Incorporating a Topographic Hydrological Gradient into an ESM-Coupled Land Model

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Introduction

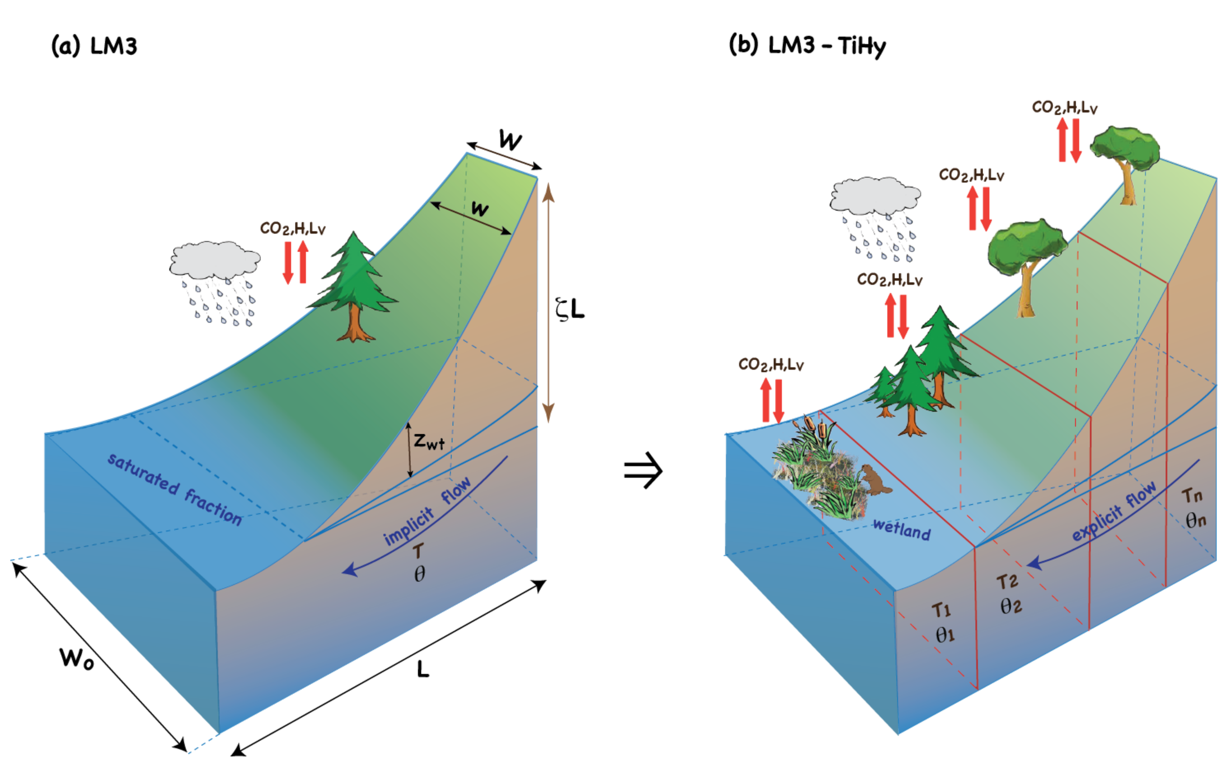
1. Soil moisture is a crucial control on soil carbon and nitrogen cycling, and its impact on soil carbon accumulation is highly nonlinear.
2. Earth System Models (ESMs) generally only represent the average soil moisture state in grid cells at scales of 50-100 km, and as a result are not able to adequately represent the effects of subgrid heterogeneity in soil moisture, especially in regions with large wetland areas.
3. We addressed this deficiency by developing a subgrid hillslope-hydrological model (TiHy) embedded within the Geophysical Fluid Dynamics Laboratory (GFDL) land-surface model.

A. One or more representative hillslope geometries are discretized into land model tiles along an upland-to-lowland gradient in each grid cell.

B. The hydrological model is coupled to the Carbon, Organisms, Respiration, and Protection in the Soil Environment (CORPSE) model. Soil carbon is vertically resolved in the model, allowing more realistic interactions with hydrology in wet areas.

Methods

Figure 1: Discretization of representative hillslope into tiles. Each tile has its own surface fluxes and vertically-resolved state variables for soil physics and biogeochemistry. Groundwater flows among the tiles.



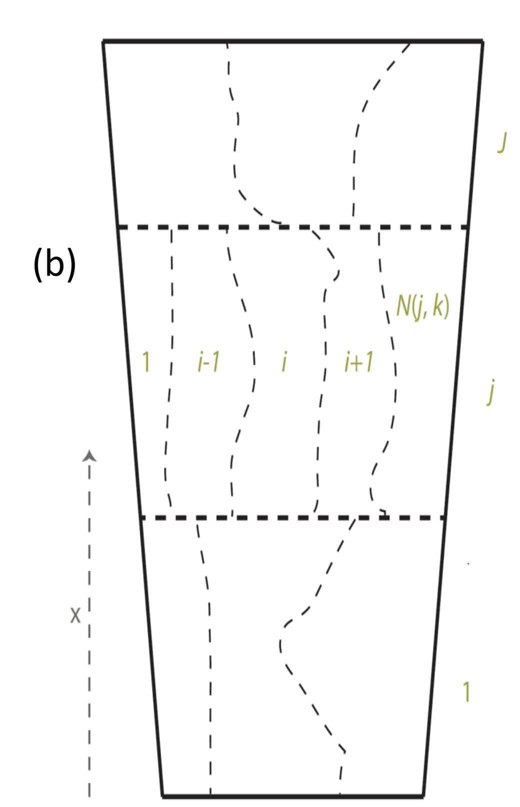
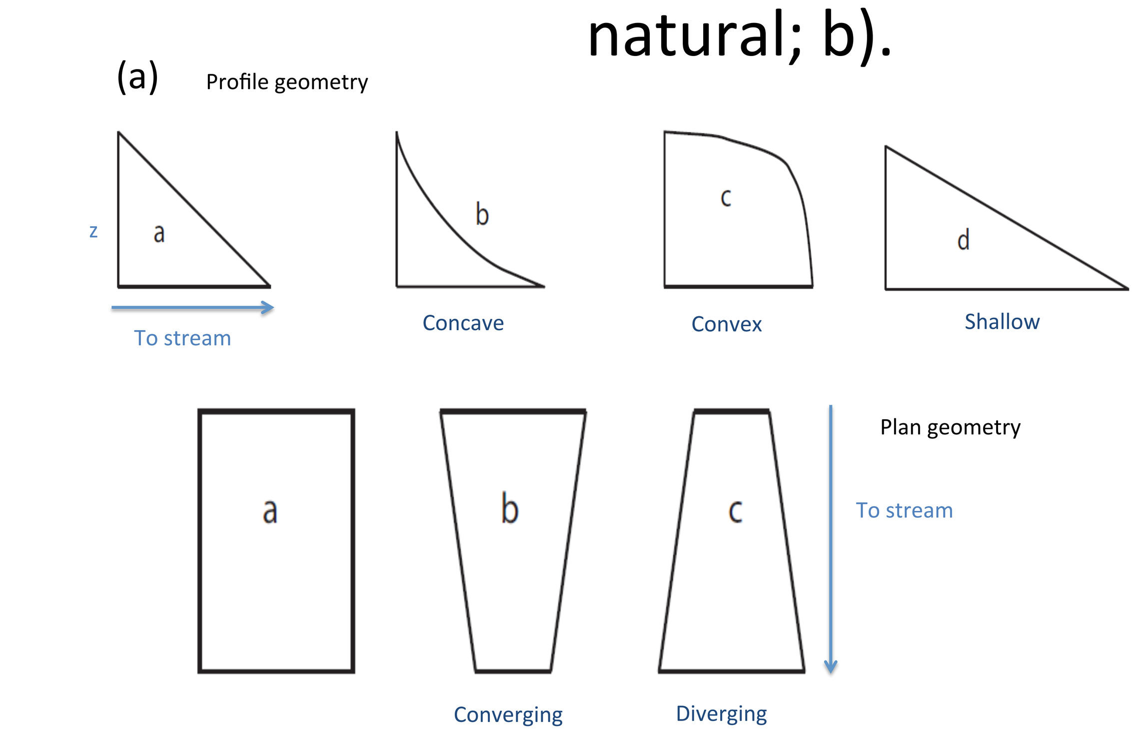
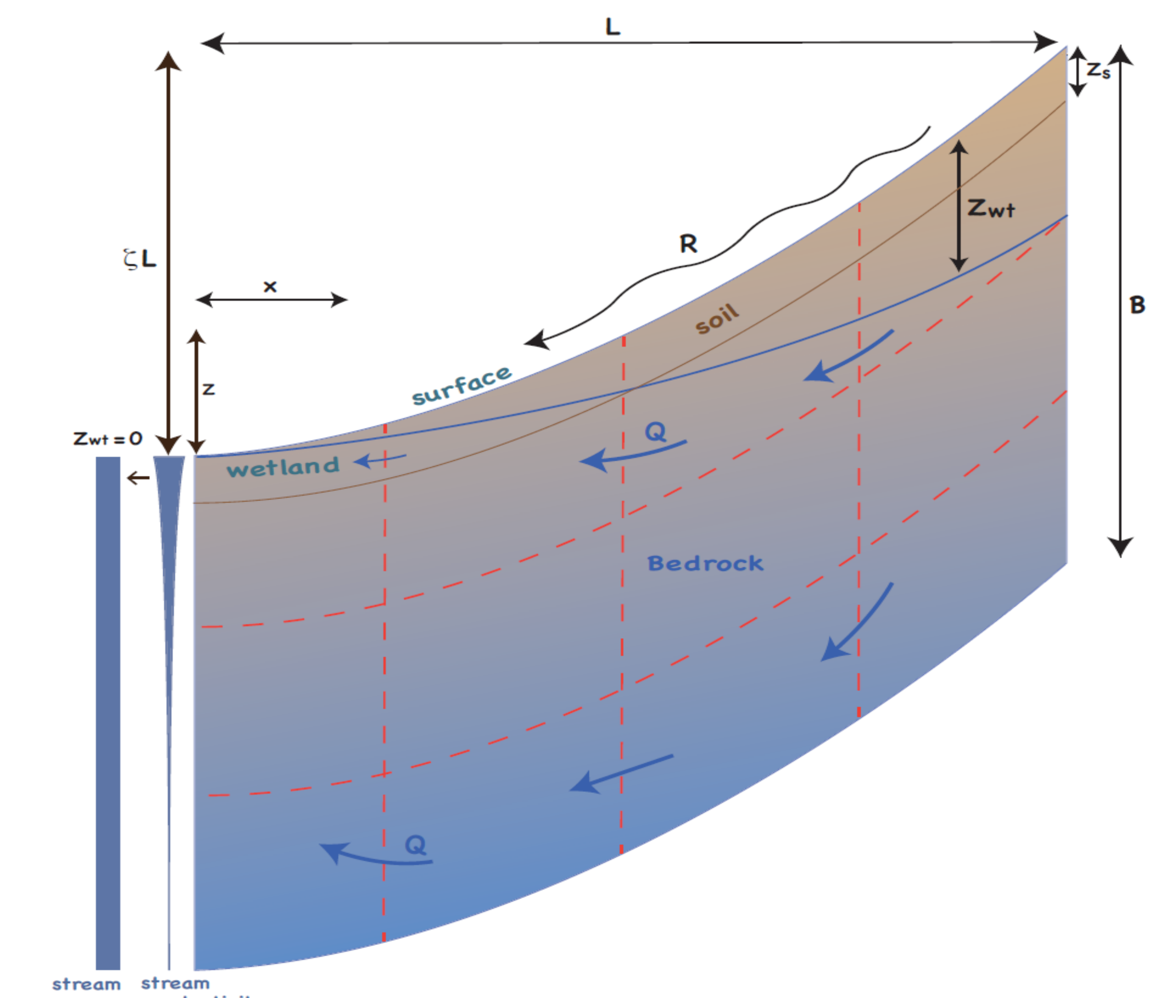



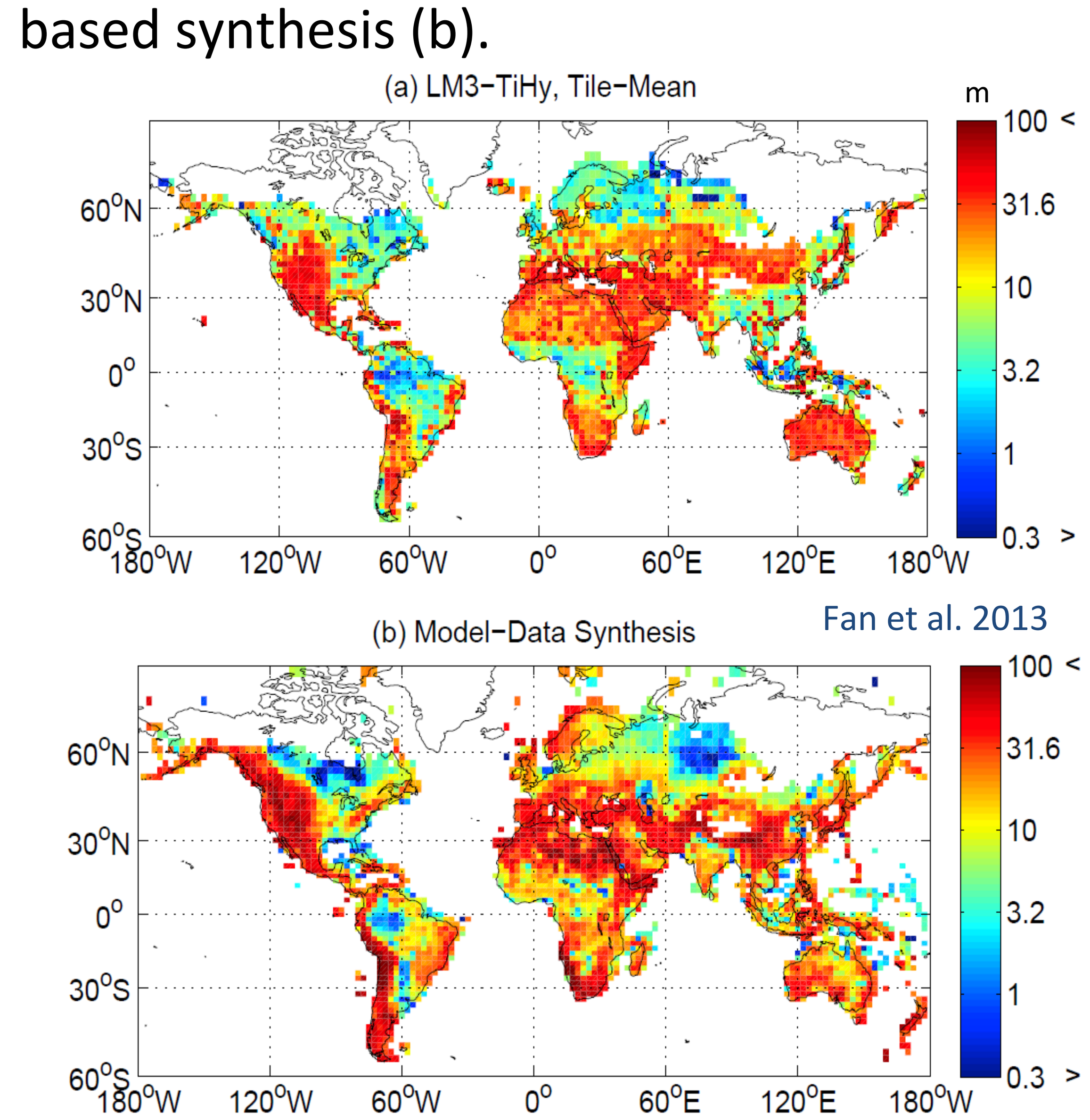
Figure 2: Each gridcell can have several representative hillslopes (a), each with many tiles. These tiles can be further subdivided into vertical clusters when disturbance occurs (human and natural; b).

Figure 3: Implementation of hillslope hydrology. Darcy's Law is discretized vertically and horizontally to describe the 2D flow field Q both above and below the water table depth z_{wt}. Surface runoff R flows directly to the stream, which has finite depth and zero hydraulic head.



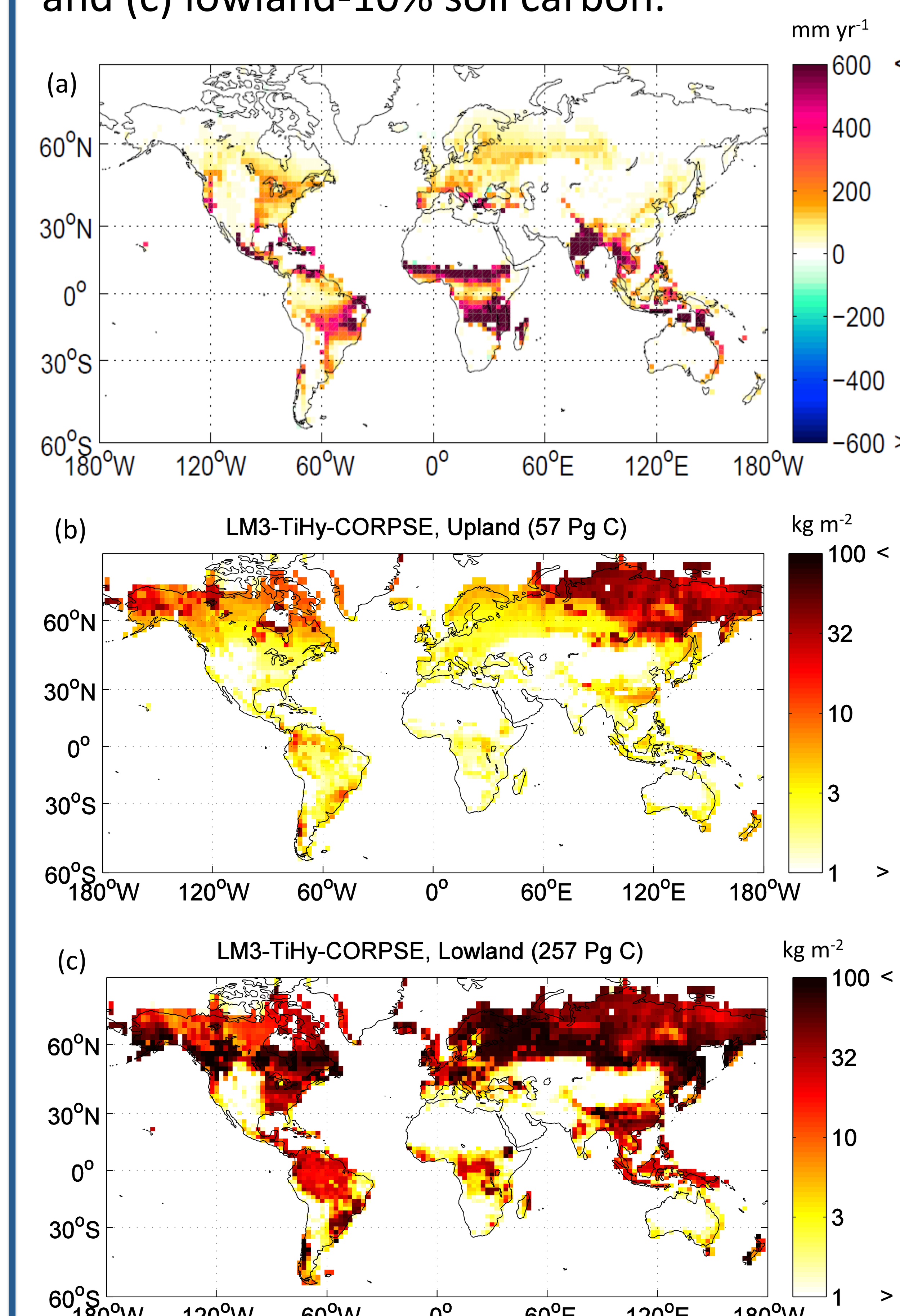
Results

Figure 4: Comparison of global water table depth (m) in TiHy (a) to an observationally-based synthesis (b).



Hillslope hydrology tends to cluster into three regimes: wet and well-drained, wet and poorly-drained, and dry.

Figure 5: (a) Difference between lowland and upland evapotranspiration (mm yr^{-1}); 500-yr spin-up (b) upland-10% soil carbon (kg m^{-2}) and (c) lowland-10% soil carbon.



Discussion

The hillslope discretization has small effects on mean physical fluxes in standalone-land experiments, but causes large simulated differences between upland and lowland ecosystems in the same gridcell, including large effects on biogeochemical cycling: mean soil carbon storage increases substantially in some areas.

Acknowledgments

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