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

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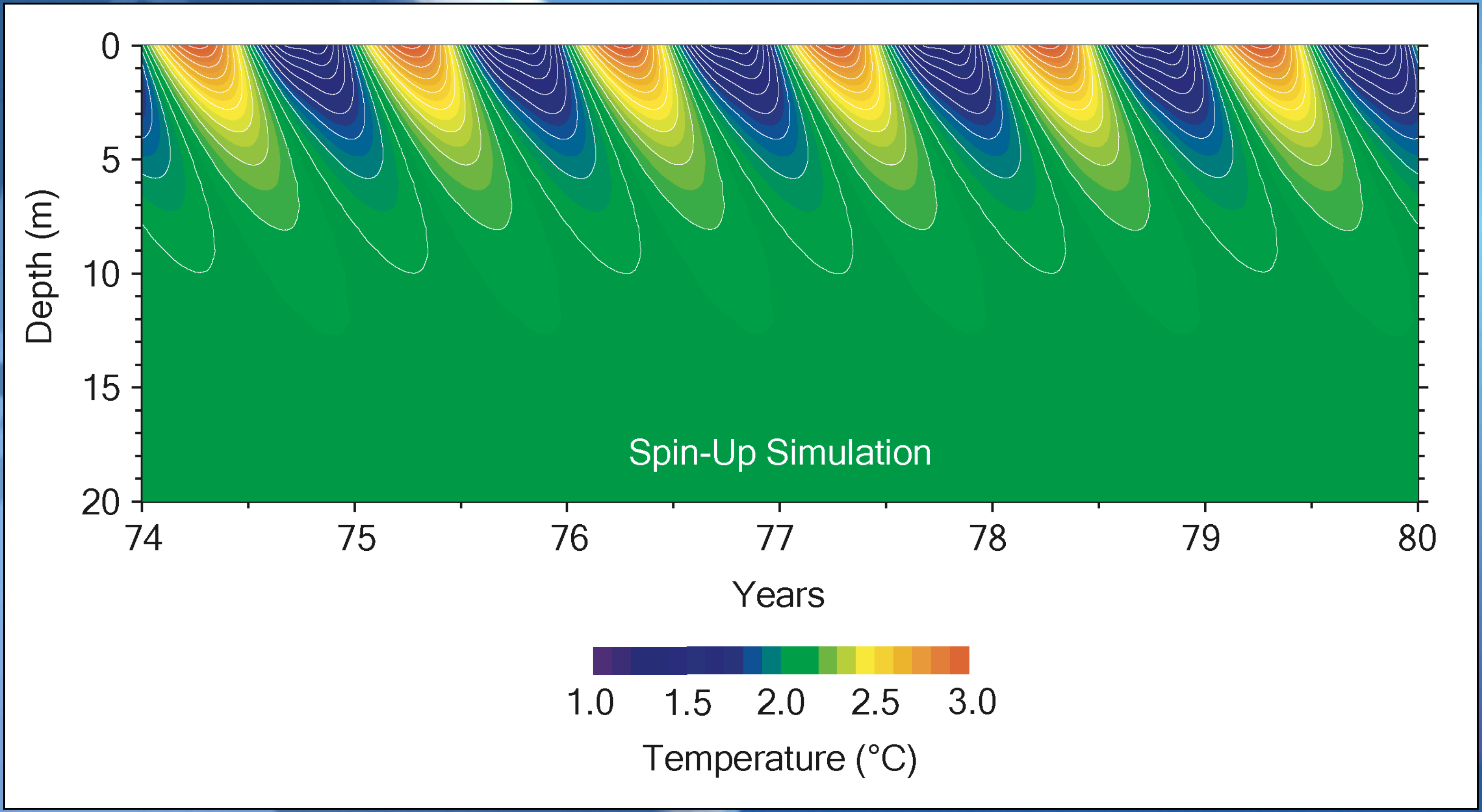
Outline

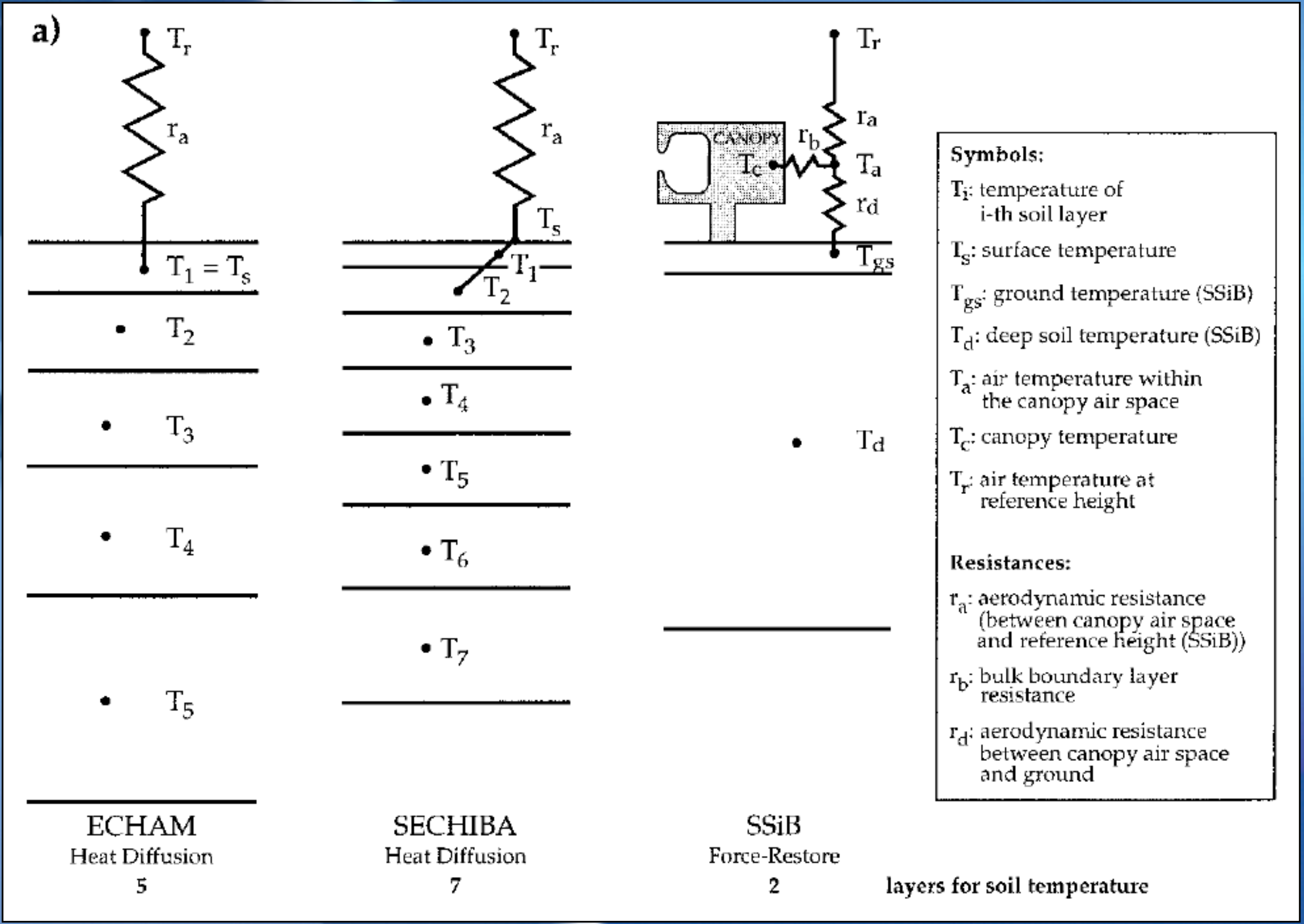
- Short background on the subsurface thermodynamic component of land-surface models
- Quantify the sensitivity of subsurface thermodynamic models to the depth of lower-boundary conditions
- Discuss implications of results for climate simulations with General Circulation Models (GCMs)

Land-Atmosphere Coupling and Subsurface Thermodynamics



Stieglitz, M. and J.E. Smerdon, Characterizing land-atmosphere coupling and the implications for subsurface thermodynamics, *J. Clim.*, in press.

Schematic Example of the Subsurface Scheme in Land-Surface Models



Symbols:

T_i: temperature of i-th soil layer

T_s: surface temperature

T_{gs}: ground temperature (SSiB)

T_d: deep soil temperature (SSiB)

T_a: air temperature within the canopy air space

T_c: canopy temperature

T_r: air temperature at reference height

Resistances:

r_a: aerodynamic resistance (between canopy air space and reference height (SSiB))

r_b: bulk boundary layer resistance

r_d: aerodynamic resistance between canopy air space and ground

Shultz, J.P. et al. (1998), Land surface energy and moisture fluxes: Comparing Three Models, *J. App. Met.*, 37, 288-307.

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

Model	Depth of Lower Boundary
NCAR Community Climate System Model (CCSM3)	3.43 m
Geophysical Fluid Dynamics Laboratory	1.5-6 m
Goddard Institute for Space Studies	3.44 m
Max-Plank Institute for Meteorology (ECHAM3)	10 m
European Centre for Medium-Range Weather Forecasts	2.89 m

Two Different Steady-State Solutions to the One-Dimensional Diffusion Equation

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

Infinite Half-Space Solution

$$A_{IHS} = e^{-kz}$$

$$\phi_{IHS} = kz$$

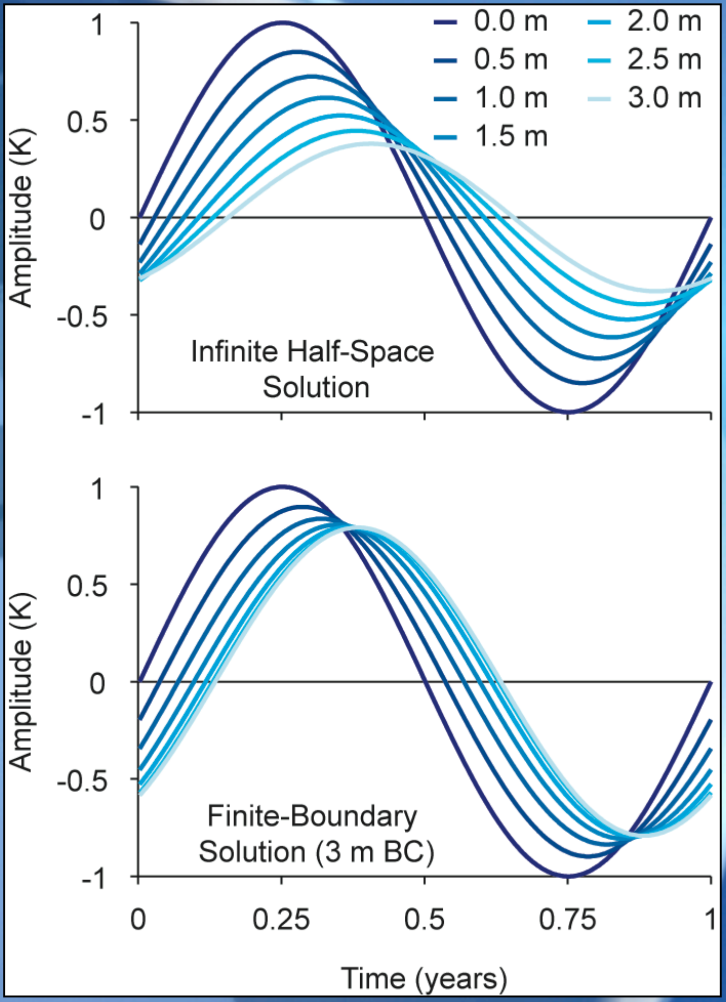
Finite-Boundary Solution

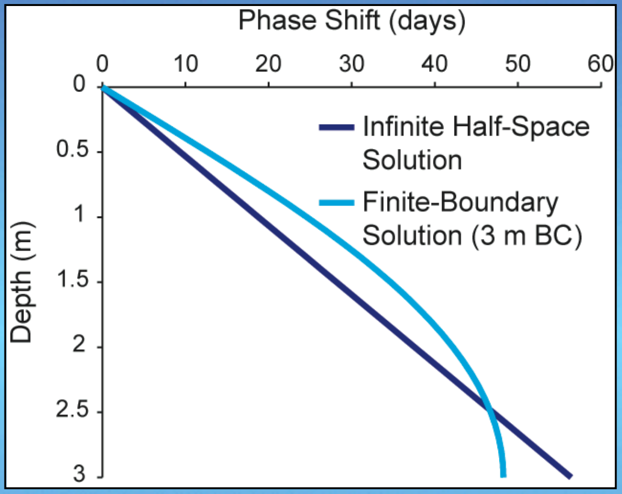
$$A_{FB} = \left(\frac{\cosh[2(l-z)k] + \cos[2(l-z)k]}{\cosh[2lk] + \cos[2lk]} \right)^{1/2}$$

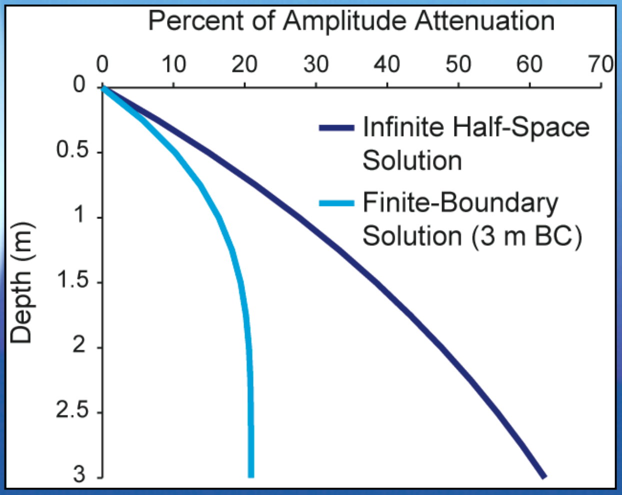
$$\phi_{FB} = -\arg\left(\frac{\cosh[k(l-z)(1+i)]}{\cosh[kl(1+i)]} \right)$$

Where $k = \left(\frac{\pi}{\tau\kappa}\right)^{1/2}$, τ is the period of the harmoic, κ 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

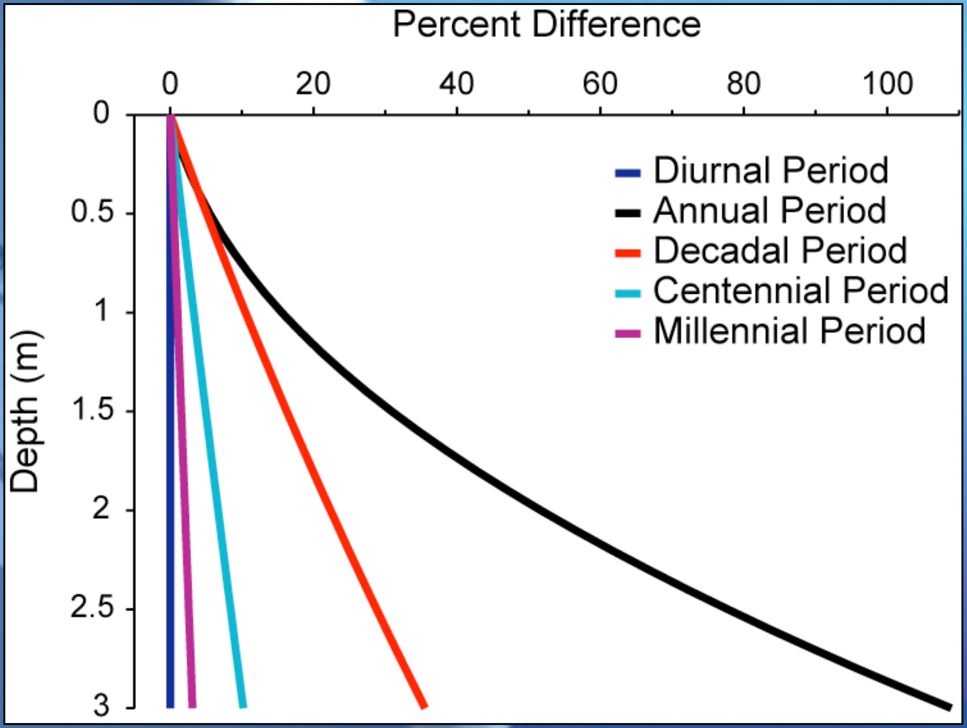






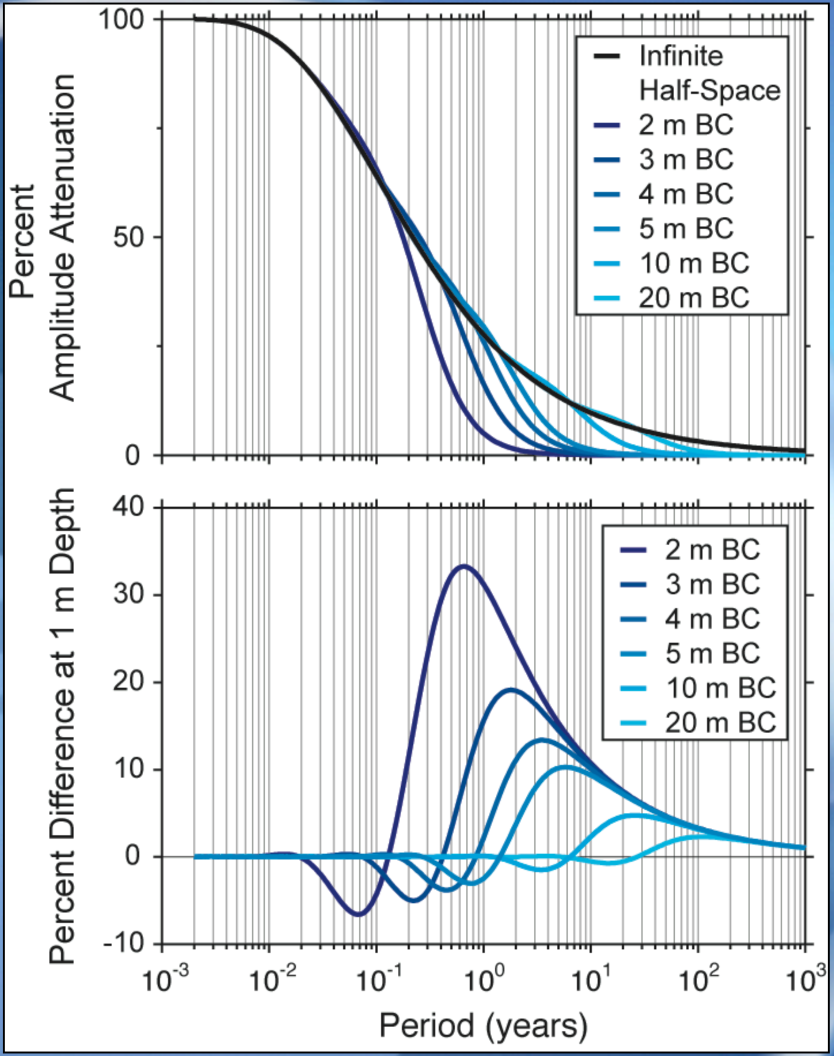
Smerdon, J.E. and M. Stieglitz, Simulating heat transport of harmonic temperature signals in the Earth’s shallow subsurface: Lower-boundary sensitivities, *Geophys. Res. Lett.*, in press.

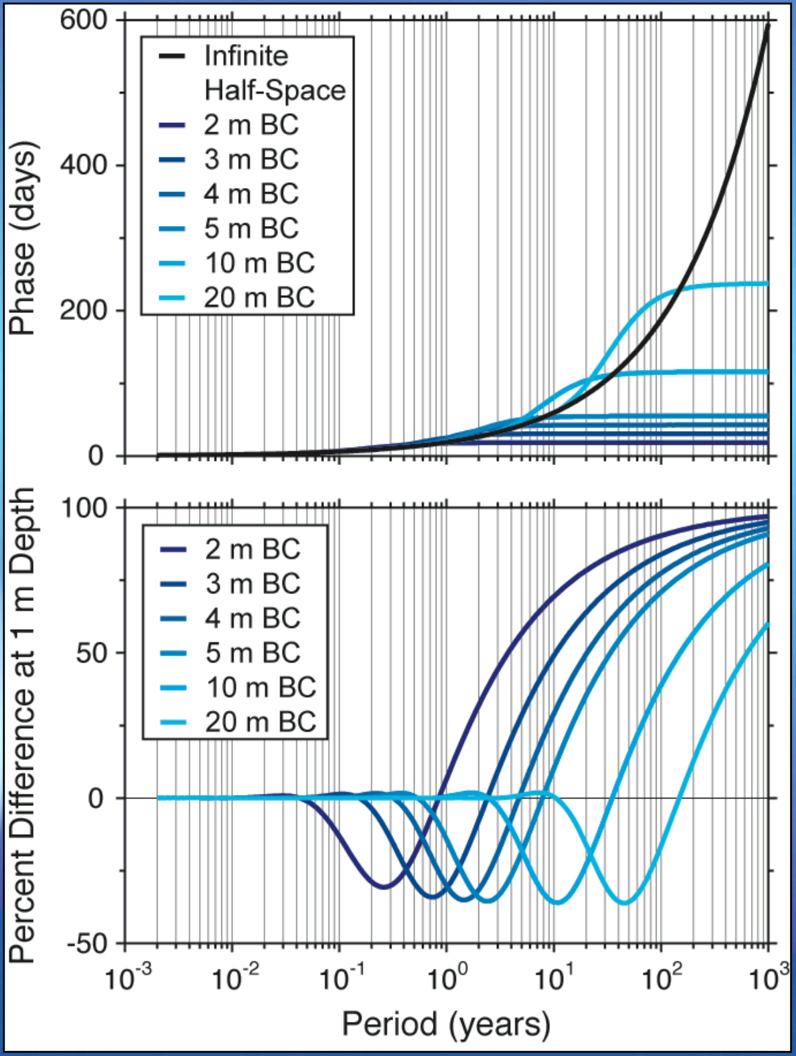
Differences between the Infinite Half-Space and Finite-Boundary Solutions are Depth Dependent



Smerdon, J.E. and M. Stieglitz, Simulating heat transport of harmonic temperature signals in the Earth's shallow subsurface: Lower-boundary sensitivities, *Geophys. Res. Lett.*, in press.

Amplitude and Phase Sensitivities to Finite-Lower Boundaries





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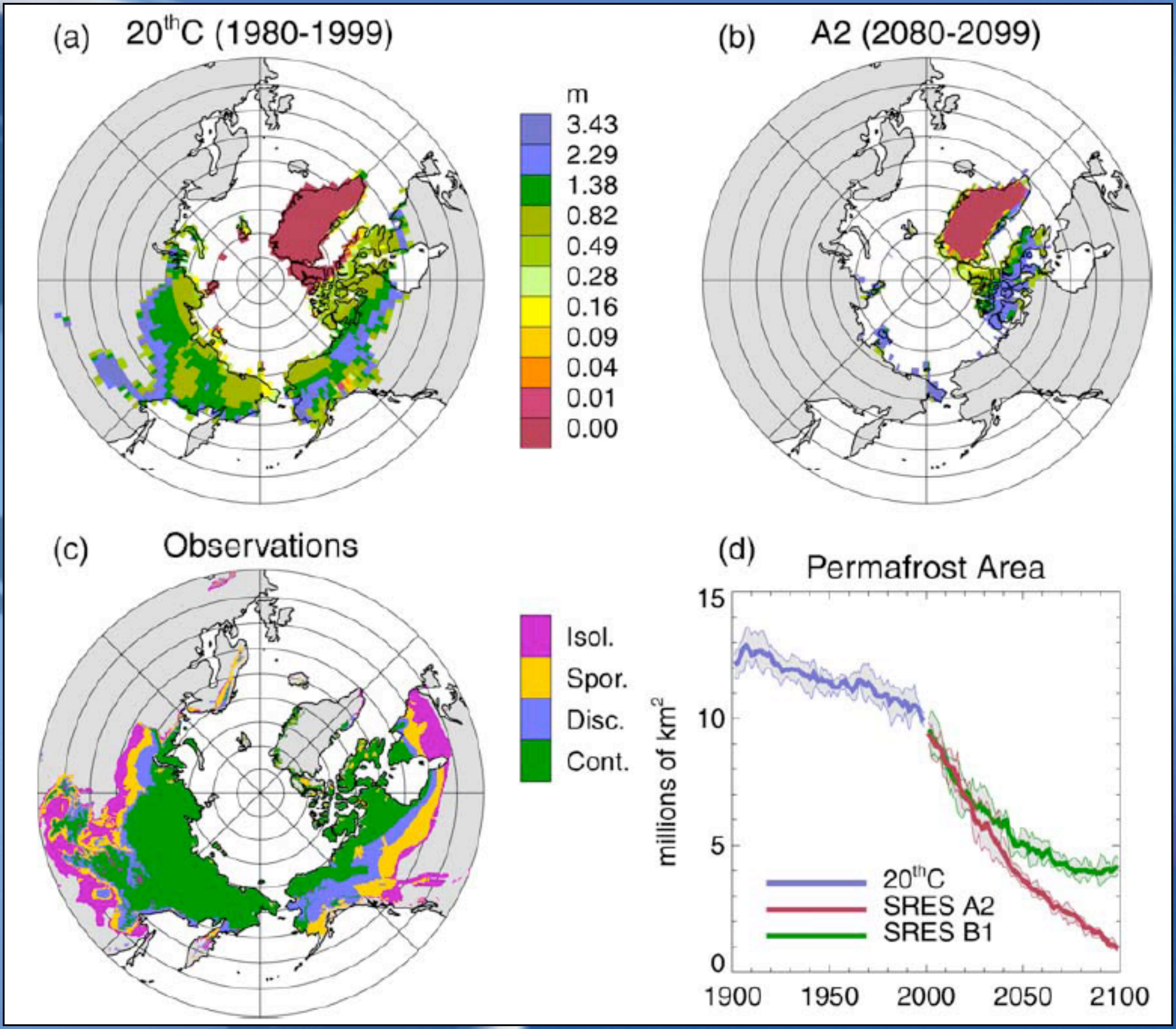
Implications for Modeling Studies

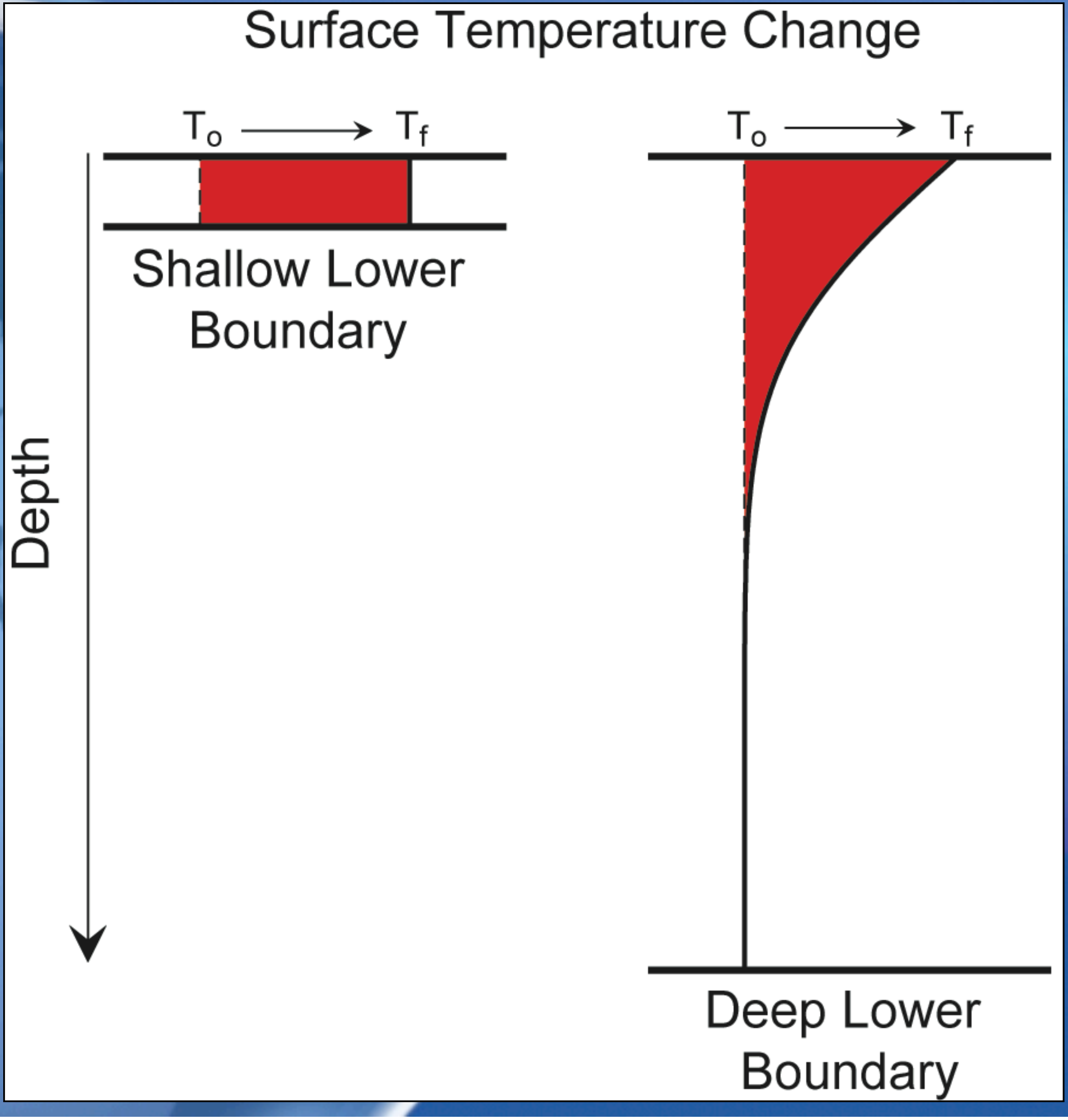
- The effects described herein can affect model assessments of processes tied to subsurface temperatures:
    - soil microbial activity
    - vegetation changes
    - freeze-thaw cycles
    - hydrologic dynamics
- There is also the potential for these effects to impact land-atmosphere fluxes of water 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

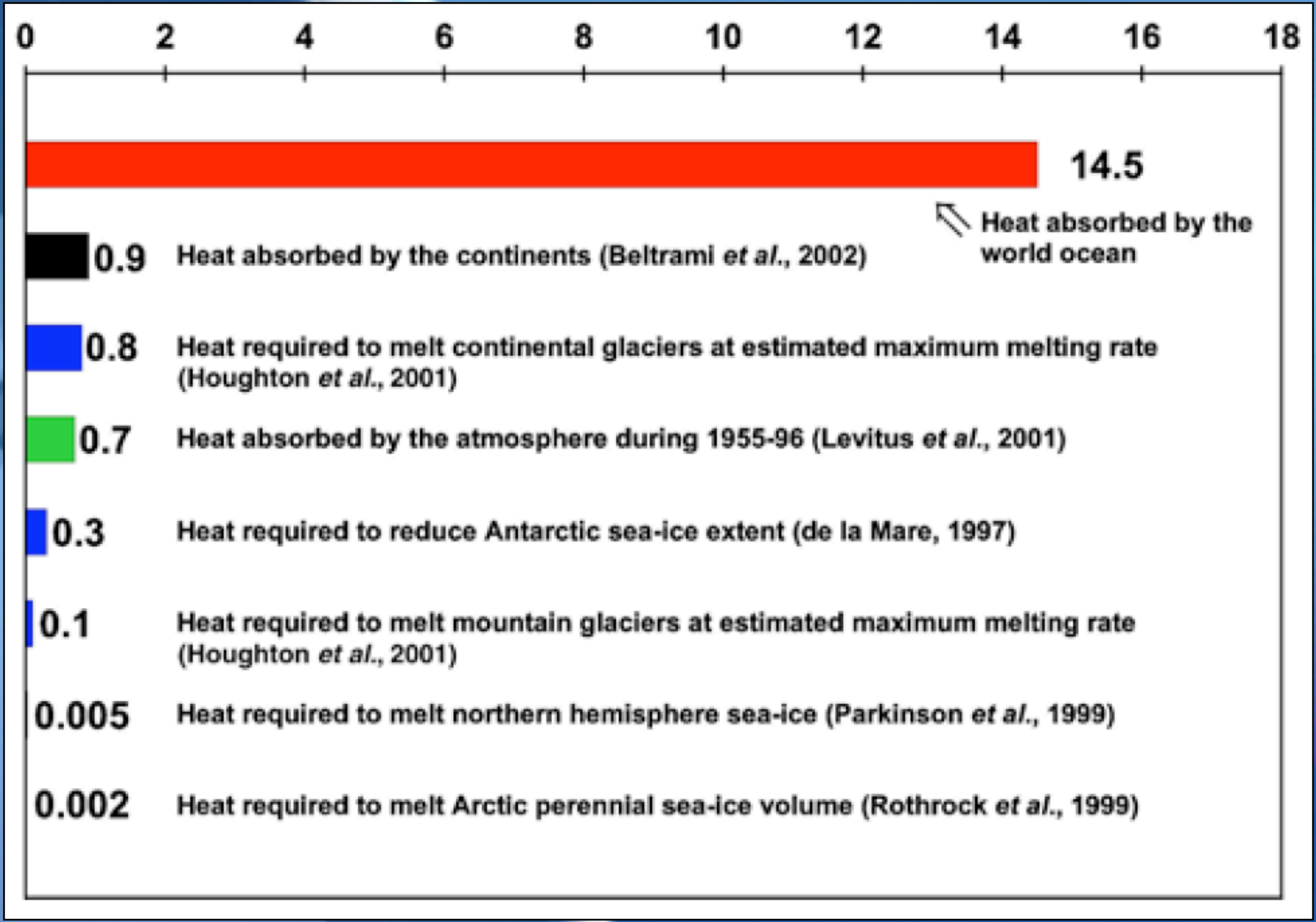


Lawrence, D. M., and A. G. Slater (2005), A projection of severe near-surface permafrost degradation during the 21st century, *Geophys. Res. Lett.*, *32*, L24401, doi:10.1029/2005GL025080.

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} J)



Levitus, S., J. Antonov, and T. Boyer (2005), Warming of the world ocean, 1955–2003, *Geophys. Res. Lett.*, *32*, L02604, doi:10.1029/2004GL021592.

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.