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Discussions

Interactive comment on "Evaluating digital terrain indices for soil wetness mapping – a Swedish case study" *by* A. M. Ågren et al.

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Answer to interactive comment on "Evaluating digital terrain indices for soil wetness mapping – a Swedish case study" by A. M. Ågren, W. Lidberg, M, Strömgren, J Ogilvie and P. A. Arp.

Anonymous Referee #2 Received and published: 27 May 2014

There are some very nice element to this paper, however they are rather hidden by the over-complicated analysis used in the paper.

The paragraphs need to be shorter.

We have shortened the paragraphs.

I think some major changes and simplifications would help the paper. I became lost in sections as to what the focus of the paper was. Is this a paper on terrain analysis methods; is it a statistical classification exercise or was it a ground truth exercise?

It is all of that; it compares different terrain analysis methods against the ground truth using common statistical measures. We have now clarified the aims of this study accordingly:

"The aim of this study, therefore, is to further advance and test the accuracy of flow-channel and soil wetness mapping as it is currently aided by the increasing availability of LiDAR (Light Detection and Ranging) data for generating bare-earth digital elevation models (DEMs)."

"Soil wetness maps intended to guide forest planning and related operational decision making need to be as reliable as possible at meter-by meter resolution across large areas. For that reason, this study analyzes and compares LiDAR-derived TWI, TPI and DTW maps and seven other DEM-derived soil wetness indicators (topographic landform, flatness, puddles, toe-slopes, aspect, profile and plan curvature) in terms of their general applicability, accuracy and conformance in emulating actual soil wetness along streams and lakes for Swedish conditions."

I think the paper needed to address the issue of trafficking through saturated ground. However I do not believe this paper has really added to discussion on this problem in terms of any recommendations or management options. Does knowledge of wetness patterns allow better management? If yes, I would expand this part into the paper. The paper refers to the issue in the abstract; the introduction and then briefly in the conclusion. The authors must decide if this is a paper about the problems of machinery driving through wet soils or not?

We now added in the introduction:" To mitigate against soil disturbances, forest operations traffic through wet and moist areas and across flow channels should be avoided. Doing so would greatly reduce environmentally and economically costly forest operation “surprises”. Among these are, e.g., the increasing costs associated with non-anticipated culvert requirements for stream crossings, inappropriate delineations of machine-free zones, increases in machine down-time, loss of wood (quality and quantity) because of poor wood-landing locations, inefficient silvicultural investments (e.g., failed plantations), errors in summer versus winter cutting allocations, and accelerated costs regarding harvest block access (Arp, 2009). Until now, areas that are sensitive to soil disturbances have not yet been mapped at resolutions sufficient to be included in forestry planning operations. But, with new and reliable high-resolution flow-channel and wet-area mapping and follow-up field inspections, best-management practices can be enhanced with added financial and economic benefits, to guide machine traffic away from wet areas through on-board navigation. “

In terms of further comments and future work: Since the DTW maps outperformed the other terrain indices in this scientific study, it is currently the method that we recommend for practical forest management. The DTW maps are currently being tested at several forest companies on a trial bases in Sweden. The companies in Sweden currently work to change their practice and planning so that the areas that will be most heavily trafficked by the forest machines are based on the soil moisture maps. For ex. on wetter more sensitive soils only the more lightweight harvester machine should drive while the heavy forwarder should only drive on dry soil with good bearing capacity. During 2015-2016 we will evaluate the implementation of the maps in the industry, both from an environmental perspective and a forest production perspective. But the management perspective will be the focus of another more applied article later. Here we only validate the soil moisture maps.

The abstract is full of jargon and acronyms.

We have now clarified the abstract and all acronyms are explained in the abstract.

The bulk of the abstract refers to terrain analysis methods and in essence it sounds good. But, I think the paper does not back up the abstract and the terrain analysis

does not back up the trafficking issue.

Yes, we agree that the terrain analysis methods were missing from the introduction and have now inserted such a section and also clarified the aims, as noted above.

The paper is reliant on a classification of land units, based on soil properties and this does seem to be a very robust way of characterizing the wetness map. As the soil classification is so good, and given the later analysis it might suggest that more soil mapping effort may be all that is needed to define sensitive saturated zones.

Yes, all this can be done using more soil mapping in the field. This is how it is done in practice today, however, it costs a lot of time and money. Today the practitioner has to walk around all the clear-cut to make decisions of where to drive, each clear-cut takes on average 4-5 hours of planning in the field. Using these high-resolution maps in field the entrepreneur will know in advance which are the most suitable soils to drive on and can just go to certain key points to ground-truth the maps. Calculating a map over an area that would take a week to field-map can be done within a few minutes in the computer with digital terrain indices. The new maps therefore have great potential in reducing both the environmental costs and the planning costs of forest soil driving.

I am surprised that the text did not discuss connectivity of flow pathways. Also can the authors define the subsurface flow pathways and surface pathways more clearly? It is the switch from subsurface fed saturated zones turning into saturated zones containing open channel flow that seems most important to this study.

Entered into the discussion: “Hence, by varying the threshold for stream flow initiation, spatial and temporal variability of the stream network and adjacent wet soils can also be modelled, with setting lower and larger threshold values for wet and dry seasons, respectively. For example, a 4 ha flow-initiation threshold tends to reflect general end-of-summer flow and soil wetness. In comparison, DTW maps based on 1 m DEMs and setting 1 to 2 ha flow initiation thresholds are useful (i) for planning or locating road-stream channel crossings except for sandy landforms such as, e.g., floodplains and glacial outwash (Campbell et al. 2013), and (ii) for estimating the distribution of wet-area obligatory species (Hiltz et al. 2012; White et al. 2012). Lowering the flow-initiation threshold further to 0.5 and 0.25 ha would emulate soil wetness and soil trafficability during wet summer weather and the snowmelt season (Murphy et al., 2011). Going from flat to montane areas may also require a downward change in the flow initiation threshold from 4 ha, as a reported by Jaeger et al. (2007). In arid regions, flow initiations and related depth-to-water mapping may increase to 1000 ha or more during dry and drought seasons."

Also, in reference to subterranean flow channels:

The highest resolution bare-earth DEMs produce the best DTW results across natural landscapes. However, where roads cross streams, it is necessary to ensure natural flow connections across roads. This can be done by breaching the DEM (i) at all known culvert and bridge locations, and/or (ii) at potential road blocks and related ditch diversions. Where there are flow-path uncertainties, or where the streams braid, flow accumulation algorithms other than D8 can be used to generate the DTW-determining flow channel network. Where the land is drained by way or subterranean infrastructure, it becomes important to "burn" this infrastructure into the bare-earth DEM to prescribed depths. Seepage locations and springs that occur outside upslope topographic control (e.g., artesian wells; seepage emerging from permeable bedrock) can also be incorporated into the DTW-generating algorithm by adding these locations as additional DTW = 0 defining locations.

The primary use of TWI in most applications is to allow a dynamic mapping of wetness in time. It is the change in seasons and changes during storm events that are the focus of most studies. This classification seems static and not dynamic, and as it is not fed into a hydrological model such as TOPMODEL.

Yes, temporal variations in soil wetness can be included, but this study focuses on mapping average soil conditions. We now include a short discussion on seasonal

variability in soil wetness mapping. We are also working on another manuscript on seasonal dynamics to be published later.

The dynamic element can be introduced in two ways for DTW: (i) Produce multiple DTW maps according to preset season-specific flow initiation thresholds, as discussed above. (ii) Use the chosen DTW map to emulate / index soil moisture variations from ridge top to depression based on a non-spatial hydrology model using daily weather for precipitation and air temperature, as described by D.J. Vega-Nieva, P.N.C. Murphy, M. Castonguay, J. Ogilvie, P.A. Arp. 2009. A modular terrain model for daily variations in machine-specific soil forest trafficability. Canadian Journal of Soil Science. Volume 89, Pages 93-109.

I will assume that large areas of DEM can be created for the study areas. So I believe that TWI and DTW can be created for large areas. Therefore the onus is now on the test of accuracy, which is the main part of the paper. So the main test is mapping indices against the ground truth which is the soil- based classification. The paper now gets into trouble. Generally the jargon and the acronyms make the task of reading and understanding the text quite difficult. I do like the DTW index as it is simple and informative - so keep this. However, can it be made dynamic to reflect the season and storm event dynamic?

Yes, see Vega et al. 2009, as indicated above.

I do not like Fig 2, as this is a classification of something that is already classified, i.e. the soil property. I also do not believe the detailed statistical analysis is adding anything to this paper.

It depends who is reading it: a practitioner may skip through this section, after getting the basic message: DTW is better than the other indices in terms of emulating soil wetness, based on the detailed transect determinations. Fig.2 illustrates this clearly, by way of the relatively narrow and fairly scale-independent outcome for the DTW results. Researchers that have long worked with indices such as TWI want to know how DTW actually stacks up against the other wetness indices by way of statistical analyses. As such, we need Fig 2, and the related background and discussion to place this paper into the general GIS-based hydrological context. Retaining Fig. 2 is also important to fulfil the aim of this study: to compare different terrain analysis methods against ground truth. The OPLS method is a good way of (i) tracking many variables and (ii) evaluating both their predictive power and (iii) for checking how much of the wetness index variability is not related to each particular DEM-derived wetness index, i.e., how much wetness uncertainty remains with each particular wetness index. In principle, therefore, Fig. 2 and the related texts is there for documenting the outcome of the results in statistical terms. The first two sections of the revised Results will guide the reader towards understanding Fig. 2.

I would rewrite 2.4. There is too much detail and the methods are not really telling me anything. Can one simple statistic be used?

Yes, see Table 2 as it showcases how DTW stack up against the field-determine soil wetness observations, and in terms of already mapped wetness categories. In addition, Fig.2 is a good way of taking many variables and displaying their wetness predictive power in a simple graph. Granted, the OPLS method has only been around for a few years, and so it is not yet commonly used. We therefore explain in the methods section how this method is used, to guide the reader's interpretation by way of the first two paragraphs of the results.

The second statistical analysis re. the confusion matrix is a common way of assessing map data. We have included this matrix so that this study can be easily compared with other map conformance studies.

Fig 3 is good but needs to be justified as there are many papers on DEM resolution effects.

Yes, there have been many studies focusing on DEM resolution effects, which generally found TWI to be better than the other DEM derived topo- indices that are also referred

to in this article (e.g., curvature, aspect, toe slope , TPI, etc.). IN reference to TWI in particular, we now write: "…the TWI dots do not form a tight cluster but cut across the positive side of the horizontal axis, with strongest soil wetness prediction performance for TWI24 for Areas 1 and 3, and TWI50 for Area 2. In addition, TWI calculated at 2 m resolution (i.e. TWI2) scored low on the predictive axis and high on the orthogonal axis (poso[1]), thereby indicating that high resolution DEMs are not suitable for TWI-based soil wetness determinations. This is also illustrated in Figure 3."

Fig 4 is good but too much is going on. Try zooming in to a detailed area of study.

That is what we do in the two lower panels.

Fig 5 is also good.

Thank you.

The points about the crucial role of channel initiation is also good. A figure could help reflect this.

We added more to this point in the discussion, as shown above. In addition, how channel initiation can be used to emulate seasonal dynamics will be addressed in another study.

This is where I think the emphasis of the paper and the analysis should change. I would like to see more maps and more verification evidence on the maps (and not using false positive statistics etc...). Maps that use overlays of the TWI, the soil classes, Dtw and DEMs are very convincing. Through visual matches and anomalies the reader can quickly evaluate the goodness of fit. Maps allow a broader hydro-geomorphological interpretation of the goodness of fit rather than just using a blind statistic. So my conclusion is to keep most of the paper. Add some new map-based analysis (showing the accuracy of methods).

All good points, and yes, there are already good articles that show overlays of DTW and TWI overlays on images, bare-earth DEMs, etc. (most presently residing at http://watershed.for.unb.ca/publications). And there are many videos further underscoring the benefits of DTW mapping (see http://watershed.for.unb.ca/media/). However, in reference to this article, we need to bring out measures of accuracy and reliability in a statistical way. The measures we use for false positives and negatives are common. Altogether, we are sending this article to the high impact journal HESS for which statistical evaluations are absolutely needed to confirm scientific advances.

I would then add new text on the case study and on the importance of machinery driving through wet zones. Can you discuss the options of where to drive and when to drive the machinery or even if you need a bridge across the permanent wet areas?

Without going into detail, the paragraph near the end of the discussion addresses some of the issues: It is suggested that the DTW derived soil wetness maps can be used to reduce environmentally and economically costly off-road traffic surprises such as unacceptable rutting. "For example, a recent DTW advance dealt with mapping potential and actual soil disturbance impacts for the purpose of off-road soil trafficability assessment (Campbell et al. 2013). Additional forestry benefits refer to improving harvest scheduling (summer versus fall versus winter), in-field harvest navigation, selecting tree seedlings by species for within-block planting dry versus moist and wet sites, optimizing block access routes, and guiding in-block harvesting and wood-forwarding trails (Arp 2009). Further operational benefits refer to knowing how to lay-out the harvest and skidding trails depending on current or forecasted weather conditions by changing the DTW index by flow-initiation threshold, when and where to harvest and/or to scarify depending on the prevailing weather and soil conditions. The DTW-determining flow-channel networks are of interest in themselves as these determine where trails should avoid ephemeral streams, or where to use brush mats to avoid soil compaction and subsequent sub-surface flow blocking. (For practitioner accounts of DTW-derived benefits within the forestry, lay-out for oil and gas extraction, and park management, see http://watershed.for.unb.ca/media/)."

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