Simulation of subsurface sensible heat transport: Sensitivity to lower-boundary conditions

Jason E. Smerdon
Lamont-Doherty Earth Observatory of Columbia University

Marc Stieglitz
Georgia Institute of Technology
Outline

• Short background on the subsurface thermodynamic component of land-surface models

• Quantify the sensitivity of subsurface thermodynamic models to the depth of lower-boundary conditions

• Discuss implications of results for climate simulations with General Circulation Models (GCMs)
Land-Atmosphere Coupling and Subsurface Thermodynamics

Schematic Example of the Subsurface Scheme in Land-Surface Models

### Lower-Boundary Depths in Land-Surface Schemes used in Some Common General Circulation Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Depth of Lower Boundary</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCAR Community Climate System Model (CCSM3)</td>
<td>3.43 m</td>
</tr>
<tr>
<td>Geophysical Fluid Dynamics Laboratory</td>
<td>1.5-6 m</td>
</tr>
<tr>
<td>Goddard Institute for Space Studies</td>
<td>3.44 m</td>
</tr>
<tr>
<td>Max-Plank Institute for Meteorology (ECHAM3)</td>
<td>10 m</td>
</tr>
<tr>
<td>European Centre for Medium-Range Weather Forecasts</td>
<td>2.89 m</td>
</tr>
</tbody>
</table>
Two Different Steady-State Solutions to the One-Dimensional Diffusion Equation

Solution:  \[ T(z,t) = A \sin\left(\frac{2\pi t}{\tau} + \varepsilon - \phi\right) \]

Infinite Half-Space Solution

\[ A_{\text{HHS}} = e^{-kz} \]
\[ \phi_{\text{HHS}} = kz \]

Finite-Boundary Solution

\[ A_{\text{FB}} = \left(\frac{\cosh[2(l-z)k] + \cos[2(l-z)k]}{\cosh[2lk] + \cos[2lk]}\right)^{1/2} \]
\[ \phi_{\text{FB}} = -\arg\left(\frac{\cosh[k(l-z)(1+i)]}{\cosh[kl(1+i)]}\right) \]

Where \( k = \left(\frac{\pi}{\tau \kappa}\right)^{1/2} \), \( \tau \) is the period of the harmonic, \( \kappa \) is the thermal diffusivity, and \( l \) is the depth of the lower boundary.
Infinite Half-Space and Finite-Boundary Solutions to the One-Dimensional Diffusion Equation

Differences between the Infinite Half-Space and Finite-Boundary Solutions are Depth Dependent

Amplitude and Phase Sensitivities to Finite-Lower Boundaries

Implications for Modeling Studies

• The effects described herein can affect model assessments of processes tied to subsurface temperatures:
  • soil microbial activity
  • vegetation changes
  • freeze-thaw cycles
  • hydrologic dynamics

• There is also the potential for these effects to impact land-atmosphere fluxes of water and energy, which could in turn affect atmospheric simulations. It is unclear, however, whether the reported effects are large enough to be significant.
Permafrost Simulations with GCMs are an Example of Potentially Affected Calculations

Shallow Lower Boundaries will affect the Amount of Heat Stored in the Subsurface
Heat Gained By Various Components of the Climate System During the Last 50 years of the 20th Century ($x 10^{22} \text{ J}$)

Conclusions

• Lower-boundary conditions can corrupt the evolution of temperature signals in a manner that is not representative of heat transport in the Earth’s subsurface; the effects are dependent on the frequency surface oscillations, subsurface thermophysical properties, and the lower-boundary depth.

• Many land-surface models have used lower boundaries that will most strongly affect the behavior of annual to decadal signals.

• Model assessments of processes tied to subsurface temperatures will be clearly affected.

• Further investigations are required to determine whether atmospheric simulations are affected, although the effect is likely small.