

Climate-change-projection constraints from inaccurate estimates of the required depth of Land Surface Models

Norman Steinert¹, J. F. González-Rouco¹, S. Hagemann², E. García-Bustamante³, P. de Vrese⁴, J. Jungclaus⁴, S. Lorenz⁴, C. Melo-Aguilar¹

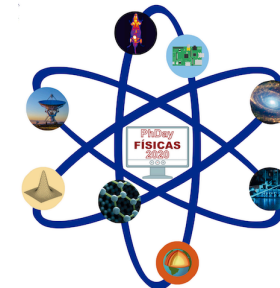
¹Departamento de Física de la Tierra y Astrofísica, Universidad Complutense de Madrid, Madrid, Spain

²Helmholtz-Zentrum Geesthacht, Geesthacht, Germany

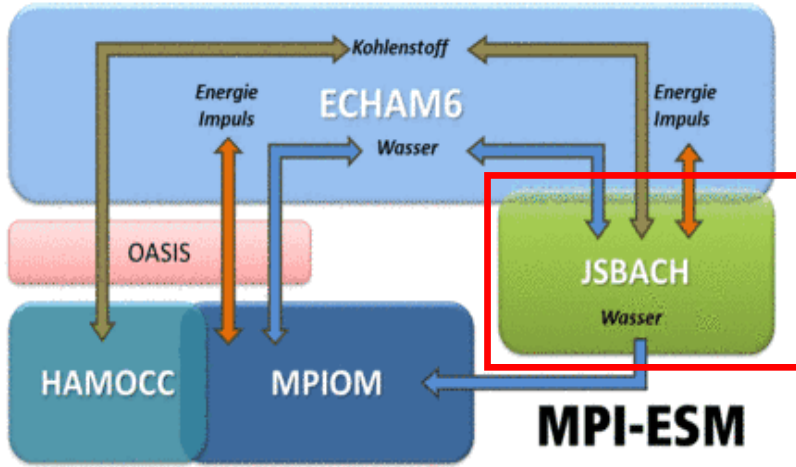
³Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Madrid, Spain

⁴Max Planck Institute for Meteorology, Hamburg, Germany

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Too shallow soil in state-of-the-art climate models



www.mpimet.mpg.de, Stevens et al., 2013;
Jungclaus et al., 2013

The **longer** the surface temperature signal period, the **deeper** the impact in the ground (until amplitude is attenuated to 0)

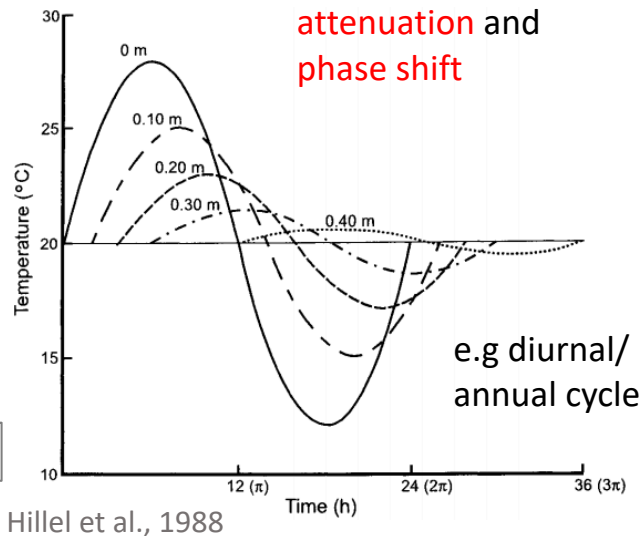
LSMs are not **infinitely (INF)** deep and usually have a bottom boundary at around **10m** depth (**LIM**)

Temperature penetrates the ground with **amplitude attenuation** and **phase shift**

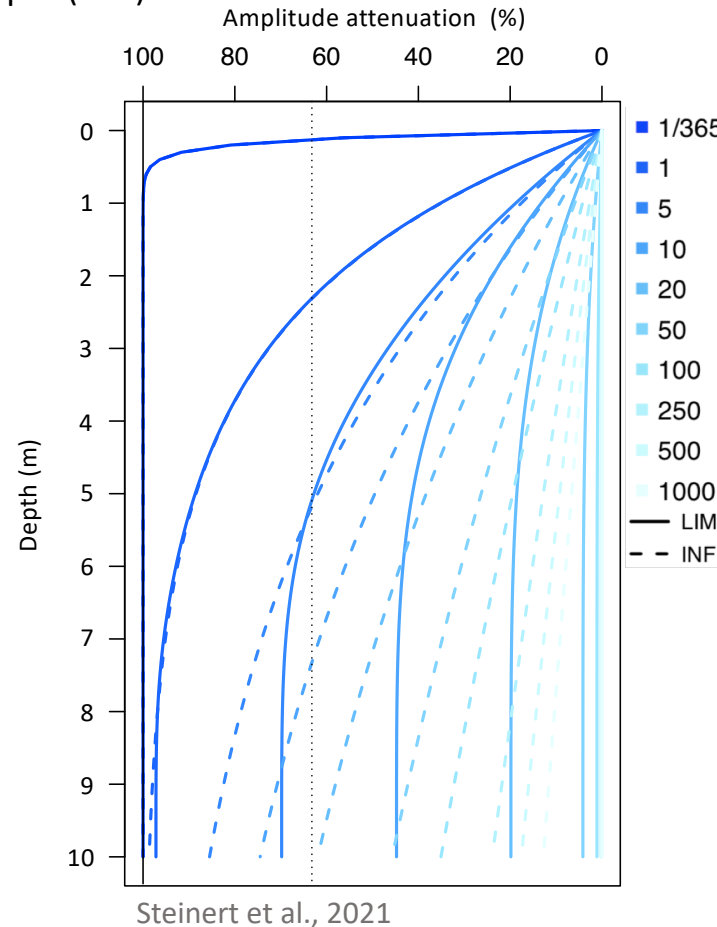
Land Surface Model (LSM) component (e.g JSBACH) accounts for important ground processes:

- **Thermodynamic**
- **Hydrology**
- **Biochemistry**

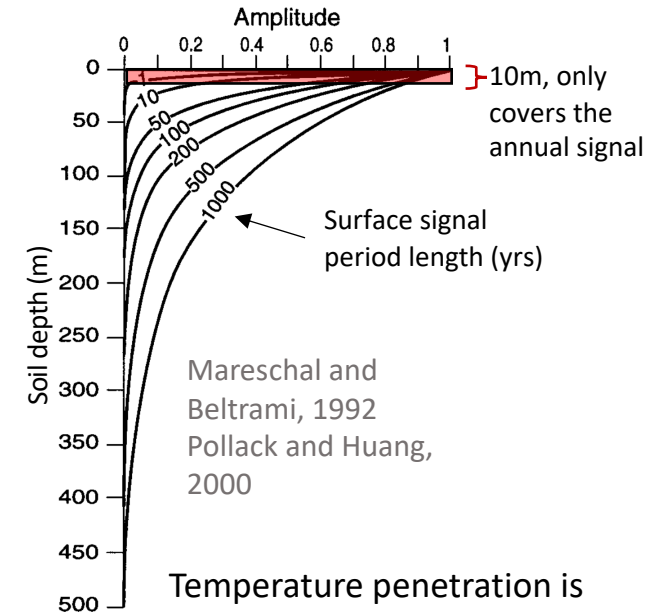
Steinert et al., 2020



Hillel et al., 1988



Steinert et al., 2021



Mareschal and Beltrami, 1992
Pollack and Huang, 2000

Temperature penetration is **compromised** by **too shallow lower boundaries** in LSMs (differences between LIM and INF)

10m is too shallow for 21st century climate projections ...

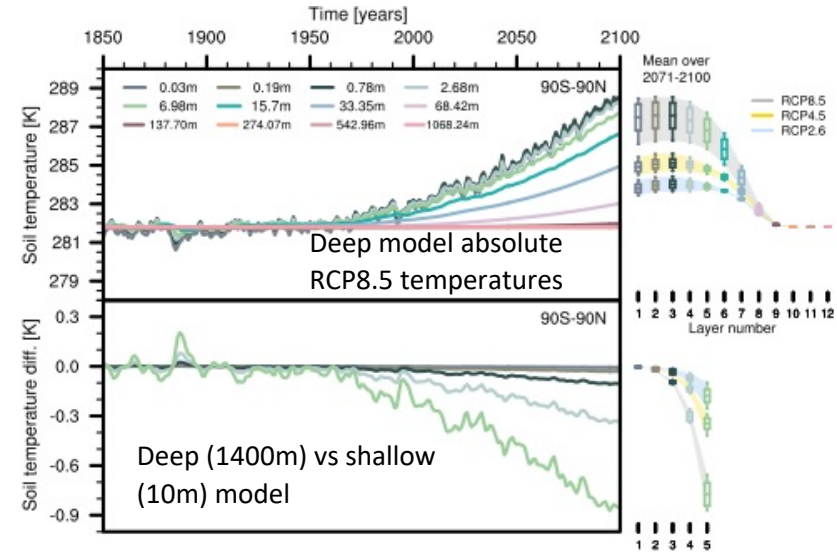
So, we increase it to 1400m!

González-Rouco et al., 2020,
Steinert et al., 2020, Steinert et al., 2021

Significant impact of increased soil model depth

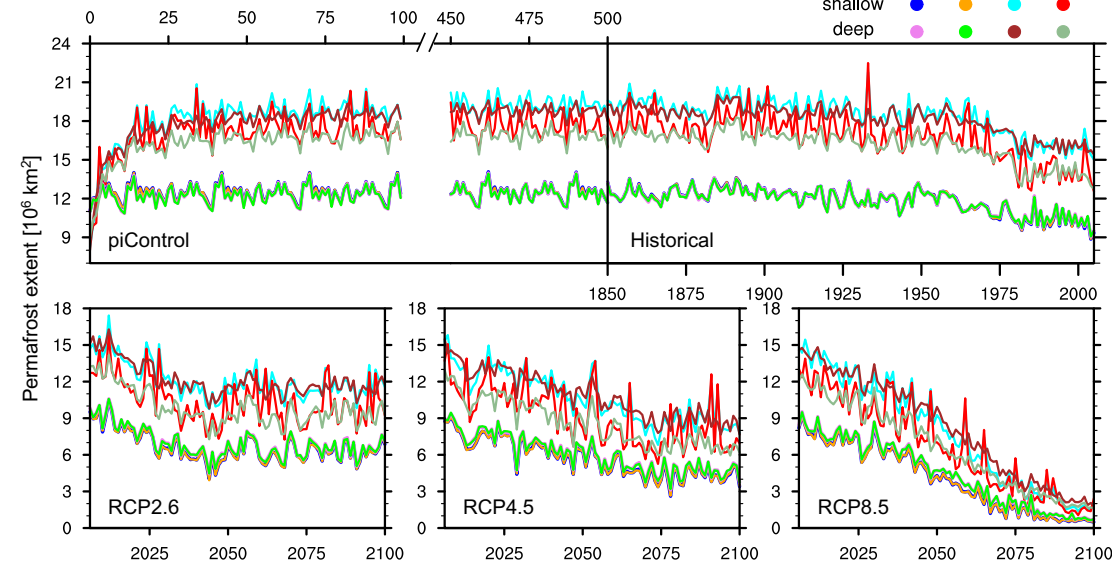
1. Thermal state

González-Rouco et al., 2020



Our work has shown **significant impact** of increasing the depth of a Land Surface Model **from 10m to 1400m** for:

1. Ground **thermal state** (largest impact on northern high latitudes, up to 2K difference)
2. Capacity and distribution of **energy storage** (5-10 times)
3. Simulation of **permafrost** (significant carbon release uncertainty)



Steinert et al., 2020

2. Permafrost Extent (10^6 km^2)

The dilemma:

Over-simplification of the soil

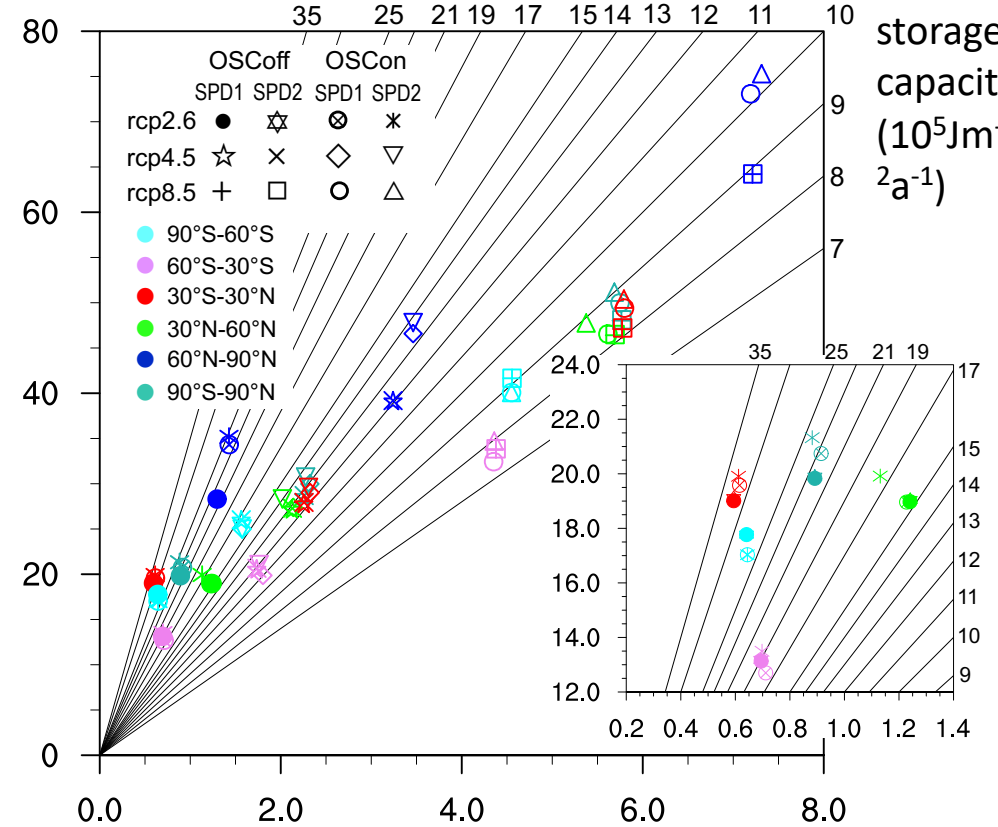
Where is the "sweet spot"?



What is the minimum model depth required?

Computational effort increases with complexity

Steinert et al., 2020



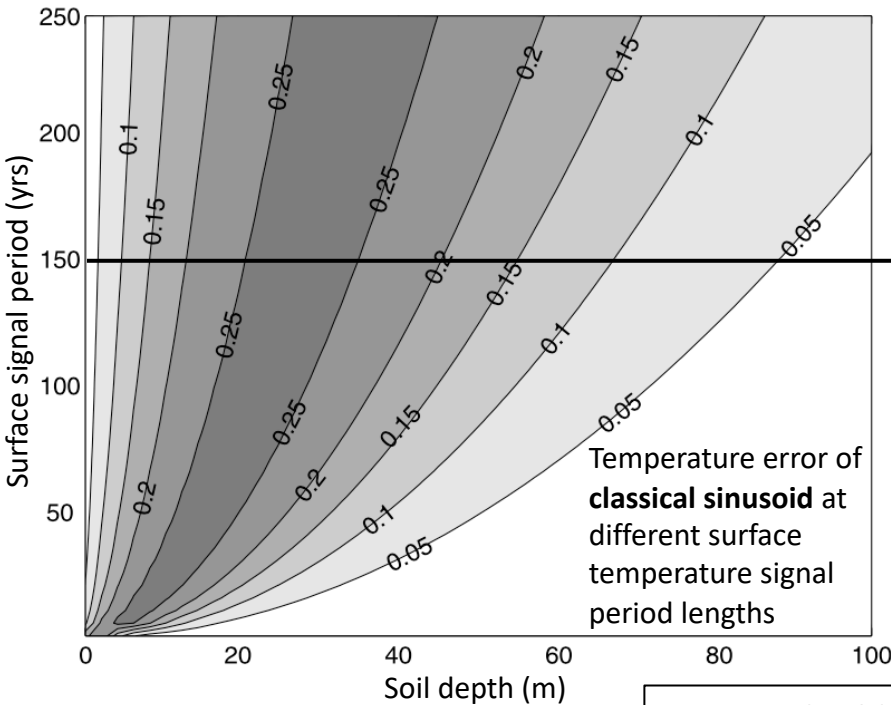
3. Energy storage capacity ($10^5 \text{ J m}^{-2} \text{ a}^{-1}$)

More accurate estimates of the required soil model depth

Estimation of **temperature error (TE)** between deep (infinite) and shallow model (finite)...

...based on a **classic sinusoid**

$$TE = \sqrt{\frac{1}{H} \frac{1}{t} \sum_{j=1}^t \sum_{i=1}^H \xi^2 \Delta z \Delta t}$$



Adjustment of the **classical sinusoid (CA)** to better fit the 21st century **temperature projection of the deep model (SIM)**

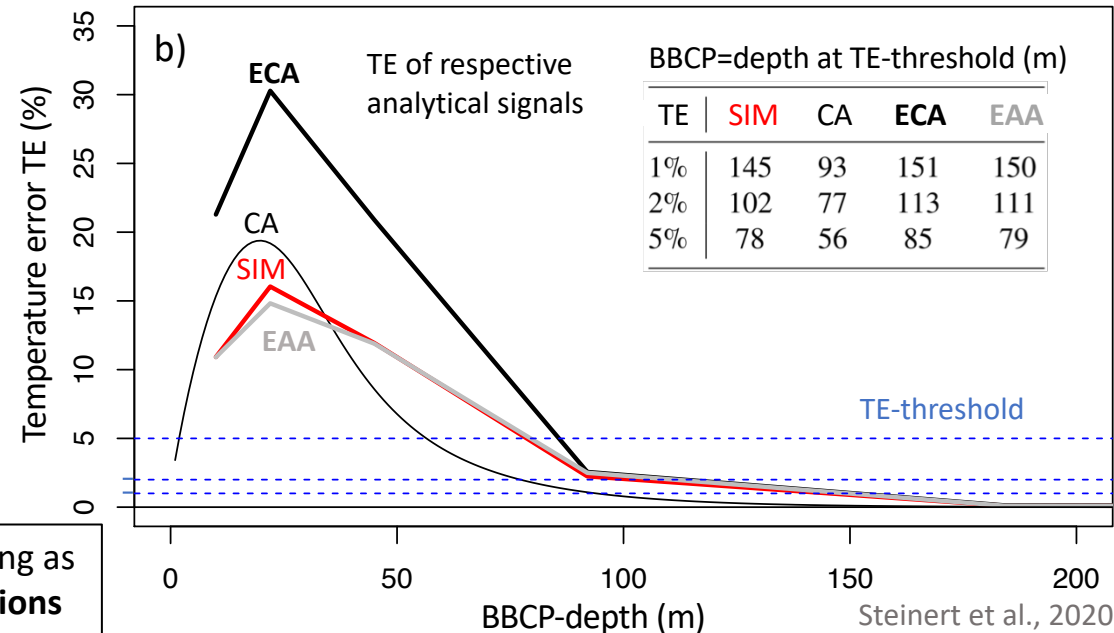
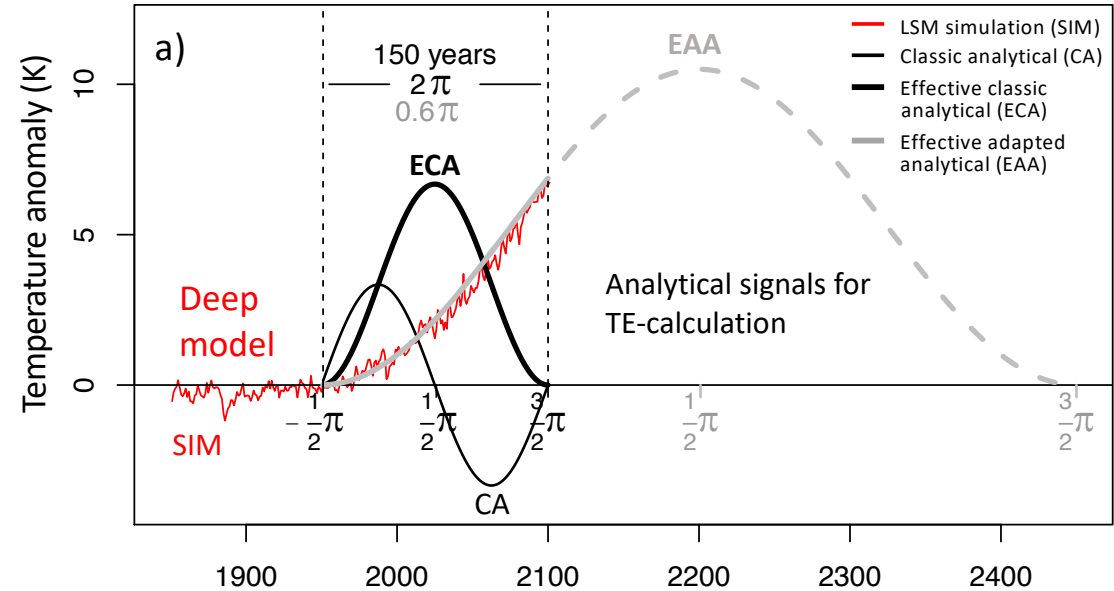
-> **Optimized analytical function (EAA)**

Calculate TE of the respective signals in (a)

(e.g. classic sinusoid; CA)

Optimized approach gives a **50% larger model depth required** at 1% TE-threshold
3-times larger TE with non-adapted signal

Pro: Applicable to any surface signal shape, as long as it can be estimated by **basic trigonometric functions**



Alexeev et al., 2007; Steinert et al., 2020

Steinert et al., 2020