Geophysical Research Abstracts
Vol. 13, EGU2011-1640, 2011
EGU General Assembly 2011

Analyses of a hierarchy of frozen soil models for cold region study—The justification, ability, and uncertainty

Qian Li (1), Shufen Sun (2), Yongkang Xue (3,4)

(1) Center for Monsoon System Research, Institute of Atmospheric Physics, Chinese Academy of Sciences, P.O.BOX 2718, Beijing, 100190, China (qian@mail.iap.ac.cn), (2) State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences, P.O.BOX 9804, Beijing, 100029, China (ssf@lasg.iap.ac.cn), (3) Department of Geography, University of California, Los Angeles, CA,90095-1524,USA (yxue@geog.ucla.edu), (4) Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, CA,90095-1524,USA (yxue@geog.ucla.edu)

Regions with frozen ground cover approximately 55%-60% of exposed land surface in the Northern Hemisphere. Frozen ground processes produce great effects on global and regional climate and hydrology, as well as CO2 and CH4 balance over permafrost land. Because more observational evidence revealed the complexity of frozen soil processes and their importance in climate system, numerous simple and sophisticated frozen soil models have emerged during the past four decades and become increasingly important in climate research. However, the reliability and value of models are often unknown. The justification of different levels of model complexity and their ability to cover diverse conditions in space and time are sometimes unquestioned. It is important to comprehensively examine and categorize different frozen soil models based on physical principles, assumptions, as well as relationship of each other; it is also desired to derive simple models with the ability to cover diverse conditions in space and time, which should help better understand frozen soil processes and applications of these models in climate research.

In this study the frozen soil models are classified into different levels according to the complexity of the governing equations, which normally included coupled heat and mass transport processes. Based on scale analysis, models with different levels of complexity were derived from the most complicated frozen soil model (Level 1 model). The Level 1 model includes a detailed description of mass balances of volumetric liquid water, ice, as well as vapor content. It also considers contributions' of heat conduction, phase change, liquid flow, and vapor gas diffusion to the energy balance. But the complexity and the necessity to introduce an unproven assumption in the model limit its applicability in the study of frozen soil. Physical and mathematical justifications for simplifying the Level 1 models to different levels' models are discussed. In this study, the Level 1, 2, 3, and 4 models represent decreasing complexity in the governing equations. The Level 2 model still takes the coupling effect of mass and heat transport into consideration. However, it does not require the information of phase change rate, therefore, does not require any additional assumptions. The Level 3 model neglects the liquid water flow, and vapor gas diffusion in the energy balance equation based on the Level 2 model and the Level 4 model doesn't include vapor diffusion to the mass balance based on Level 3 model. It has been found that current widely used frozen soil models can well be classified into these four levels.

In addition to the governing equation, another important aspect in frozen soil modeling is the numerical solution. Because it is normally required to assume ice content in the numerical iteration and during the phase change (from ice/liquid to liquid/ice), large latent heat releases, improper guessing of ice content are often lead to unstable solutions. To overcome the difficulty in numerical procedure, a new method of substituting soil enthalpy and total water mass for soil temperature and volumetric liquid water content, respectively, in governing equations is introduced for each level of the frozen soil models.

The models with different complexity levels and with different variables in their governing equations are assessed with observational data from the Tibetan Plateau to test their ability and assess the uncertainty. The preliminary evaluation for the period with no snow cover but frozen ground shows that, at the Tibetan D66 site, the models with different complexity produce similar accuracy of soil temperature except at the top soil layer during the melting/freezing period. The model, including the contribution of vapor flux due to matric potential gradient to water balance, performs the best at this site. For the Tibetan D105, different levels' models produce less discrepancy, indicating the justification for most currently used models. More evaluation with snow cover period and data from different sites are necessary. Meanwhile, compared with the corresponding original models, the frozen soil model versions with enthalpy and total water mass for governing equations appear to produce consistently better performance.