R: Dynamic Roots in ALM

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Objective

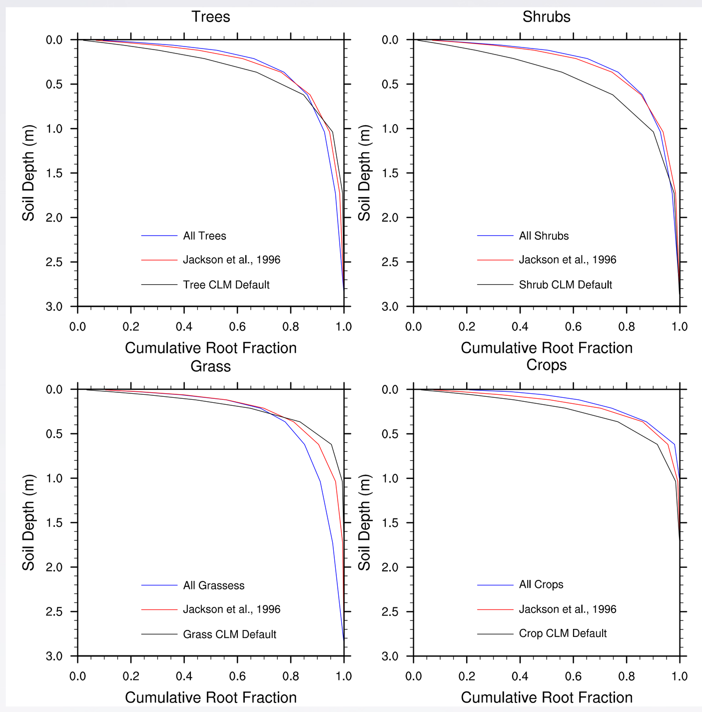
Background:

Roots are responsible for water and nutrient uptake and therefore couple above and below-ground systems. Roots respond to their environment with foraging strategies to maximize resource acquisition. In order to allow ecosystems to respond to changes in environment from climate change, roots must be allowed to adapt to heterogeneity of water and nitrogen in the soil.

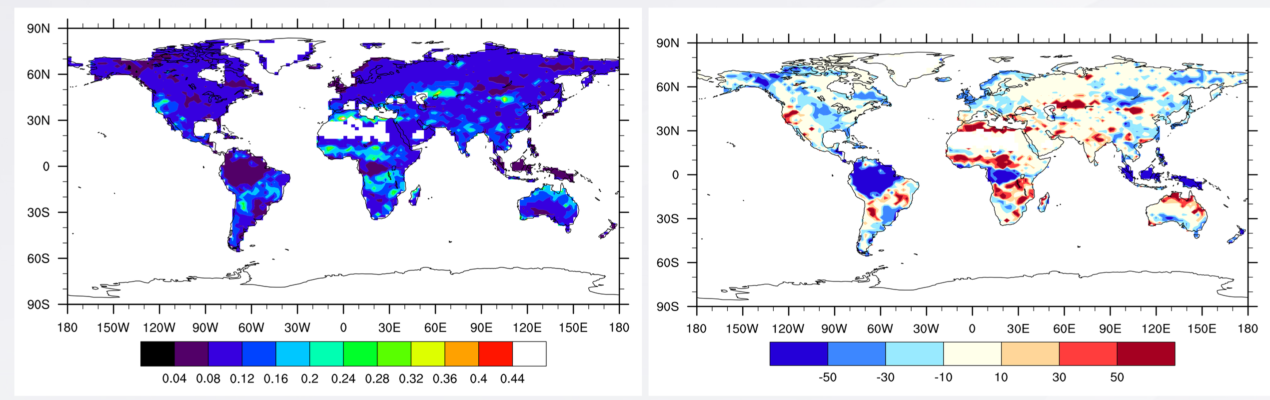
ALM has fixed rooting depth and distribution similar to the exponential distribution of Jackson et al. (1996). The exponential distribution of roots agrees well with global observations, but does not allow changes in root distribution from changes in water or nutrients, nor does it capture the rooting profile of ecosystems in arctic or arid regions. Furthermore, crops undergo rapid root development under short timescales which is not reflected in ALM and can result in an over- or underestimate of crop productivity. At a minimum, root profiles should include time varying structure.

The goal of this study is to develop a new approach for root representation to resolve the horizontal structure of roots. This allows plasticity of roots under non-uniform profiles of water and nitrogen, influencing the above ground vegetation dynamics.

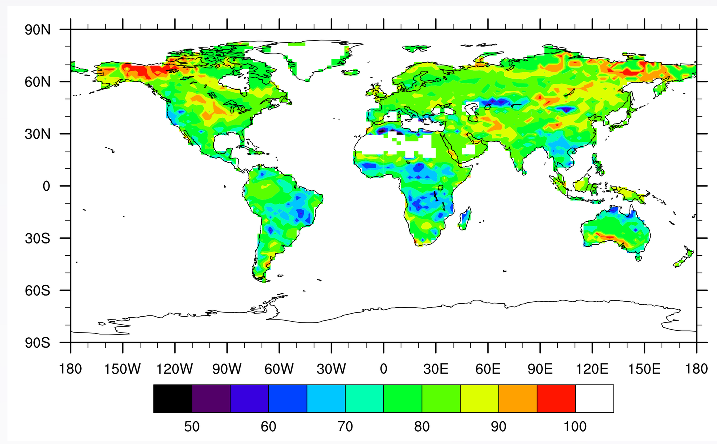
The dynamic roots model is designed to optimize root distribution for both water and nitrogen uptake, but with a priority given to plant water demands.



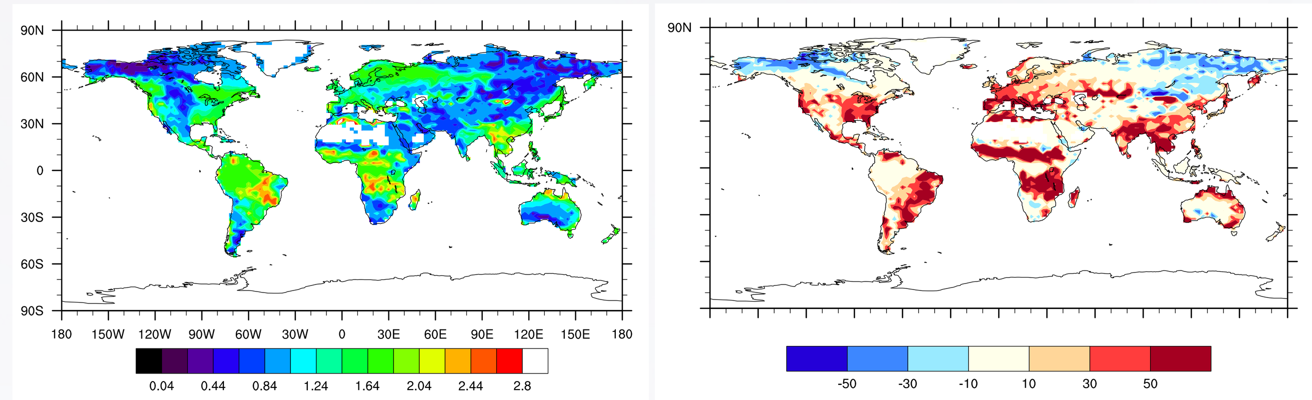
Average cumulative root fraction aggregated across PFTs compared with observations, and the default ALM root configuration.



Left: Soil depth (m) above which 50% of root biomass exists, with a mean of 0.12 m. Shallowest profiles are in croplands, some meadows and prairies, deeper profiles are found in desserts.
Right: Percent change in depth of 50% root biomass between the default ALM root representation and the dynamic root model. Biggest change occurs in the tropics where the dynamic root model decreases depth where 50% biomass is found, but in arid regions increases the depth at which 50% of root biomass is located.



Percentage of roots above 30 cm. Indicates that 50% of root biomass is found in top 30 cm.



Left: Same as above except for 95% root biomass, with a mean depth of 1.28 m. Regions with higher precipitation result in deeper depth where 95% root biomass is found. In general the depth decreases with increasing latitude. Dry tropical savannahs have a majority of root biomass found in deeper soil depths.
Right: Same as above except for 95% root biomass. The largest changes in depth of 95% root biomass are along precipitation gradients – higher precipitation results in a deepening of the root profile. The largest increases in depth of 95% root biomass are in the dry tropics and in the Mediterranean regions. In arctic, most root biomass is found at shallower depths with dynamic roots.

Approach

Root Distribution:

The model is initialized with the default root profile, but fine root carbon in each soil layer is updated each timestep as:

$$\rho_j = C * fr + C_{new} * \left((1 - w_{limit}) * \frac{rswa}{\sum rswa} + w_{limit} * \frac{rsmn}{\sum rsmn}\right)$$

Where w_{limit} is the water availability in the root zone:

$$w_{limit} = \sum \frac{\log\left(\frac{minpsi}{psi}\right)}{\log\left(\frac{minpsi}{maxpsi}\right)} * fr$$

And the water (*rswa*) and nitrogen(*rsmn*) availability in each soil layer (*j*) are:

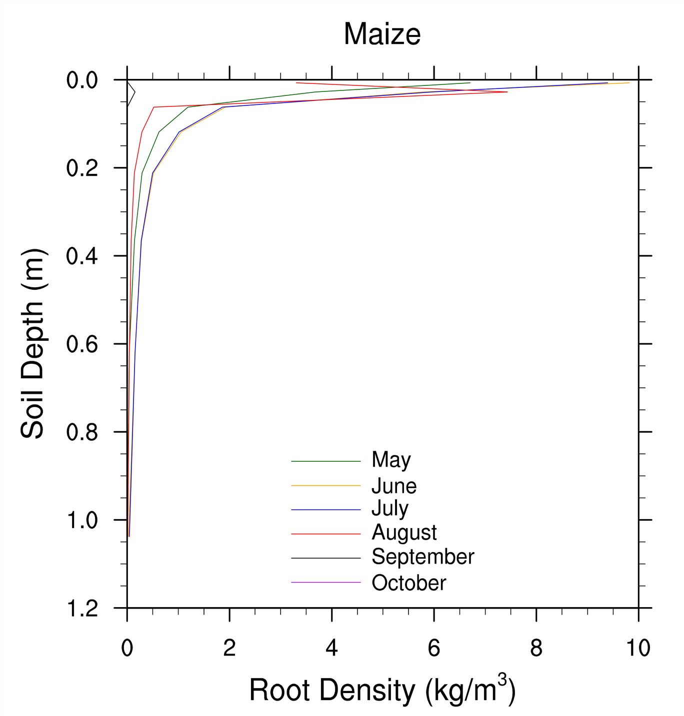
$$rswa_j = \frac{\log\left(\frac{minpsi}{psi}\right)}{\log\left(\frac{minpsi}{maxpsi}\right)} \qquad rsmn_j = sminn\_vr_j$$

The new root fraction (*fr*) is then:

$$fr = \frac{\rho_j}{\sum \rho_j}$$

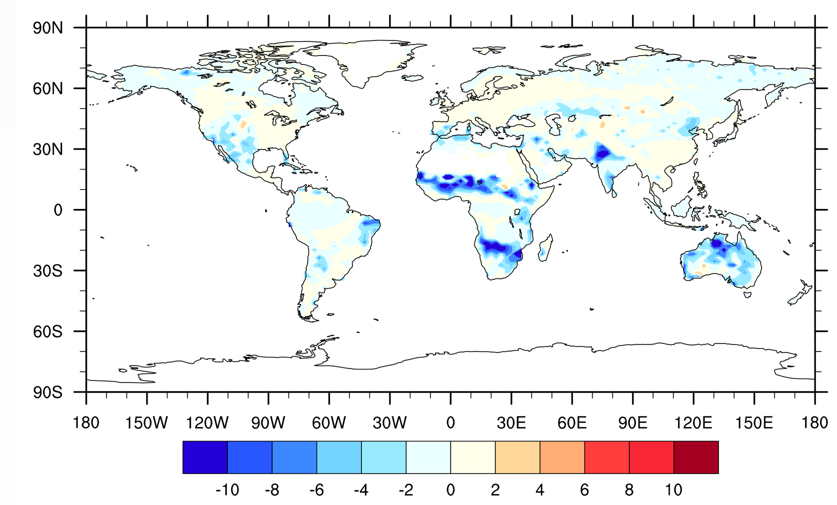
Root Depth (crops only):

- Initial root depth is ~ 4 cm
- Roots grow linearly with Growing Degree Days (GDDs)
- Max depth reached at grain fill: Maize: 1.2 m, Wheat: 0.9 m, Soybean: 1.6 m

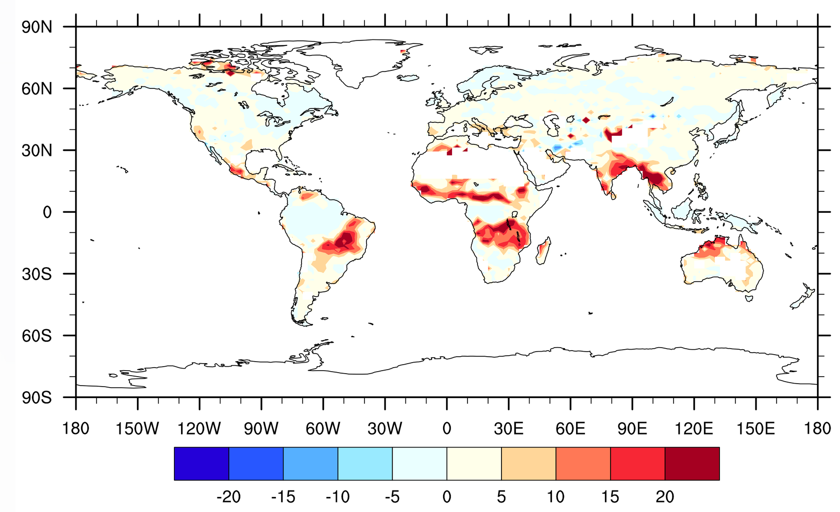


Density of roots in each soil layer over the growing season for maize crop.

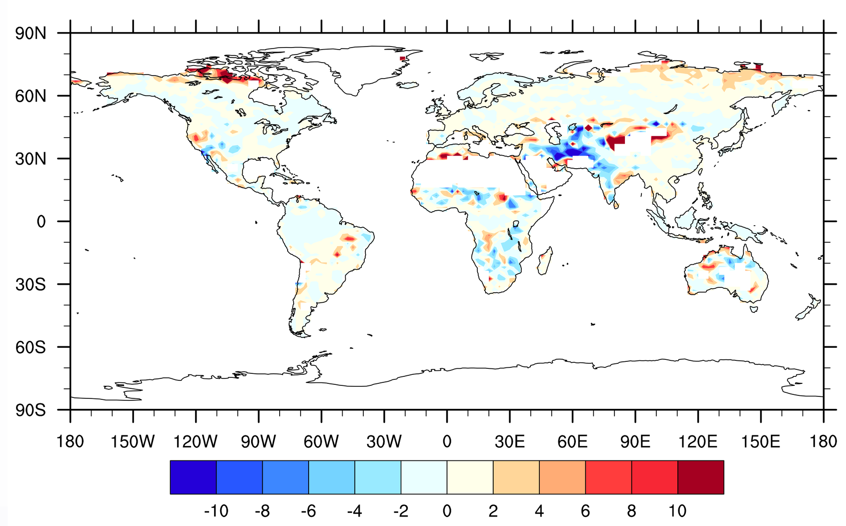
Impact



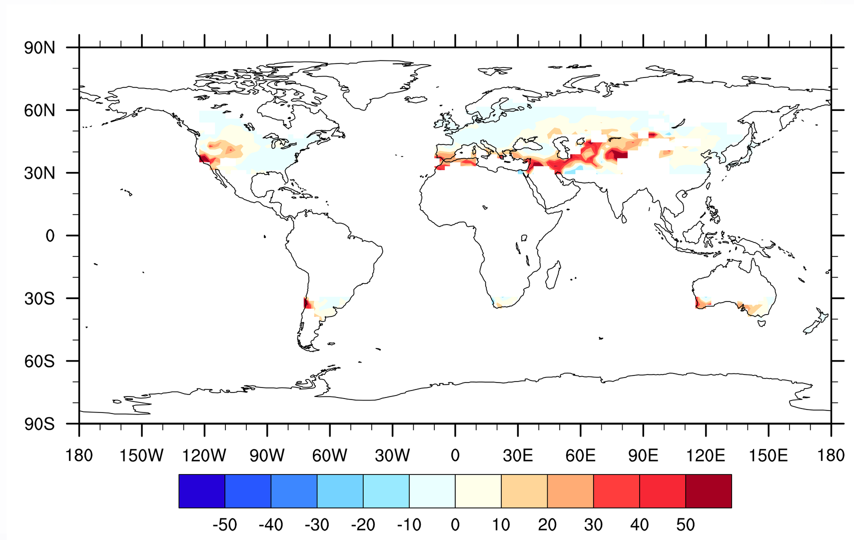
Percent change in soil water content (proxy for water uptake) between the default ALM root representation and the dynamic root model. The global average soil water decreases -0.85%.



Percent change in GPP between the default ALM root representation and the dynamic root model. The global average GPP increases 4.3%.



Percent change in nitrogen uptake between the default ALM root representation and the dynamic root model. The global nitrogen uptake increases 1.2%.



Percent change in crop yield between the default ALM root representation and the dynamic root model. The global average yield increases 4.7%.

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