Basic information

Model Name: AHC_1D_mixture_transient_GST.py

Input Card: AHC_params.inpts

Soil Card: <user specified name>

GST Card: <user specified name>

Running the model

You must have the following four files in your project directory:

1. AHC_1D_mixture_transient_GST.py (No edits required. All input supplied with #2-4)
2. AHC_params.inpts
3. A soil card, name specified in AHC_params.inpts
4. A GST card, name specified in AHC_params.inpts

After editing the AHC_params.inpts file as necessary, run the following command:

% python AHC_1D_mixture_transient_GST.py

Model description

This model is based on the apparent heat capacity approach for one-dimensional heat conduction with phase change in porous media using a mixture model of soil grains/rock matrix, water, ice and air. The soil freezing characteristic curve (SFCC) is based on the work of Levell (1957), which has two input parameters *a* and *b*. This SFCC allows for a freezing point depression as well as a mixture of frozen and unfrozen water below the freezing point. The soil moisture profile is based on the input Van Genuchten parameters found in the soil card, as well as a user specified water table depth found in AHC_params.inpts. We use a semi-implicit finite difference numerical scheme to solve the nonlinear PDE. More details on the numerical approach can be found in the notes PDF.

The upper boundary condition is a transient ground surface temperature (GST) specified in the GST card. This file should provide 365 days of daily mean GST values, one for each Julian day of the year (neglecting leap year). The model uses a one-day time step by default. The bottom boundary condition is set to a geothermal gradient, stipulated in the AHC_params.inpts file.

The model is set to output the mean annual ground temperature profile, mean annual unfrozen water content profile, and the mean annual frozen water content profile for each year of the

simulation. The model also provides the ground temperature profile, unfrozen water content profile, and frozen water content profile from each day of the final year of the simulation.

Below is a list of key names that can be provided through the AHC_params.inpts file. If a given key name is not listed in the AHC_params.inpts file, the model will use the default value listed.

Spatial and Temporal Parameters		
Key	**Description**	**Default**
Model_Depth	Depth of the model domain. $[m]$	50.0
Node_Spacing	Spacing of the model nodes. $[m]$	0.1
Sim_Years	Number of years in the simulation. $[y]$	100
Soil Component Parameters		
Key	**Description**	**Default**
Specific_Heat_Rock	Specific heat of the soil grains or rock matrix. $\left[\frac{J}{kg\,^{\circ}C}\right]$	790.0
Density_Rock	Density of the soil grains or rock matrix. $\left[\frac{kg}{m^3}\right]$	2690.0
Thermal_Conductivity_Rock	Thermal conductivity of the soil grains or rock matrix. $\left[\frac{W}{m\,^{\circ}C}\right]$	4.5
Specific_Heat_Water	Specific heat of water. $\left[\frac{J}{kg\,^{\circ}C}\right]$	4.187e3
Density_Water	Density of water. $\left[\frac{kg}{m^3}\right]$	999.8
Thermal_Conductivity_Water	Thermal conductivity of water. $\left[\frac{W}{m\,^{\circ}C}\right]$	0.58
Specific_Heat_Ice	Specific heat of ice. $\left[\frac{J}{kg\,^{\circ}C}\right]$	2.108e3
Density_Ice	Density of ice. $\left[\frac{kg}{m^3}\right]$	916.8
Thermal_Conductivity_Ice	Thermal conductivity of ice. $\left[\frac{W}{m\,^{\circ}C}\right]$	2.18
Specific_Heat_Air	Specific heat of air. $\left[\frac{J}{kg\,^{\circ}C}\right]$	1.0

Density_Air	Density of air. $\left[\frac{kg}{m^3}\right]$	1.3
Thermal_Conductivity_Air	Thermal conductivity of air. $\left[\frac{W}{m\,^\circ C}\right]$	0.035
Latent_Heat_Fusion	The latent heat of fusion. $\left[\frac{J}{kg}\right]$	334e3
Soil Profile		
Key	**Description**	**Default**
Water_Table_Depth	Depth of water table (stationary during simulation). [m]	0
Soil_File	Name of the file describing the soil properties along the profile.	None. The Soil_File must be supplied. Example file below.
Initial and Boundary Conditions		
Key	**Description**	**Default**
GST_File	Name of the file containing the ground surface temperature data.	None. GST_File must be supplied. Example file below.
Geo_Heat_Grad	Geothermal gradient applied at bottom boundary. $\left[\frac{^\circ C}{m}\right]$	0.0
Init_Temp	Initial temperature in the subsurface (uniform value). $[^\circ C]$	0.0
Output Plotting		
Key	**Description**	**Default**
Plotting_Times	Years of simulation at which to plot a snapshot of the model output. (Basic plotting)	None. Model will not create a plot.

Example of Soil_File

```
Depth,Porosity,theta_s,theta_r,Alpha,N,a_eta,b
1,0.36,0.36,0.07,0.50,1.09,0.1314,0.197
2,0.36,0.36,0.07,0.50,1.09,0.1314,0.197
3,0.36,0.36,0.07,0.50,1.09,0.1314,0.197
4,0.36,0.36,0.07,0.50,1.09,0.1314,0.197
5,0.36,0.36,0.07,0.50,1.09,0.1314,0.197
6,0.36,0.36,0.07,0.50,1.09,0.1314,0.197
7,0.36,0.36,0.07,0.50,1.09,0.1314,0.197
8,0.36,0.36,0.07,0.50,1.09,0.1314,0.197
9,0.36,0.36,0.07,0.50,1.09,0.1314,0.197
10,0.36,0.36,0.07,0.50,1.09,0.1314,0.197
20,0.36,0.36,0.07,0.50,1.09,0.1314,0.197
30,0.38,0.38,0.048,0.80,1.09,0.321,0.271
40,0.05,0.05,0.001,0.001,1.68,0.321,0.271
50,0.05,0.05,0.001,0.001,1.68,0.321,0.271
```

This file gives the soil properties at depths of 1, 2, 3, 4, 5, 6, 7, 8, 10, 20, 30, 40, and 50 meters. The model will assume a linear variation in soil properties between given depths. Below is a list of soil properties that may be provided through the Soil_File.

Parameters in Soil_File		
Key	**Description**	**Default**
Porosity	Porosity of soil. $[-]$	0.25
theta_s	Saturated water content. $[-]$	0.25
theta_r	Residual water content. $[-]$	0.05
Alpha	α parameter for van Genuchten model. $\left[\frac{1}{m}\right]$	0.5
N	N parameter for van Genuchten model. $[-]$	2.0
a_eta	Product of the a parameter for the Lovell model and the maximum possible water content. $\left[\frac{1}{℃}\right]$	0.1
b	b parameter for the Lovell model. $[-]$	0.2

Note: The a_eta parameter describes the product of the a parameter and η (maximum possible water content) at a given depth in the soil column. The η value is controlled by the van Genuchten

parameters at the stipulated water table depth. Below the water table depth, η is equal to θ_s (the saturated water content). Above the water table, η is a value between θ_r and θ_s based on the van Genucthen parameters. In the model, the unfrozen water content is based on the work by Lovell (1957):

$$\theta_l = \eta(x)\begin{cases}1 & T > T^* \\ a(-T)^{-b} & T < T^*\end{cases}$$

However, in Lovell's original work, the unfrozen water content is expressed as

$$\theta_l = A * (-T)^{-B}$$

where the author reports values of A and B for various soil types. Therefore, the reported A values from Lovell's original work (1957) and the a_eta parameter in this model are equivalent.

Example of GST_File

```
Day,Month,GST
1,1,-1.158529015
2,1,-1.090702573
3,1,-1.858879992
4,1,-2.756802495
5,1,-2.958924275
6,1,-2.279415498
7,1,-1.343013401
8,1,-1.010641753
9,1,-1.587881515
10,1,-2.544021111
```

This shows only the first 10 days of GST values; however, the GST_File must include 365 days (neglecting leap year) of mean daily GST.

Example AHC_params.inpts

```
# This is an example input card for the AHC_1D_mixture_transient_GST.py code.
# See the input parameter list for details.
# Start comment lines with '#' symbol.

# Domain
Model_Depth = 50.0
Node_Spacing = 0.1

# Time
Sim_Years = 50

# Rock/Soil
Specific_Heat_Rock = 800.0
Density_Rock = 2800.0
Thermal_Conductivity_Rock = 4.2

# Water
Specific_Heat_Water = 4187.0
Density_Water = 999.8
Thermal_Conductivity_Water = 0.58
Latent_Heat_Fusion = 334000.0

# Ice
Specific_Heat_Ice = 2110.0
Density_Ice = 916.8
Thermal_Conductivity_Ice = 2.2

# Air
Specific_Heat_Air = 1.0
Density_Air = 1.3
Thermal_Conductivity_Air = 0.04

# Plotting Times
Plotting_Times = 10,20,30,40,50

# GST File
GST_File = GST_test.txt
Geo_Heat_Grad = 0.25
Init_Temp = -5.0

# Soil Parameters
Soil_File = soil_params.txt
Water_Table_Depth = 10.0
```