What's new in CLM4 relative to CLM3.5

Changes to CLM4 beyond CLM3.5 (Oleson et al., 2008a; Stöckli et al., 2008) include updates throughout the model. The hydrology scheme has been modified with a revised numerical solution of the Richards equation (Zeng and Decker, 2009; Decker and Zeng, 2009); a revised soil evaporation parameterization that removes the soil resistance term introduced in CLM3.5 and replaces it with a so-called β formulation, as well as accounts for the role of litter and within-canopy stability (Sakaguchi and Zeng, 2009).

The snow model is significantly modified via incorporation of SNICAR (SNow and Ice Aerosol Radiation) which represents the effect of aerosol deposition (e.g. black and organic carbon and dust) on albedo, introduces a grain-size dependent snow ageing parameterization, and permits vertically resolved snowpack heating (Flanner and Zender, 2005; Flanner and Zender, 2006; Flanner et al., 2007). The new snow model also includes a new density-dependent snow cover fraction parameterization (Niu and Yang, 2007), a revised snow burial fraction over short vegetation (Wang and Zeng, 2009) and corrections to snow compaction (Lawrence and Slater, 2009).

CLM4 also includes a representation of the thermal and hydraulic properties of organic soil that operates in conjunction with the mineral soil properties (Lawrence and Slater, 2008). The ground column has been extended to ~50-m depth by adding five additional hydrologically inactive ground layers (making a total of 15 ground layers, 10 soil layers and 5 bedrock layers; Lawrence et al., 2008). An urban landunit and associated urban canyon model has been added which permits the study of urban climate and urban heat island effects (Oleson et al., 2008b). The PFT distribution is as in Lawrence and Chase (2007) except that a new cropping dataset is used (Ramankutty et al., 2008) and a grass PFT restriction has been put in place to reduce a high grass PFT bias in forested regions by replacing the herbaceous fraction with low trees rather than grass. Grass and crop PFT optical properties have been adjusted according to values presented in Asner et al. (1998), resulting in significantly reduced albedo biases. Soil colors have been re-derived according to the new PFT distribution.

The model is extended with a carbon-nitrogen biogeochemical model (Thornton et al., 2007; Thornton et al., 2009; Randerson et al., 2009) which is referred to as CLM4CN. CN is based on the terrestrial biogeochemistry Biome-BGC model with prognostic carbon and nitrogen cycle (Thornton et al., 2002; Thornton and Rosenbloom, 2005). CLM4CN is prognostic with respect to carbon and nitrogen state variables in the vegetation, litter, and soil organic matter. Vegetation phenology and canopy heights are also prognostic. A detailed description of the biogeochemical component can be found in Thornton et al. (2007). Note that CLM4 can be run with either prescribed satellite phenology (CLM4SP) or with prognostic phenology provided by the carbon-nitrogen cycle model (CLM4CN). Additionally, a transient land cover and land use change, including wood harvest, capability has been introduced that enables the evaluation of the impact of historic and future land cover and land use change on energy, water, and momentum fluxes as well as carbon and nitrogen fluxes. The dynamic global vegetation model in CLM3 has been revised such that the carbon dynamics (e.g. productivity, decomposition, phenology, allocation, etc.) are controlled by CN and only the dynamic vegetation biogeography (competition) aspect of the CLM3 DGVM is retained.

Several other minor changes have been incorporated including a change to the atmospheric reference height so that it is the height above z_o+d for all surface types. The convergence of canopy roughness length z_o and displacement height d to bare soil values as the above-ground biomass, or the sum of leaf and stem area indices, goes to zero is ensured (Zeng and Wang, 2007). Several corrections have been made to the way the offline forcing data is interpreted. The main change is a vastly improved and smooth diurnal cycle of incoming solar radiation that conserves the total incoming solar radiation from the forcing dataset. Additionally, in offline mode rather than partitioning incoming solar radiation into a constant 70%/30% direct vs diffuse split, it is partitioned according to empirical equations that are a function of total solar radiation. Finally, to improve global energy conservation in fully coupled simulations, runoff is split into separate liquid and ice water streams that are passed separately to the ocean. Input to the ice water comes from excess snowfall in snow-capped regions. The biogenic volative organic compounds model (BVOC) that was available in CLM3 has been replaced with the MEGAN BVOC model (Heald et al. 2008).

Taken together, these augmentations to CLM3.5 result in improved soil moisture dynamics that lead to higher soil moisture variability and drier soils. Excessively wet and unvarying soil moisture was recognized as a deficiency in CLM3.5 (Oleson et al. 2008a, Decker and Zeng, 2009). The revised model also simulates, on average, higher snow cover, cooler soil temperatures in organic-rich soils, greater global river discharge, lower albedos over forests and grasslands, and higher transition-season albedos in snow covered regions, all of which are improvements compared to CLM3.5.

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