GI_Forum 2021, Issue 1
Page: 137 - 142
Best Practice Paper
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DOI: 10.1553/giscience2021_01_s137

Helping forest owners to manage forest carbon – the Forest Flux project

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Abstract

Forest Flux https://www.forestflux.eu/ will renew forestry value-added services in Earth Observation (EO) by creating and piloting cloud-based services for committed users on forest carbon assimilation and structural variable prediction. Forest Flux exploits the explosive increase of high-resolution EO data from the Copernicus program and developments of cloud computing technology. It implements a world-first service platform for high-resolution maps of traditional forestry variables together with forest carbon fluxes. Forest Flux will allow the users to improve the profitability of forest management while taking care of ecological sustainability. The Forest Flux services are implemented on the Forestry Thematic Exploitation cloud platform https://f-tep.com/. In 2020, nearly 700 thematic maps on forest stand and carbon flux variables were delivered to nine specific users in a form that was applicable to their operational forest management systems. The last project year 2021 focuses on map product refinement and improving user services, which eventually lead to operational service concepts. Forest Flux is an Innovation Action project of the European Union, Grant Agreement No. 821860.

Keywords: forestry, carbon, satellite, earth observation, biomass, cloud platforms

1 Introduction

Until recently, detailed information on the forest carbon cycle has not been available due to a lack of scientific understanding, spatial data availability, limited processing capacity, and the complexity of implementing this information in business processes.

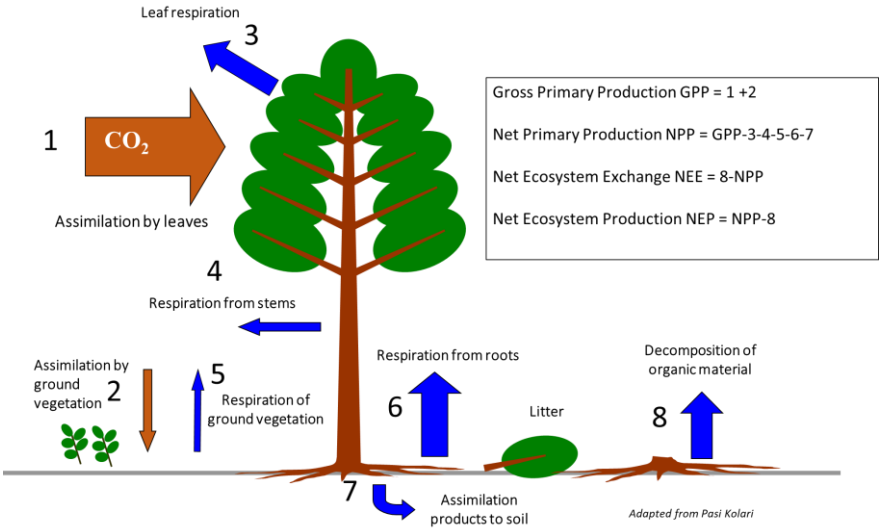

Figure 1: Carbon flux variables computed in Forest Flux project.

Forest Flux will renew forestry value-added services in Earth Observation (EO) by creating and piloting cloud-based services for committed users on forest carbon assimilation and structural variable prediction (Figure 1). The services utilize Copernicus satellite data. The services are driven by sustainable forest management, EU forest strategy, the Bioeconomy Action Plan, and the demands of environmentally aware end-users of wood industry products.

Forest Flux exploits the explosive increase of high-resolution Earth observation data with 10-to-20 metre resolution, particularly from the Sentinel 2 satellite of the Copernicus program. The recent developments of cloud computing technology are utilized in data value-adding. It implements a world-first service platform for high-resolution maps of traditional forestry and carbon flux variables. Forest Flux will allow the users to improve the profitability of forest management while taking care of ecological sustainability. Forest Flux is an Innovation Action project of the European Union's Horizon 2020 program, Grant Agreement 821860. The project started in 2019 and will be completed at the end of 2021.

Forest Flux uses a holistic approach in a single processing chain. Already during the project, forestry and carbon data are integrated into the decision-making processes of selected core users. The Forest Flux services are implemented on the Forestry Thematic Exploitation cloud platform https://f-tep.com/. It uses the CreoDIAS infrastructure as the satellite data supply and processing infrastructure.

Forest Flux will establish the leadership of European industry in the sustainable utilization of forest resources. The computing infrastructure is specifically targeted for EO data and forestry users, and it will be fully functional by the end of the project. The web-based human and machine interfaces will enable market access unrestricted by country boundaries, and facilitate easy commercial interactions of players of different sizes and backgrounds.

2 Concept

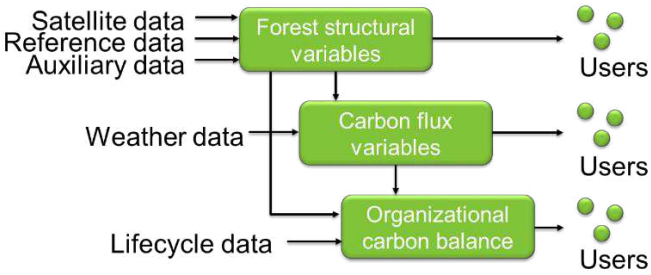

Figure 2: The three service groups of Forest Flux.

The services of Forest Flux are composed of three main blocks: 1) Forest structural variable services, 2) Carbon flux services, and 3) Organizational carbon balance services (Figure 2).

Forest structural variable services comprise of forest cover mapping and estimation of forest variables that have been traditionally measured in the field. The provided information includes tree height, basal area, stem diameter, stem volume, density, and tree species. The forest inventory service can be implemented for several years, or at defined intervals.

Forest change services are also part of the service block of structural variables. These services offer mapping of changes in forest cover between given target years. Possible change types include changes between land cover classes due to forest harvests, or forest damage.

Forest ecology inventory services include two types of products: fragmentation and structural diversity products. The products of this service are computed from outputs of forest inventory service. The Forest ecology inventory indicators indicate the proportion of wooded area within a selected grid cell area (e.g. 1 km^2), number of wooded patches with a unit area, wooded area perforation density, number of tree species, and tree height variability within the selected grid cells.

Forest ecology change computes changes between two ecology products that represent different points of time.

The forest structural variable services provide information on forest area, forest status, and their changes. The inventory considers one target year, whereas the change services provide information about forest changes between the years.

Carbon flux services provide information on the **biomass and carbon balance of the forests**. Forest structural variables derived from EO are used to initialize the forest model PREBAS (Minunno et al., 2019; Tian et al., 2020). Carbon (C) stocks and fluxes are computed for the year of the structural variable mapping and for the future, providing forest growth and C balance forecasts.

The outputs of the biomass and carbon balance service are: maps of above and below-ground tree biomass, soil C stocks, vegetation carbon, yearly averaged Evapotranspiration, Gross Primary Production (GPP), Net Primary Production (NPP), Net Ecosystem Exchange (NEE)

(Figure 1). Mapping using the PREBAS model allows spatial identification of carbon sinks and sources and monitoring particular vegetation stresses, such as water stress.

Biomass and carbon fluxes can be monitored for years for which ground reference, satellite, and weather data are available. Several structural forest variable estimations over years help to improve the carbon flux and growth models. Forecasts for future fluxes and forest growth can be computed by applying different climatic and forest management scenarios.

The **organizational carbon balance** builds on the previous service layers: forest structural variable estimation and carbon storage and fluxes while adding one additional layer: the wood harvested from the forest and manufactured into wood-based products.

The carbon storages and fluxes from the previous step, carbon in trees and soil, the fluxes between these storages and atmosphere, are in other words augmented with third carbon storage, wood-based products, and the associated carbon fluxes. Part of these fluxes are carbon emissions from the execution of wood harvesting, transport, and manufacturing processes, including recycling. Another aspect considered for the wood-based carbon product storage is the substitution of non-renewable materials with renewable ones.

Dedicated user involvement, strong commercial interests, rapidly developing online markets, and demonstrated excellence of the consortium make the Forest Flux service platform sustainable beyond the end of the project.

3 Pilot services

Pilot services were conducted for nine users in five countries in Europe and South America. In total, approximately 700 thematic maps were delivered for the forest management systems of the users. For each user, a Service Agreement was prepared. This agreement defined the site and desired contents of the services. The users assessed the delivered maps and associated information of uncertainties. The assessment results were used to improve the services for the second pilot that has been conducted in 2021.

The main high-resolution (HR) satellite data were Copernicus Sentinel-2 Multispectral Instrument (MSI) images with a ten-metre spatial resolution that was also the resolution of the output maps except for the ecology products where the resolution was one square kilometre. Supplementary satellite data for before the year 2015 were obtained from Landsat 8 Operational Land Imager (OLI). The wall-to-wall satellite data were augmented by a sample of Very High Resolution (VHR) satellite imagery with sub-meter resolution. Images from several VHR satellites including Worldview-2, Geoeye-1, Pleiades, Deimos, and Kompsat 3, available on the Data Warehouse of Copernicus, were analysed. These data were used to augment incomplete ground reference data on some pilot sites.

The ground reference data were mostly provided by the users. Openly available ground sample plot data of high quality were available for the whole country in Finland. These data were used for the training of the models for satellite image interpretation and for uncertainty analyses. The principal method for the estimation of forest structural variables was the Probability method of VTT (Häme et al., 2013, 2001).

For changes, VTT's Autochange method was applied (Häme et al., 2020). Probability and Autochange software were run on the Forestry cloud TEP platform. A significant amount of new software for the improvement of the image analysis process was developed in Forest Flux. Figure 3 and Figure 4 give examples of the Forest Flux maps.

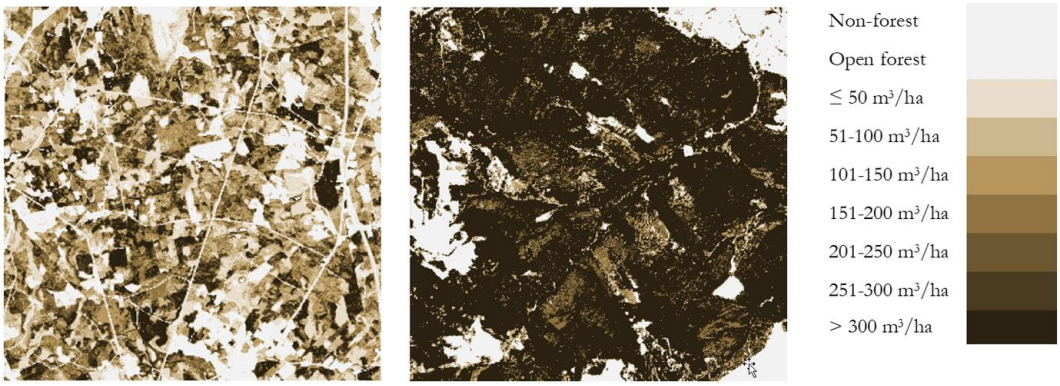

Figure 3: Stem volume maps computed in the first pilot services Forest Flux on 7 km x 7 km areas in Finland and Romania. The relative RMSE was in Finland 52% and bias 0.1 m3/ha and in Romania 59% and 2.3 m³/ha, respectively. The uncertainties were computed at the level of ground sample plots using an independent plot sample. The uncertainties are smaller for larger areas.

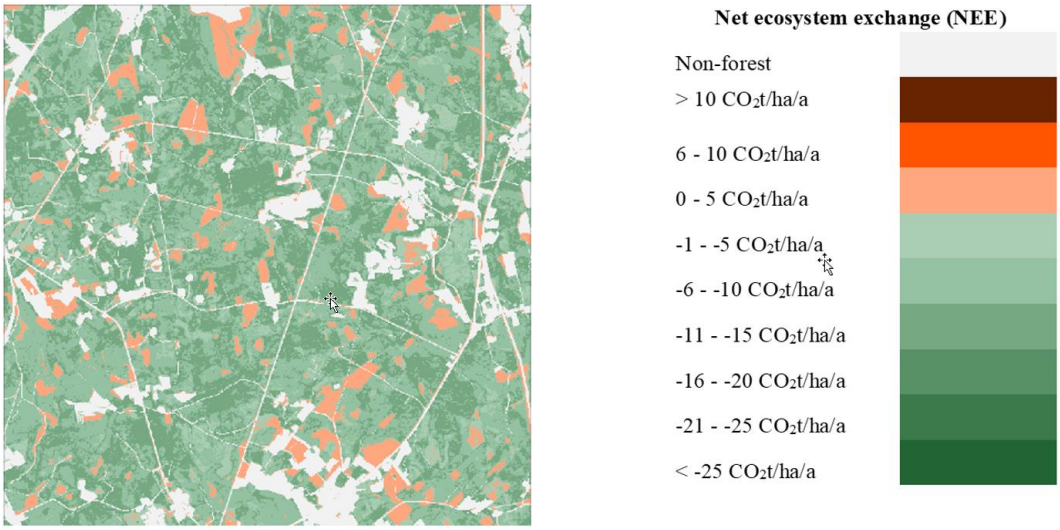

Figure 4: Net ecosystem exchange for in the Finnish study site. Negative values mean carbon assimilation and positive carbon emission. The emission sites represent recent regeneration areas.

Conclusions

Relatively complex production chains were developed during the two first years of the Forest Flux project. The second pilot services for the same users means approaching an operational status of the service provision. All the users were willing to continue receiving Forest Flux services in pilot stage two. The feedback showed requirements for increasing the accuracy of estimations. A positive assessment was received from sites where the ground reference data were poor because also the earlier information on forest resources was inaccurate. In Finland, where the quality of the reference data was good, the existing information of forest resources is also accurate. The satellite data will be augmented with Airborne Laser Scanner (ALS) observations when demand for accuracy is high and these data are available.

During the last project year, a business plan for the operational services will be developed together with the provision of the second pilot services.

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