

Therefore, the calculation of peat carbon emissions aims to determine the amount of CO₂ released into the atmosphere due to the decomposition of peat organic matter or land clearing activities (fire; logging; drainage; addition of fertilizers) which affects the volume of peat. The amounts of emissions from peat soils over a period of time can be calculated based on the changes in carbon stored in peat soil. For this reason, an MRV (measurable, reportable, and verifiable) system of measuring and monitoring carbon emissions and peatland subsidence is necessary. Estimating carbon emissions requires two components which are activity data and emission factors. Activity data is the change in land cover over several periods, obtained through a radar approach while emission factors are the values obtained from the in-situ measurement and the constant conversion from C to CO₂ (IPCC, 2006).

InSAR is a technique in radar remote sensing to measure deformation in the earth's surface which is calculated based on

* Corresponding author

the change in phase difference between two SAR image acquisitions (Zebker and Werner, 1994). Some previous research has been proved InSAR as an effective technique to monitor subsidence not only in urban areas (Aobpaet et al., 2013) but also in peatlands (Hoyt et al., 2020; Khakim et al., 2020; Umarhadi et al., 2022). Peatlands in neighbor regions were monitored by measuring differences in water table depth (Hooijer et al., 2012; Nusantara et al., 2018). However, peat subsidence in South Kalimantan has not yet been extensively studied by either tracking of water table depth or geodetic techniques such as leveling, GNSS observation, and InSAR.

With the study area located in several areas of South Kalimantan, the research has strategically used the advanced InSAR technique, namely Persistent Scatterer (PS) InSAR (Crosetto et al., 2016) with the integration of small baseline approach (Hooper, 2008) to accurately calculate the value of peat subsidence to the cm-mm level. Furthermore, CO₂ emission would be estimated based on the integration of in-situ measurements and the time series InSAR analysis.

2. METHODOLOGY

2.1 The study area

The research project was located both in Banjar Regency and Banjarbaru City, South Kalimantan, Indonesia shown in Figure 1. Peatland ecosystems had been existed in the regency even there was one of the districts name after the abundant peat soil, Kecamatan Gambut. Banjar Regency had an area of 4,668.50 km² and consisted of 20 districts. The altitude of it was a range between 0 and 1,878 m from the mean sea level. Mostly, the land use was dominated by the national forest with an area of 86,510 ha (Bappeda, 2013).



Figure 1. Location of the study area in Banjar Regency and Banjarbaru City, South Kalimantan, Indonesia. Source of satellite images: Google Earth

2.2 Parameters to estimate CO₂ emission

Considering the two previous sub-sections, we furtherly can estimate CO₂ emission using those parameters and additional supporting data. The relationship between CO₂ gas emission monitoring and water depth was discussed by Hooijer et al. (2010) and Zhou et al. (2016) and used in this study to calculate CO₂ emission from water depth change which can be expressed as follows:

$$CO_2 \text{ emission} = \text{area} \times WT \times CO_2 1m(t/y) \quad (1)$$

and a modification into:

$$CO_2 \text{ emission} = 3.67 \times \text{area} \times WT \times Cm(t/y) \times P \quad (2)$$

with $CO_2 1m(t/y) = 3.67 \times C_m$
 $WT = \text{peat subsidence rate (cm/y)} / XO$
 $C_m = \text{carbon content} \times \text{peat bulk density} \times XO$

where $3.67 = \text{the conversion factor from C to } CO_2$
 $\text{area} = \text{drained or burned area within peatland area (ha)}$
 $WT = \text{average groundwater depth change in the study area (cm/y)}$
 $C_m = \text{C loss at an average groundwater depth of 1m (t C/ha/y)}$
 $XO = \text{the coefficient of the linear relationship between subsidence and water table change}$
 $P = \text{the percentage of C released as } CO_2$

Further detail regarding the formulas can be read from Dahdal (2011). Since the unavailability of water table change data in the study area, we assumed that XO the coefficient value of water table change and subsidence rate is $\sim 0.04 - 0.1$ (Wösten et al., 1997; Wösten and Ritzema, 2001). However, it was eliminated in the extended calculation due to a relationship between WT and C_m . For the percentage of P , we used 100% in a condition that all carbon loss was converted into CO₂ and methane emissions were negligible. Another option can be taken from a 92% oxidation of the total subsidence for peatlands drained over 18 years which was used for estimating the CO₂ emission rate by Hooijer et al. (2012). The formula to estimate CO₂ finally can be calculated as follows:

$$CO_2 \text{ emission} = 3.67 \times \text{area} \times \text{peat subsidence rate} \times \text{carbon content} \times \text{peat bulk density} \times P \quad (3)$$

According to equation (3), the estimation of CO₂ can be calculated based on the parameters generated by in-situ and InSAR observation. Figure 2 shows an illustration of parameters needed to estimate CO₂ emission. Carbon content and peat bulk density were collected from ground in-situ measurement in Banjar Regency and its surroundings while peat subsidence rate can be continuously monitored by the space-borne time series InSAR technique, namely radar remote sensing. Since the map of the peatland area was unavailable in the study area, we used another alternative to solve this issue. The land cover can be classified based on optics remote sensing as substitution data finding how much the area of peatland is. We processed the image classification from Landsat-8 to generate a peatland area in South Kalimantan.

2.3 The time series InSAR method

We utilized an archive of multi-temporal Sentinel-1 SAR images from January 2019 to February 2021. 66 Descending SLC images from VV polarization with the area of interest in South Kalimantan, Indonesia. The path, frame, and absolute orbit of the selected C-band image were 105, 601, and 26077, respectively. An external digital elevation model from SRTM 1 arc-second was used to minimize the error from the topography effect.

233 interferograms were generated based on the time series InSAR algorithm, Persistent Scatterer with Slowly Decorrelated

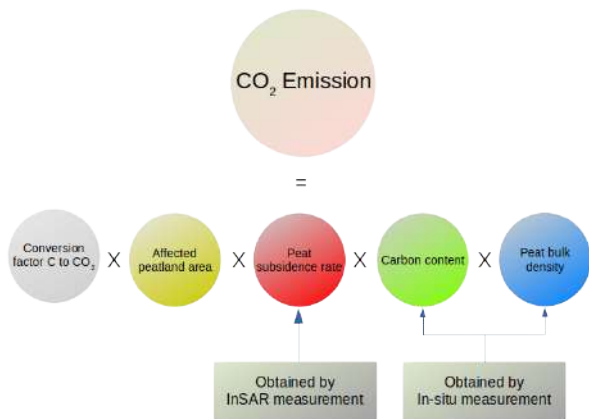


Figure 2. An illustration of parameters needed to estimate CO₂ emission based on InSAR and In-situ surveying data.

Filtered Phase (SDFP) (Hooper et al., 2004; Hooper, 2008). The configuration of SDFP was mainly developed from the small baseline method (Berardino et al., 2002; Schmidt and Buergermann, 2003) with an improvement to consider characteristics of stable phase within multi-master and slave pairs. The technique mostly was known as incorporation between the PS and Small Baseline Subset (SBAS) approach. To avoid decorrelated signals due to surface characteristics mostly covered by soils and vegetation, we performed the network pairs with a perpendicular baseline of 100 m and a temporal baseline of 50 days. Figure 3 shows the result of the small baseline configuration used in the research of peatland subsidence monitoring.

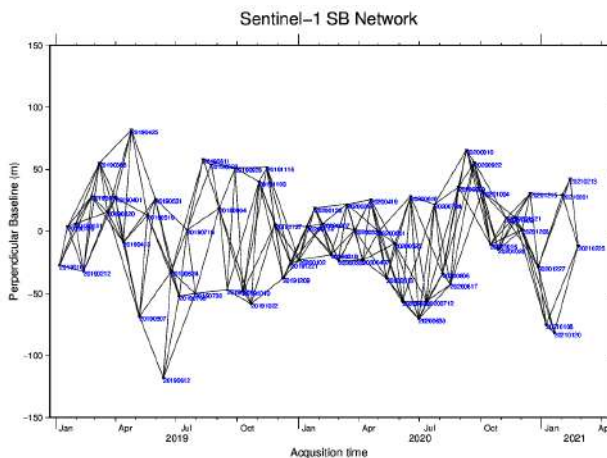


Figure 3. The small baseline network was created to process the time series InSAR technique with the PS-SDFP algorithm

The InSAR processing was generally divided into two main steps. The first step was an interferometric chain in which SLC images were firstly coregistered to a super master image and continued to range and azimuth filtering (Hanssen, 2001). Interferogram formation was performed with multi pairs created from the small baseline network and the differential InSAR was executed using SRTM data. Furthermore, we identified the candidate of PS with amplitude difference dispersion (ADD) with a threshold less than 0.6. The wrapped product of interferograms was analyzed with the phase stability estimation and SDFP pixels selection. The final PS points subsequently were 3D unwrapped (Hooper and Zebker, 2007) to the original

value of 2ϕ cycles and the unwanted signals due to other effects such as the spatially look angle error, the digital elevation model (DEM) error, the atmospheric artifact, and the orbital error was reduced. The last procedure was an inversion of displacements from the small baseline to single master mode using the Gauss–Markov theorem. Finally, the time series displacement was generated and the subsidence rate can be determined from the PS distribution of mean velocity in the observed study areas.

2.4 In-situ measurement of carbon content

The parameters used in the calculation of carbon stock are peat area, peat soil depth, bulk density (BD), and carbon content (C-organic/C-org) in each peat sampling area. Peat soil sampling in measuring peat depth and carbon content (C-org) using the Eijkkamp peat drill, consisting of a peat sampler, 5–9 extension rods, and one pair of handles. Meanwhile, BD is calculated from soil samples taken with a ring sampler. BD of peat was determined in the laboratory by the gravimetric method.

While the determination of the C content by the loss on ignition method, all organic matter present in the soil sample was burned at 5500C for 6 hours. Burned organic matter will evaporate and the remaining material is inorganic material such as soil clay, grains of dust, and fine sand. The weight loss of oven-dried soil samples in combustion is the weight of organic matter. The conversion from the weight of organic matter to the weight of C-org uses a factor of 1/1,724. This method is semi-quantitative because the weight loss during the ash process only describes the organic matter content. The conversion factor of 1/1,724 is a general number of the relationship between organic matter and carbon (Agus, 2009; Agus et al., 2011).

3. RESULT AND DISCUSSION

The results are divided into the InSAR observation and in-situ measurement. The first sub-section concerns explain the subsidence rate that occurred in Banjar Regency and its surrounding where mostly peatland soil surfaced on the bare land region. The next sub-section describes the extraction parameters of carbon content that were useful to estimate CO₂ emission. They were taken directly from in-situ measurements held twice to find the information of bulk density, depth of peatland, and a total of C organic. Then, we estimated CO₂ emission based on the generated parameters in the study area.

3.1 Subsidence rate in peatland area observed by the time series InSAR

The PS-SDFP technique was used to detect subsidence in Banjar Regency and its surrounding. Although the detected signal of surface displacement can not be distinguished directly between peatland and non-peatland regions, we presented generally the subsidence that occurred in the study area.

Figure 4 shows the rate of the line of sight (LOS) displacement within 39 and -45 mm/year. The south region was more impacted by subsidence than the north region. The maximum subsidence rate in the most southern area can reach -45 mm/year but the northern area had a general rate of -15 mm/year. We also detected uplift areas (the blue color) and assumed that the cause could be the effect of anthropogenic activities such as a new residential development, atmospheric artifacts, or noise that cannot be eliminated in the time series InSAR processing. Another

reason was the imperfect removal of phase residual (Fattahi and Amelung, 2013) due to an inaccurate external DEM to define man-made objects in this suspected area.

We plotted some samples of time series displacement distributed in the stable and deformed areas. As shown in Figure 5, Point 1 (114.7235991°, -3.4282887°) was located in the suburban land use and belonged to the stable area. Since the land use was for human settlements, the area did not cover with peat soil. Point 2 (114.687122°, -3.517750°) was located in the southwest of the study area, Landasan Ulin Selatan, close to TS5 and TS6 points (Figure 6). Point 3 (114.750508°, -3.501066°) was located in the southeast of the study area, Sambangan, near TS29 and TS30. Point 4 (114.707546°, -3.379838°) was located at the northern part of the study area, Pematang Panjang, close to TS11 and TS12 while point 5 (114.702434°, -3.417620°) was located in Landasan Ulin Barat near to TS25 and TS26. In order to avoid a misinterpretation of the displacement trend, two SAR scenes on 03 March 2020 and 25 February 2021 were eliminated in the time series displacement since we found the phase jump as the presence of spike noise.

The area of point 3 was the highest subsidence rate in Banjar Regency while point 2 was the second-highest rate. The area of point 2 was mostly covered by wetland vegetation with the land use of cultivated land. Based on the ground investigation, some were former burn areas and the rest has mostly changed to arable land for oil palm plantations. Furthermore, the land use of point 3 was bare land prepared for the expansion of residential housing. We found that this region barely surfaced by peat wetlands. Meanwhile, in the north part which was the location of points 4 and 5, the regions were mainly untouched by anthropogenic activities (e.g. deforestation, urbanization, and land degradation).

3.2 Carbon content from in-situ data

The result of laboratory analysis for soil samples collected in the in-situ surveys is presented in Table 1. 17 samplings have been successfully extracted to measure carbon content in Banjar Regency. The Bulk Density range for peat is generally around 0.02 – 0.3 t/m³ depending on its maturity, density of the peat, and the level of inorganic matter. For all points except TS2 and TS3, the bulk density was more than 0.65 because the peat soil was scarcely found from the collected samples. Moreover, the percent total organic C is still in the range of peat C org content, they are 18-58% if the analysis uses the loss on ignition method.

The carbon content of peatland was calculated from BD and C organic total extracted from soil materials of 17 sample points. The result of carbon content approximately was around 9 - 44 t/m³ distributed in Banjar Regency and Banjarbaru City. Figure 7 shows a clear picture of peat soils found in the in-situ point of TS13. It was located in drained peatland near the region of Landasan Ulin Selatan. Table 1 shows the carbon content of 17 areas sampling about 0.1-0.3 t/m³. Page et al. (2002) suggested an average carbon content volume (Cv) value of peatland is 0.06 t/m³. However, based on observations from hundreds of peat samples from Sumatra and Kalimantan (Agus et al., 2011), the Cv value cannot be the same for each site. The value differences are determined by the level of peat maturity. Cv ranged from 0.082±0.035 t/m³ is classified as sapric, 0.057±0.026 as hemic, and 0.046±0.025 t/m³ as fibric. The homogeneity of Cv values could result in large errors in the estimation of emissions and carbon stocks based on a subsidence value.

Sample Codes	Bulk Density g/cm ³)	C organic total (%)	Carbon Content (t/m ³)	Depth of Peat (cm)
TS1	0.601	52.60	0.316	15
TS2	0.694	54.21	0.376	15
TS3	0.713	55.42	0.395	12
TS4	0.661	50.00	0.331	1
TS5	0.446	54.36	0.243	12
TS6	0.570	54.15	0.309	10
TS11	0.227	46.07	0.104	72
TS12	0.166	49.71	0.082	220
TS13	0.496	53.19	0.264	12
TS15	0.251	53.24	0.133	16
TS16	0.274	51.76	0.142	10
TS17	0.245	52.81	0.129	11
TS18	0.337	54.27	0.183	9
TS25	0.473	47.93	0.227	9
TS26	0.164	49.06	0.008	21
TS29	0.305	52.93	0.161	18
TS30	0.324	53.71	0.174	16

Table 1. Carbon content parameters of peatland extracted by in-situ surveys in Banjar Regency and Banjarbaru City, South Kalimantan, Indonesia.

The relationship between subsidence rate and the depth of peatland can clearly show that the higher the value of subsidence, the thinner the depth of peat soil. Point 4 (TS11 and TS12) presented the northern part of the observed area was a primary forest hence peat soils were abundant proved by the depth of peat soils until 220 cm. On the other hand, the southern part (points 2 and 3) has been involved in human activities that harmed natural resources, especially in peatland areas. Deforestation and land degradation have been occurred in the highest subsidence rate areas where the original primary forest altered to oil palm plantations and development of residential housing. These areas mostly had the depth of peat soil with a range between 1 and 21 cm.

Drainage peatlands (Figure 7) caused by land-use change in need of oil palm cultivation lead to a decrease of the peat depth in time and oxidation for half of the carbon stored in Indonesia. It can be deduced CO₂ emission increase of 6.5 ppm in case of drainage for peat extraction (Siegert and Jaenicke, 2008).

Since the reduction of carbon stocks in peatland is related to subsidence, it influences the sustainability of agricultural business in peatlands. The use of peatlands for agriculture needs to consider sustainability and environmental aspects. For the reason of peatlands used for agriculture, a sustainable peat management system must be applied. Considering the relatively low productivity of peatlands and the important role of peatlands as a buffer for environmental quality, it is necessary to try to minimize the use of peatlands for land development.

3.3 Estimation of CO₂ emission using the available data

Considering a limit number of in-situ measurements, CO₂ emission would be provided by two scenarios; a) point-wise estimation from the available in-situ data and InSAR and b) an interpolation grid of in-situ points using the IDW method overlaid by both the affected peatland area and peat subsidence.

Firstly, Table 2 presents the result of CO₂ emission based on point-wise in-situ data. The drained and burned area is assumed to be equal to the spatial resolution of the InSAR result which is 30 m x 30 m. A significant subsidence rate is considered as the loss of carbon stored in peatland and produced CO₂ emission

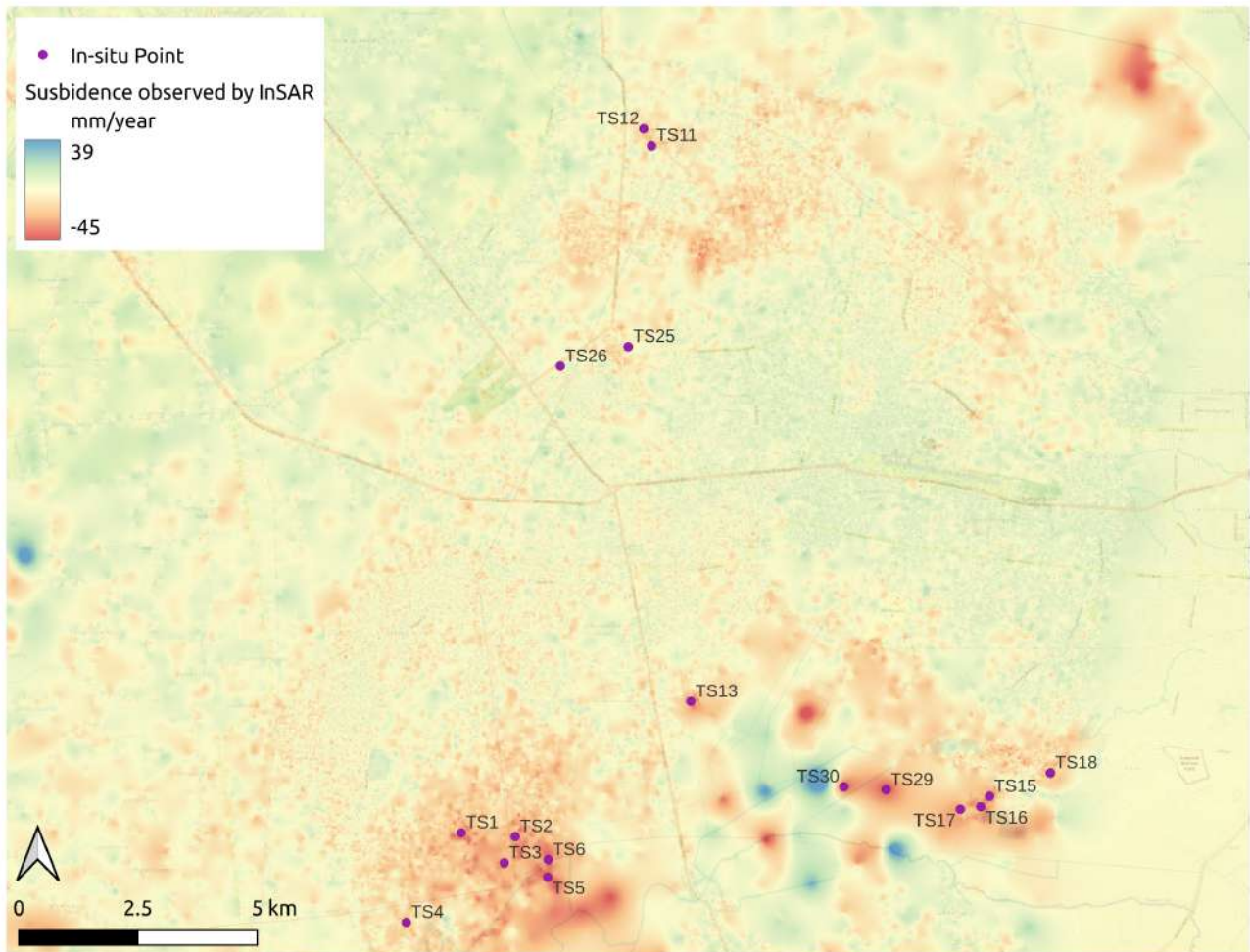


Figure 4. Map of subsidence rate in Banjar Regency and Banjarbaru City, South Kalimantan, Indonesia and its surroundings observed by Sentinel-1 Descending SAR data from 2019 to 2020.

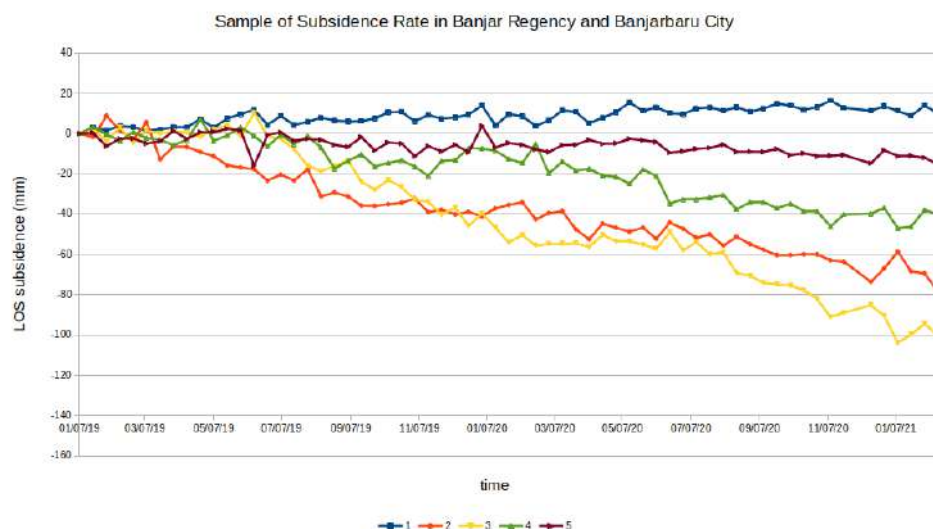


Figure 5. Sample of the time series InSAR results in Banjar Regency and Banjarbaru City, South Kalimantan, Indonesia.

which is calculated by multiplying the subsidence rate by the peat bulk density and carbon content.

For the second scenario, the map was generated by the inter-

polation grid of bulk density and carbon content from in-situ measurement points, then subsidence rate map from InSAR, as well as peatland area data in the study area were obtained from the supervised classification method based on Landsat-8 optical



Figure 6. The field documentation was located at the point of TS5 and TS6. The in situ data was collected along a stream where part of the small peat deposits was visible and the access was relatively easy.



Figure 7. A picture of peat soils found in drainage peatlands, Landasan Ulin Selatan, Banjarbaru City, Indonesia.

remote sensing. Figure 8 shows the value of CO₂ emissions in the range of 0 - 0.364 tC ha⁻¹ yr⁻¹. It also has a large land subsidence rate of -47.34 mm/yr. The southern part of the study area tends to have a higher value of CO₂ emissions than the northern part, as in point 26 there is a peatland area that has the lowest emission of 0.00001 tC ha⁻¹ yr⁻¹. The total area of peatland suffered by land subsidence of 4,636.98 ha is estimated to have a total CO₂ emission of 1.699 tC ha⁻¹ yr⁻¹.

Regarding a complete oxidation process, we computed the percentage of C released as CO₂ of 100%. It means that carbon loss because of peat subsidence fully contributed to carbon dioxide emissions in the study area. Our result found that the highest CO₂ emission from peat oxidation of 0.27 tC ha⁻¹ yr⁻¹ or to be exactly 3.02 CO₂/year/0.09 ha located in the southwest study area, namely Kecamatan Liang Anggang, Banjarbaru City near TS 3 and 6.

Estimation of carbon emissions based on subsidence according to Wösten et al. (1997), assuming no fires occur, contributes to 60% of subsidence value while compaction is 40%. In contrast, Couwenberg et al. (2010) reported that the peat decomposition

Sample Codes	Area (ha)	Peat subsidence rate (mm/yr)	P (%)	CO ₂ ems (t C ha ⁻¹ yr ⁻¹)
TS1	0.09	-30.99	100	0.19
TS2	0.09	-27.11	100	0.23
TS3	0.09	-29.19	100	0.27
TS4	0.09	-22.37	100	0.16
TS5	0.09	-41.85	100	0.15
TS6	0.09	-42.35	100	0.25
TS11	0.09	-11.14	100	0.01
TS12	0.09	-13.34	100	0.01
TS13	0.09	-25.07	100	0.11
TS15	0.09	-26.15	100	0.03
TS16	0.09	-21.6	100	0.03
TS17	0.09	-35.06	100	0.04
TS18	0.09	-26.8	100	0.05
TS25	0.09	1.02	100	0
TS26	0.09	-6.066	100	0
TS29	0.09	-45.98	100	0.07
TS30	0.09	-47.32	100	0.09

Table 2. Estimation of CO₂ emissions (ems) based on point-wise in-situ data in Banjar Regency and Banjarbaru City, South Kalimantan

process resulted in 40% in subsidence value. For example, in TS1, the subsidence rate is 30.99 mm/y, which means 12.39 mm contributed from peatland decomposition and the rest 18.6 mm made by consolidation.

Various factors affect the rate of peat decomposition, which affects the rate of emission too. Emission rates can be different depending on peat maturity classified based on the stage of decomposition, fertilization, and the influence of plant root respiration. The highest peat maturity classified as sapric, based on a percent of organic matter value, is located on TS 11, 12, 25, and 26. The rate decomposition of organic matter in that sites is mostly humified with the C organic of 48.90 (Agus et al., 2011). It made the subsidence rate and the emission rate is lower too than the others, especially in TS 25, 26 the emission rate of 0.4 and 0.29 t.C/ ha/year, respectively.

4. CONCLUSION

We performed a process of space-borne InSAR method to determine the area of subsidence in the peatland regions of South Kalimantan, Indonesia. A campaign of in-situ surveys was done in purpose to get the information of carbon storage in the chosen sample areas. The observation of SAR interferometry and in-situ data can be used to estimate CO₂ emission implementing the association between the area of peatland that was drained or burned, peat subsidence rate, the peat bulk density, and carbon content.

Further development of our research would be a mapping of CO₂ emission regionally in Banjar Regency, Banjarbaru City, and other areas in South Kalimantan. Moreover, we would like to increase in-situ measurements regularly and add monitoring of water table depths as a validation of the subsidence rate derived by radar remote sensing data.

ACKNOWLEDGEMENTS

The authors would like to thank the Japan-ASEAN Science, Technology and Innovation Platform (JASTIP) with the program of JASTIP-NET 2021: Partnership and Networking

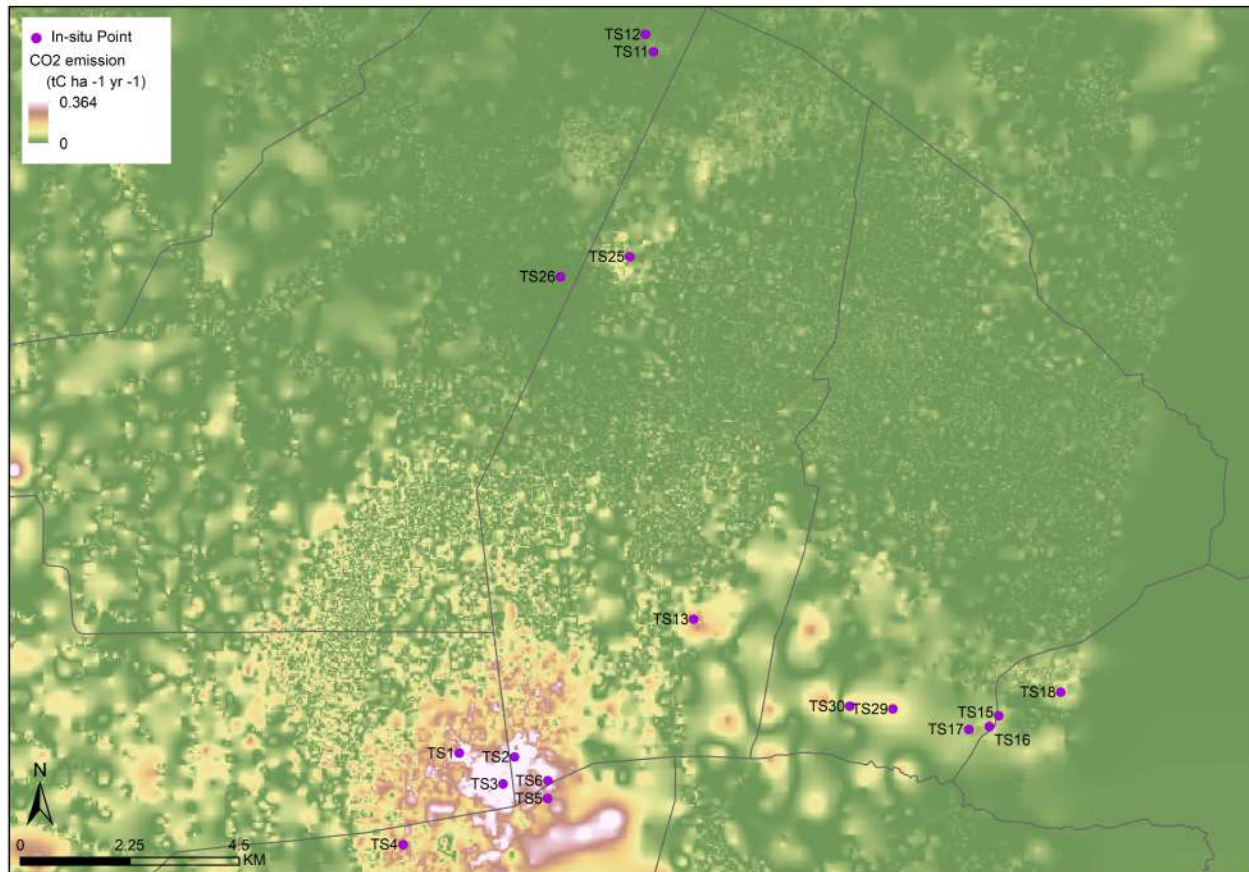


Figure 8. A map of CO₂ emission in Banjar Regency and Banjarbaru City, South Kalimantan, Indonesia estimated by the in-situ measurement and satellite remote sensing.

(WP1) for supporting the research of peatland in South Kalimantan. We gratefully acknowledge Copernicus Open Access Hub for the free products of Sentinel-1 SAR data and the Global Land Cover Facility (GLCF) for providing DEM SRTM.

References

- Agus, F., 2009. Panduan metode pengukuran karbon tersimpan di lahan gambut. *Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian, Bogor and World Agroforestry Centre, SEA, Bogor, Indonesia*.
- Agus, F., Hairiah, K., Mulyani, A., 2011. *Pengukuran cadangan karbon tanah gambut*. World Agroforestry Centre (ICRAF).
- Aopaet, A., Cuenca, M. C., Hooper, A., Trisirisatayawong, I., 2013. InSAR time-series analysis of land subsidence in Bangkok, Thailand. *International Journal of Remote Sensing*, 34(8), 2969-2982. <https://doi.org/10.1080/01431161.2012.756596>.
- Bappeda, 2013. *Rencana Tata Ruang Wilayah Tahun 2013-2032*. Pemerintah Kabupaten Banjar.
- Berardino, P., Fornaro, G., Lanari, R., Sansosti, E., 2002. A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms. *IEEE Transactions on Geoscience and Remote Sensing*, 40(11), 2375-2383.
- Couwenberg, J., Dommain, R., Joosten, H., 2010. Greenhouse gas fluxes from tropical peatlands in south-east Asia. *Global Change Biology*, 16(6), 1715-1732. <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2486.2009.02016.x>.
- Crosetto, M., Monserrat, O., Cuevas-González, M., Devanthery, N., Crippa, B., 2016. Persistent Scatterer Interferometry: A review. *ISPRS Journal of Photogrammetry and Remote Sensing*, 115, 78 - 89. <http://www.sciencedirect.com/science/article/pii/S0924271615002415>. Theme issue 'State-of-the-art in photogrammetry, remote sensing and spatial information science'.
- Dahdal, B., 2011. *The use of interferometric spaceborne radar and GIS to measure ground subsidence in peat soils in Indonesia*. University of Leicester.
- Dradjat, M. S., Hidayat, M., Mulyono, 1986. Subsidence of peat soils the tidal swamplands of barambai, south kalimantan. *Symposium on Lowland Development in Indonesia*, International Institute for Land Reclamation and Improvement, Wageningen.
- Fattahi, H., Amelung, F., 2013. DEM Error Correction in InSAR Time Series. *IEEE Transactions on Geoscience and Remote Sensing*, 51(7), 4249-4259.
- Hanssen, R., 2001. *Radar Interferometry: Data Interpretation and Error Analysis*. Remote Sensing and Digital Image Processing, Springer Netherlands.

- Hooijer, A., Page, S., Canadell, J., Silvius, M., Kwadijk, J., Wösten, H., Jauhiainen, J., 2010. Current and future CO₂ emissions from drained peatlands in Southeast Asia. *Biogeosciences*, 7(5), 1505–1514.
- Hooijer, Page, S., Jauhiainen, J., Lee, Lu, X. X., Idris, Anshari, G., 2012. Subsidence and carbon loss in drained tropical peatlands. *Biogeosciences*, 9.
- Hooper, A., 2008. A multi-temporal InSAR method incorporating both persistent scatterer and small baseline approaches. *Geophysical Research Letters*, 35(16), n/a–n/a. <http://dx.doi.org/10.1029/2008GL034654>. L16302.
- Hooper, A., Zebker, H. A., 2007. Phase unwrapping in three dimensions with application to InSAR time series. *J. Opt. Soc. Am. A*, 24(9), 2737–2747. <http://josaa.osa.org/abstract.cfm?URI=josaa-24-9-2737>.
- Hooper, A., Zebker, H., Segall, P., Kampes, B., 2004. A new method for measuring deformation on volcanoes and other natural terrains using InSAR persistent scatterers. *Geophysical Research Letters*, 31(23). <https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2004GL021737>.
- Hoyt, A. M., Chaussard, E., Seppäläinen, S. S., Harvey, C. F., 2020. Widespread subsidence and carbon emissions across Southeast Asian peatlands. *Nature Geoscience*, 13(6), 435–440. <https://doi.org/10.1038/s41561-020-0575-4>.
- IPCC, 2006. 2006 IPCC guidelines for national greenhouse gas inventories. *Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan*.
- Khakim, M. Y. N., Bama, A. A., Yustian, I., Poerwono, P., Tsuji, T., Matsuoka, T., 2020. Peatland subsidence and vegetation cover degradation as impacts of the 2015 El Niño event revealed by Sentinel-1A SAR data. *International Journal of Applied Earth Observation and Geoinformation*, 84, 101953. <https://www.sciencedirect.com/science/article/pii/S0303243419300571>.
- Nusantara, R. W., Hazriani, R., Suryadi, U. E., 2018. Water-table Depth and Peat Subsidence Due to Land-use Change of Peatlands. *IOP Conference Series: Earth and Environmental Science*, 145, 012090. <https://doi.org/10.1088/1755-1315/145/1/012090>.
- Page, S. E., Siegert, F., Rieley, J. O., Boehm, H.-D. V., Jaya, A., Limin, S., 2002. The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature*, 420(6911), 61–65. <https://doi.org/10.1038/nature01131>.
- Rina, Y., Noorinayuwati, B., 2007. Persepsi Petani Tentang Lahan Gambut Dan Pengelolaannya. *Repositori Publikasi Kementerian Pertanian Republik Indonesia*.
- Schmidt, D. A., Buergermann, R., 2003. Time-dependent land uplift and subsidence in the Santa Clara valley, California, from a large interferometric synthetic aperture radar data set. *Journal of Geophysical Research: Solid Earth*, 108(B9), n/a–n/a. <http://dx.doi.org/10.1029/2002JB002267>. 2416.
- Siegert, F., Jaenicke, J., 2008. Estimation of carbon storage in Indonesian peatlands. *Dalam Rieley*, 10, 15–19.
- Umarhadi, D. A., Widyatmanti, W., Kumar, P., Yunus, A. P., Khedher, K. M., Kharrazi, A., Avtar, R., 2022. Tropical peat subsidence rates are related to decadal LULC changes: Insights from InSAR analysis. *Science of The Total Environment*, 816, 151561. <https://www.sciencedirect.com/science/article/pii/S0048969721066390>.
- Wahyunto, B., Bekti, H., Widiastuti, F., 2000. Maps of Peatland Distribution. *Area, and Carbon Content in Papua*, 2001.
- Widyati, E., 2011. Kajian optimasi pengelolaan lahan gambut dan isu perubahan iklim. *Tekno Hutan Tanaman*, 4(2), 57–68.
- Wösten, J., Ritzema, H., 2001. Land and water management options for peatland development in Sarawak, Malaysia. *International Peat Journal*, 59–66.
- Wösten, J., Ismail, A., van Wijk, A., 1997. Peat subsidence and its practical implications: a case study in Malaysia. *Geoderma*, 78(1), 25–36. <https://www.sciencedirect.com/science/article/pii/S001670619700013X>.
- Zebker, H. A., P. A. R. R. M. G. A. G., Werner, C. L., 1994. On the Derivation of Coseismic Displacement-fields using Differential Radar Interferometry - the Landers Earthquake. *Journal of Geophysical Research*, 99(B10), 617–634.
- Zhou, Z., Li, Z., Waldron, S., Tanaka, A., 2016. Monitoring peat subsidence and carbon emission in indonesia peatlands using insar time series. 6797–6798.

© 2022. This work is published under <https://creativecommons.org/licenses/by/4.0/>(the “License”). Notwithstanding the ProQuest Terms and Conditions, you may use this content in accordance with the terms of the License.

XXIV ISPRS Congress Oral Presentation

XXIV ISPRS Congress <isprs@conftool.com>

Fri, Apr 29, 2022 at 5:58 PM

Reply-To: papers@isprs2020-nice.com

To: noorlaila@geodesy.its.ac.id

Cc: noorkomala.sari@ulm.ac.id, rahmat.arief@lapan.go.id, dzaniadzaniyal@gmail.com

Dear Noorlaila Hayati,

You were recently notified about being awarded a poster presentation at the XXIV ISPRS Congress. In addition to a poster presentation, **your contribution was awarded an oral presentation**. Congratulations!

The program will be released shortly. The presenting author will soon receive a personalized link giving them access to their speaker's account, where they will find all information about the poster presentation (day/time/poster session).

Each live presenter should **prepare a 10 min oral presentation** and expect 3 min of questions. Please respect this schedule; if not, the session chair will cut you off.

All presenters (live or remote) must upload a 10 min pre-recorded presentation on the digital congress platform in their speaker account. All oral pre-recorded presentations will be available on the XXIV ISPRS congress digital platform/web TV during and after the event. If you do not upload your oral pre-recorded presentation, your talk will not be available online on the platform or the ISPRS media library!

Live presenters: Questions will only come from participants physically in your session room (there will be no interaction between the room and the remote participants).

Remote presenters: Your pre-recorded presentation will be seamlessly broadcast in the session room during your scheduled presentation. Please note that there will be no questions after your prerecorded presentation.

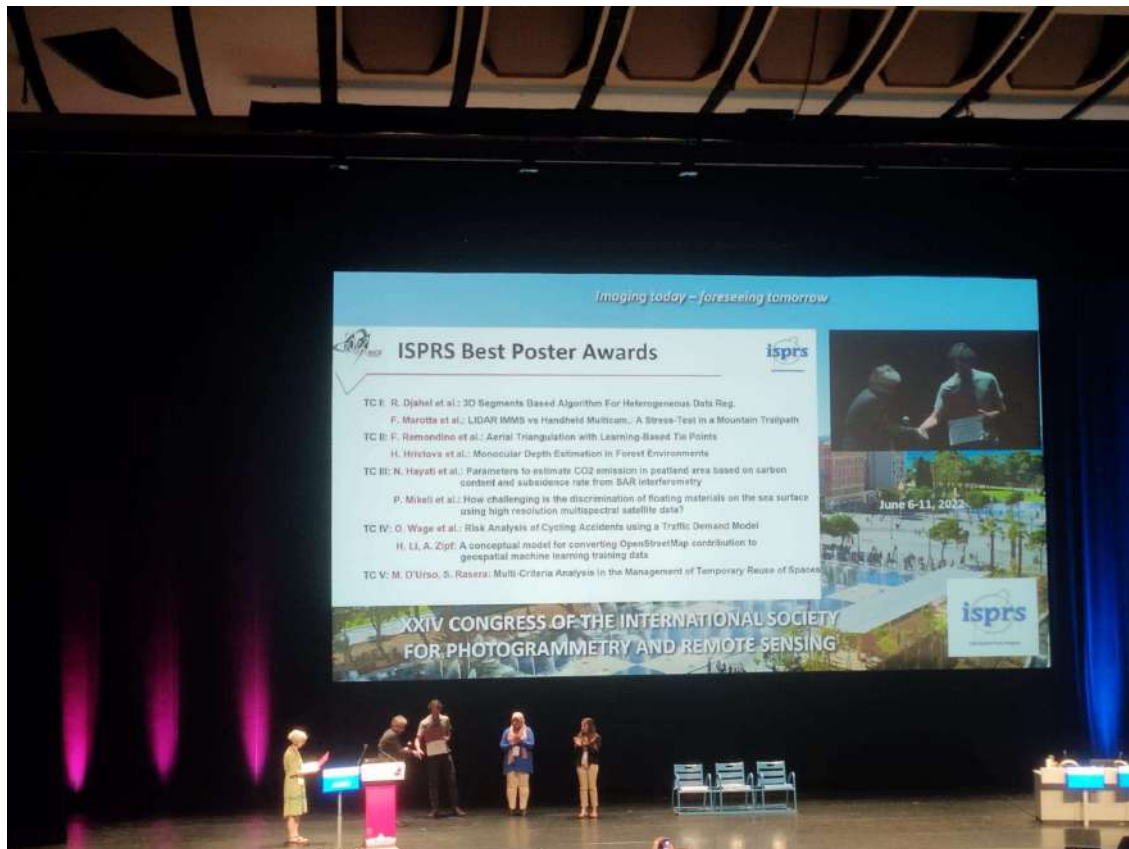
Best regards,
Program Chairs

--

XXIV ISPRS Congress

Submission/registration website: <https://conftool.com/isprs-congress/>

General website: <http://www.isprs2022-nice.com/>



Imaging today – foreseeing tomorrow



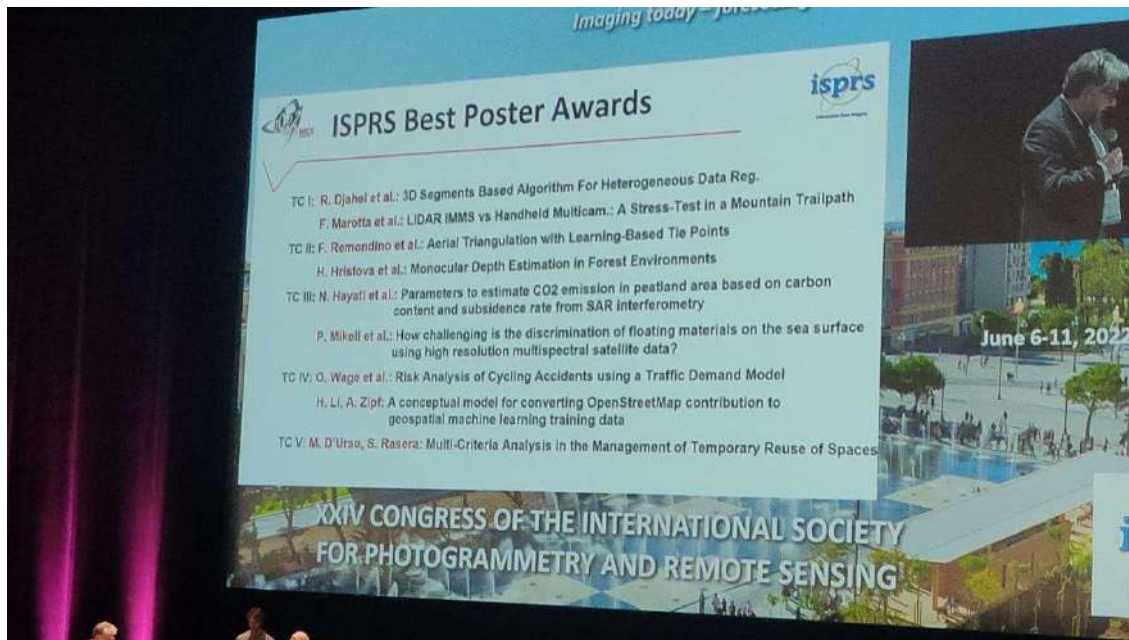
ISPRS Best Poster Awards



- TC I: R. Djahel et al.: 3D Segments Based Algorithm For Heterogeneous Data Reg.
F. Marotta et al.: LIDAR IMMS vs Handheld Multicam.: A Stress-Test in a Mountain Trailpath
- TC II: F. Remondino et al.: Aerial Triangulation with Learning-Based Tie Points
H. Hristova et al.: Monocular Depth Estimation in Forest Environments
- TC III: N. Hayati et al.: Parameters to estimate CO2 emission in peatland area based on carbon content and subsidence rate from SAR Interferometry
P. Mikellì et al.: How challenging is the discrimination of floating materials on the sea surface using high resolution multispectral satellite data?
- TC IV: O. Wage et al.: Risk Analysis of Cycling Accidents using a Traffic Demand Model
H. Li, A. Zipf: A conceptual model for converting OpenStreetMap contribution to geospatial machine learning training data
- TC V: M. D'Urso, S. Rasera: Multi-Criteria Analysis in the Management of Temporary Reuse of Spaces

**XXIV CONGRESS OF THE INTERNATIONAL SOCIETY
FOR PHOTOGRAMMETRY AND REMOTE SENSING**





Imaging today – foreseeing tomorrow



ISPRS Best Poster Awards



- TC I: R. Djahel et al.: 3D Segments Based Algorithm For Heterogeneous Data Reg.
F. Marotta et al.: LIDAR IMMS vs Handheld Multicam.: A Stress-Test in a Mountain Trailpath
- TC II: F. Remondino et al.: Aerial Triangulation with Learning-Based Tie Points
H. Hristova et al.: Monocular Depth Estimation in Forest Environments
- TC III: N. Hayati et al.: Parameters to estimate CO2 emission in peatland area based on carbon content and subsidence rate from SAR Interferometry
P. Mikellì et al.: How challenging is the discrimination of floating materials on the sea surface using high resolution multispectral satellite data?
- TC IV: O. Wage et al.: Risk Analysis of Cycling Accidents using a Traffic Demand Model
H. Li, A. Zipf: A conceptual model for converting OpenStreetMap contribution to geospatial machine learning training data
- TC V: M. D'Urso, S. Rasera: Multi-Criteria Analysis in the Management of Temporary Reuse of Spaces

**XXIV CONGRESS OF THE INTERNATIONAL SOCIETY
FOR PHOTOGRAMMETRY AND REMOTE SENSING**





Imaging today – foreseeing tomorrow

ISPRS Best Poster Award

- TC I: R. Djahel et al.: 3D Segments Based Algorithm For Heterogeneous Data Reg.
F. Marotta et al.: LIDAR IMMS vs Handheld Multicam.: A Stress-Test in a Mountain Trailpath
- TC II: F. Remondino et al.: Aerial Triangulation with Learning-Based Tie Points
H. Hristova et al.: Monocular Depth Estimation in Forest Environments
- TC III: **N. Hayati et al.: Parameters to estimate CO2 emission in peatland area based on carbon content and subsidence rate from SAR Interferometry**
P. Mikellì et al.: How challenging is the discrimination of floating materials on the sea surface using high resolution multispectral satellite data?
- TC IV: O. Wage et al.: Risk Analysis of Cycling Accidents using a Traffic Demand Model
H. Li, A. Zipf: A conceptual model for converting OpenStreetMap contribution to geospatial machine learning training data
- TC V: M. D'Urso, S. Rasera: Multi-Criteria Analysis in the Management of Temporary Reuse of Spaces

XXIV CONGRESS OF THE INTERNATIONAL SOCIETY FOR PHOTOGRAMMETRY AND REMOTE SENSING