Deltares
Enabling Delta Life

Exploration of efficient and cost-effective use of LiDAR data in lowland/peatland landscape mapping and management in Indonesia

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Contact:
aljosja.hooijer@deltares.nl
ronald.vernimmen@deltares.nl

Topics

- **Summary**
- **Method for creating elevation models from ‘strip’ LiDAR data (not full coverage)**
- **Creating peat thickness models from elevation models**
- **Limitations of peat thickness mapping using elevation models**
- **Other applications of LiDAR data in support of improved peatland management**
  - **Flood risk**
  - **Historical subsidence**
  - **Forest canopy height and degradation**
  - **Water levels in canals**
- **Annex: Deltares project record**

NOTE:

- ***This document is in Powerpoint format because of the large number of graphics included, however it is not meant to be a presentation.***
- ***This document will be updated by May 2016 as new results become available.***

SUMMARY 1 – background

Peat consists of 90% water and 10% organic material that is mostly carbon. After drainage, peat will decompose, and often burn, causing carbon emissions to the atmosphere, as well as land subsidence that results in flooding. Peatlands are therefore not really ‘land’ in the normal sense, but should be managed as wetlands with high water levels and limited disturbance to keep the carbon stored and the surface above flood levels. This lesson has been ignored in many countries through history, often leading to flooding and land abandonment. At present, the problem is most urgent in SE Asia where 20-25 million hectares of peatland are largely deforested, drained and increasingly burning, and serious questions may be asked about the future sustainability of this approach to peatland management. See these studies for examples:

http://www.biogeosciences.net/7/1505/2010/bg-7-1505-2010.pdf

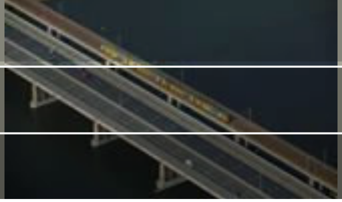
http://www.biogeosciences.net/9/1053/2012/bg-9-1053-2012.pdf

https://www.deltares.nl/en/projects/flooding-projections-for-oil-palm-plantations-in-the-rajang-delta-peatlands-sarawak-malaysia/

https://www.deltares.nl/en/projects/impact-assessments-for-pulp-and-oil-palm-plantations-in-the-kampar-peninsula-peatlands-riau-indonesia/

Better data is needed for better management. Elevation models can be used to produce peat thickness maps as well as flood risk models. Such maps are needed to determine what activities are possible on peatland, as deep peat is known to be unsuitable for many uses. With better maps, better spatial planning and zoning is possible that minimizes carbon emissions, fire risk and flood risk.

SUMMARY 2 – Deltares activities



Deltares, with partners in several projects (see ANNEX), is pioneering the use of rapid, large-scale and cost-effective LiDAR data collection in coastal lowlands, for spatial planning, management of peatlands and modelling of flood risks.

We are applying new methods in Indonesia that reduce LiDAR cost by almost tenfold (by not flying full coverage) while still yielding elevation models that are accurate enough (90% within 0.5 m) for the purpose of landscape scale assessments of flood risk, peat thickness and related parameters. Peat thickness mapping applying this data is most accurate in peat landscapes where peat thickness is over 3 metres; however for the lowest lying areas with shallow peat other ground-based methods will be required for peat mapping.

All method descriptions, data and full accuracy assessments for elevation models and peat thickness will be provided in the public domain upon request, to groups doing relevant research on these topics in SE Asia.

Apart from information on surface elevation, landscape morphology and peat thickness as determined from surface elevation models, LiDAR data may also be used for measuring and monitoring flood risk, subsidence rates, degradation/growth conditions in forest and plantations, and water levels in canals. Methods are being explored to apply these methods at the large scale, especially in areas where ground access is prohibitive for field monitoring.

New projects are now started that aim to further increase coverage of LiDAR data over coastal zones in Indonesia.

New approach to cover large areas at reduced cost

Airborne LiDAR or Laser Altimetry is the most accurate and fastest method for establishing land surface elevation models, especially in vegetated and built-up areas where other methods such as satellite radar are not suitable. It is widely applied globally. However it is a costly technique, certainly when applied to the hundreds of millions of hectares of lowland that urgently require such data globally.

To be able to cover large areas at greatly reduced cost, we have developed an approach that does not require data to be collected full coverage but yield good results with coverage of approximately 10-15% of the area of interest (as explained in *Figure 3*), reducing cost up to tenfold. A further benefit of this approach is that the time it costs to collect and process data is greatly reduced, which is important in urgent applications, or in regions where conditions suitable for airborne LiDAR data collection occur only during a limited period of the year.

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Development and application in Indonesia

We have tested and applied this new approach to using airborne LiDAR in Indonesia, which has over 30 Million hectares of coastal lowland for which no accurate elevation models exist at present (2016). Elevation models derived from SRTM (Shuttle Radar Topography Mission) data are still often used, but this has an associated error of several (sometimes many) metres, especially in vegetated areas, which makes it unsuitable for most applications in lowlands that are only a few metres above Sea level.

Indonesia's coastal lowlands suffer from several problems that urgently require accurate elevation models. This includes flooding by rivers, heavy rainfall and sometimes the Sea (i.e. tsunamis), which is getting worse as the land subsides after clearing and drainage. But also major forest loss, fires and carbon emissions in peatlands that make up 15 to 20 Mha of land, i.e. about half of all lowland, along the coastlines of Sumatra, Kalimantan and Papua.

Deltares and partners have produced LiDAR based elevation and peat thickness models in several projects in Kalimantan and Sumatra starting in 2007, for increasingly large areas and with increasing accuracy (*Figure 1*).

The most recent and largest LiDAR based elevation model produced by Deltares (for APP) will be presented here; it covers much of East Sumatra (with part of West Kalimantan to be added) and aims to support improved management of peat and water in *Acacia* plantations and the peat landscapes in which they are situated. See here for project description:

https://www.deltares.nl/en/projects/reducing-impact-plantation-operations-peatlands-indonesia-2/

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Development and application in Indonesia

FIGURE 1 Overview map of all LiDAR data applied by Deltares in projects in Sumatra and Borneo (Indonesia and Brunei). Maximum peat extent in Indonesia is determined as in Figure 2.

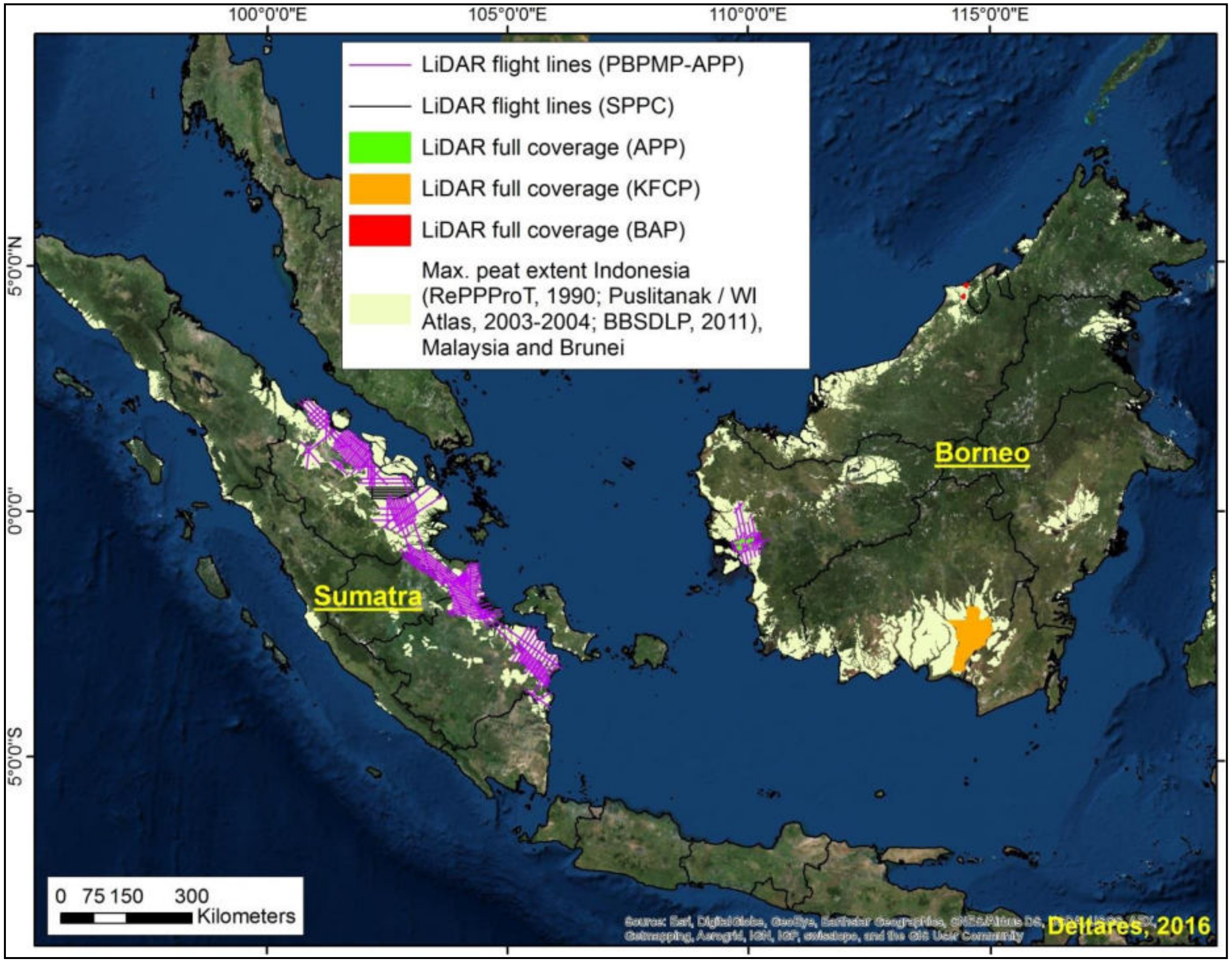
Projects using LiDAR are:

► 2010-14: KFCP; Central Kalimantan; Ausaid funded.

► 2013-15: SPPC; SE Asia; with WI and UGM; NORAD funded.

► 2014-15: BAP; Brunei; with WI; Shell funded.

► 2014-15: PBPMP; Indonesia; APP funded.



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Determining the peat extent to be mapped

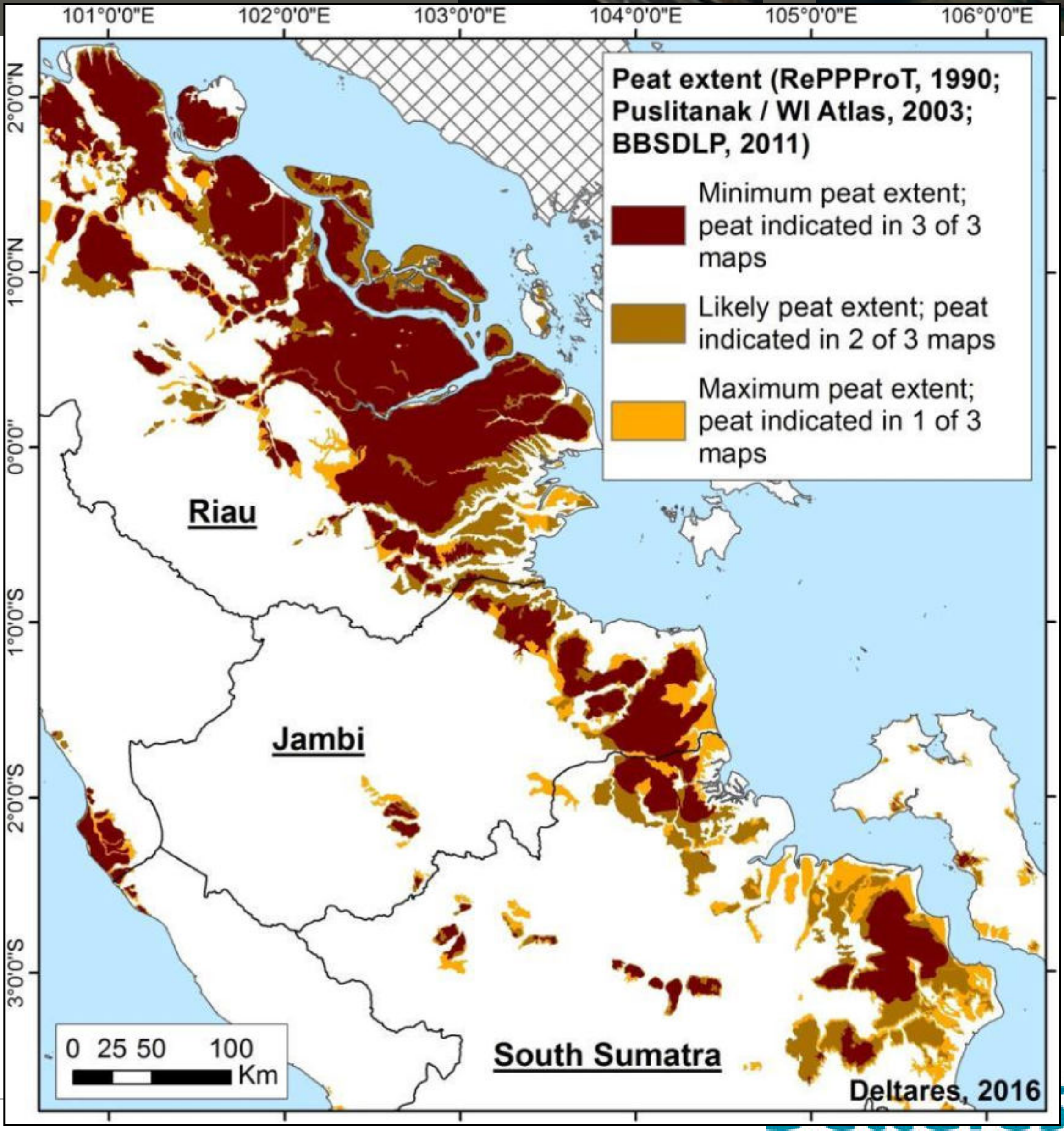
The LiDAR based approach can be used to determine the extent of areas of deep 'dome shaped' peat from elevation models, from the shape of the landscape or from estimated peat thickness. In Indonesia, we find it to be usually suitable for mapping peat that is over 3 or possibly 2 metres in depth. However it is less suitable for mapping the full extent of peatland because there are areas of shallow peat that can not be distinguished from LiDAR images. We therefore do not map the full peat extent using LiDAR data.

To plan the area over which airborne LiDAR data should be collected for mapping of peat landscapes, we first determine minimum, likely and maximum peat extent from three existing maps (*Figure 2*).

Determining the peat extent to be mapped

FIGURE 2 Minimum, likely and maximum peat extent in East Sumatra (Riau + Jambi + South Sumatra) as determined from three existing maps (RePPProT 1990; Puslitanak / Wetlands International Peat Atlas 2003/04; BBSDLP 2011).

Note that while the maximum peat extent map overreports in some areas, it underreports in other areas that have so far never been mapped as being peat, by any source. Both overreported and underreported areas may be identified visually from Landsat images or other satellite sources.



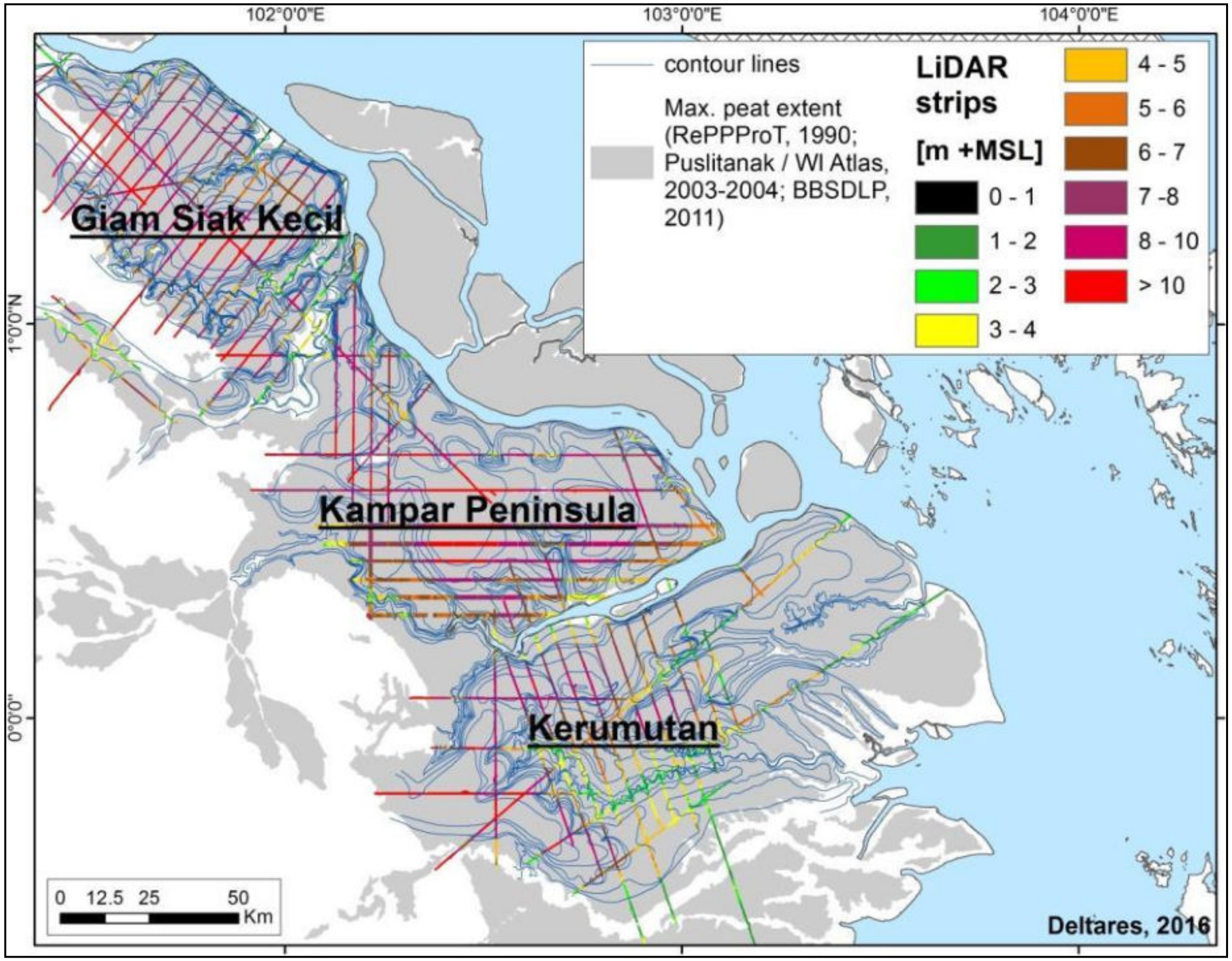
Method for creating a surface elevation model from LiDAR strip data

Over the period of April to May 2015, LiDAR data were collected covering the coastal peatlands of East Sumatra along a total of ~9,600 km of flight lines at 5 to 10 km intervals (*Figure 1; Figure 3*). The LiDAR data were referenced to Mean Sea Level (MSL) through linking the LiDAR data to 6 national second order vertical control benchmarks distributed throughout the survey area; referencing was verified against actual Sea levels as occurring in the LiDAR data. Vegetation signal was filtered out, yielding ‘strips’ of LiDAR data points representing surface elevation only; contour lines at 1 m intervals were manually drawn between ‘data strips’ of 500 m wide (*Figure 3*), aided visually with Landsat composite images in the background to take into account location of rivers and general landscape morphology (*Figure 7*), to improve accuracy of the resulting surface elevation model that was created through inverse distance interpolation between strip data and contour lines (*Figure 4; Figure 5; Figure 6*).

Method for creating a surface elevation model

FIGURE 3 LiDAR STRIPS and manual contour lines for the major peat landscapes along the Riau coastline (Giam Siak Kecil, Kampar Peninsula and Kerumutan).

Contour lines are drawn manually by geographers, interpreting landscape patterns from the position of coastline, rivers and other morphological features. Maximum peat extent is determined as in Figure 2.



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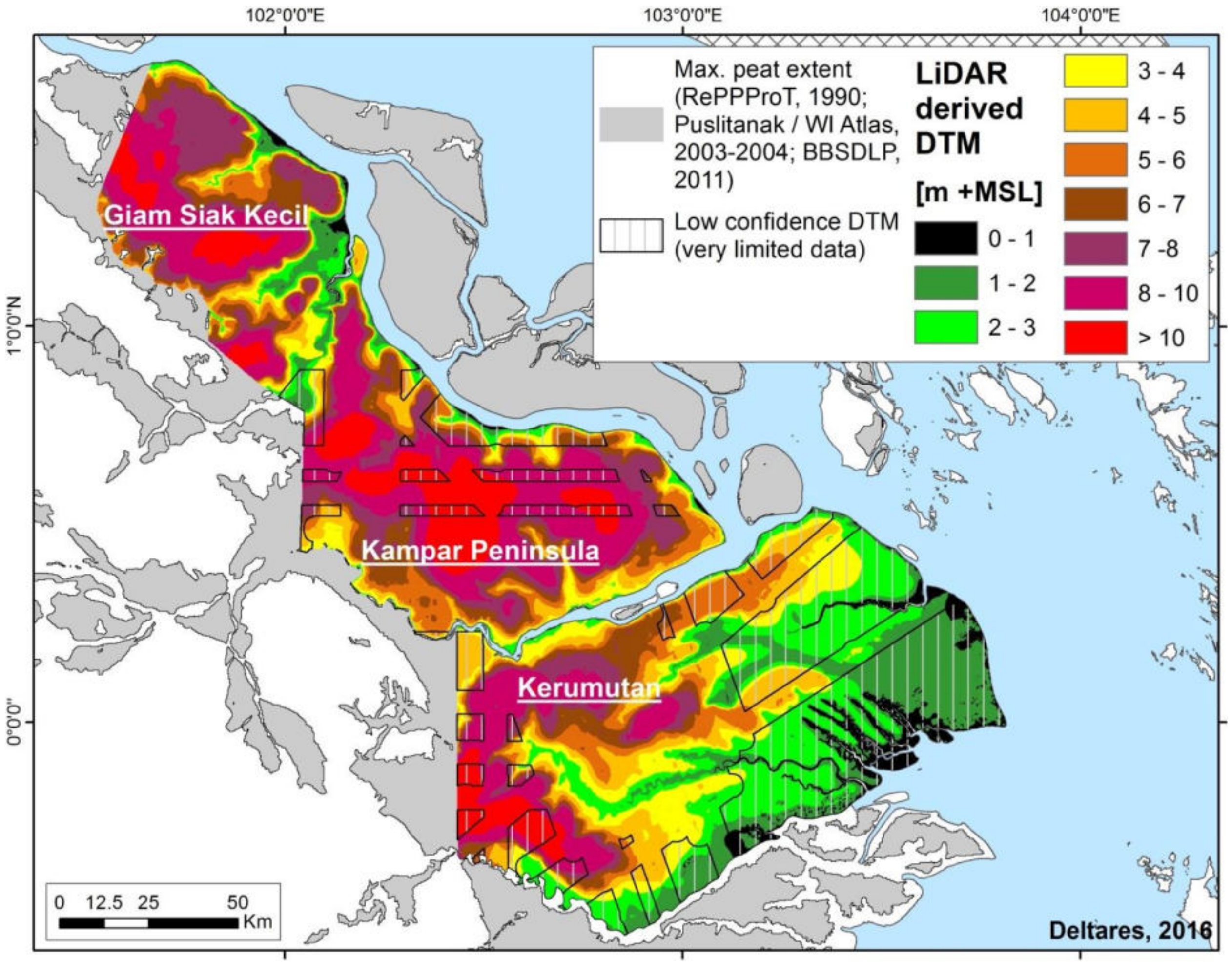
Method for creating a surface elevation model

FIGURE 4 LiDAR based surface elevation model for the major peat landscapes along the Riau coastline (Giam Siak Kecil, Kampar Peninsula and Kerumutan).

Maximum peat extent is determined as in Figure 2.



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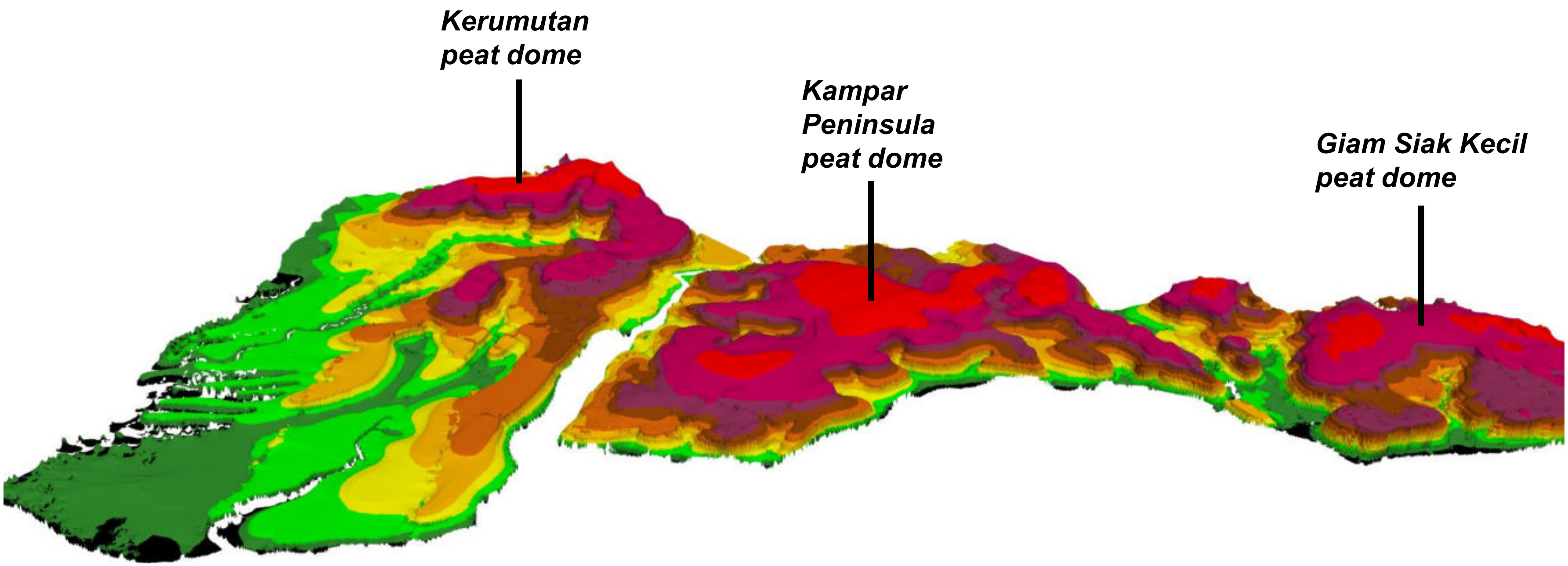
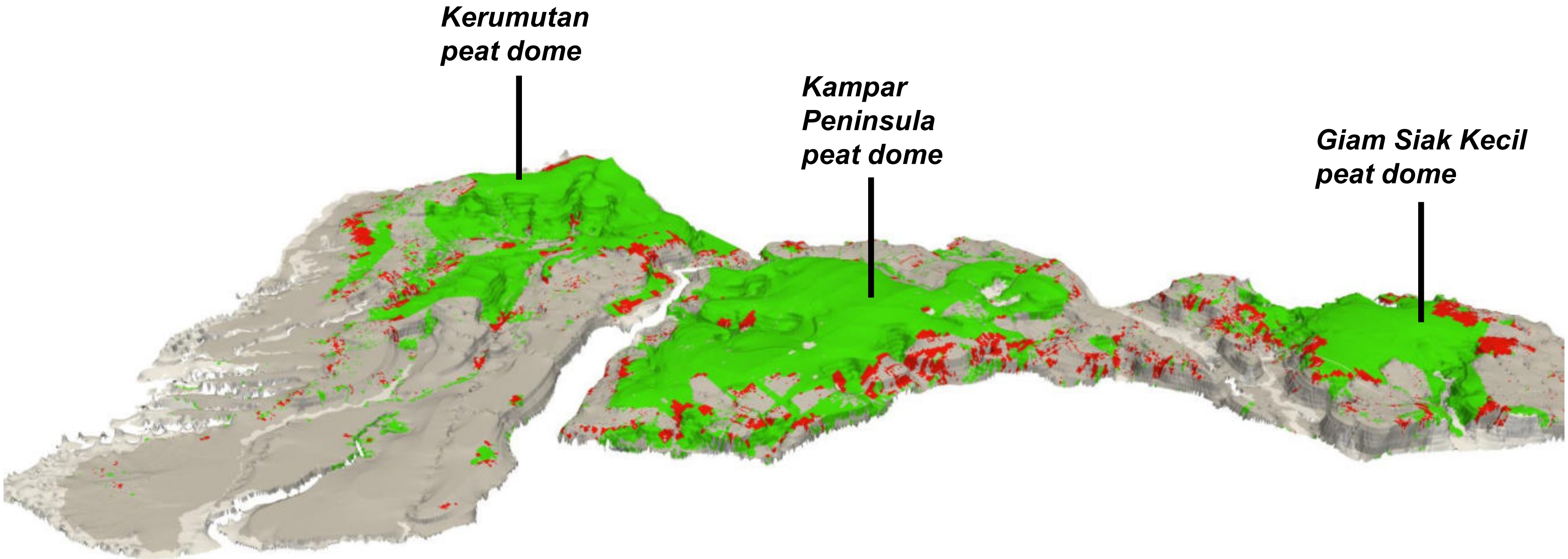
Method for creating a surface elevation model

FIGURE 5a 3D version of the Kerumutan, Kampar Peninsula and Giam Siak Kecil peat landscapes along the Riau coastline. See Figure 4 for legend.



Method for creating a surface elevation model

FIGURE 5b 3D version of the Kerumutan, Kampar Peninsula and Giam Siak Kecil peat landscapes (GREY*) showing how remaining peat swamp forest (GREEN**) is still occupying substantial areas on top of the peat domes, but is affected by fire (RED).***



****Likely peat extent as determined from 3 existing sources; see Figure 2***

*****Forest in 2012, as mapped by Margono et al. (2014)#***

******Forest that was burnt or partly burnt since 2012, as indicated by MODIS hotspots***

#Margono BA, Potapov P, Turubanova S, Stolle F, Hansen M, 2014. Primary forest cover loss in Indonesia over 2000-2012. Nature Climate Change, http://dx.doi.org/10.1038/nclimate2277

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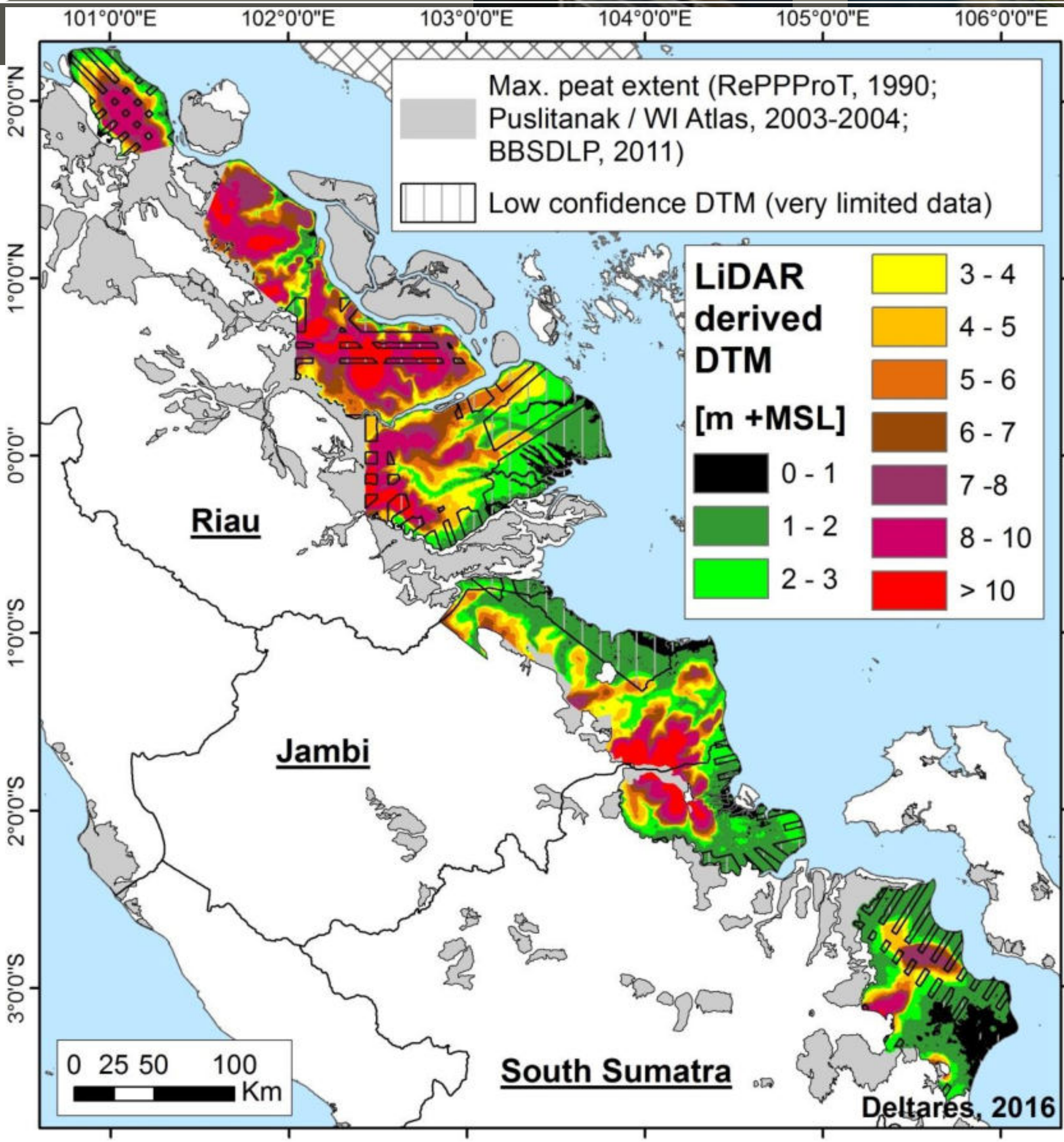
Method for creating a surface elevation model

FIGURE 6 LiDAR based surface elevation model for East Sumatra (Riau + Jambi + South Sumatra).

Maximum peat extent is determined as in Figure 2.



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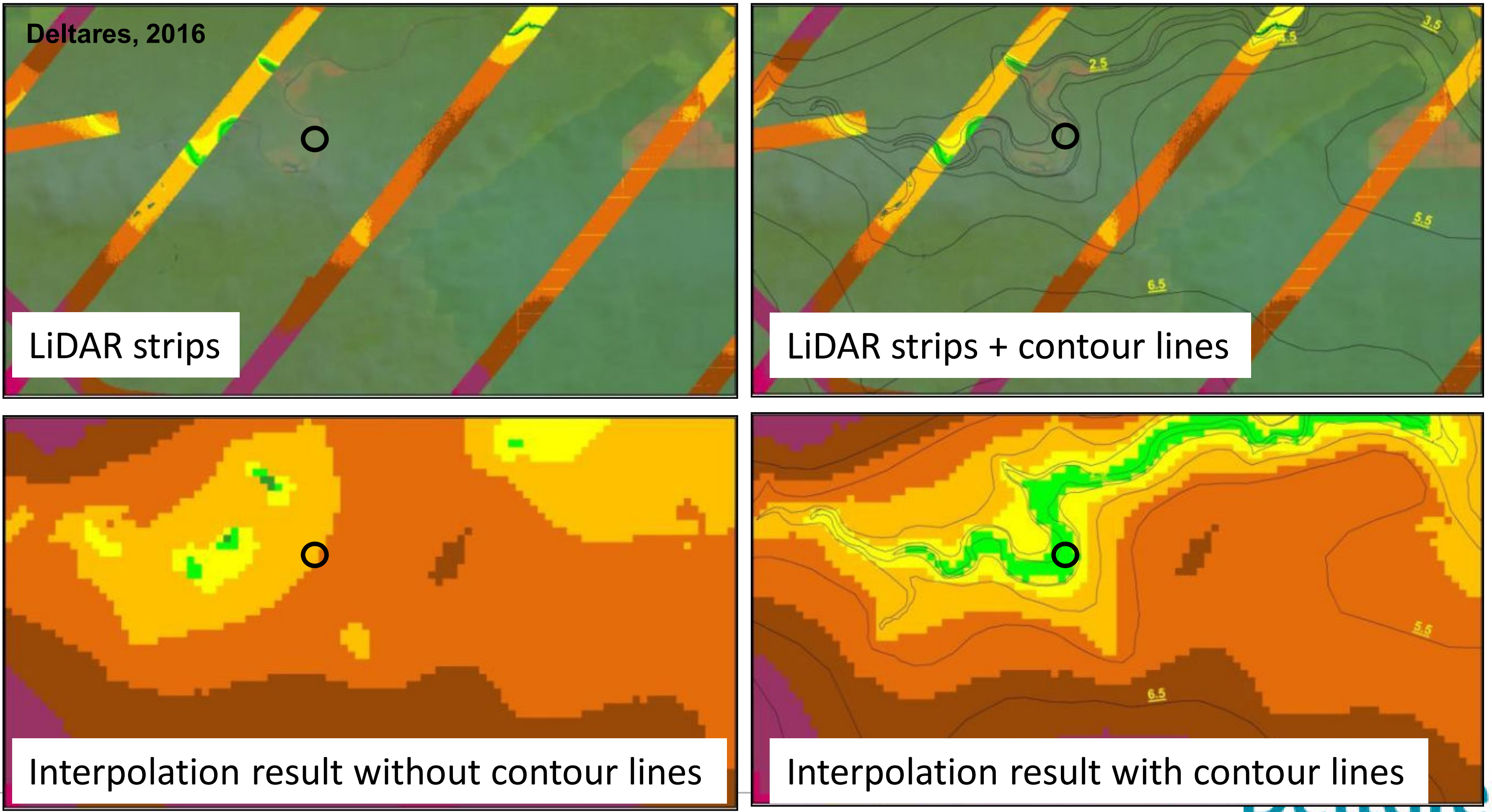
Method for creating a surface elevation model

FIGURE 7 Example of the effect of manually adding contour lines before interpolating LiDAR elevation information, as compared to the result without contour lines. The top figures show a Landsat image in the background.



Accuracy of surface elevation model

The map with accuracy ranges is shown in *Figure 8*.

Where LiDAR data are available, the vertical accuracy of the surface elevation model is within 0.25 m.

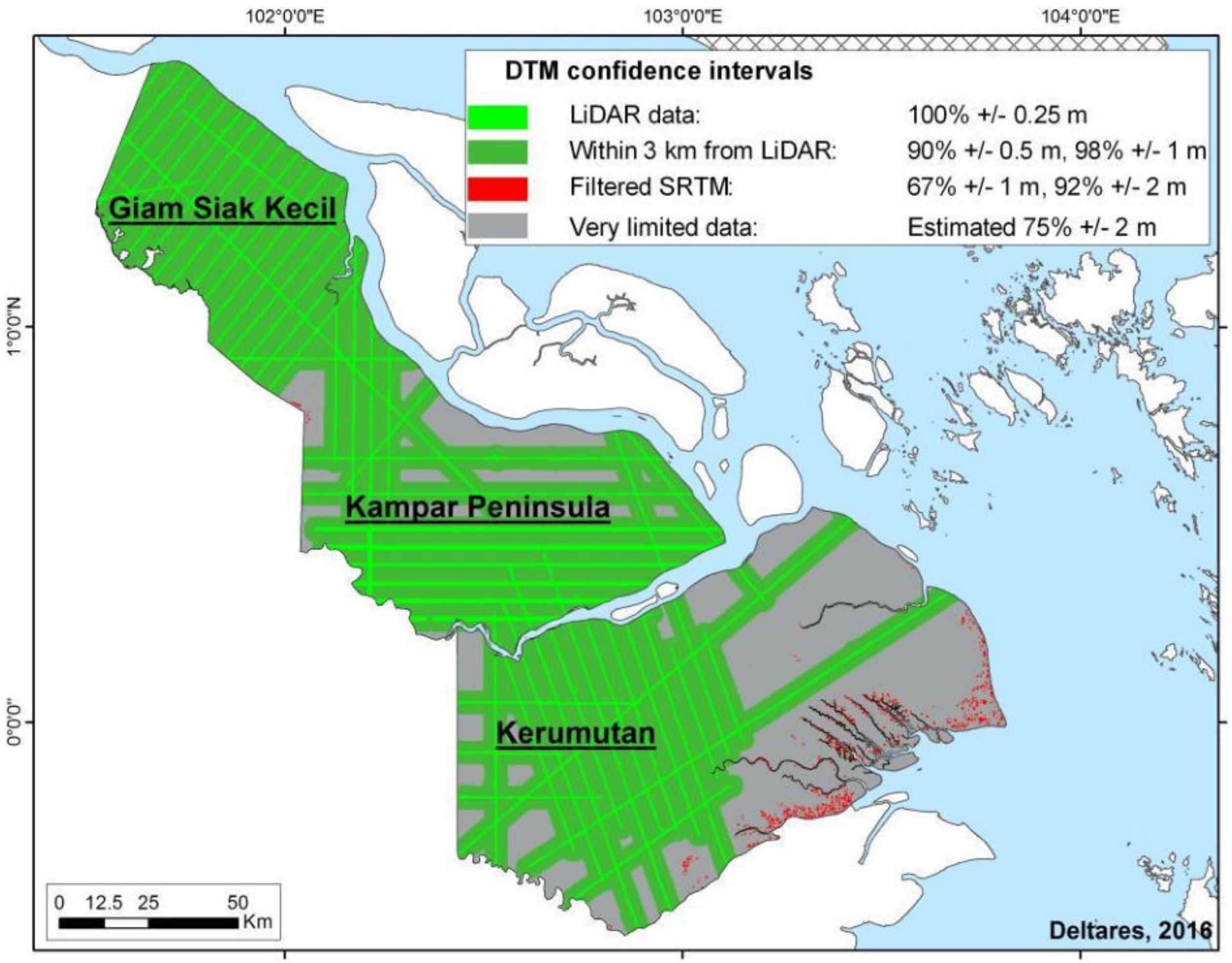
The accuracy of LiDAR data interpolated between strips could be determined from a full coverage dataset in Central Kalimantan (KFCP; *Figure 1*) that allowed comparison of the interpolated data with the full coverage data. It was found that the interpolated data are within 0.5 m accurate for 90% of the area, and within 1 m accurate for 98% of the data. These accuracy ranges are also applied to East Sumatra pending further validation (*Figure 8*). This is considered accurate enough for most applications, but full coverage data will be needed for detailed water management design purposes in some complex area.

Beyond 3 km from LiDAR strips, we do in principle not use the LiDAR data to create an elevation model, unless SRTM data show that the area is extremely low and flat in coastal zones. In such areas, we use both LiDAR and filtered SRTM data to create a DTM, which however results in highly inaccurate elevation models.

Accuracy of surface elevation model

FIGURE 8 Estimated accuracy levels of the LiDAR based elevation model for the major peat dome landscapes along the Riau coastline (Giam Siak Kecil, Kampar Peninsula and Kerumutan).

TO BE REVISED IN MAY 2016.



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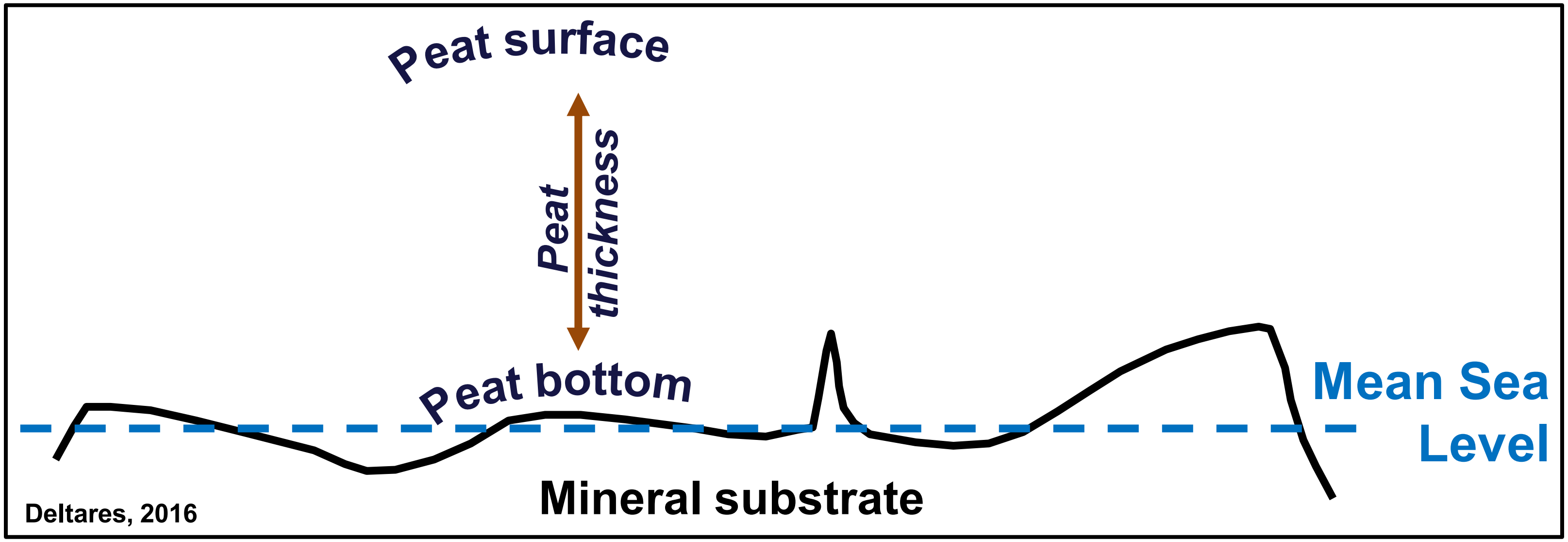
Using the surface elevation model to create a peat thickness model for peat landscapes

Coastal peatlands in SE Asia started development some 5,000 years ago in areas swamped by river water after Sea levels rose. The bottom of most peatland is therefore still near Mean Sea Level (MSL) today (*Figure 9*). Applying 1,265 field (auger) measurements of peat thickness to the peat surface elevation model for three major peat landscapes in Riau, we find that 76% of peat bottom observations is within 2 m above or below MSL. This percentage is expected to increase considerably after additional data become available in May 2016.

Note that for many applications, such as assessments of land suitability for agriculture and of carbon stock available to fire, it suffices to know whether the bottom of the peat is above or below the local flood limit. If the peat bottom is below the flood limit, the land will inevitably be flooded once all the peat is removed by fires and oxidation. The flood limit in Indonesia's coastal lowland varies from 1 m to 4 m, depending on tidal range, distance from the Sea and river discharges, but is usually above 2 m; if the land surface is below that elevation only flood tolerant crops may be grown. The peat bottom in over 90% of observations in Riau is less than 2 m above MSL (Figure 10). It follows that the large majority of Riau's coastal peatland area will eventually flood semi-permanently, and become unproductive, if drainage is started or continued.

Using the surface elevation model to create a peat thickness model for peat landscapes

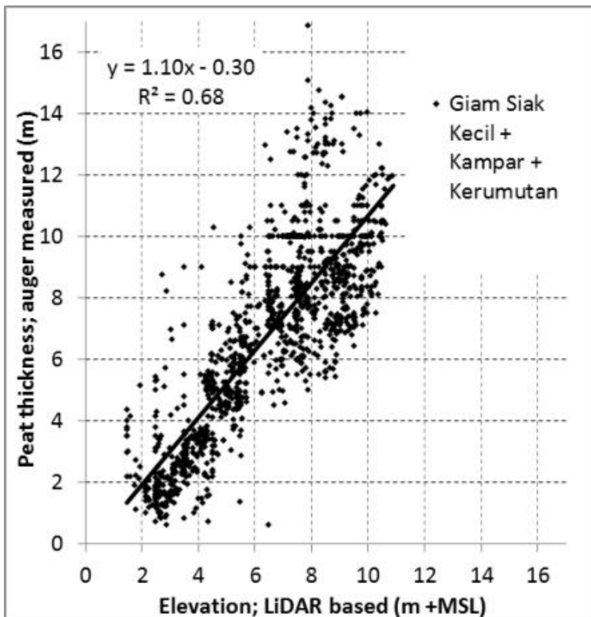
FIGURE 9 Schematic profile through a coastal peat dome, showing how the peat bottom is usually around Mean Sea Level.



Using the surface elevation model to create a peat thickness model for peat landscapes

FIGURE 10 LEFT: Graph of LiDAR based surface elevation vs peat thickness (as measured in the field using augers) in the major peat landscapes along the Riau coastline (Giam Siak Kecil, Kampar Peninsula and Kerumutan).

RIGHT: Statistics for the same data.



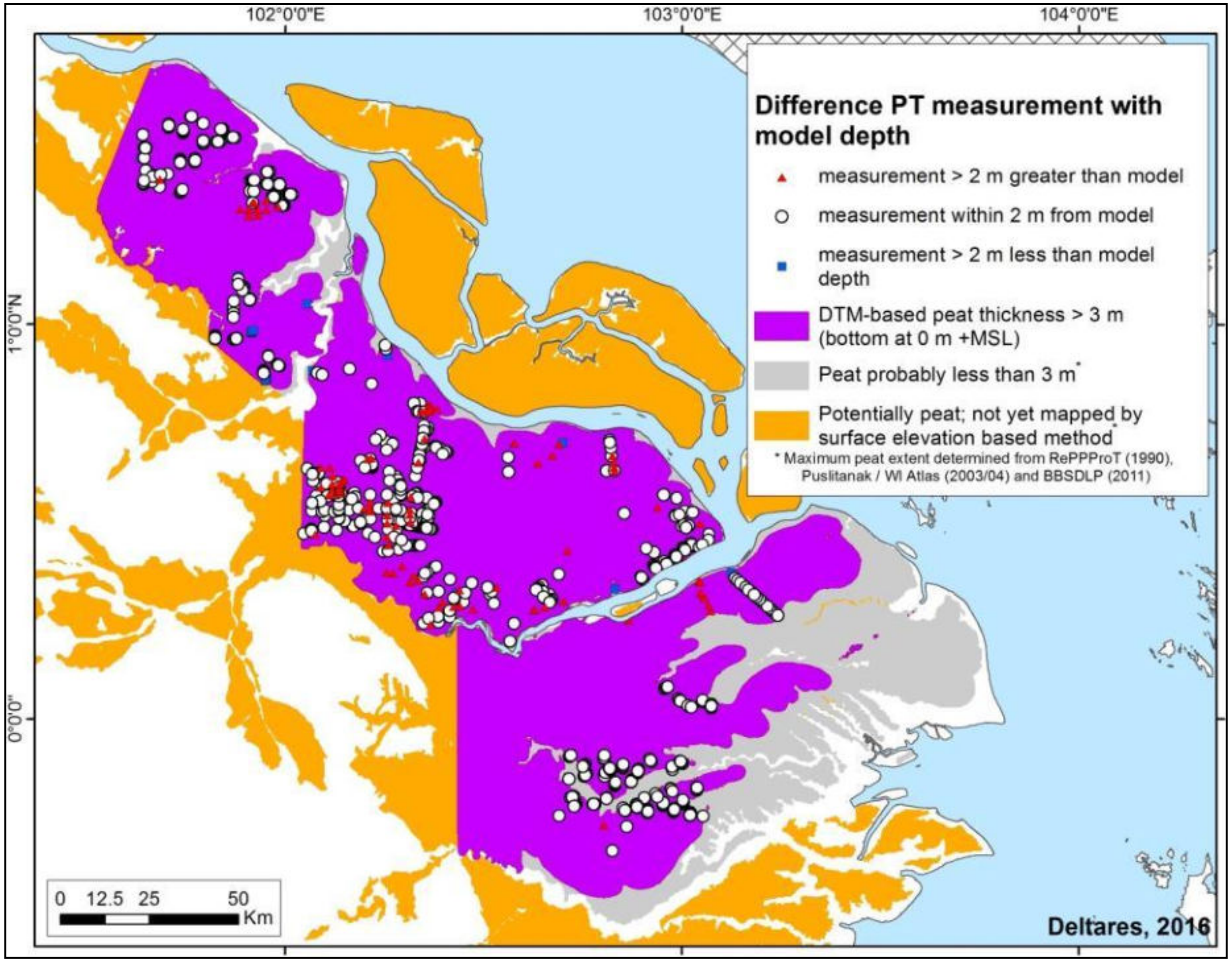
NOTE: THIS DATA WILL BE UPDATED BY MAY 2016 AS ADDITIONAL PEAT THICKNESS BECOME AVAILABLE THAT ALLOW QUALITY CONTROL OF THE OLDER DATA AND REJECTION OF SOME DATA.

	STATISTICS OVER FIELD MEASUREMENTS																	
		Elevation			Peat Thickness							Peat Bottom						
Landscape	# field measurements	Average	Standard deviation	Median	Average	Standard deviation	Median	% > 3 m	% > 5 m	within +/- 1 m from model (with peat bottom at 0 m +MSL)	within +/- 2 m from model (with peat bottom at 0 m +MSL)	Average	Standard deviation	Median	% < 0 m +MSL	% < 'MEDIAN' m +MSL	% < 2 m +MSL
Giam Siak Kecil	337	7.6	1.5	7.5	7.9	2.2	8.1	95	92	33	61	-0.4	2.0	-0.6	59	50	86
Kampar	570	7.3	2.0	7.7	8.1	2.7	8.3	97	88	48	76	-0.8	1.9	-0.5	60	50	96
Kerumutan	358	3.8	1.3	3.5	3.4	1.9	2.9	46	14	61	91	0.4	1.3	0.7	21	50	98
GSK + Kam + Ker	1265	6.4	2.4	6.9	6.7	3.2	7.1	82	68	48	76	-0.3	1.8	0.0	49	50	94

Using the surface elevation model to create a peat thickness model for peat landscapes

FIGURE 11 Peat thickness map for peat deeper than 3 m, for the major peat landscapes along the Riau coastline (Giam Siak Kecil, Kampar Peninsula and Kerumutan), as determined from LiDAR data by assuming the peat bottom is at 0 m + MSL. Also indicated is whether field (auger) peat thickness measurements yield values that are more than 2 m different from this map.

NOTE: THIS DATA WILL BE UPDATED BY MAY 2016.



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Limitations of peat thickness mapping using elevation models

The determination of peat thickness from LiDAR based elevation models has been shown to work very well in areas where the peat surface is clearly dome-shaped. However, the method does have the following limitations:

1. In some areas, the peat surface is not dome shaped, either naturally or because much peat was already lost after drainage in recent decades. In such areas the peat is often shallow and the relation between peat surface and peat thickness is less clear.

2. In other areas, especially further inland, the bottom of the peat is not near MSL and sometimes not flat, as the peat has developed over a pre-existing landscape that was not a river floodplain or coastal mangrove. In inland areas, too, the peat is often shallower.

3. <u>In such areas as identified under [1] and [2], often areas with shallow peat, peat thickness mapping using LiDAR is not accurate and other methods (especially ground augering) are required.</u> For Sumatra, we estimate this area to be in the order of 20-30% of the total peat area. Therefore, we refer to the LiDAR based method as Coastal Peat Landscape Mapping, rather than full Peatland Mapping. We do not think that one single method can be applied to accurately map all peatland, in all landscape settings and under all land uses. <u>The LiDAR based method is therefore a contribution to a set of methods that jointly can be applied to map all peatland, but it can not be the only method to map all peatland.</u>

Limitations of peat thickness mapping using elevation models

A further limitation of elevation models derived from LiDAR along strips at 5 to 10 km distance is that they are meant principally to identify patterns at the larger landscape scale. For applications that require detailed elevation data, such as detailed water management design in plantations with complex morphology, often enhanced due to surface subsidence, additional full coverage LiDAR data may be required.

For detailed water management design, Deltares now develops separate DTMs based on LiDAR collected along strips at 2.5 km distance with all perimeter canals along the plantation boundary (where elevation differences will be greatest over short distance because of differential subsidence under different water management regimes inside and outside plantations) also covered by LiDAR. This will suffice for water management purposes. In a few limited areas however, where the highest possible accuracy is required for research purposes, we will apply full coverage LiDAR.

Other applications of LiDAR data in support of improved peatland management

Apart from measuring the elevation of the peat surface, LiDAR data can be used to determine several other parameters that are important to understanding management impacts and options in peatland:

1. Flood risk (*Figure 12*)

2. Historical subsidence rates in peatland, from the time of drainage to the time of LiDAR data collection (*Figure 13; Figure 14*).

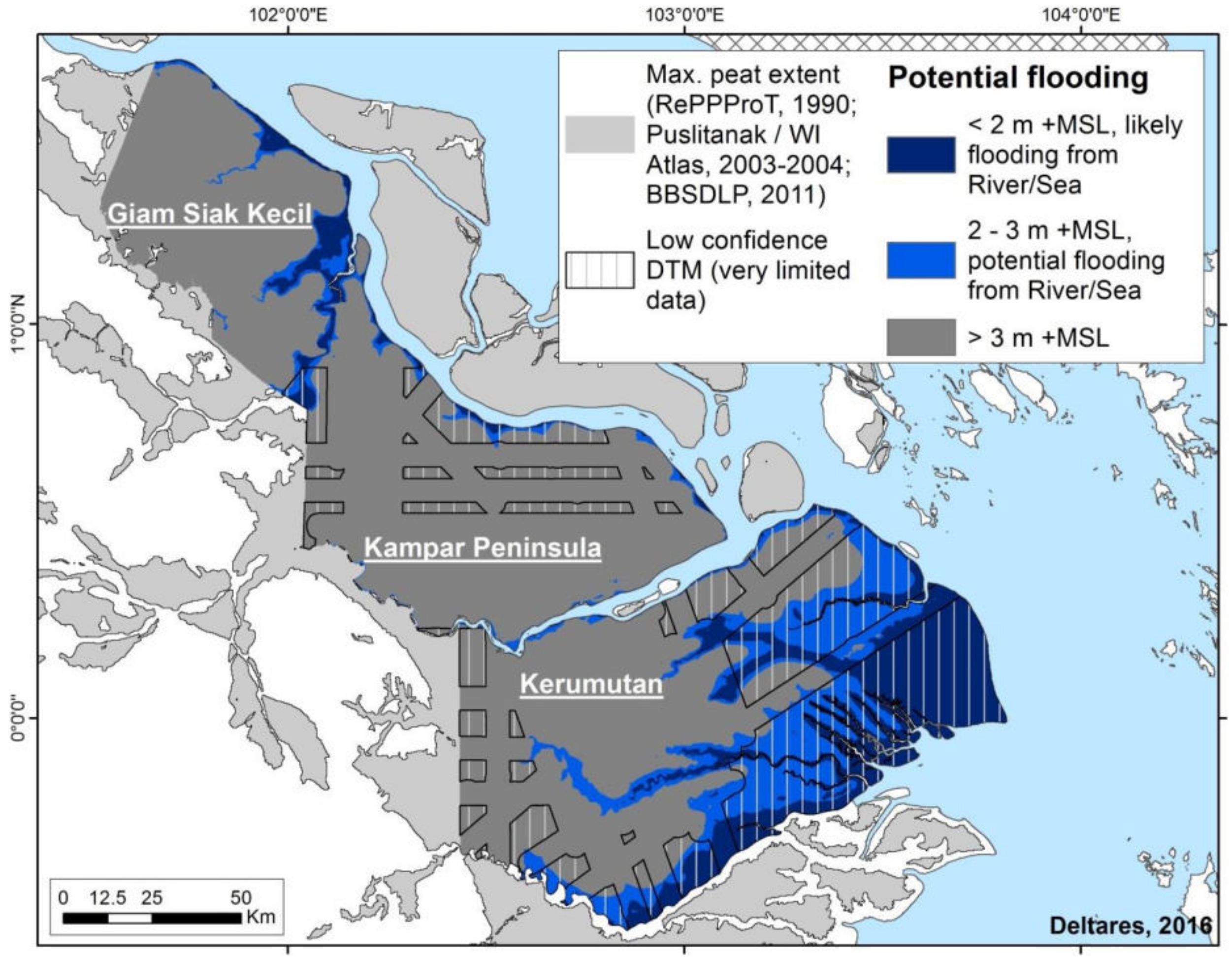
3. Forest canopy structure can be determined, which is useful in determining forest degradation status and management improvement requirements (*Figure 15*).

4. While LiDAR data are sometimes not considered a good measure of water level, it is found that LiDAR in tropical peatland can in fact be used as a very accurate measure of water levels in canals as there is always some detritus or algae at the surface (*Figure 16*). As there is an urgent need to raise water levels in peatlands in Indonesia, to reduce fire risk and carbon emissions and forest loss, such a tool to rapidly and repeatedly measure water levels over large areas is urgently needed.

Other applications of LiDAR data in support of improved peatland management: flood risk

FIGURE 12 Tentative example of likely and potential flooding extent in 2015, assuming that these correspond to areas below 2 m MSL and 2-3 m MSL.

Actual flood levels are more variable in space, and can be higher in some areas. Work towards a refined flood risk map is ongoing.



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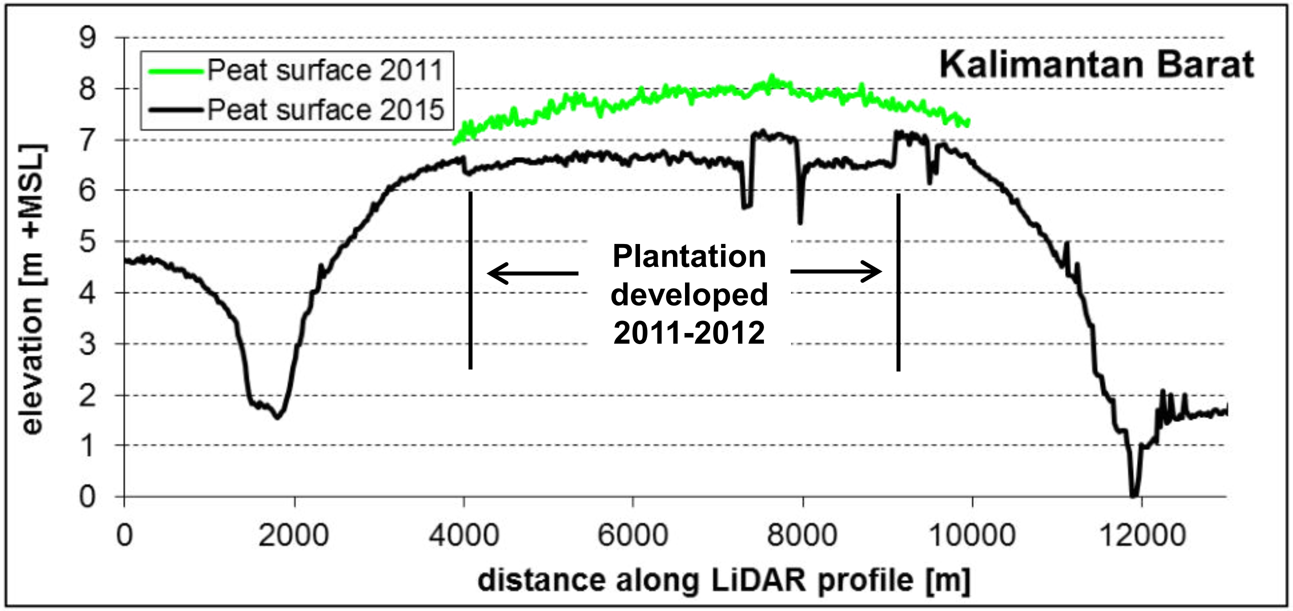
Other applications of LiDAR data in support of improved peatland management: historical subsidence

FIGURE 13 LiDAR derived peat surface elevation over a peat dome in West Kalimantan, before and after plantation development (forest clearing and drainage) in a previously intact area.

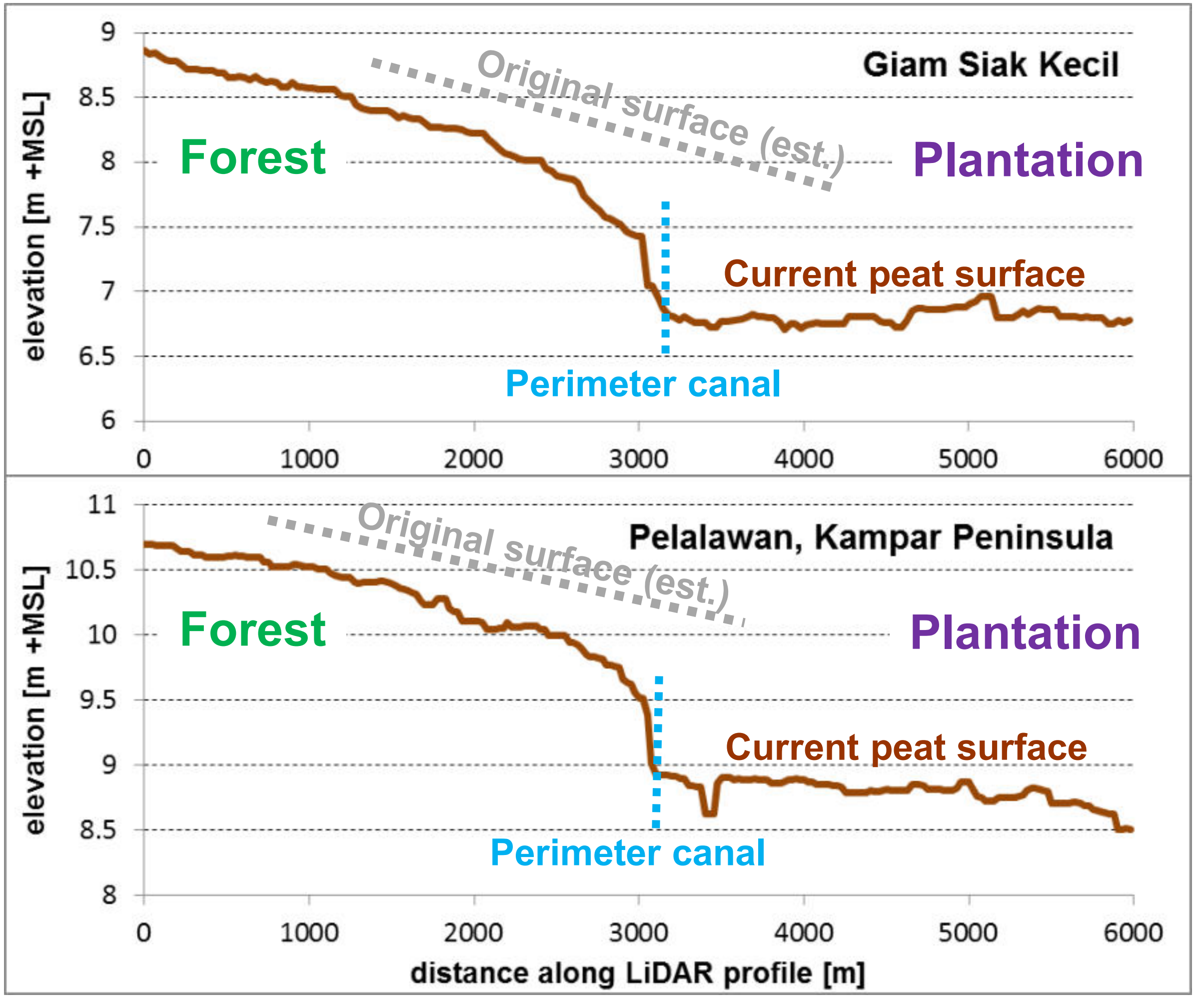
A distinct peat surface drop by 1–1.25 m is evident inside the plantation, in 3–4 years. The peat surface just outside the plantation has dropped by ~0.5 m.



Other applications of LiDAR data in support of improved peatland management: historical subsidence

FIGURE 14 LiDAR derived peat surface elevation along two transects crossing the perimeter canal between plantations in Riau, Sumatra (developed 10–15 years ago) and remaining forest, on deep peat (~10m).

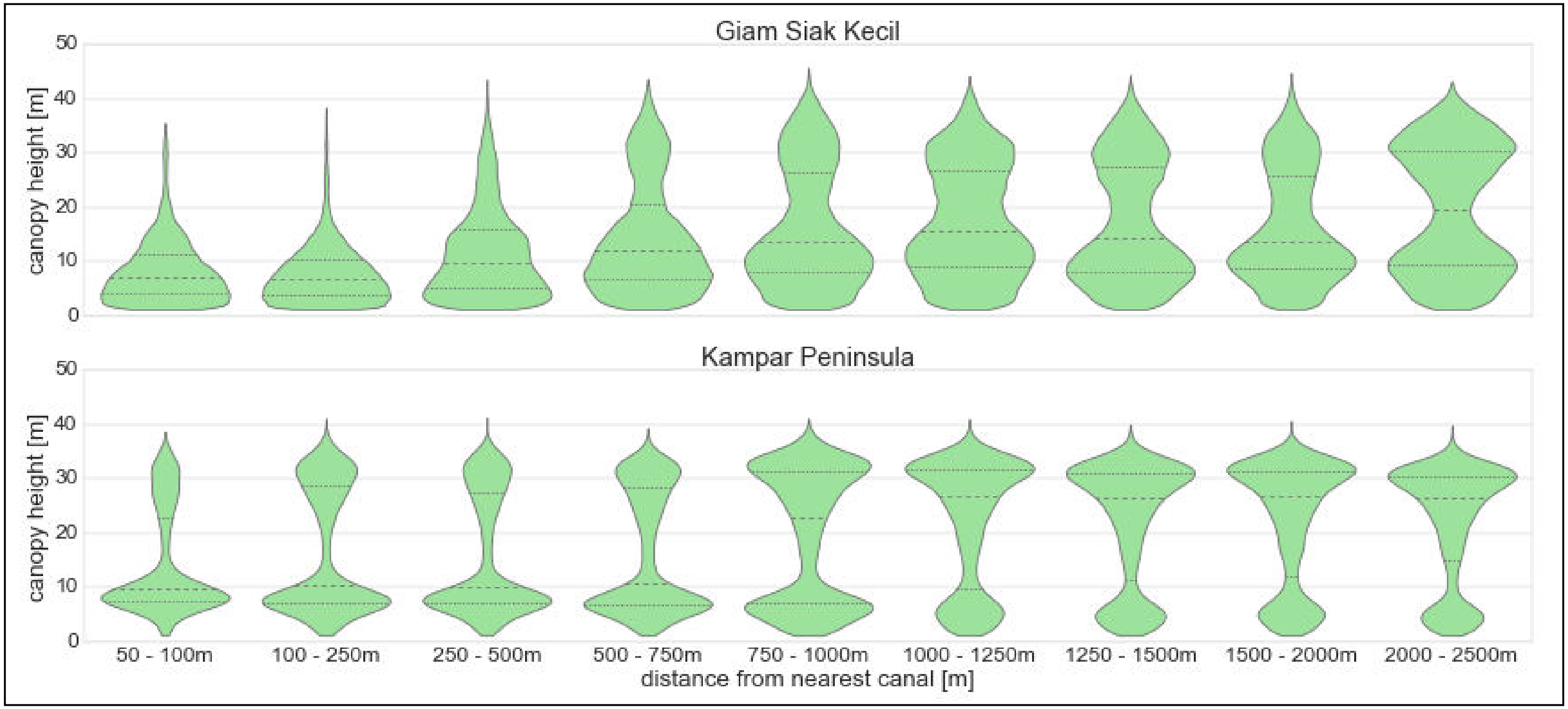
A drop by ~1–1.5 metre is evident in both cases, relative to the estimated original position of the peat surface.



Other applications of LiDAR data in support of improved peatland management: canopy height and degradation

FIGURE 15 Example of the height distribution in forest canopy as a function of distance to plantation perimeter canal on very deep peat (>10m), as determined from LiDAR data. The map indicates the transect locations. Historical data and visual inspection of the orthophoto suggest that no logging or fire has occurred along these two transects, indicating that canopy degradation close to the plantation is due to plantation drainage alone.

Edge effect



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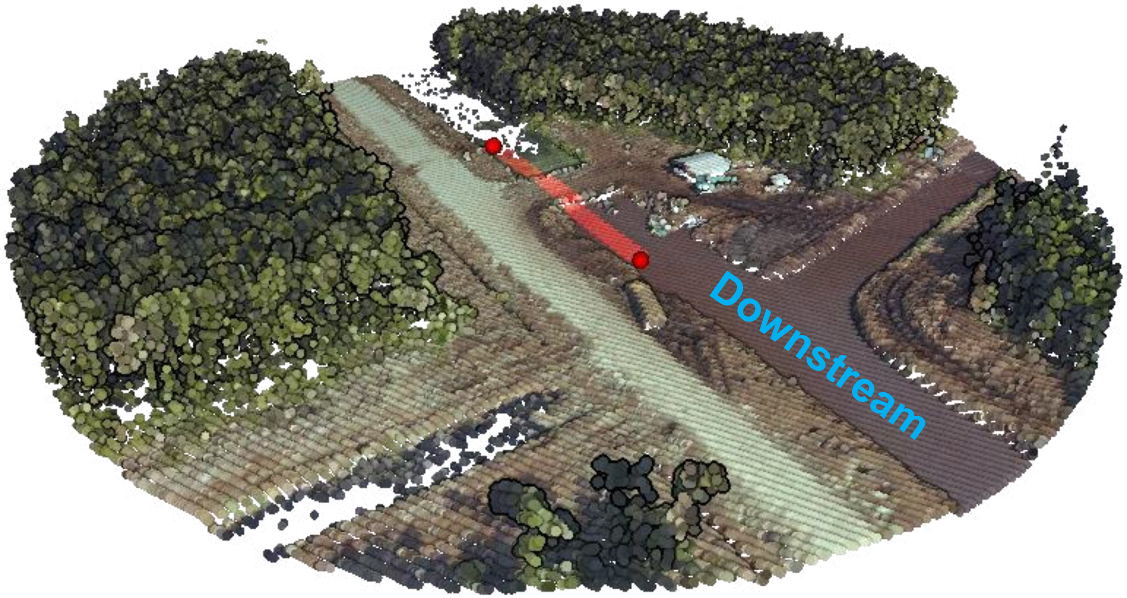
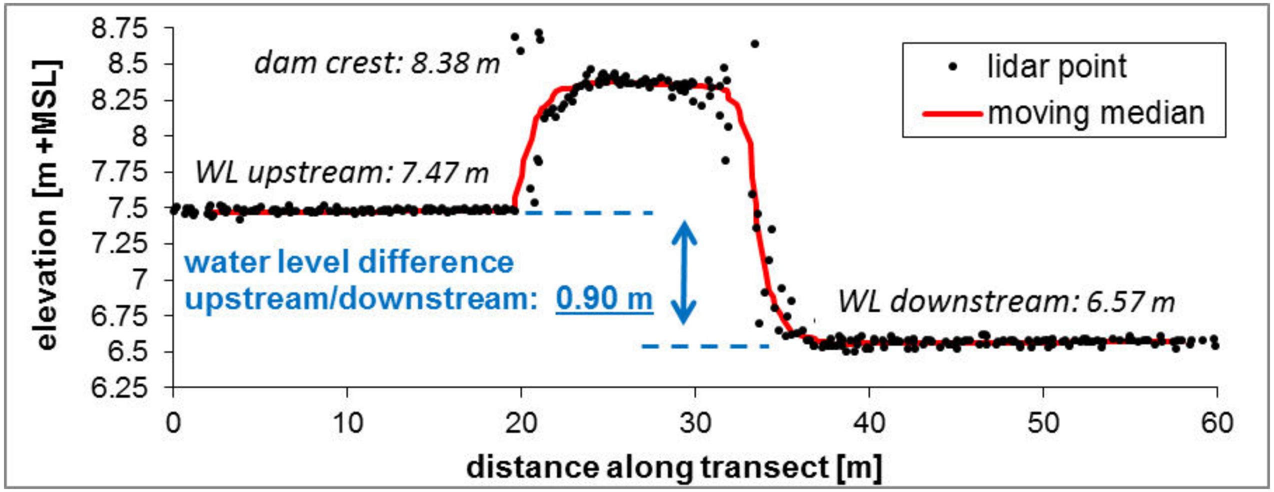
Other applications of LiDAR data in support of improved peatland management: canal water levels

FIGURE 16 Example of the water levels upstream and downstream of a dam in an Acacia plantation on peat.

TOP: 3D image of location combining LiDAR data and orthophoto.

BOTTOM: Profile over dam, showing a water level difference across the dam of 0.9 m.





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ANNEX – Deltares 10-year record of major peatland mgt projects in SE Asia involving mapping

1. ***SBMSP (2006-2010; Science Based Mgt Support Project; for APRIL):*** *included field mapping in Acacia plantations and forest; Kampar Peninsula*
2. ***CKPP (2006-2007; with WI; NL funded****): rapid field mapping of elevation and peat thickness for all of EMRP*
3. ***EMRP Master Plan (2007-2009; NL funded):*** *broad assessments of EMRP area in Kalteng including field mapping*
4. ***WACLIMAD (2010-2012; NL funded):*** *desktop studies using existing map sources*
5. ***KFCP (2009-2014; Australia funded):*** *intensive field surveys and full coverage LiDAR over 500,000 ha in EMRP*
6. ***QANS (2012-2013; with EMM and UGM; NL funded):*** *comparison of existing maps (Sumatra, Kalimantan); first assessment of how strip-based LiDAR could generate sufficiently accurate DTMs for planning*
7. ***BAP (2013-2014; with WI; for Shell):*** *peatland DTM and carbon stock map for Badas peat dome in Brunei using full coverage LiDAR*
8. ***SPPC / MIPP (2013-2015; with WI & UGM; Norad / CLUA funded):*** *focus on Sarawak and Kampar Peninsula; included LiDAR data collection over Southern Kampar Peninsula with UGM*
9. ***PBPMP (2014-16 / 19; Peatland Best Practice Mgt Project; for APP):*** *includes LiDAR DTMs and peat thickness models for all peat landscapes in which APP has concessions on peat. Total area covers >2 Mha; validation data collected in all concessions (~1 Mha).*
10. ***KeHIJAU Berbak Project (2015-2018; MCA):*** *detailed peat mapping around W side of Berbak NP, 'Tahura'; involves field and LiDAR data.*
11. ***South Sumatra Partnership for Landscape Mgt Support Project*** *(2015-2019; UKCCU & Norway): includes component 'Rapid national inventory of peatland surface elevation and forested lowland peat dome landscape conservation opportunities, using LiDAR data'*

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