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Summary paper for session F13: Terrain analysis and geomorphometry with high resolution terrain data

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Abstract:

In preparing this session, our view of a high resolution DEM (Digital Elevation Model) took into consideration the outcomes from the inaugural terrain session at MODSIM 07. From the diverse papers presented at that session the definition had to be broadened from merely a DEM with a spatial resolution of 10 metres or better and a vertical accuracy of tens of centimetres and based on dense measurements rather than interpolation from sparse contours or spot heights. Instead, the definition of a high resolution DEM became defined more by the landscape process scale the researcher is interested in. If this scale can be matched by the DEM resolution and data capture technique then the DEM can be defined as high resolution.

The papers from this Modsim09 terrain analysis session focus on DEM stitching and error correcting, more efficient and capable computation algorithms for large datasets and new or revised software applications particularly related to dense-noisy data. Of interest is the emergence of bathymetry either from an external source to be integrated with DEMs or as a product from deriving DEMs from LiDAR.

This paper summarises the current status of data capture, processing, integration and application of high resolution digital elevation models from the papers presented in the MODSIM09 conference. Knowledge gaps and future research directions are identified.

Keywords: *Terrain Indices, DEM, LiDAR, SRTM, Photosynth*

1. INTRODUCTION

This paper follows from a previous summary paper presented at MODSIM07 (Summerell and Gallant, 2007) as a review of the papers presented and the progress of modelling and data technologies. The main message from that conference was that the requirements of model applications are often out of step with the technologies for acquiring and handling data, i.e., that users constantly desire larger areas and finer resolutions but the capacity to collect, process or store them is limited.

Rapid developments in high resolution data capture techniques to create DEMs have occurred in recent years. This in part is due to the increasing availability of large storage devices and faster computing power. Radar and LiDAR (Light Detection and Ranging) data acquisition methods are still becoming more widely available resulting in much wider availability of high resolution DEMs. We are now seeing a rapid expansion and use of this technology. The rapid growth of these high resolution DEMs has in part moved faster than researchers have had time to assess and utilise the data to its full extent. Many questions still persist such as: Do these radar and LiDAR data capture methods require specific pre-processing routines? Do I need accurate field data validation to determine the true quality of the data? Is it more appropriate in some cases to rely on DEMs that are derived through more traditional creation methods such as interpolation from contour data?

This session aims to bring together users of high resolution data sets to share our collective experiences on the application of approaches and uses. We hope to fast track our understanding of the latest technologies for creation and highlight the areas we need to focus our thoughts and attention when choosing to use a high resolution data set. DEMs, as with any model are a compromise between reality and what is achievable with available technology. We should keep asking ourselves whether the compromises embodied in the data suit the purposes for which we are using the data.

This session was broken into four main themes.

(1) Dem data preparation for radar and LiDAR DEMs.

(2) Handling of large DEM data sets.

(3) Resolution and accuracy.

(4) Terrain analysis applications with high resolution DEMs.

2. PAPER SUMMARIES BY THEME

2.1. DEM data preparation for RADAR and LiDAR DEMs

Smart GM, Bind J, and Duncan MJ

Smart *et* al discussed the common use of LiDAR for flood plain mapping and the need for bathymetric measurements to complete parts of the DEM that are under water. They point out the bathymetric data collection is time consuming, expensive and difficult to integrate with LiDAR DEMs. For hydrological studies often the depth of water bodies ends up being estimates. Smart *et al* have developed a novel approach in flowing water bodies to estimate water body depths by using the returns of the LiDAR on the water surface to reverse engineer the Mannings formula (used for calculating flow) to estimate depth. Because the water surface is known and if a flow measurement is taken critical parameters in the Manning formula can be calculated such as water slope, estimates on roughness, distances etc., with the only unknown being bed level (or water depth). The method was tested against Bathymetry measurements in New Zealand on the Waiau River on the Canterbury Plains, with very successful outcomes.

This is a creative use of lidar elevation data to produce bathymetry, hard-to-get data that is becoming increasingly in demand. The method has its limitations (water has to be flowing fast enough for the bed variations to be expressed in the water surface) but is interesting and promising.

Hutchinson MF, Stein JA, and Zhu T.

The paper by Hutchinson *et al*. describes modifications to the ANUDEM, a locally adaptive elevation gridding procedure (Hutchinson 1989). A strength of ANUDEM is in sophisticated drainage enforcement when interpolating DEMs. ANUDEM is known to many of us as a reliable interpolation tool carefully tuned to the specific needs of elevation data. This significant update of the underlying method allows more effective use of dense noisy data that is the basis for most new DEMs, be that lidar, radar or photogrammetric data.

The fact that the authors have undertaken this modification is an acknowledgement that the future of DEMs rests on these dense noisy data sets. It is also a reminder that most of those data sets are not good representations of the terrain in their supplied form, at least for quantitative analysis for geomorphic and hydrologic purposes. They need to have some intelligent processing applied to them to treat the noise and remove spurious obstructions to water flow. On the other hand, their accuracy and detail compared to contour-based DEMs means we need to be careful of our normal assumptions of connected flow paths and absence of depressions. High resolution data, despite the noise, provides most benefit (compared to DEMs derived from sparse contours, spot heights and stream lines) in low relief landscapes especially where real depressions are common.

2.2. Handling of large DEM datasets

Wallis C, Wallace R, Tarboton DG, Watson, DW, Schreders KAT, Tesfa TK

Wallis *et al* use a parallel processing method to increase efficiency when undertaking the process of pit removal from DEM data. With higher resolution DEMs these fundamental GIS processes are becoming computationally difficult in terms of computer resources. The paper describes a parallel implementation for pit removal using the Message Passing Interface (MPI). The algorithms in this method work by decomposing the working domain into tiles where each tile is processed separately and then the DEM is re-assembled. Results showed that for small DEM no efficiency gains were observable but as the DEM size increased the processing speeds significantly increased.

This paper supports the view that new, very large data sets are challenging for conventional methods and more sophisticated software is needed in some instances. Terrain analysis practitioners will need to become familiar with parallel computing methods if we want to keep working with the latest data. Off-the-shelf GIS and terrain analysis software (e.g ArcGIS, SAGA, Grass and TAPES-G) are, to our knowledge, unable to make use of supercomputers and clusters for parallel processing. What are the prospects for seeing parallel processing methods become mainstream? And what can we as users of these software products do to encourage developers to provide software that copes with increasingly large DEMs?

Manion G, Ridges M

Manion and Ridges indicate that as environmental data is becoming finer, often there are larger spatial differences with the study domain between data points. As the spatial domain of the data increased the current methods for analysing this data (such as survey gap analysis methods) have become very computationally intensive. Manion and Ridges outline a technique of optimising the speed of the survey gap analysis by dividing key components of the algorithm between the RAM and hard disk drive. In doing so they exploit the speed of physical memory for processing while storing key environmental distance metrics on the hard drive between iterations, thus reducing the need for recalculation. A look up table of detailed distance metrics remains unchanged creating the only file that needs to be stored, hence reducing storage demand resources.

In spite of increasing memory and processing capacity, data always seems to be growing faster than our capacity to process it! Hence creative approaches like this one will continue to be valuable. Analysing large data sets often means that we have to pay attention to how we access the data – this is true for many forms of terrain analysis on large DEMs too. The interaction between algorithms and data structures is important e.g. algorithms that need to trace flow paths, so can’t be processed in a pre-defined order. Caching methods that sit between the computation and the storage are needed to produce usable software tools, and different algorithms will need different caching methods. Relying on automated memory management techniques like ‘garbage collection’ seem not to produce the most reliable and efficient software.

2.3. Resolution and accuracy

Gallant J. and Austin J.

The Gallant and Austin paper tackled the problem of combining several DEMs into a single coherent surface. They found several different issues in overlap areas that needed treatment in quite specific ways and were not able to automate the process. A lot of manual editing work was required to remove inaccurate data that resulted from interpolation or estimation in areas without supporting measurements.

We can expect to see an increasing demand for stitching data as time goes by and surveys progressively fill in gaps between existing high resolution DEMs. Gallant and Austin suggest two things that would make the stitching job easier: including overlaps with existing data when specifying the collection of new data rather than abutting or leaving small gaps so that differences between the old and new data can be detected and treated; and identifying where DEMs are supported by measured data and where they are reliant on interpolation, so that the relative reliability of different sources in overlaps can be assessed.

Kinsey-Henderson A.

This paper tackles similar problems to that of Gallant and Austin except that rather than problems stitching DEMs from disparate sources, Kinsey-Henderson faced systematic errors between flights lines in the same dataset, this time with overwhelming overlap. The methods described in the paper have largely dealt with the inconsistencies found in the data. The systematic problems are numerously documented by various authors who have taken their own approaches and a standard solution has not emerged at this stage. It is timely in that the providers of this technology have only just started tackling these problems with scanner setup and electronics, and this Tully analysis can be used to monitor the performance of any corrective measure..

These problems highlight the need for users or purchasers of data to test the quality of the data before putting it to serious use, and a reminder that conversations between users and data providers about problems with the data can benefit both parties.

Dowling T., Read A. and Gallant J.

Dowling et al revisited the $1m^2$ study area presented in Modsim07 on the application of a 2.5cm resolution DEM in erosion studies. In that paper two main issues were identified a) the higher the accuracy of DEMs the more frequently they needed resurveying and b) the manual methods used to collect the DEM made it almost prohibitive. This Modsim09 paper investigates a technology from Microsoft, called Photosynth, that was released in the interim that allows a simple, low cost and effective photogrammetric alternative to the manual method.

This paper highlights the transient and leap-frog nature of need and technology. Apart from the ability to do more frequent monitoring it appears to have improved the accuracy of the DEM despite the very noisy nature of the data. Although not yet tested it suggests that even finer resolution DEMs are achievable from the technology and opens the door for truly multi resolution studies, albeit of reasonably small areas. Photosynth appears to be a viable technology for deriving detailed DEMs of study areas small enough to be captured photographically.

2.4. Terrain analysis applications with high resolution DEMs

Summerell G., Wilford J., Shoemark V., Grant S. and Walker J.

Summerell *et al.* used a high resolution passive microwave airborne remote sensor (Polarimetric L-band Multibeam Radiometer, PLMR) to measure soil moisture responses after a rainfall event in a 46km^2 catchment. The paper looked at the conceptualizations of our current understanding of landscape controls that influence the soil moisture patterns in the landscape. Three indices were used for a visual comparison. (1) A weathering index (2) Topographic Wetness Index (TWI) and (3) SPOT satellite imagery for land cover. Each of these data sources indicated some areas of soil moisture responses from the PLMR. The authors indicate that the next step in this study are to look at multi criteria analysis of terrain and land cover indexes to try and find the correct mix of variables needed to represent the PLMR images so that downscaling studies from coarser PLMR data can follow.

This type of study adds to our understanding of where terrain parameters (such as TWI) are useful predictors of soil moisture and where other factors dominate.

Manion G

The inherent nonlinearity commonly encountered in large scaled ecological data sets often presents problems for linear regression models generated with data from highly diverse biological groups, such as plants and invertebrates. This can be especially frustrating when working in regions exhibiting high rates of spatial turnover in biological composition.

Novel techniques such as generalised dissimilarity modelling accommodate this nonlinearity with the application of piecewise polynomials or splines to address the curvilinear relationship between increasing ecological distance and, observed compositional dissimilarity between sites. But to make spatial predictions using raster data, one needs to be able to use the modelled coefficients to transform environmental surfaces.

This paper presents a flexible technique that has many applications, not only ecological, to enable non-linear transformations of raster data.

3. DISCUSSION AND CONCLUSIONS

The discussion points and conclusions from Modsim07 are still current although the papers from this session indicate progress, particularly in technique and software development, catching up with the data collection technologies. The following points are from Modsim07 with comments with respect to progress and relevance to Modsim09 papers.

- that we are at an inconvenient stage in terrain analysis research where we can capture and store fine scaled DEMs but to a large degree we are only just beginning to work out how to process, transfer and manipulate these data sets. ***Still true but evidence of trying to close the gap.***

- as a response this session has established the view point that a high resolution DEM is relative to the scale of the landscape process you are trying to represent, and to overcome data handling, storage, transferability issues, authors in this session simplified high resolution DEMs to give more representation in areas where the landscape processes are needed and remove data in areas of less relevance. ***Not relevant this time***

- the challenge for researchers is to not be driven by technology of DEM data capture but to find a suitable resolution to answer the question being asked. This requires an assessment of the most viable coupling of spatial resolution and coverage area. In some cases the best technologies still cannot quite match our technical requirements, such as identifying floodplain channel networks. ***Still being driven by technology except maybe Photsynth which caught up with an existing need.***

- another consideration when selecting a DEM resolution is that we need to consider that as DEMs become finer and more detailed they will become more susceptible to becoming outdated in the vertical context. Some future research questions that have arisen from this session are***; Still true and photosynth type***

technology helps, Lidar on the other hand, with apparently substantial systematic errors, may not give the correct answer twice.

• We need to be careful that the algorithms we are developing for processing and manipulating DEMs will work for DEMs acquired by different techniques. The most common problem will be that algorithms developed to work with smooth interpolated DEMs may not work on the noisy DEMs resulting from some data capture techniques. We should not expect users to have to remove noise in order to apply routine algorithms. ***Done in principle Hutchinson et al – big step in that direction.***

• We need to develop a library of algorithm techniques to avoid duplication of effort as we now begin advancing our research direction towards using finer scaled DEMs. We should encourage use and refinement of good methods rather than the creation of a range of competing slightly different methods. ***Still relevant particularly for Lidar processing it seems***

• What use can we make of the multiple returns acquired from data acquisition techniques such as LiDAR? ***Bathimetry is a good start - innovative***
• What are the most efficient ways to utilise technology for data storage and handling. Are new DEM storage formats required in addition to fixed resolution grids? ***Nothing new in this area yet***
• Can coupling of other data sources with DEMs increase the interpretability of data sets without necessarily needing to use finer scaled DEMs? ***Nothing new in this area yet***
• Can we integrate DEMs at different resolutions to provide different but compatible elevation data for different purposes? ***Nothing new in this area yet***
• Can we provide good advice on fitness-for-purpose of different DEMs? Can we provide tools for DEM quality assessment? ***Nothing new in this area yet***

We are seeing development of new software such as the revised ANUDEM to account for new dense-noisy data sets that are applicable from the SRTM (30m res) down to the Photosynth (2.5cm res) scales.

We are, however, not seeing new terrain analysis methods being developed that recognise the different nature of high resolution data like Lidar. The representation of channels is an area of concern: most analysis methods still consider a channel to be a single pixel wide. This has been relatively inoffensive while working at 20 – 30 m resolution, but becomes increasingly untenable at 10, 5 and 2 m resolution. Hence the attraction of combining channel bathymetry with terrestrial DEMs. But that does not solve the problem of estimating hydrological properties such as contributing area and slope in channel areas. The assumption that water flows according to the local surface slope makes no sense where the surface is covered in flowing water. We need to find better ways of representing channels that can be linked to practical hydrological models - a middle ground between simplistic terrain analysis and detailed hydrodynamics.

Perhaps we need to renew the conversation between the DEM community and the hydrology community.

For MODSIM11 we would like to encourage participants of this session to consider these research questions and prepare papers that will progress our understand for data capture, processing, integration and application of high resolution DEMs.

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REFERENCES

All papers cited are from this session.