Freeze and Thaw Column Verification

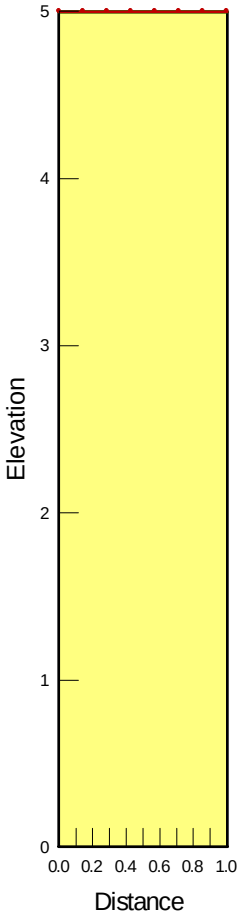
1 Introduction

The objective of this illustration is to show how the freezing and thawing algorithm in VADOSE/W compares with the well established TEMP/W formulation. There are multiple linked analyses in this file.

Feature Highlights

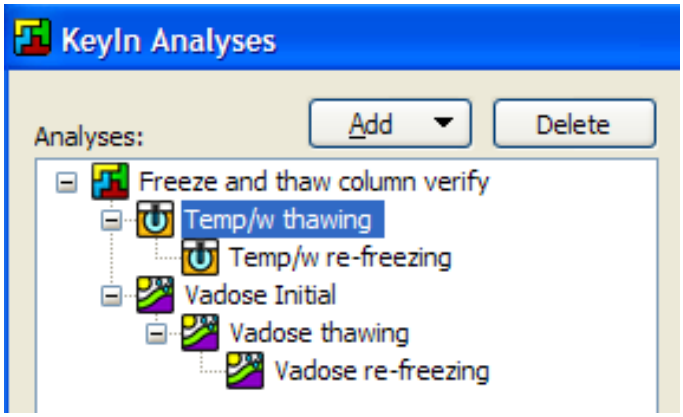
- Steady state and transient thawing and freezing
- Simplified thermal model in uncoupled analysis
- Verification with TEMP/W

2 Geometry and boundary conditions



The geometry of the model is a simple one dimensional column with an initial temperature of -2 C throughout. The initial temperature was applied in a steady state analysis but it could have been applied using the "activation temperature" feature in the material model set up.

Two transient analyses were set up to model the thawing and re-freezing of the column. In the first thawing analysis, the top of the column is then subjected to a warmer temperature of +5 C for 1000 days. This was followed by a re-freezing analysis with a -2 C for another 1000 days. The analyses were set up so that the results of one became the input conditions of the other as shown below.



The file is set up with both TEMP/W and VADOSE/W analyses so that a direct comparison of results can be made.

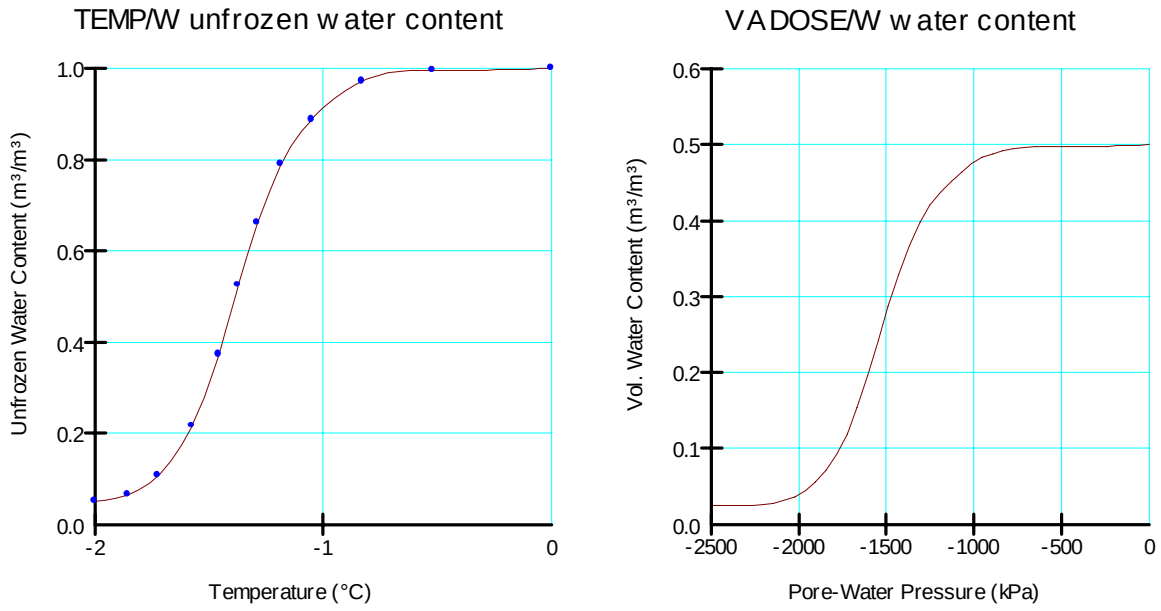
In the tree diagram you can see that there are two TEMP/W and three VADOSE/W analyses. The TEMP/W branch of the tree is only solving for temperatures whereas the VADOSE/W analyses must solve both temperature and water pressure. In order to ensure the column remained saturated, the initial and transient hydraulic boundary conditions assumed a pressure head of 1m at the top of the column.

3 Material properties

In order to get the same answers in both TEMP/W and VADOSE/W it is necessary to input the same geometry, boundary conditions, and material properties. The first two are quite straight forward to ensure in GeoStudio because they are created once and shared across analyses. The material properties are a little more complicated to set up because they are input somewhat differently in each model.

TEMP/W requires that the user input an Unfrozen Water Content function, whereas VADOSE/W computes the Unfrozen Water Content function based on the water content function and a conversion factor related to the Clausius Clapeyron equation. The details of the conversion are discussed in the VADOSE/W Engineering Methodology book. The fundamental conversion factor is that for every degree Celsius below zero, there is a corresponding increase in pore-water suction of 1110 kPa. Thus, create an unfrozen water content function (with slope $d\theta/dT$) it is necessary to divide each pressure value in a water content function by 1110 kPa/C.

The image on the left is the unfrozen water content function specified in TEMP/W, while that on the right is the corresponding water content function input into VADOSE/W. The VADOSE/W solver will then change this to the same unfrozen water content function as TEMP/W when doing the analysis for latent heat release during phase change.



Comparison of the functions shows that the TEMP/W function "y" range is from zero to 1.0. This is because it is a normalized function. The TEMP/W solver will multiply the ratio between zero and 1.0 by the user input soil water content value of 0.5. The VADOSE/W function is not normalized and therefore applies to any water content. In this case, the hydraulic boundary conditions are such that the soil will remain saturated with a water content of 50%. Both analyses therefore have the same water contents and the same stored latent heat.

The other thermal properties required in the analysis are quite simple to input and in fact are shared. Both models use the "Simplified" thermal model with input values as shown below.

Thermal Properties

Thermal Conductivity:		Volumetric Heat Capacity:		Activation Temp:
Unfrozen:	120 kJ/day/m/°C	Unfrozen:	2500 kJ/m³/°C	-2 °C
Frozen:	120 kJ/day/m/°C	Frozen:	2500 kJ/m³/°C	

4 Discussion of results

There is not a lot of discussion required. The intent of the analysis is to show how VADOSE/W, with adjustments to ensure similar soil property data is applied, can give the same results as TEMP/W for freezing and thawing. The following sets of figures confirm this.