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Editorial

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Hydrological Dynamics are Critical to Greenhouse Gas Cycling

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Greenhouse gas cycling is an important component of earth system models that are used to project our future climate. Major physical, chemical and biological processes and controls of greenhouse gas cycling are often incorporated into biogeochemistry models of these gases. In particular, the hydrological cycle has long been linked to these models. However, more adequate hydrological models are still critically needed.

Existing biogeochemistry models often contain a simple single-bucket hydrological model. In these hydrological models, the water is simply balanced so as to estimate soil moisture and water fluxes, which are then used to drive biogeochemical processes. These pixel-based hydrological and biogeochemistry models are then extrapolated to regional scales to quantify greenhouse gas cycling. This paradigm ignores the lateral flow induced by elevation or topographical differences between grids across the landscape, biasing estimates of key water fluxes, moisture, and water table depth, leading to errors in the quantification of greenhouse gas emissions.

Greenhouse gas modeling requires more sophisticated hydrological models that are able to simulate soil wetness dynamics across the landscape. In the dry areas of terrestrial ecosystems, soil decomposition is dominated by aerobic reactions, leading to CO_2 release, while in wet areas, more CH_4 is generated through methanogenesis process. Areal changes of wetness across landscape will shift the ratio of these two carbon-based greenhouse gases, as well as the rate of N_2O emissions as a result of nitrification and denitrification processes that are principally controlled by moisture conditions. The differentiated rates of aerobic and anaerobic soil decompositions affect nutrient cycling (e.g. inorganic nitrogen availability through mineralization), in turn affecting the rate of ecosystem carbon assimilation through an impact on photosynthesis. Moisture conditions also influence the level of evapotranspiration, which facilitates plant photosynthesis and productivity *via* altered stomata openness and CO_2 diffusion amount into plant leaves.

As a good example for the critical coupling of hydrological and biogeochemical cycles, more adequate hydrological models to quantify the fate of the large amounts of carbon stored in the Arctic are critically needed. This is mainly due to the fact that in current cold-region hydrological models, the effect of thawing permafrost is often insufficiently modeled. Geomorphic effects of permafrost thaw and climate on inundated area dynamics are also understudied. Furthermore, those models are generally not capable of accounting for the effects of microtopography and simulating wetland type as well as distribution featured with hummocks and hollows, which are critical to differentiate CO_2 and CH_4 emissions. However, current modeling of water dynamics and the distribution of hummocks and hollows at very fine spatial scales tend to be a challenge computationally, and a lack of more detailed landscape information is another limiting factor. With more satellite and remote sensing information on landscape morphology available and computing capability increasing, such hydrological models become increasingly possible. From a point of view of the soil physical process, a fully coupled model that incorporates the whole range of soil thermal and hydrological processes, especially freezing and thawing processes, should improve hydrological modeling, thereby bettering greenhouse gas accounting.

The distribution and area of wetlands, water bodies, and upland ecosystems affected by hydrological cycling is critical to greenhouse gas cycling at regional and global scales. Estimates of current global wetland areas from ground and satellite instruments vary in an order of magnitude. Improved modeling of the distribution and extent of these ecosystems, at a sufficiently high resolution will improve greenhouse gas estimations. Further, the linkage of climate, land, vegetation, groundwater, freshwater bodies, ocean systems and human activities should improve modeling of dynamics of soil wetness, area of water bodies, wetland, and water table depth that control the biogeochemical cycles.

Finer temporal-scale hydrological models might also improve biogeochemistry modeling as the biogeochemical processes occur at fine temporal scales. The coarse temporal-scale (e.g., monthly) dynamics of water fluxes, moisture, wet and dry area, and water table depth disconnect with the chemical and biological processes, and bias greenhouse gas quantification. Taken together, developing more comprehensive process-based hydrological models that operate at finer temporal and spatial scales should be a priority to improve current biogeochemistry and earth system models.

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