

Reply to: Interactive comment on GO2OGS: a  
versatile workflow to integrate complex geological  
information with fault data into numerical  
simulation models  
Anonymous Referee #1

T. Fischer et al.

October 12, 2015

**Abstract**

We would like to thank the reviewer for the thorough review of our manuscript. We tried to address all comments and listed the changes as a summary below.

All edits are also signified in the updated manuscript with colored text. Unless stated otherwise, we will refer to the page and line numbers of the edited document in the way “p #, l #” (p for page, l for line).

Furthermore, we added an edited manuscript without showing the changes.

## 1 General comments

- 1.1 Structure: [...]** However, jumping between software description, study sites description as well as approaches and strategies included within the workflow makes the paper more complicated to understand. I recommend to the authors to check the overall structure to help the reader to get easier access to the content. For example, in section 1.2 there is site description which is not needed for the following sections; software description is followed by site description which is again followed by a software and literature study. The authors may check whether an inclusion of the literature study into the introduction is possible. Also section 2.2.2 could be shifted to a later position to differentiate between the explanation of the workflow and the validation set-ups. Rename subtitles may also help to clarify.

Thank you for the careful evaluation of the manuscript. We restructured the mentioned sections to improve the readability. With that, we tried to combine all necessary descriptions to the appropriate places, especially the description of setups A and B, which were located in subsection 2.2.2, are now part of section 1.2. Also, section 2.2.1, describing the results of step ② was restructured during the revision process.

- 1.2 Outlook:** In the outlook section a large part is describing possible improvements of the model, but this was only used for showing the applicability of the general workflow. Here the main focus drifts from the workflow into direction of the regional model. Please check if these statements are needed.

Thank you for addressing this issue. We revised the whole section, keeping the outlook for the numerical model, while providing possible solutions for the raised outlook questions, and additionally offering likely valuable improvements of the proposed workflow (see section 4.2).

**1.3 Generality: The workflow seems primarily thought to be used by OpenGeoSys modelers. How can the workflow be transferred to other software packages. This is discussed shortly in the conclusions and could be more highlighted.**

Thank you for this valuable comment. In our manuscript, we use OpenGeoSys to show the applicability of our workflow to integrate the hydro-geological information. In our workflow, we use open-source formats for the output of the intermediate or final resulting meshes, which was intended to make the workflow independent from OGS itself. Based on this comment, we hope we could clarify this even more in page 4, line 23, as well as through restructuring and revising the conclusions paragraphs in p 21, l 7 ff.

## **2 Specific Comments**

**2.1 Page 6310: Line 8: At this position the reader cannot know what is similar to the approach used here**

We deleted “similar” (page 2, line 8).

**2.2 Page 6311: Line 17: delete therefore**

We deleted “therefore” (p 3, l 18).

**2.3 Line 22: GOCAD was mentioned before, explain abbreviation the first time it is used**

Moved to first occurrence in text (p 3, l 6).

**2.4 Line 24: acquire information is better replaced by display information**

We emphasized the display of the information within the context (p 3, l 25ff).

**2.5 Page 6313: Line 9: Please explain abbreviations or provide references at the first time they are stated**

We added appropriate citations for GMSH [1] and TetGen [2] (p 5, l 22).

**2.6 Page 6317: Paraview is explained but there is a software section before (sections 1.2 and 1.3)**

Section 1.2 presents the fundamental motivation describing the necessary and required modeling tools. Section 2.1.2 describes the used methods to solve the

raised issues. Although we understand the motivation to combine and present the software in one section, we think that it is not necessary to know about Paraview in the problem description (1.2) but only in the methods section (2.1.2). Paraview could very well be replaced by any other visualization tool, while GOCAD could not that easily (albeit the generality of the workflow). Therefore, we think it was better to keep the current structure.

**2.7 Page 6318: Please see suggestion on the structure, the story of Set-up A ends here and is only in a section titled description of set-ups.**

In the course of restructuring (compare the reply to comment 1.1), we hope we could clarify the relevance of setup A.

**2.8 Line 8: If set-up A remains please refer after Influins to the literature study**

Due to the restructuring, the reference is given in the same paragraph now (see section 1.2).

**2.9 Page 6320: Line 6: This subtitle has no number?**

Thank you for the comment. We corrected the missing numbering (p 13, l 23).

**2.10 Line 21: a fault**

Corrected (p 14, l 11).

**2.11 Page 6322: Line 9 to 17: Are these equations really needed as they include widely used flow calculation principles.**

The groundwater flow equations can be formulated in various ways (e.g. by pressure or head). We wanted to give a clear explanation about the formulation we employed. Additionally, we used the equations to describe the boundary conditions. Therefore, we think it is better to include the mathematical description in this short manner.

**2.12 Line 25: meshes**

As we describe in p 6322, l 21 (original manuscript), we are only dealing with the mesh of setup B. The usage of the plural form (meshes) is therefore not appropriate. We hope we have solved possible confusions about the uses of the meshes through the rewritten section of site description (compare Replies 1.1 and 2.7).

**2.13 Page 6323: Line 12: were removed**

Corrected (p 16, l 25).

**2.14 Page 6324: Line 18: delete generally and include identical in this case**

Thank for the suggestion; we replaced the text passage (p 18, l 2).

**2.15 Line 24-29: What is the thickness of the high permeable layer compared to the other layers?**

The top layer is set to the first one or two upper cells of the mesh (“... all cells which own nodes that are exposed to the upper boundary ...”). Its thickness is less than 1 percent of the total thickness at the boundary regions and is even less in the central modelling region. We added a statement on the thickness in compare p 18, l 11f.

**2.16 Page 6326: Line 3: MatGroup is named material group in the previous text or MatG in table 1.**

Thank you for the remark. We substituted MatGroup p 19, l 16 using “material group”. In table 1 the abbreviation “MatG” is introduced in the table caption.

**2.17 Figures: Fig. 2: Reconstruct = Reconstruction**

Changed word in the figure. See Fig. 1 of **this** document.

**2.18 Fig. 3: Why Fig. 3 includes the geological units of Fig. 4 and Fig. 5?**

We put the legend of the geological units in a separate figure (Fig. 3) since the information of the geological units would be hard to read if put within, e.g. Fig. 2. Furthermore the legend is reused in Fig. 5 and Fig. 7. From our point of view, using a separate figure for the legend tremendously improves the spacing of the other figures.

**2.19 Fig. 3 is not mentioned in the text.**

Fig. 3 is mentioned in the captions of Fig. 2, Fig. 5 and Fig. 7.

**2.20 Fig. 5: Scale and orientation are missing**

The location and orientation of the fault within the study domain is given in Fig. 1.

We added length scales within the sub-figures (see Fig. 2 of this document).

**2.21 Fig. 6: There are colors on the right-hand side figures but no colored bars?**

We changed the colours of the example element at the right side to omit confusion, see Fig. 3 of this document.

**2.22 Fig. 8, 9 and 10 and page 6328, line 13-17: Why the difference between S1 and S2 scenarios is described. Intuitively, the importance of heterogeneous structures and faults is better shown when both scenarios are compared to measurements not to each other.**

Comparing the simulation results of the two scenarios we noticed huge differences in the flow paths (original Fig. 11), which was also a basic research question to be answered within the INFLUINS project. Based on the fact that we did not put too much effort in the calibration of the model (as this was not our intention), the heads did not show that fundamental differences. We therefore firstly think, that without any further calibration, a comparison of both scenarios to measurements would not add any scientific value to our study. This, however, could very well be of importance to our second conclusion, which is that the apparent differences in the flow paths have much stronger influences on subsequent questions of groundwater management and further simulations, eg. including mass or heat transport.

**2.23 Fig. 8: There are single columns of extreme higher thickness?**

These columns are the remaining elements of the faults that are not deleted in the process of removing the Basement (see Table 1 and Sect. 3.2.1 of the original manuscript). These single columns specifically visualize the position of the faults. We added an explanation to the caption of the figure.

**2.24 Fig. 9: Increase readability of axes!**

We improved the readability of the axes, see Fig. 4.

**2.25 Fig. 11: Increase resolution and readability of axes!**

We increased readability of the axes (see Fig. 5).

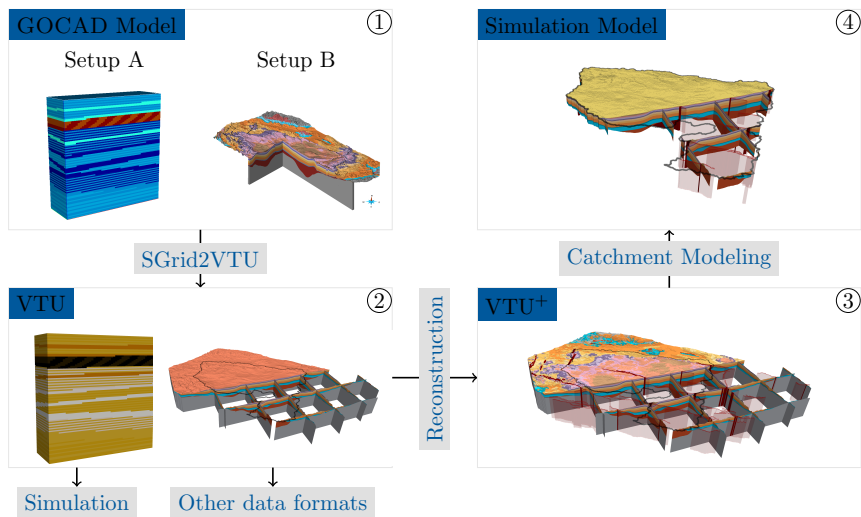


Figure 1: Workflow of GO2OGS for GOCAD to OGS mesh conversion; “Setup A” shows a model of different sedimentary layers; “Setup B” shows a model of the Thuringian Syncline (legend given in Fig. ??); see Sect. ?? for description of setups.

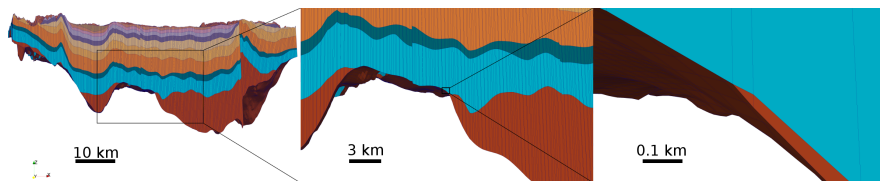


Figure 2: Mesh elements at non-continuous geological units, vertical cross section A–B (see Fig. ??) through GOCAD model at different magnification levels, vertical exaggeration 20 $\times$ , legend given in Fig. ?? .

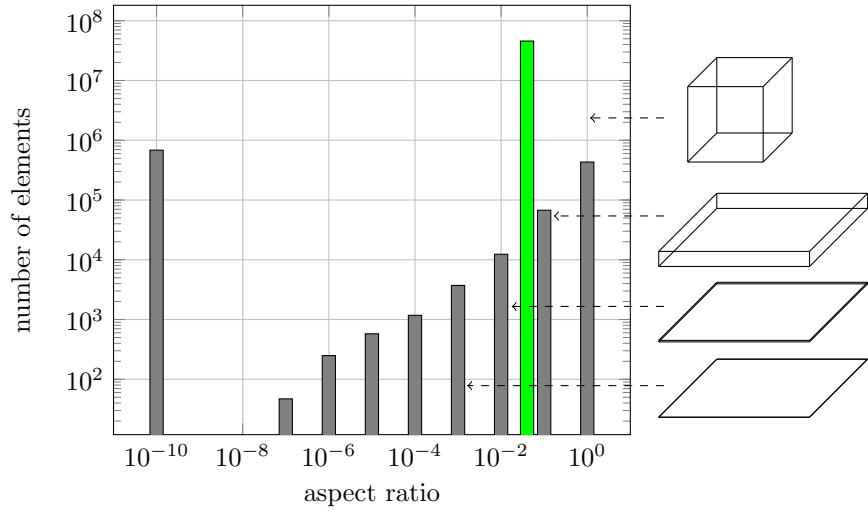


Figure 3: Histogram of aspect ratio classes for read GOCAD SGrid mesh data (gray) and reconstructed mesh data (green), sample elements for selected aspect ratios.

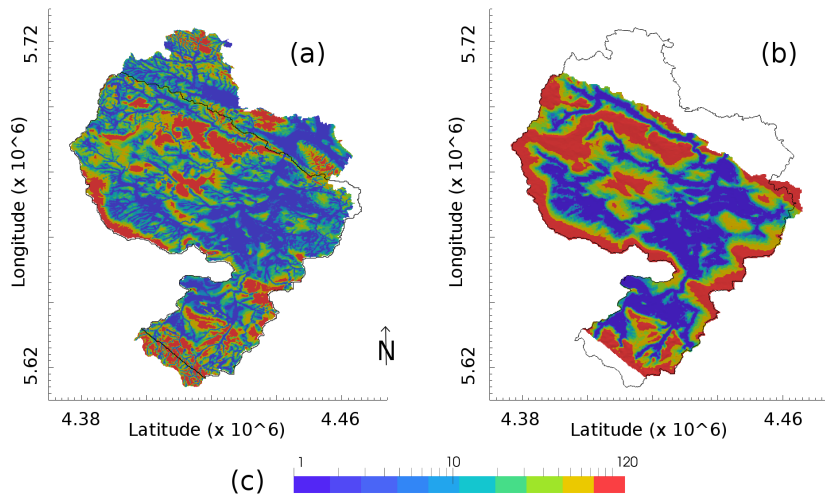


Figure 4: Comparison of observed and simulated depth from surface to groundwater level; observation data courtesy of TLUG, based on regionalized observations of groundwater head measurements: (a) observation, resolution  $10\text{ m} \times 10\text{ m}$ , (b) simulation, resolution  $250\text{ m} \times 250\text{ m}$ , (c) legend depth to groundwater surface (m).



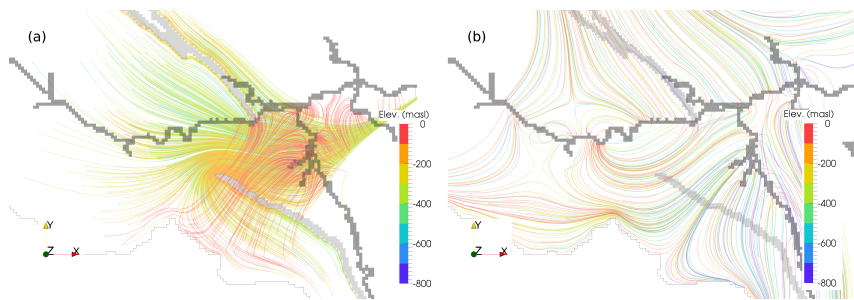


Figure 5: Detail of flow paths near faults and bottleneck structure, pathlines colored by elevation; area shown in Fig. ??: (a) heterogeneous simulation S1, (b) homogeneous simulation S2.

## References

- [1] Christophe Geuzaine and Jean-François Remacle. Gmsh: A 3-D finite element mesh generator with built-in pre- and post-processing facilities. *International Journal for Numerical Methods in Engineering*, 79(11):1309–1331, 2009.
- [2] Hang Si. TetGen, a Delaunay-Based Quality Tetrahedral Mesh Generator. *ACM Trans. Math. Softw.*, 41(2):11:1–11:36, February 2015.

Reply to: Interactive comment on GO2OGS: a  
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Anonymous Referee #2

T. Fischer et al.

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**Abstract**

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## 1 Specific Comments:

- 1.1 **In Algorithm 1, the functionality of step 7 Integrate split nodes into structured grid is clearly shown in Fig.4b, but how it has been exactly accomplished is not clear. The algorithm 1 is recommended to explain more on step 7 instead of listing all the read and write steps.**

We revised the Algorithm 1 and hope we could clarify the integration of the split nodes in Step 7 (see p 11). We also added a sketch (Fig. 5 revised manuscript, Fig. 1 of this document) to describe the integration of split nodes (see p 11, l 3ff).

**1.2 The verifying case Setup A does not have faults or outcropping layers, after employing Algorithm 1 as stated in the paper, it would be a structured grid and actually does not need step 7 in the conversion, and also there is no simulation conducted on it. The purpose of Setup A is recommended to declare more clearly.**

With setup A, we want to show that the workflow is also applicable for less complex setups. During addressing the previous comment, we tried to improve the description of algorithm 1 (step 7). We also tried to clarify the relevance of setup A during restructuring the relevant section of the manuscript (see sections 1.2 and 2.2.1) and hope, that we could eliminate any remaining confusion.

**1.3 The mesh quality has been studied and discussed in section 2.3. The interaction between the elements number for reconstruction and element quality are clear (Figure 7), but a sensitivity analysis on how the aspect ratio is changing with the reconstruction resolution (horizontal and vertical) would be preferred, as it would be a good hint on how the resolution could be chosen.**

We understand that the choice on the specific resolution is a very important step in numerical modeling; among others, this choice is depending on issues like available computing resources (cpu speed, RAM size) or the processes that are investigated.

The aspect ratio of an element is defined through the ratio of the smallest by the longest line segment (compare equation 2, in section 2.1.1). In our case, the smallest line segment of any element will always be the vertical spacing (thickness of element), while the longest will be given through the horizontal extent.

In our approach, we can specify all resolutions (vertical and horizontal) as arguments of the algorithms (compare Step 1 of Algorithm 2) and are thus able to calculate the aspect ratio of the final elements a priori. Therefore, we think that a sensitivity analysis how the aspect ratio depends on the reconstruction resolution would not add any scientific value here, as the aspect ratio can indirectly be given through the parameters of Algorithm 2.

Yet, we acknowledge that this might very well be different, if one would use tetrahedrons or prisms, where the aspect ratio could not be calculated before the reconstruction.

1.4 In Algorithm 2, how the unstructured grid and faults have been resampled is clear, but whether there would be conflicts existed when resample the cells near the fault zones is not clearly shown. Therefore, a case on reconstruction near the faults would be preferred to be shown as Fig 5.

We added a figure to show how the resampling is done and what the results are near the faults (see Fig. 2, and section 2.2.1).

1.5 In Page 6314, line 2, Petrel is considered as a groundwater flow simulation code, which might not be the case

Thank you for pointing this out - we removed the mentioning of Petrel there (see p 6, l 18).

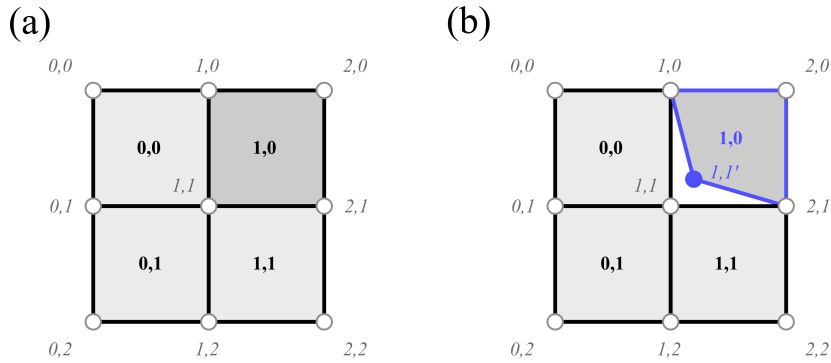


Figure 1: Schematic representation of implementation of split nodes into a structured mesh (a) resulting in an unstructured mesh (b) of quadrilateral elements; grey border hollow dots symbolize element nodes; node indices are represented in italic, element indices are represented in bold.

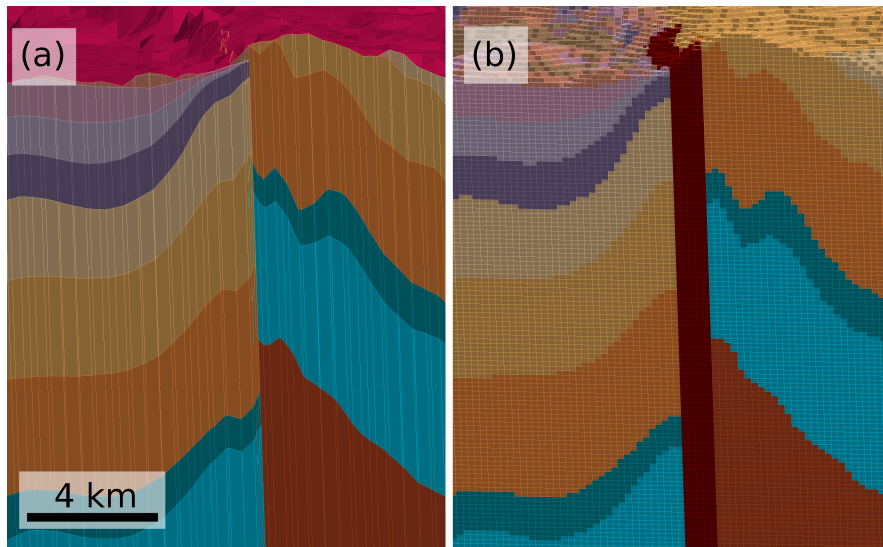


Figure 2: Exemplary comparison of meshes before (a) and after (b) the resampling along a fault; vertical exaggeration  $10\times$ , legend given in Fig. ??, position of viewpoint shown in Fig. ??.

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T. Fischer et al.

October 12, 2015

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## 1 Specific comments

**1.1 In the title, the authors use a word versatile to describe his strategy. However, I do not know whether it is suitable for other situations without using GOCAD and VTU, and whether the mesh creation method is suitable for other numerical models? Maybe the authors can remove this.**

We think that the fundamental approach we present could be useful to other workflows that similarly try to achieve an integration of data from one software product to another one using any data format. In this sense, the workflow is not limited to GOCAD or Petrel or any other specific software, which has also been acknowledge by the other two reviewers.

In this context, it seems important to underline that the outcome of steps ② to ④ can be used independently from our choice of the numerical model (OpenGeoSys). This is due to the selection of the output format: we are aware of the fact that there is a multitude of different modeling software existing and

that many modellers tend to choose those numerical toolboxes which they are familiar with. By using the open-source framework VTK, we assure that this model choice is not limited by the output format of our methodology.

Although, we do not provide a workflow that will work with *any* combination of software or data formats, we think that we offer a relatively close approach to an universally applicable one.

Therefore, we would like to keep the word “versatile” in the title of the manuscript.

We tried to underline this fact even more by revising section 4.1.

**1.2 In the first section, the authors discussed the importance of integration of data and models for collaborative work and comprehensive research. It is indeed a hot topic currently, and there are much research has been done in this fields, especially data conversion between models, model integration and sharing though web, et al., the author may reference more papers about model integration and talked about some essential difficulties when build a versatile workflow.**

Thank you for suggesting to add more citations to support the relevance of the topic. We provided more citations of recent works in the problem description ([1, 4, 2, 3], see section 1.1).

**1.3 The authors use the abbreviation of VTU, VTK in the abstract and first paragraph, but give their full names in the later parts. I think the full names should be given when these words appeared for the first time.**

Thank you for pointing this out. We added the full names of the abbreviations VTU and VTK at the first occurrence in the full text (compare p 5, l 5).

**1.4 In section 2, I suggest to put the explanation of EQ.1 also in 2.1 background because it seems undertake the same task as 2.1.1 and 2.1.2.**

Thank you for the comment; as suggested, we moved the respective paragraphs into section 2.1.



**1.5 According to the workflow introduced in 1.4, maybe 2.2 Converting gocad SGrid data to an open data format can be changed to 2.2 Converting GOCAD SGrid data to an open data format and its quality evaluate.**

Due to the change in the structure, we think that the former title of this section is appropriate.

**1.6 Please explain VTU+ in figure 2.**

We added an explanation on p 14, l 16.

**1.7 Maybe g in Figure 3 should be G.**

This is correct, thank you for this keen observation. We corrected the mistake (compare 1).

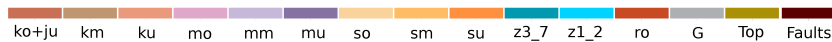


Figure 1: Legend for geological units of “Setup B”; for abbreviations see Table ??.

## References

- [1] N J Hardebol and G Bertotti. DigiFract: A software and data model implementation for flexible acquisition and processing of fracture data from outcrops. *Computers and Geosciences*, 54:326–336, 2013.
- [2] S. Ragetti, F. Pellicciotti, W.W. Immerzeel, E.S. Miles, L. Petersen, M. Heynen, J.M. Shea, D. Stumm, S. Joshi, and a. Shrestha. Unraveling the hydrology of a Himalayan catchment through integration of high resolution in situ data and remote sensing with an advanced simulation model. *Advances in Water Resources*, 78:94–111, 2015.
- [3] Chaopeng Shen, Jie Niu, and Kuai Fang. Quantifying the effects of data integration algorithms on the outcomes of a subsurfaceland surface processes model. *Environmental Modelling & Software*, 59:146–161, 2014.
- [4] Qiang Wu, Hua Xu, and Xukai Zou. An effective method for 3D geological modeling with multi-source data integration. *Computers & Geosciences*, 31(1):35–43, 2005.