Numerical assessment of freezing/thawing process over Tibetan Plateau: the role of vapor flow

Lianyu Yu[1], Yijian Zeng[1], Zhongbo Su[1]
1. Faculty of Geo-Information Science and Earth Observation, University of Twente, Enschede, Netherlands.

Key words: Freezing/Thawing process, numerical assessment, vapor flow, Tibetan Plateau

1 Introduction

Most of freezing/thawing (hereafter as FT) models differed not only in the physics representing the FT process, but also in many other ways: e.g. discretizing techniques, parameterization of latent heat during freezing/thawing, various regions. These factors make the intercomparison results confused and hard to identify the underlying difference between the various FT parameterizations. Moreover, soil water and heat are strongly coupled during FT, neglecting this coupling process in most of the current models limited their capability of accurate description of soil FT physics. In addition, how and to what extent the vapor flow affects the soil water and heat dynamics in frozen soils lack of a detail research.

In this paper, we aimed to i) conduct an intercomparison of different FT parameterizations based on a fully coupled water and heat model; ii) investigate the mechanism of water and heat transfer of FT process.

2 Review of different FT parameterizations

The water and heat flow during FT process can be generally characterized by three main set of parameters: unfrozen water content, hydraulic conductivity and heat capacity/ conductivity, current models employed different parameterizations(Table 1).

Table 1: Different model parameterizations for frozen soil

Model	Unfrozen water content	Hydraulic conductivity *K*	Heat conductivity	Soil water and heat transfer	Reference
Noah-MP	SFC (Clapeyron + Clapp and Hornberger)	Clapp and Hornberger + ice correction coefficient	Johansen method	uncoupled	Yang, et al. (2011)
CLM 4.5	SFC (Clapeyron + Clapp and Hornberger)	Clapp and Hornberger + ice correction coefficient	Johansen method	uncoupled	Oleson, et al. (2013)
SHAW	SFC (Clapeyron + Brooks-Corey)	Clapp and Hornberger, reduced linearly with ice content	De Vires method	coupled	(Flerchinger and Saxton, 1989)
COUPMODEL	Energy phase change	Van Genuchten + impedance factor	Kersten method	coupled	(Jansson, 2012)
CLASS	Energy phase change	Clapp and Hornberger + ice correction coefficient	Johansen method	coupled	Verseghy, (2009)
HTESSEL	SFC (empirical function of soil temperature)	Weighted values between unfrozen and frozen hydraulic conductivity	Johansen method	uncoupled	(Viterbo et al., 1999)
HYDRUS	SFC (Clapeyron + Van Genuchten)	Van Genuchten + impedance factor	Modified Campbell method	coupled	(Hansson et al., 2004)
Colm	SFC (Clapeyron + Clapp and Hornberger)	Clapp and Hornberger + ice correction	Johansen method	uncoupled	(Dai et al., 2001)

3 Design of numerical model experiment

CTRL1-2 were to assess the effect of different hydraulic parameterizations on the simulations; EXP1-3 were to find the optimal thermal parameterization to capture the dynamics of soil FT process.

Table 2: Numerical experimental design to assess the different FT parameterizations

Experiment		**Unfrozen Water Content**		**Hydraulic Conductivity**		**Heat Conductivity**			
		Clapeyron + VG	Clapeyron + CH	VG	CH	D63	F81	T16	J75
CTRL1		√		√		√			
CTRL2			√		√	√			
CTRL1	EXP1	√		√			√		
	EXP2	√		√				√	

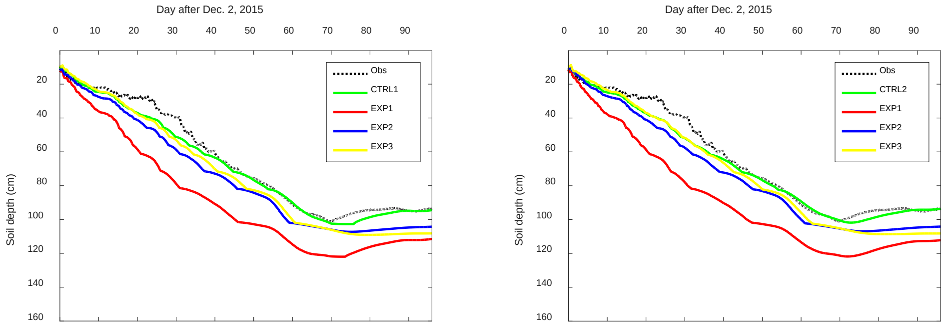
	EXP3	√		√				√
	EXP1		√		√	√		
CTRL2	EXP2		√		√		√	
	EXP3		√		√			√

Note: VG, Van Genuchten (van Genuchten 1980); CH, Clapp and Hornberger (Clapp and Hornberger 1978); Heat conductivity: J75, Johansen thermal conductivity method (Johansen et. al 1975); T16, Simplified De Vries method (Tian et. al 2016); D63, De Vries method (De Vries et. al 1963); F81, Farouki method (Farouki et. al 1981).

4 Results

4.1 Assessment of soil thermal conductivity parameterizations

Given the soil component, de Vries' parameterization is recommended to mimic the thermal conductivity of frozen soils.

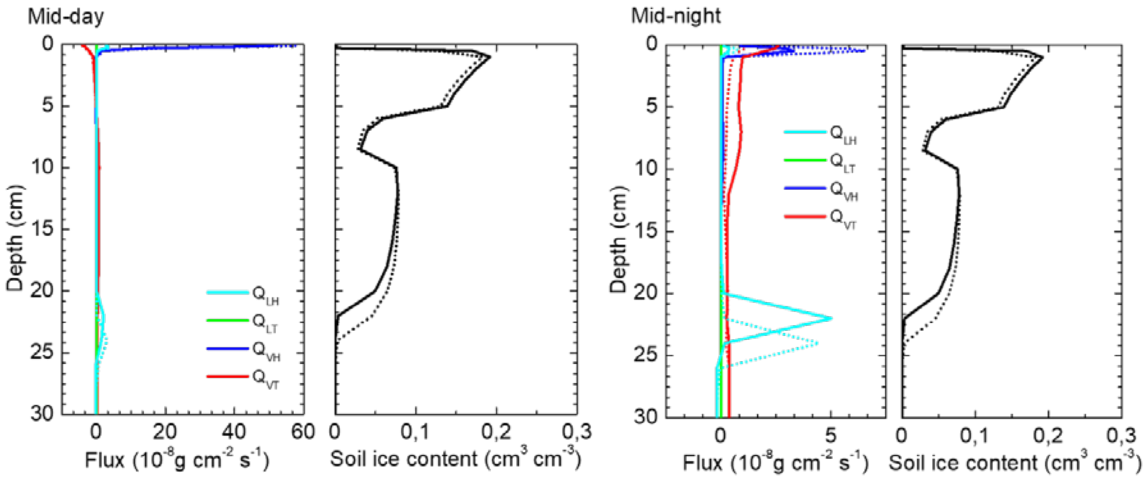


(a) Van Genuchten (b) Clapp and Hornberger

Figure 1: Comparison of observed and simulated soil freezing front using different parameterizations of thermal conductivity (EXP1-3) with (a) Van Genuchten and (b) Clapp and Hornberger hydraulic schemes.

4.2 Mechanism of water and vapor transfer in frozen soils

The main findings are: 1)Isothermal liquid water fluxes(Q_{LH}) move upwards to the freezing front. 2)Thermal liquid fluxes(Q_{LT}) very small, can be ignored. 3)During night time, Thermal vapor fluxes(Q_{VT}) evaporates from the freezing front and move water fluxes upwards. 4)Isothermal vapor fluxes(Q_{VH}) dominant at top 1cm soil layers, upwards.



—— Solid lines: Dec. 11 2015 ------ Dashed lines: Dec. 12 2015

Figure 2: The simulated vertical profiles of the thermal and isothermal liquid water and vapor fluxes, soil ice content at 1200 and 0000 h of a typical freezing period during 11 and 12 Days after Dec. 1. 2015. Positive/negative values indicate upward/downward fluxes.

References

[1] Zeng, Y., Z. Su, L. Wan, and J. Wen. Numerical analysis of air-water-heat flow in unsaturated soil: Is it necessary to consider airflow in land surface models? *J. Geophys. Res.*, 116, D20107, (2011).

[2] Zeng, Y., Z. Su, L. Wan, and J. Wen. A simulation analysis of the advective effect on evaporation using a two-phase heat and mass flow model. *Water Resour. Res.*, 47, W10529, (2011).