ForestFlow - Shifting the balance? Dissolved carbon fluxes from forests under future rainfall regimes

WP1 Hydrological site characterisation

The project performed a detailed hydrological site characterization in two Belgian ICOS-sites: Brasschaat (Scots pine) and Vielsalm (mix of beech and Douglas fir). The physical features of relevance for the hydrological impact modelling were assessed at two spatial scales: the local areas where a detailed sampling was performed, and the scale of the entire watershed at coarser resolution. The small grid analysis allowed to directly couple phenology and biogeochemistry analysis to hydrological fluxes. These physical features were afterwards combined with advanced hydrological time series analyses, to assess both hydrological characteristics of the whole watersheds and of the specific sampling sites.

WP2 and WP3: Biogeochemistry and tree phenology as mediator of soil water fluxes

In order to quantify Dissolved Organic Carbon (DOC) export from the ICOS station of Brasschaat in Belgium, we had as a first objective the adaptation of the structural design of the iFLUX sampler® to enable it to measure vertical instead of horizontal fluxes in an unsaturated environment. Unfortunately, the adaptation of the iFLUX sampler® was not successful, and for this reason, the methodological objective of this study was revised from adapting the iFLUX sampler® to the creation and design of a Zero Tension Lysimeter (ZTL). The sampler designed received the name of Zero Tension Lysimeter (ZTL3D) and was created by Selective Laser Sintering (SLS) using Nylon 12.

Due to excessive drought and the initial problems with the sampler design, we decided to opt for an experimental approach first, rather than an observational approach as opted in the proposal. Both extensive in-field irrigation and rain simulation experiments were performed.

The results show a non-negligible role of DOC in the site C balances. The higher DOC fluxes at deeper soil layers also have ecological relevance. By transferring DOC to deeper layers where decomposition is slower, long-term C sequestration in subsoils could increase, while also the opposite may occur: that the increased input of DOC primes the activity of decomposers, resulting in increased decomposition of subsoil SOM and thus in net losses of SOM.

Results confirm the importance of DOC as a non-negligible flux of C travelling from terrestrial ecosystems to rivers and oceans, which in case of integration of large drainage surfaces, amount to high inputs. Increases in DOC inputs due to extreme rainfall events will result in increases in lateral fluxes that will affect the biogeochemistry and ecology of inland waters and estuaries. It has only been recognized in recent years that the lateral flux of DOC is large and affects the functioning of downstream ecosystems. The ecological impact of the increased DOC fluxes due to worsening rainfall extremes was –to the best of our knowledge- never before assessed.

WP4: Hydrological modelling

For the hydrological modelling of the two study areas, a novel hydrological modelling approach was implemented and applied, to conduct the hydrological impact investigations. Both a lumped and spatially distributed catchment model were developed. Particular focus was given to the modelling of the temporally changing conditions including extreme wet and dry soil and surface states. The hydrological model was extended with a carbon model based on two main submodules: one for modelling soil organic carbon (SOC) and one for estimating dissolved organic carbon (DOC). We considered production and decomposition processes of SOC and DOC, as well as DOC leaching. Coupling to the soil moisture module based on Aquacrop was done, accounting for the vertical distribution of soil moisture and drainage. The approach allowed flexibility, both in the spatial resolution and the model structure (in terms of processes).

The soil organic carbon was simulated based on the RothC scheme, and the DOC was simulated based on the JULES-DOCM and ORCHIDEE-SOM conceptualization. Production and decomposition processes of SOC and DOC, as well as DOC leaching, were considered per user-defined layer. Carbon dynamics were simulated up to 2 m depth, considering the globally available data per depth such as soil texture and root distribution. The model does not include a dynamic vegetation model, but accounts for the seasonal and vertical distribution of plant residues based on literature values. Preliminary results showed that the spatial patterns of SOC, from which DOC is derived, are in accordance with SOC patterns observed for regional and global maps, such as SoilGrids. Furthermore, results for Brasschaat showed that the magnitude and seasonal distribution of heterotrophic respiration, actual evapotranspiration, and to some degree soil moisture is in accordance with field observations.

WP5: Climate scenario analysis

Precipitation regimes and extremes are subject to changes at regional scale over Belgium in the context of the global climate change. The changes in the frequency, intensity and duration of extremes, e.g. drought and extreme rainfall, especially are a focus of interest. In view to understand the changes in these regimes and to elaborate possible mitigation measures, the interplay between the large scale climate changes with the regional aspects, e.g. land use, is of particular relevance for integrated regional earth system models, which aim at coupling climate, land surface, and hydrological models, hence incorporating possible feedbacks between the earth system components. In setting-up those coupled systems, we first need to quantify the model uncertainties and gauge the validity of the future scenarios that could be provided. This step is essential because the improvement of information given downstream by impact models is strongly linked to the quality of the climate model. For climate, two models, both used at KMI, are evaluated: the ALARO-0 climate model, and the SURFEX v8 land surface model, an up-dated version of the land surface model used at KMI, which can account for the carbon cycle and the vegetation development. For ALARO-0, the variables transferred to land surface/hydrological modeling (global radiation, wind speed, air temperature, precipitation) compares very well to ground observations, but with a larger uncertainty on annual precipitations. A strong consistency between runs forced by 2 different Global Circulation Models over the past 40 years, which indicates that no systematic bias correction is needed for further use in land surface/hydrological models or in using future scenarios. For SURFEX v8, components of local simulations over the sites of interest have been compared to remote sensing data products. It shows the water cycle components are well simulated over the sites and could be used directly, while components from the carbon cycle, as the structural leaf parameters (Leaf Area Index) and Gross Primary Production, tend to be shifted in time, and may require model adaptations and/or correction prior to be used by any downstream models or when coupled in regional earth system models. Land use/land cover is another sensitive input to climate and land surface models. As we shift to modelling at higher resolution, changes in land use may also have higher impact on the water/carbon components modelling, and more accurate maps including time lines (in the past and in the future), may be required. Land use/land cover maps covering Belgium useful for climate runs have been reported and an equivalence to the classification needed by SURFEX has been established as to be used for further developments.

Overall conclusion

The relative importance of dissolved and gaseous export of carbon from forests under different precipitation regimes remains largely unexplored, partly because of technical constraints to accurately measuring dissolved export fluxes, and partly due to a strong focus on greenhouse gas balances in current research infrastructures.

Forestflow aimed to:

-Quantify dissolved organic carbon export from deciduous and coniferous forest, and hereby close ecosystem carbon balances in two Belgian ICOS-sites

-Quantify the seasonality in dissolved vs. gaseous carbon export from forests: tree phenology and rain regime are hypothesized to be the main control factors

-Investigate whether shifts in gaseous vs. dissolved carbon export occur during rain events and persistent drought

-Model future alterations in the forest carbon balance, by implementing the results in coupled climate, hydrological and forest ecosystem biogeochemical models.

ForestFlow was not able to overcome the complete challenges as set above. The IFlux sampler proved not to be capable as of yet to perform as expected under non-saturated soil conditions. Sufficient time to redevelop the sampler was not available, so the decision was taken to develop new 3D printed lysimeters. The methodological advances here allowed to assess DOC fluxes during extreme rainfall for the first time. The advances also proved to be valuable for other researchers, and a methodological paper was published. It is clear from the results that current DOC export estimates from forest soils, based on conditions during 'normal' weather, cannot stand under future climate regimes. During only on extreme rain event only, more DOC is exported on a daily basis, than current estimates for monthly DOC export subsoil based on earlier studies. Despite the major challenges we were confronted with (extreme droughts, COVID-19 and an unexpected need to develop a new sample), ForestFlow results clearly indicate that shifting DOC fluxes could be crucial for the forest carbon balance, potentially shifting soil storage from a net sink to a net carbon source.

Due to the complexity in achieving the data on the in-field DOC fluxes, the full coupling to the hydrological modelling, both at the local and basin scale, has not been fully developed yet. Still, a working hydrological model for both ICOS site was developed, and a coupled DOC flux model is now available. Equally for regional modelling, key to coupling to IPCC scenarios for precipitation, key adaptations needed were made to the ALARO-0 climate model, and the SURFEX v8 land surface model. Water cycle components were well simulated over the sites and could be used directly, while components from the carbon cycle, as the structural leaf parameters (Leaf Area Index) and Gross Primary Production, tend to be shifted in time, and may require some model adaptations and/or correction prior to be used in regional earth system models.

Keywords:

Forests; dissolved carbon export; future climate; extreme rain events; soil lysimeter