Quality Management for 3D/4D Meteorologic Data with Paraview and GRASS GIS

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Abstract

Data quality control by visualisation is a commonly applied method, but it is limited to two-dimensional data and is not useful in very large datasets. In a case study we applied this technique to soil erosion caused by heavy precipitation. The data input for this erosivity study is provided by weather radar. Artefacts in the radar signal and errors in the processing chain have to be identified and filtered before feeding the radar-derived precipitation data into erosivity models.

To highlight the future potential of FOSS geoinformatics tools for advanced 3D/4D visualisation we showcase a work in progress based on the tools GRASS GIS and PARAVIEW for visual quality control. In the future, these tools could be equipped with web service interfaces (e.g. OGC WPS) and could be orchestrated in a scientific work flow. The power of this processing chain could be enhanced by the utilisation of emerging Grid technologies.

1. Introduction

FOSS tools in the field of Geoinformatics provide options for advanced 3D/4D visualisation. To highlight the future potential, we showcase a work in progress based on the tools GRASS GIS and PARAVIEW for visual quality control for weather radar data products used in a soil erosion study from South Africa.

The large bodies of data collected by observing systems cannot be assessed easily by visual inspection because the number of data objects is too large and often the data have more than two dimensions. Since most pre-view formats are limited to two-dimensions, new pre-view formats are needed. In our test case we used FOSS components to routinely produce pre-views of radar precipitation data for studies on soil erosion.

Soil erosion is a major factor in environmental degradation processes that cause a demise of farming and widespread poverty. Soil erosion is influenced both by natural and man-made causes. Major agents of soil erosion are heavy precipitation events, e.g. thunderstorms, where the run-off erodes the top soil layer and cuts deep gulleys into the landscape.

In our case study we looked at soil erosion caused by heavy precipitation, especially the rainfall erosivity factor which controls the active erosion process. The precipitation data are derived from weather radar data, which were kindly supplied by the South African weather service METSYS (METSYS 2008) for previous work in this area (Löwe 2003). However, artefacts in the radar signal and errors in the processing chain have to be identified and filtered before feeding the radar-derived precipitation data into erosivity models.

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In our test case, a new class of erosivity models was introduced (REI: Rainfall Erosivity Index), which includes the temporal change of precipitation input over an area (Seuffert, Busche and Löwe 1999). This approach differs from the standard approach, which only considers the sum of precipitation at a given location. While the optimum parametrisation of the model remains to be defined, it could be demonstrated that the model output, based on radar-derived REI data, compares well with the expected results (Löwei, n press 2008). Attempting to set up proper parameters for the erosivity model requires rainfall maps portraying the actual precipitation.

Maps of rainfall fields are traditionally interpolated from the observations of networks of single point rain gauges. Because of the limited availability of such networks and the difficulties involved in the interpolation of non-equidistant data grids, weather radar provides the only available spatially continuous input data for such erosivity studies.

Ground based radar stations scan the lower atmosphere for distances of up to 200km and up to 18 km altitude. A dataset, which describes the reflectivity of the hydrometeors (i.e. rain, snow, etc.) within the observed volume of space, is generated every five minutes. The volume of the resulting data voxels is 1 km^3.

As the most common visualisation, the vertical axis of the 3D reflectivity volume is collapsed onto a 2D map of maximum reflectivity. The rainfall fields are then derived from this map of maximum reflectivities. The resulting precipitation fields are the input for erosivity models.

2. Precipitation Radar Images - Preview Formats

The model has been set up using GRASS GIS in combination with a Clips Expert System (CLIPS 2008) assessed via CAPE (CAPE 2008).

In the test case, it was necessary to monitor both the quality of the input data stream and the output stream of erosivity maps created by simulation.

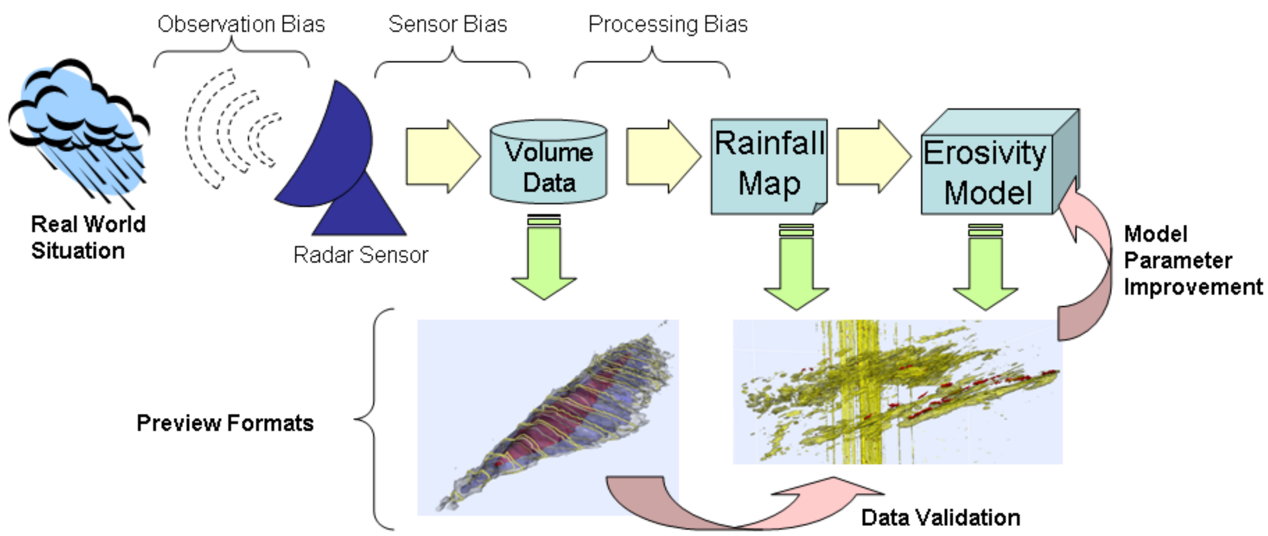

Figure 1. Overview over the combined use of two preview formats for radar data validation and the iterative improvement of erosivity model parameters. Each preview image summarises the data

Daily preview images of the recorded radar reflectivity volumes for the test region for selected days were created. This allowed us to retrospectively identify erosivity model output generated from biased precipitation data.

The ingestion of the radar reflectivity volumes and the derivation of precipitation maps was handled with GRASS GIS (GRASS Development Team 2008) . Since GRASS allows for 3D-Volume creation and processing, the preview formats were derived from the geo-referenced input data.

The NVIZ 3D-visualisation tool is part of GRASS and allows direct access to the spatial data. The currently available options for volume rendering are limited, which led to the use of Paraview for visualisation and animation (Paraview 2008). GRASS and Paraview can be used in a loosely coupled scenario based on using the file system for data transfer. At the current state of development, the only common file format is a non-binary ASCII-format, which results in rather large files for each preview image (600Mb). Once binary exchange file formats will be supported by GRASS, the transfer process will improve significantly.

Obviously, errors and artefacts in the primary 3D data will affect the derived 2D rain rate map. However, erroneous data cannot be identified once they are transformed into a 2D dataset. Errors in the radar signal may result from atmospheric conditions (radar-beam foreshortening, attenuation effects, sunrise), ground target reflections (tall buildings, ships or topography), or sensor related data bias (processing errors within the radar sensor and data generation). Any kind of systematic errors or bias hidden in the input data will severely affect the model output. To improve the quality of erosivity models requires some form of quality control on the data input.

Preview formats of data are commonly used tools to achieve an overview over the content and quality of a given set of data. However, high volume spatio-temporal data preview formats have to be more sophisticated than merely reducing the resolution displayed. In addition, the processing power needed to produce preview objects might be considerable (Klump, in press 2008).

Visual inspection of the radar data in our study is possible, but not feasible since radar snapshots of the atmosphere are generated every five minutes. Thus the complete set of data for one year would comprise 105,120 datasets, which is clearly beyond the capacities of processing by human inspection. Large datasets, like in this case study, call for new pre-view formats that would allow a visual inspection of data quality.

3. The Contoured Frequency by Altitude Diagram (CFAD)

A common preview format used in meteorology is the Contoured Frequency by Altitude Diagram (CFAD) that collapses a 3D weather situation into a 2D diagram of weather intensity against altitude (Figure 2) (Yuter and Houze 1995). Isolines of radar reflectivity are used to contour the data and aid interpretation. The CFAD only shows a snapshot of the weather situation but requires image animation to show the dynamics of the weather processes over time.

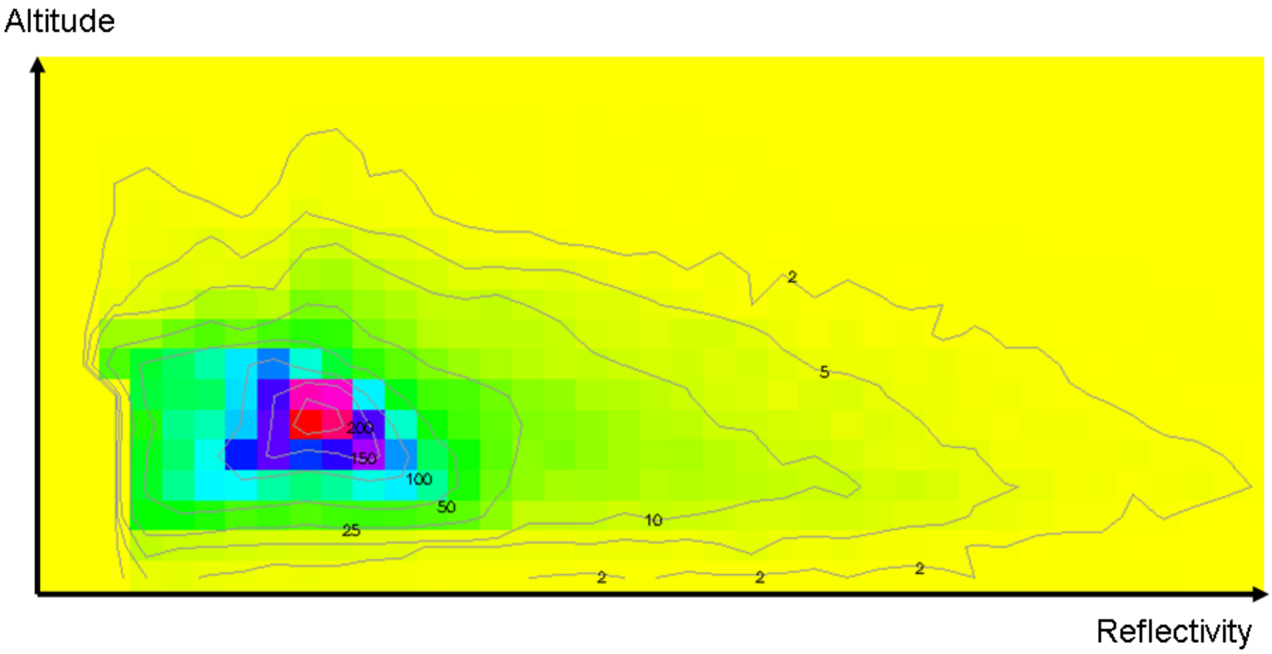

Figure 2. Contoured Frequency by Altitude Diagram (CFAD). Numbers on contour lines give the number of voxels in the observation area with a given radar reflectivity. The CFAD gives a snapshot of weather intensity at different altitudes in the lower atmosphere

4. Adding the Time Dimension: Introducing the CFATD

Adding the time-dimension extends the CAFD (Figure 2) to a Contoured Frequency by Altitude and Time Diagram (CFATD, Figure 3). Data can be contoured in space and show as "isotubes" instead of isolines. The CFATD gives a quick overview of the weather situation and its evolution over time, but also readily shows systematic errors in the data. The main benefit of this approach is the accessibility of the preview format to audiences beyond the field of radar meteorology.

The use of scale planes for altitude, time and reflectivity thresholds allows to assess the provided information. This display of CFATD diagrams helps the observer to identify time intervals of relevant data of extreme weather events by defining a reflectivity threshold as a kind of filter.

In addition, the overall shape of the isotubes provides clues towards the quality of the data. It allows a meteorologist to judge the state of the lower atmosphere, while non specialist are provided with a basic estimate of the performance of the sensor system. Preview images of systematically biased radar signals deviate from the rather "organic" appearance of "well formed" CFATD diagrams and appear more "blocky". Analysis of the data quality based on CFATD thus improves the reliability of the derived erosivity data sets.

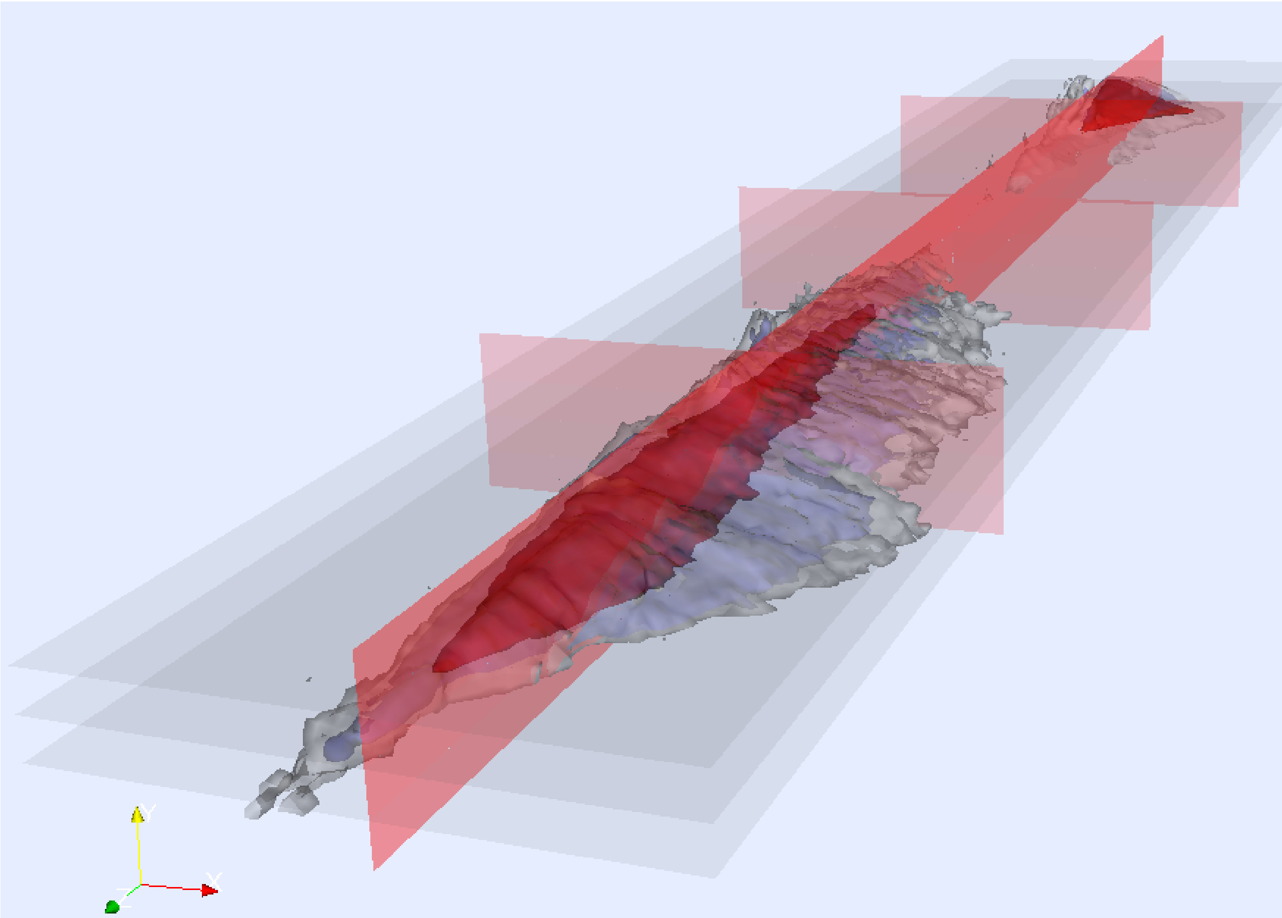

Figure 3. Example of a CFATD. Note the scale planes segmenting the volume in the time (vertical red planes), altitude (horizontal grey planes) and reflectivity (single red plane) dimensions. The time-dimension spans along the volume body from the foreground of the figure to the background. This figure does not provide information about the location of the reflectivity counts

5. Radar Reflectivity in Space and Time

Since the output of the erosivity model is highly dependent on the quality of the precipitation input data both in time and in space, 2D animations were used from the start to verify the plausibility of the spatial pattern. Similar to weather radar animations used in weather forecasts, the moving precipitation fields were shown, which were trailed by ribbon like erosivity fields resembling shadows. However, this kind of visualisation was not suitable to provide a overview over the observed time span. The calculation of totals for each spatial cell would lose the specific temporal pattern which is unique to the model approach. Therefore, the previously animated erosivity/rainfall maps were stacked into another 3D-volume which provides information about the temporal pattern of both precipitation strength and the model response (Figures 4-6).

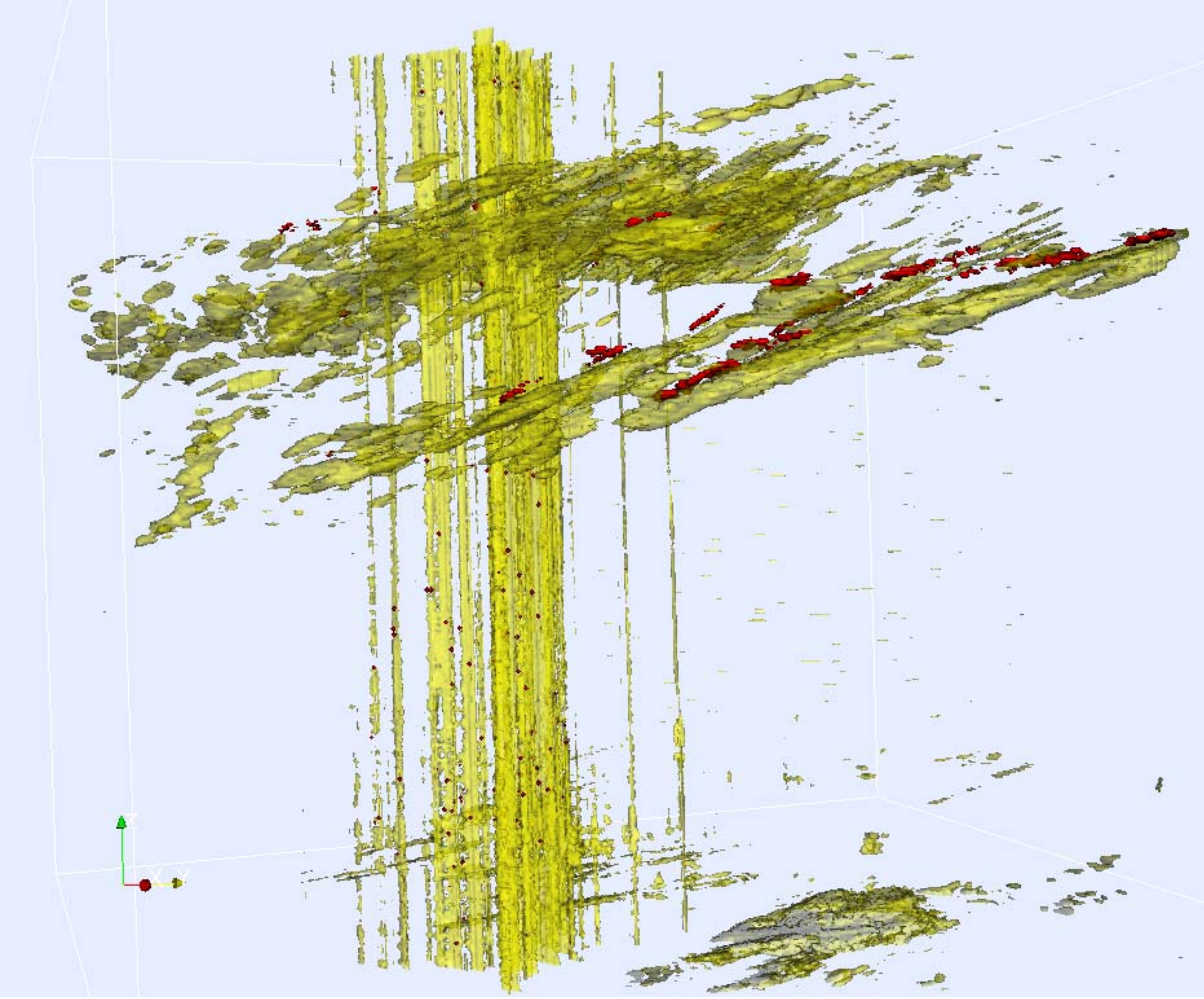

Figure 4. Preview image of a full day of precipitation fields (yellow) and resulting erosivity signals (red). The bottom of the image shows the start of observed time span while its top shows the end. The vertical linear structures represent noise caused by topographical radar echos. The upward angle of the shown precipitation fields and the derived erosivity impulses correspond to speed of motion. Please note that the image does not show real louds of water vapour. The cloud-like structures indicate instead time intervals during which precipitation occurred at a given location

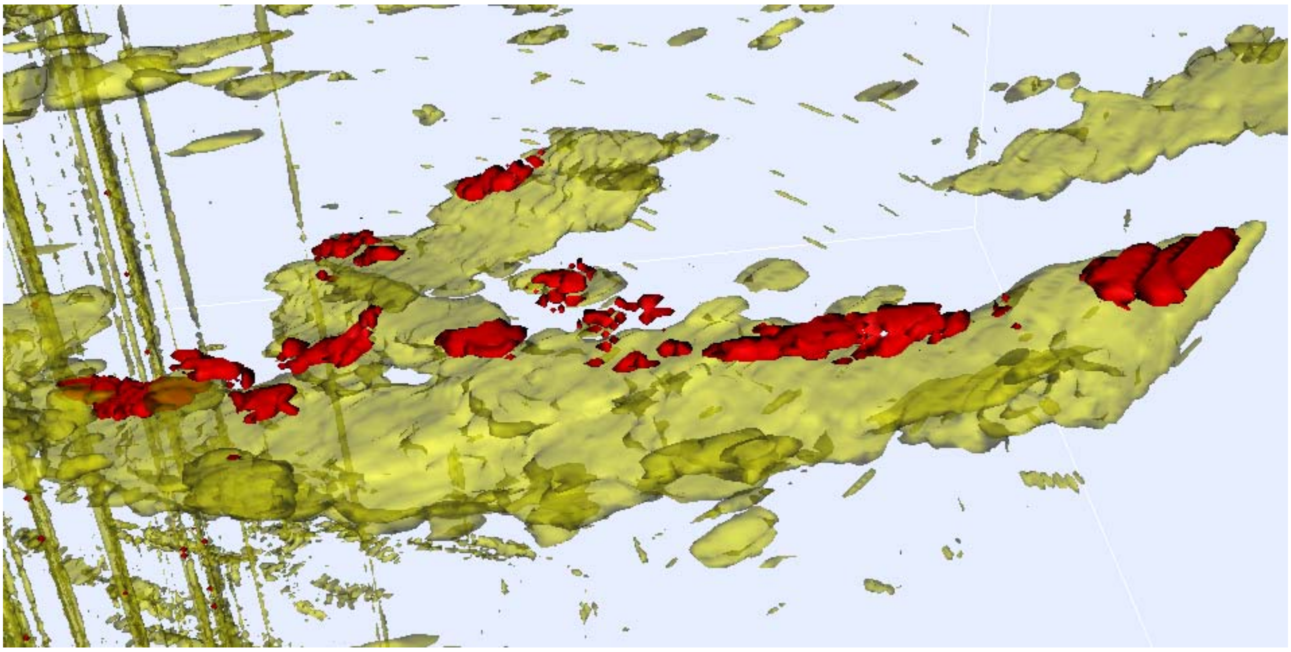

Figure 5. Detailed top-view of the track of a precipitation field (yellow) and the derived erosivity pulses (red). Note the highly localized distribution of the erosivity pulses. This information can be used to calibrate the interaction between point-sampling rain gauge networks, weather radar calibration and soil erosion plots

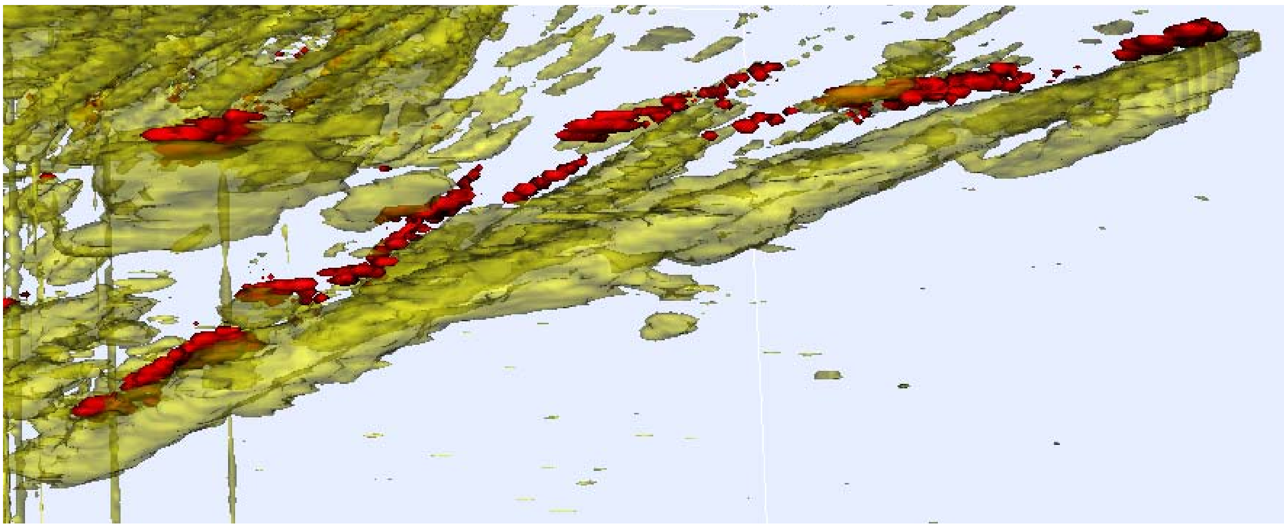

Figure 6. Same precipitation field as shown in figure 5. Its resulting erosivity pulses shown in side-view. Note the temporal delay between the yellow precipitation volume and the red erosivity pulses. This is caused by the temporal shut-off constraint by the model. While the erosivity pulses appear opaque in this figure, the model-predicted strength of the erosivity signal can be used to iteratively improve the model output

6. Conclusions

Research conducted with tools offered by information technology provide us with a wealth of data, too large to glimpse through the narrow formats offered by common preview formats (Klump, in press 2008). Our case study on radar derived precipitation data for erosivity models showed that new pre-view formats based on automated processing of large datasets have the potential to significantly increase the quality of input data fed into, and results derived from, numerical modelling.

"Preview-Space" and the 4D space of the original meteorological observation can be brought into overlap only by reducing the number of dimensions. As demonstrated, FOSS GI tools proved to be suitable for populating "Preview-space" with content. The tools also showed to be powerful enough to be used for exploratory data analysis by charting new features hidden in the vast amounts of data.

7. Outlook

In this work we described a processing chain for novel pre-view formats as a dedicated structure. However, with a Service Oriented Architecture approach, data sources and data processing could be orchestrated into processing chains for on-demand production of complex data products.

In our example, CFATDs as preview formats could be routinely generated through OGC Web Processing Services (WPS). WPS is a relatively new technological standard, one of its first implementations is PyWPS, a Python-based WPS package. This package could be used to provide a standardised web-service interface to access GRASS (PyWPS 2008).

Large data volumes require powerful computing resources that are not readily at hand. The emerging Grid technology might be an approach to provide much more powerful processing services to work with large datasets. The added computational power could even be used for running of and for comparing the results of ensemble simulations.

The significance of the orchestrating data sources and complex web services, such as those offered by the Grid, into digital work flows is expected to grow in the foreseeable future (Klump, Löwe, Häner and Wächter 2007). Two examples of such endeavours are the Grid project GDI-GRID (2008) and the e-science project WISENT (2008).

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