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Application of "shallow-water" numerical models for hazard assessment of volcanic flows:the case of titan2d and Turrialba volcano（Costa Rica）の核心部分の抄訳

Abstract から

Abstract

This paper introduces Titan2D, a depth averaged model of an incompressible Coulomb continuum for "shallow water" granular flows. Titan2D has been used successfully at many volcanoes to predict inundation by block-and-ash flows and debris avalanches. It can be run as a stand-alone program or through Vhub, a cyber-infrastructure platform. Practical considerations of choosing appropriate user inputs and the basics of running the model are discussed herein. Both synthetic and natural terrain examples are presented, including simulations of a block-and-ash flow generated from the gravitational collapse of a synthetic dome at Turrialba volcano (Costa Rica). These results suggest that the model should be limited to simulate cases of dense volcanic granular flows, like those produced by gravity-driven dome collapse events, but cannot be used to simulate dilute pyroclastic density currents. Finally, estimation of the Ti-tan2D resistance terms by using empirical relationships provides a good method for reducing model input uncertainties.

Titan2D によるシミュレーションによる現象の再現は、これまでの調査から、火山堆積物による密度の高い粒子流に限られるべきであり、たとえば、溶岩ドームの自重による崩壊のような（例えば雲仙の溶岩ドームの崩落による火砕流）場合に適用できるが、密度の低い噴煙に近い性質を持つ火砕流には適用できない。

Discussion and Conclusions から

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Titan2D is a freely available geophysical flow model that has been used to simulate block-and ash-flows and debris avalanches with success. It uses a depth averaged model for "shallow water" granular flows and combines numerical simulations of a flow with digital elevation data of natural terrain supported by a GIS interface. The conservation equations for mass and momentum are solved with a Coulomb-type friction term for the interactions between the grains of the media and between the granular material and the basal surface. Titan2D takes user inputs of an internal and bed friction, initial velocity, and starting geometry parameters (which can include a mass flux). Basal friction angles can also be supplied by using a 'material map', a raster containing friction values (e.g., Stinton et al., 2004; Charbonnier & Gertisser, 2009, 2012). Model outputs include flow inundation, thickness, and velocity.

The Turrialba example is intended to show the capabilities of Titan2D to model dense volcanic granular flows on natural terrain, rather than replicate or predict an actual flow. In this regard, it is worth mentioning some limitations of numerical modeling with Titan2D on the simulation of specific types of volcanic flows. As explained in previous sections, Titan2D is based on rheologi-cal laws governing the deformation and flow of dry granular material. Moreover, because of the depth-integrated form of the equations, there are constraints on the vertical velocities developed within the flow and its vertical expansion. These two aspects of the numerical model mean that flows such as lahars (mixture of water and solids) and certain types of pyroclastic density currents (surges and column-collapse flows) cannot be realistically modeled; also high vertical gradients in the topography may impose unrealistic scenarios for the model. For instance, Kelfoun et al. (2009) showed that the Mohr-Coulomb behavior is not appropriate for modeling column-collapse pyroclastic flows at Tungurahua volcano. Block-and-ash flows, however, have been satisfactorily modeled with Titan2D (e.g., Rupp et al., 2006; Charbonnier & Gertisser 2009, 2012; Procter et al., 2010; Sulpizio et al., 2010) but simulation results are limited to the dense basal part of such flows, and do not include the overlying dilute ash-cloud surge component.

To conclude, the results presented in this paper suggest that the application of 'shallow-water' numerical models like Titan2D for hazard assessment of volcanic flows can be used as predictive tools in future eruptions, but should be limited to the field of dense volcanic granular material, like those produced by gravity-driven dome collapse events. Therefore, these models cannot be used to simulate any dilute pyroclastic density currents generating by vertical column collapse, total dome disruption and directed blast scenarios. Moreover, validations of the model so far have re-vealed a rather empirical use of the friction parameters that allow adjustment of the model to different runout situations. The Heim coefficient can provide reasonable input parameters that can be used as guidelines for choosing appropriate basal friction angles based on flow volume (see Fig. 3). Calibration of these resistance terms by using well-constrained flow mobility parameters calculated from field observations provides a good method for encompassing and compensating for the lack of uncertainty around the

Titran2D は、乾いた粒子の変形や流れを支配する流体の運動則に基づいたシミュレーションを行うプログラムで、用いられている運動方程式では、物質の深さ方向の運動は小さ

いことを仮定し、それを慣らして平均化していることから、流れや層厚変化による物質の上下方向の運動には、制約条件がかかっている。このような Titan2D の性質から、水と泥の混合体であるラハール（泥流）やある種の火砕流、サージと呼ばれる指向性の強い火砕流や噴煙柱が崩壊してできる火砕流は Titan2D ではうまく再現することはできないし、急傾斜の地形条件では非現実的な結果を与える。

例えば Kelfoun 等(2009)は、噴煙柱崩壊による火砕流には、Titan2D に用いられているモール・クーロンの摩擦則を当てはめること自体が不適切なことを、Tungurahua 火山（エクアドル）の事例で紹介している。しかしながら、Block and ash flows(火山岩塊と火山灰の混合した流れ)については Titan2D はうまくシミュレーションで再現できる。しかし結果が信用できる範囲は、底の密度の高い部分の流れに限られるので、流れの表層の密度の小さい熱雲状の運動は含まれない。

この論文の結果をまとめると、Titan2D のような浅水方程式による流体の運動モデルは、将来の噴火による災害の予測評価に使えるが、適用範囲は密度の高い火山の粒子流の分野に限られる。例えば、溶岩ドームの自重による崩壊のような現象には当てはめられる。そのいっぽうで、噴煙柱の崩壊により発生する火砕流や、山体の全面崩壊や、ブラストと呼ばれる指向性を持った爆発的な火砕流（事例としてはセントヘレンズ山がある）などには適用できない。

さらにシミュレーションをうまく実行するには、摩擦に関するパラメータを、理論的にではなく、経験的に、状況に合わせてうまく調整する必要がある。