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Development of GRASS GIS Modules to Generate DEM for Geological Modeling

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Abstract

The purpose of this study is to integrate a geological model with various geospatial data in Geographical Information System (GIS) for better understanding of subsurface condition. GRASS GIS is one of the most powerful free and open source GISs that support various raster/vector data. This GIS offers many modules for management and analysis of geospatial data. However, GRASS GIS has no module for utilizing geological filed data like strike-dip in generating a Digital Elevation Model (DEM). In this study, three new modules for generating a DEM based on geological filed data have been developed. The developed modules contributes to high-accurate surface-based geological modeling in GRASS GIS. In this paper, we describe the detail of developed modules and their application into a three-dimensional geological modeling.

Keywords: GRASS; GIS; DEM; BS-Horizon; Geological Modeling

1. Introduction

After the 2011 off the Pacific coast of Tohoku Earthquake, prevention/mitigation of earthquake-induced disaster are growing concerns among the public in Japan. In particular, subsurface geological condition is one of the biggest public concern in urban areas because it greatly affects earthquake-induced disaster such as an amplification of ground motion in plane areas and a liquefaction/subsidence in coastal areas (e,g, Kazaoka et al., 2015). Three-dimensional (3D) geological modeling is an effective method to understand subsurface geological condition. In Japan, some researches have been made on 3D geological modeling in urban areas by the national government, research institutes, local governments, and universities (e.g. Nakazawa et al., 2016). In general, a 3D geological model is constructed on the basis of geological data obtained by field survey such as drilling surveys, trench surveys, and reconnaissance, and is provided in various model types. For example, surface models, solid models, and voxel models. As for developments of 3D geological modeling systems, many systems have been developed all over the world. These systems often provide modules not only for 3D modeling on the basis of many kinds of geological filed data but also for model-based geological analysis like exploration and mining. However, most modeling systems do not support geospatial data except for geological data. Even if the modeling system supports some popular geospatial data, it often takes a quite high cost. As for Geographical Information System (GIS), just like geological modeling system, most GIS supports popular geospatial data but do not provide modules for utilizing geological data.

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Integration of popular geospatial data with geological data like 3D geological model must lead to better understanding of subsurface geological condition and help hazard mapping for reducing impacts and risks of geological disasters. The purpose of this study is to implement an environment that everyone can utilize geospatial data including geological data with free- or low-cost. As a first step of our purpose, we have developed new modules available in GRASS GIS (GRASS Development Team, 2016a). The new GRASS GIS modules provide a capability to generate Digital Elevation Model (DEM) of geological surface on the basis of elevation data and strike-dip data using spline-fitting algorithm proposed by Nonogaki et al. (2012). The results of this study enables us not only to utilize geological field data but also to realize 3D geological modeling in GRASS GIS without any helps from other geological modeling systems and GISs. This paper reports the detail of the developed modules.

2. Base Software

GRASS GIS and BS-Horizon (Nonogaki et al., 2012) are used as base software for developing new modules to generate DEM. In this chapter, summary of each software are described.

2.1. GRASS GIS

GRASS GIS is one of the free and open source GISs that work in MS-Windows, Linux, Mac OSX. "GRASS GIS is used in academic and commercial setting around the world, as well as by many governmental agencies and environmental consulting companies. This GIS provides tools for spatial modeling, visualization of raster and vector data, management and analysis of geospatial data, and the processing of satellite and aerial imagery. This GIS also provides the capability to produce sophisticated presentation graphics and hardcopy maps. GRASS GIS has been translated into about 20 languages and supports a huge array of data formats" (GRASS Development Team, 2016a). From GRASS 6.4, wxPython were introduced for more flexible implementation of Graphical User Interfaces (GUIs). In this study, we have used Linux version of GRASS 6.4.4 to develop the new modules.

2.2. BS-Horizon

BS-Horizon is one of the free open source gridding tools in the field of geology and is coded in FORTRAN77. This tool is designed to determine a shape of geological surface, such as geological interface and geophysical/geochemical iso-surface, on the basis of irregularly distributed point data using B-spline fitting technology. Fundamental field data for gridding are elevation data and strike-dip data obtained from geological filed survey. Elevation data are used for constraining the height of the surface. Further, they are classified into two types: equality data and inequality data. Strike-dip data are used for constraining the trend of the surface. The characteristics that both inequality data and strike-dip data are available is unique one among existing gridding tools with B-spline fitting technology. For detail of algorithm used in the tool, see Nonogaki et al. (2012).

3. Development of New GRASS GIS Modules

For developing new GRASS GIS modules, we have prepared an xml file for GRASS GIS Layer Manager, script files for command GUI, and binary files for generating DEM. In this chapter, summary of the xml file and script files are described.

3.1. menudata.xml

menudata.xml defines menu labels (strings) displayed in GRASS GIS Layer Manager. This file must be located in a directory "$GISBASE/etc/wxpython/xml/", where $GISBASE is an install directory of GRASS GIS (e.g. /usr/lib/grass-6.4.4). Figure 1 shows an example of customized menudata.xml. In this example, definition of one main menu label and three sub menu labels are added. Text in <command> tag defines a name of new module (command). It must be same as the one of script file described in next section.

3.2. Script files for command GUI

GRASS GIS provides parser support including an auto-generated GUI (GRASS Development Team, 2016b). Thus, to develop GUI for new module (command), we have only to prepare a script file that identifies GUI setting and processing contents. The script file must be located in "$GISBASE/scripts/". Available script languages are shell, python, or perl. In this study, we have prepared three shell script files: v.in.bshorizon, v.surf.bshorizon, and r.in.bshorizon. Figure 2 shows header definitions of v.in.bshorizon. For detail of script format, see GRASS Development Team (2016b).

```
      </items>
    </menu>
    <menu>
      <label>Geomodeling</label>
      <items>
        <menuitem>
          <label>BS-Horizon opt import</label>
          <help>Import BS-Horizon opt data into a raster map.</help>
          <keywords>raster, import</keywords>
          <handler>OnMenuCmd</handler>
          <command>r.in.bshorizon</command>
        </menuitem>
        <menuitem>
          <label>BS-Horizon xyz import</label>
          <help>Import BS-Horizon xyz/dip data into a vector map.</help>
          <keywords>vector, import</keywords>
          <handler>OnMenuCmd</handler>
          <command>v.in.bshorizon</command>
        </menuitem>
        <menuitem>
          <label>DEM generation from BS-Horizon xyz data</label>
          <help>Bicubic spline interpolation with BS-Horizon.</help>
          <keywords>vector, interpolation</keywords>
          <handler>OnMenuCmd</handler>
          <command>v.surf.bshorizon</command>
        </menuitem>
      </items>
    </menu>
  </menubar>
</menudata>
```

Fig. 1. Example of customized menudata.xml.

```
#%Module
#% description: Import BS-Horizon xyz data into a vector map.
#% keywords: vector, import
#%End

#%option
#% key: input
#% type: string
#% description: Name of BS-Horizon xyz data (.xyz) or strike-
#% gisprompt: new_file,file,file
#% required : yes
#%end

#%option
#% key: type
#% type: string
#% options: elevation,strike-dip
#% description: Data type
#% answer: elevation
#% required : yes
#%end

#%option
#% key: vect
#% type: string
#% description: Name of output vector map
#% gisprompt: new,vector,vector
#% required : no
#%end
```

Fig. 2. Example of GUI setting written in shell script.

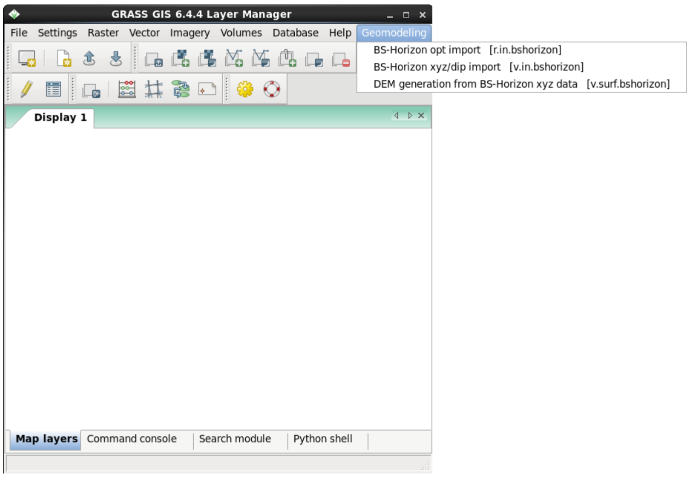


Fig. 3. Customized GRASS GIS Layer Manager automatically-generated on the basis of menudata.xml shown in Fig.1.

4. Results

Three new GRASS GIS modules have been developed: (1) v.in.bshorizon, (2) v.surf.bshorizon, and (3) r.in.bshorizon. These modules can be carried out from the customized GRASS GIS Layer Manager (Figure 3). In this chapter, roles and parameters of each modules are described.

4.1. v.in.bshorizon

This module is for importing elevation data and strike-dip data with BS-Horizon format into GRASS GIS. Figure 4 shows a GUI of v.in.bshorizon. To carry out v.in.bshorizon, we have to specify following parameters: a file name of input data and data type. We can optionally give a layer name of output vector points.

The format of elevation data is (id, x, y, z, l), where id is a unique number, (x, y, z) is a coordinate of the survey point. l is an identifier to distinguish between equality constraints and inequality constraints and has 0, 1, or, −1. $l = 0$ gives equality constraint that the surface passes through the location (x, y, z). $l = 1$ and $l = -1$ give inequality constraints that the surface passes over and under the location (x, y, z) respectively. The final line of elevation data must be (0, 9e9, 9e9, 9e9, 9). The format of strike-dip data is (id, x, y, z, $trend$, dip), where id is a unique number, (x, y, z) is a coordinate of the survey point, dip is a slope angle of the surface, and $trend$ is a direction of maximum dip measured clockwise from north. The final line of strike-dip data must be (0, 9e9, 9e9, 9e9, 9e9, 9e9). Extension of elevation data and strike-dip data must be ".xyz" and ".dip" respectively. The imported data can be drawn in Map Display by d.vect module as shown in Figure 5.

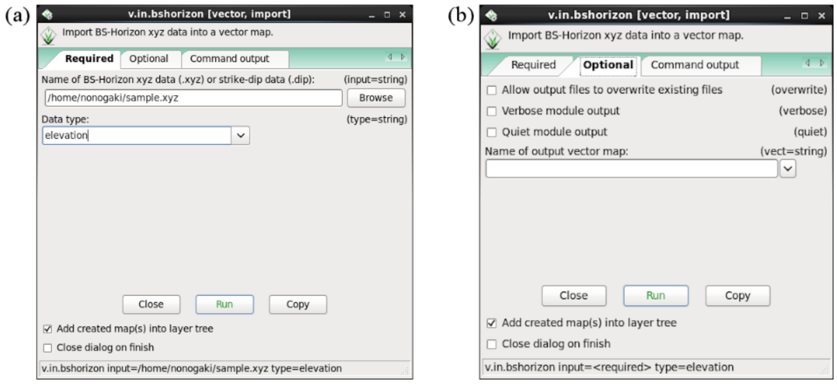


Fig. 4. v.in.bshorizon. (a) required parameter tab. (b) optional parameter tab.

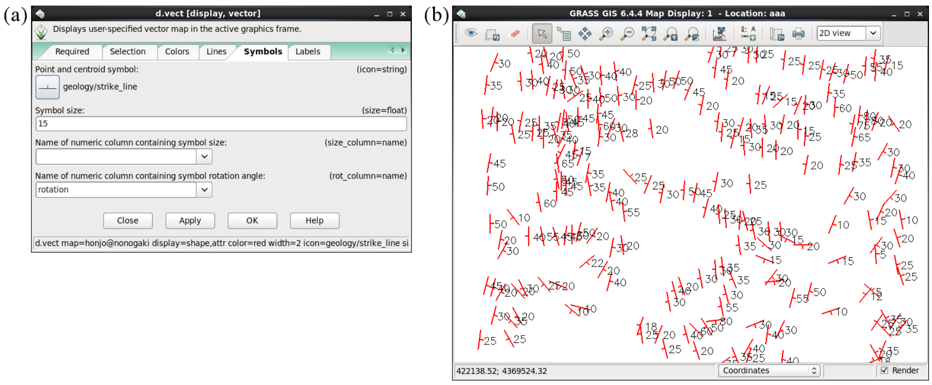


Fig.5. Example of 2D Visualization of impoerted strike-dip data. (a) d.vect command setting. (b) distribution map of strike-dip data. The strike-dip data are extracted from hand-drawn geological map (Osawa et al., 1977).

4.2. v.surf.bshorizon

This module is for generating a DEM on the basis of vector point layers imported by v.in.bshorizon. Figure 6 shows a GUI of v.surf.bshorizon. To carry out v.surf.bshorizon, we have to specify following parameters: a layer name of input vector elevation points, number of domains for defining spline bases with respect to west-east direction and south-north direction, parameters for adjusting a weight balance between accuracy and smoothness of the surface, and a layer name of output raster DEM. We can optionally use strike-dip data as fundamental data for generating the DEM. In this case, a layer name of input vector strike-dip points and a parameter for adjusting a weight balance between elevation data and strike-dip data are required. For detail of each parameters, see Nonogaki et al. (2012). The generated DEM can be output in a format of BS-Horizon optimal surface, which has an extension ".opt". Figure 7 shows an example of the DEM generated by v.surf.bshorizon on the basis of elevation data and strike-dip data.

4.3. r.in.bshorizon

This module is for importing BS-Horizon optimal surface (".opt" file) into GRASS GIS as a rater DEM. Figure 8 shows a GUI of r.in.bshorizon. To carry out r.in.bshorizon, we have to specify following parameters: a file name of input BS-Horizon optimal surface, coordinates of west-, south-, and north-edge of output raster DEM, and number of grid cells with respect to west-east direction and south-north direction. We can optionally give a layer name of output raster DEM.

5. Application of DEMs to 3D geological modeling

DEMs generated by the new modules are applicable to 3D geological modeling in GRASS GIS. For example, according to Masumoto et al. (2004), we can construct a surface-based 3D geological model using DEMs of geological interfaces. Figure 9 shows an example of 3D geological modeling using this method. Fundamental data

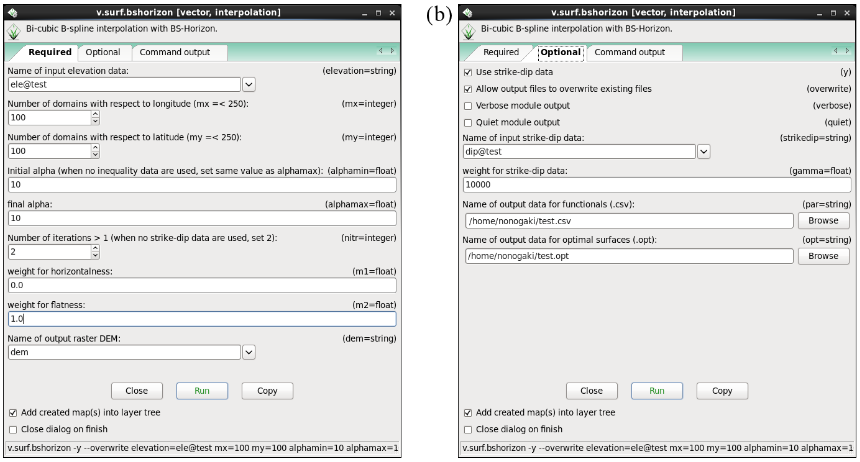
(a) (b)


Fig.6. v.surf.bshorizon. (a) required parameter tab. (b) optional parameter tab.

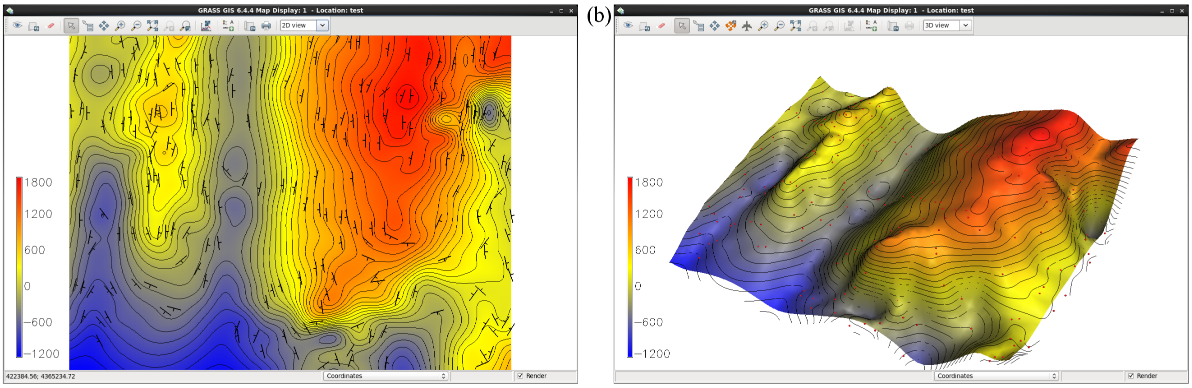
(a) (b)


Fig.7. Example of DEM generated by v.surf.bshorizon. (a) 2D visualization. (b) 3D visualization.

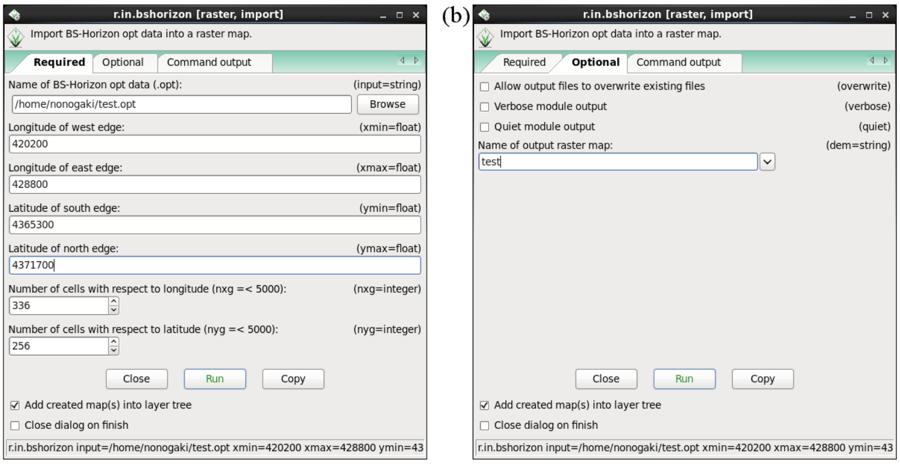
(a) (b)


Fig.8. r.in.bshorizon. (a) required parameter tab. (b) optional parameter tab.

for generating DEMs are elevation data and strike-dip data extracted from a hand-drawn geological map (Osawa et al., 1977). Figure 9 clearly shows fold structure in modeling area. In this method, the 3D geological model is virtually constructed by combining DEMs of geological interfaces and a logical model of geological structure (Shiono et al., 1998). Therefore, we can easily visualize vertical and horizontal cross-sections of the 3D model as shown in Figure 10. 2D and 3D visualizations of geological structure like Figure 10 are greatly useful for better understanding of subsurface geological condition. In addition, the geological model constructed in GRASS GIS can be integrated with various geospatial data. This must contributes to expansion of the range of geospatial analysis capable in GRASS GIS. For example, 3D visualization of potentially hazardous strata with topographical map is quite effective to management of urban infrastructures and industrial constructions.

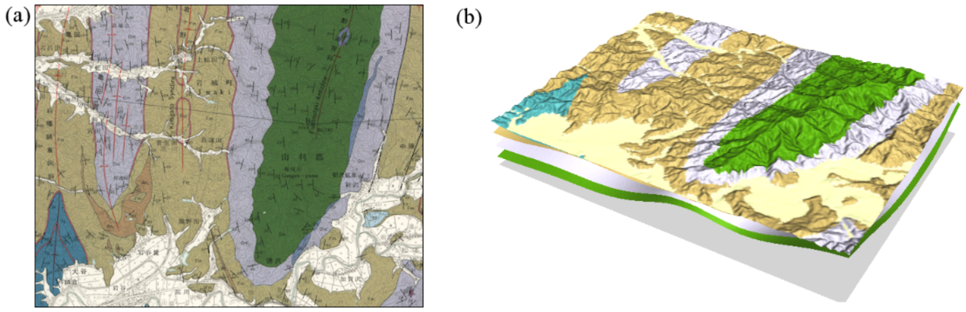


Fig.9. Example of 3D geological modeling. (a) geological map used for extracting elevation data and strike-dip data (Osawa et al., 1977). (b) 3D geological model.

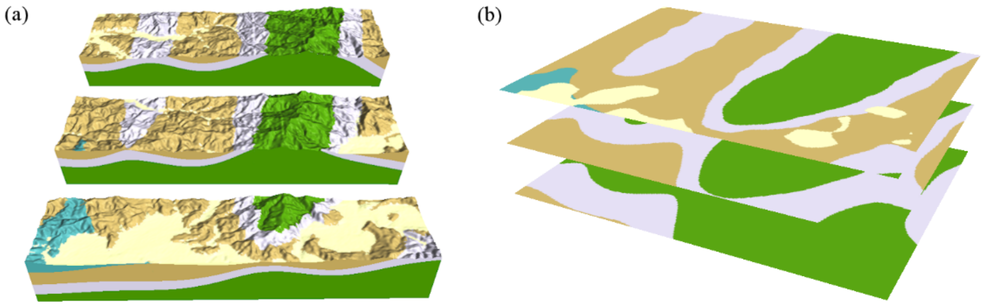


Fig.10. Cross-sections of 3D geological model. (a) Vertical cross-sections. (b) Horizontal cross-sections.

6. Conclusions

In this study, three new GRASS GIS modules have been developed. The modules enable to generate a DEM of geological surface in GRASS GIS. In addition, the modules realize integration of the geological model with various geospatial data without any helps from other geological modeling systems and GISs. This must contribute to implementation of an environment suitable for utilizing geospatial data including geological data with free- or low-cost. Future works of this study are to develop a surface-based modeling modules based on Masumoto et al. (2004) and to develop a voxel-based modeling modules on the basis of borehole data.

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