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Remote methods of estimating carbon reserves at the site of the Far Eastern carbon polygon

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Abstract: Carbon test sites are test sites located in unique ecosystems where technologies for measuring, monitoring and controlling greenhouse gases are developed and tested. The paper considers the Far East Carboniferous Polygon (FECP) site located in the Ajax Bay in the Sea of Japan in the temperate monsoon climate zone. Images of FECP were made by unmanned aerial vehicle (UAV) with additional terrestrial laser scanning (TLS) in 2024. Observed terrain models were classified by types of land usage. Heights of trees were clarified by data from open sources. Preliminary data on biomass content and carbon reserves have been calculated.

Keywords: *Carbon polygon, Carbon Stock, Remote Sensing, Terrestrial laser scanning, Unmanned aerial vehicle.*

1. Introduction

For several decades, the attention of the scientific community has been focused on the problem of climate change caused by anthropogenic emission of greenhouse gases. Great attention is paid to the problem of greenhouse gas monitoring. Specifically, to study greenhouse gas emissions and to test carbon balance control technologies in representative ecosystems, "carbon polygons" are created.

Vegetation has a main role in maintaining and keeping balance of atmospheric greenhouse gases. This fact is reflected in the UN Framework Convention on Climat Change (UN FCCC) [1] the Kyoto Protocol [2]. The Russian Federation has assumed obligations to control greenhouse emissions, as reflected in Federal Law (FL) № 296-FL dated 07/02/2021 «On limiting greenhouse gas emissions» [3, 4].

Ajax Bay in the Sea of Japan is one of the sites of a large carbone polygon project. The site belongs to the Far East Carbon Polygon. The land area of the seaside terrace of the coast occupies 4 hectares, the sea area 20 hectares. Moreover, the study area is located within the campus of the Far Eastern Federal University.

The bay area is located in the northeast of Russky Island, in Peter the Great Bay in the Sea of Japan. The bay is located between Cape Novosilsky and Cape Balka and reaches the southern shore of the Bosporus-Eastern Strait.

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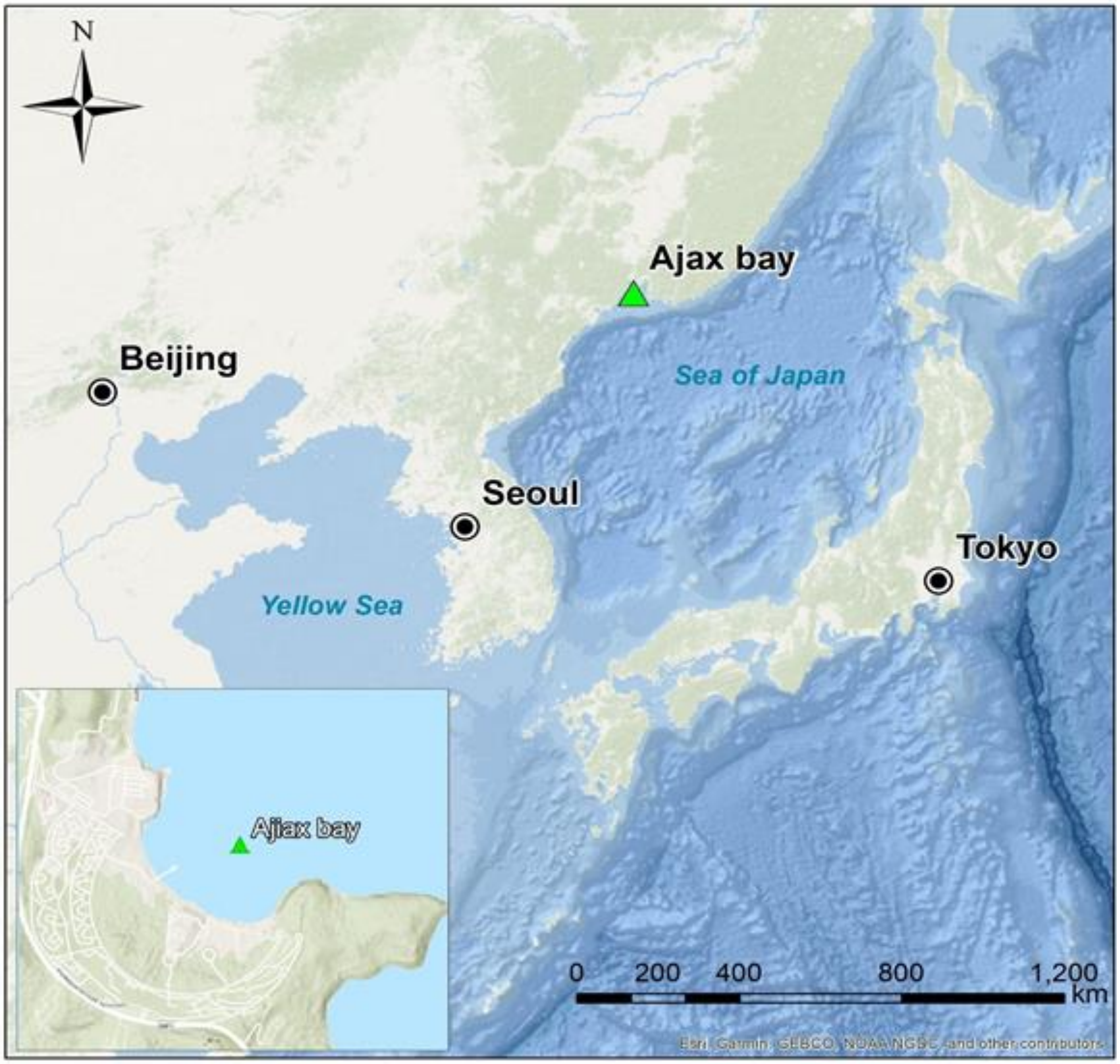

Figure 1.
Map of the study area location.

The nearest major city is Vladivostok, with population of 600 thousand people. Distance to Seoul is 740 km, to Tokyo is 1000 km, to Beijing 1300 km.

The water area is a semicircle. The shorelines are shaped by drifts and reefs. In some places reefs protrude one kilometer from the shoreline. The distance to the bottom in the backwaters decreases gradually towards the shore. The ground is dominated by pebbles, with silty and sandy soils in the north. The bay is conveniently located for stationary hydrological and atmospheric measurements.

The vegetation on land is dominated by meadow coastal vegetation. Soils at the site are meadow, soddy with low thickness humus horizon on marine sediments. Soil are light loamy, slightly acidic reaction of the environment and humus content up to 4% were observed [5]. The forest area is dominated by: oaks (Quercus mongolica), varnish trees (Ailanthus altissima), willows (Salix caprea L.) and maples (Acer barbinerve).

Remote sensing methods are widespread in the scientific practice of Russian carbon polygons. Thus, the Institute of Oceanology of the Russian Academy of Sciences created a digital elevation model of the carbon polygon in Krasnodar Krai on the Black Sea coast using aerial photo and bathymetric survey [6]. The results of processing were obtained: digital elevation model (DEM), canopy height model (CHM), bottom relief scheme (vertical accuracy is from 0.2 m in open terrain, 0.4 m in areas with fragmentary vegetation cover).

The obtained models can be further used to solve a wide range of research problems in the field of carbon cycle: geological-geomorphological, biogeographical and geoecological, modeling of greenhouse gas transport in the atmospheric air, processes of gas absorption, transformation, and emissions in the marine environment.

The paper Kuklev, et al. [7] describes the creation of DEM and orthophoto using aerial photography and aerial laser scanning (ALS). The following were obtained for a mountainous area: DEM, orthophoto, hypsometric map, slope steepness map, slope exposure map and terrace map. The orthophoto revealed active reforestation, and the DEM in combination with meteorological observations can serve for modeling microclimatic conditions.

The paper Gafurov, et al. [8] describes the creation of a digital terrain model (DTM) for estimating aboveground biomass (AGB). Multispectral imaging was carried out using the DEM to calculate vegetation indices (Chlorophyll Index (CIg), Normalized Difference Vegetation Index (NDVI), Green Leaf Index (GLI), Soil-Adjusted Vegetation Index (SAVI)), which are used to estimate biomass and carbon stocks. Lidar survey was conducted, which resulted in the following: DEM and tree height map.

The authors Bekmurzaeva, et al. [9] calculated the biomass of individual trees of different species in complex tree stands by combining multispectral and laser scanning data. The results show that by combining multispectral imaging and laser imaging, it is possible to identify trees and calculate their biomass separately.

Similar results are presented in Lian, et al. [10] which describes tree classification using photogrammetry and airborne laser scanning (ALS) based on UAVs. The authors propose to classify trees by combining multispectral orthophotos and ALS point cloud images to increase the accuracy of the classified objects. As a result of their work, the authors propose a new model that integrates aerial imagery data with ALS and creates a structure that classifies tree species more accurately. For the assessment of large areas, it is more convenient to use satellite data [11] which can be processed by similar algorithms.

Remote methods of building digital terrain models and calculations on their basis are promising and show high efficiency in comparison with manual methods. The paper demonstrates the results of the methods described above in relation to the Far Eastern Carbon Polygon site.

2. Data and Methodology

As part of the development of the FEFU campus carbon polygon, complex geodesic surveys were carried out to provide a cartographic basis for the carbon polygon and to collect primary data for further analysis.

On March 7, 2024, an aerial survey was carried out using a DJI Mavic 3 Enterprise (DJI M3E) UAV with Global Navigation Satellite Networks (GNSS) module. The imagery was taken at a speed of 15 m/s, from a height of 100 meters in real-time terrain following mode, with longitudinal and transverse image overlap of 80% and 60%, respectively. The terrain characteristic at the time of the survey is representative of the winter period.

On September 25, 2024, terrestrial laser scanning (TLS) was performed using a mobile laser scanner working with SLAM (Simulation Localization and Mapping) technology LiGrip H300 mounted on a specialized backpack with GNSS module. The operator moved steadily at an average speed of about 4 km/h.

On October 4, 2024, an aerial survey was conducted with a DJI Mavic 3 Multispectral (DJI M3M) UAV from an altitude of 60 meters in terrain following mode. Other flight parameters remained unchanged. The terrain characteristic at the time of shooting is representative of the summer period (Figure 2).

Figure 2.
Devices which were used in the work (on the right - UAV, on the left - laser SLAM-scanner with backpack.

The coordinates of the survey points are calculated in the spatial coordinate system World Geodetic System (WGS) 1984 and transformed into flat rectangular coordinates The Universal Transverse Mercator (UTM) zone 52. The coordinates are obtained from per-second GNSS data in relative positioning mode “Post Processing Kinematic”. The permanent GNSS station “VLDV”, installed on the roof of the laboratory building of FEFU, about 800 meters from the research area, was taken as a reference point. The station is equipped with a Topcon CR-G3 antenna and a PrinCe P5U multisystem receiver.

Agisoft Metashape Professional 2.1 software package was used to process the results of aerial photography. The point cloud was constructed from the photographs without compression and with soft filtering of the depth map.

The original point cloud and classified land surface points were used to construct the DEM and digital terrain model (DTM). The resolution of DEM and DTM was 8.8 cm/pix. Based on the DEM, an orthophoto of the area for the winter season with minimal vegetation was constructed with a resolution of 4.0 cm/pix (Figure 3c). The DEM and orthophoto plan from the 4.10.2024 multispectral data were obtained at spatial resolutions of 3.8 cm/pix and 1.9 cm/pix and contain standard RGB channels as well as, Green (560 nm ± 16 nm), Red (650 nm ± 16 nm) Red edge (730 nm ± 16 nm), near infrared (860 nm ± 26 nm) (Figure 3).

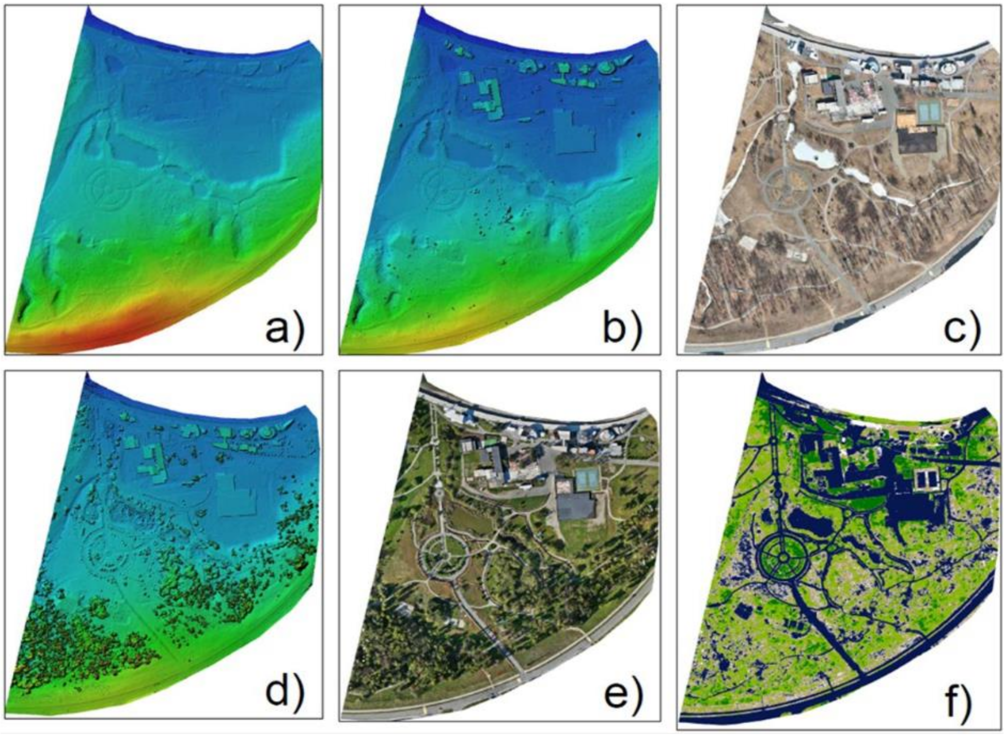

Figure 3.
Maps on March 7, 2024: a) DTM, b) DEM, c) RGB orthophoto. Maps on October 4, 2024: d) DSM, e) RGB orthophoto, f) Orthopho according to NDVI.

The TLS data were geo-referenced, colorized and merged into a single point cloud in GreenValley LiFuser BP software during post-processing. Point cloud classification and further processing was performed in LIDAR 360 software. The classified cloud was filtered from noise, ground normalized and fragmented into individual trees for further taxation.

In total, more than 1300 images, more than 1.5 billion points with a density of 10 points per cm3 were acquired for an area of 18 hectares for three surveys in 2024. In addition to the used processing tools, the geographic information systems (GIS) ArcGis and QGIS were used, in which the obtained raster data were processed with the help of raster calculator, classification, conversion, extraction, zonal statistics. NDVI was calculated for refinement in vegetation and biomass calculations.

AGB was determined based on the results of the obtained raster images of plant classification, taxation list, and reference data [12] using formula $b\times(dbh\times dbh)\times h$, where dbh is diameter at breast height(m), b is the coefficient for tree species(t m-3), h is height of the tree (m) [13]. Based on the obtained data, a scheme with an average biomass plot was created. The carbon stock is determined as $V_{ij}\times KP_{ij}$, where V_{ij} is volume stock of stem wood from stands if age group i of the predominant j breed, KP_{ij} is the conversion coefficient for calculating the AGB carbon stock of stands of group i of the predominant j breed.

3. Results and Discussion

As a result of the work done, the classification of the area by type of objects was obtained (Table 1). The division was made into classes according to vegetation types, height, and anthropogenic disturbance.

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Table 1.
Results of the classification of the area.

Type of objects	Quantity (pcs)	Average height (m)	Occupied area ($м^2$)	Percentage of total area (%)
Tall trees	217	12	73529.3	40.9
Low trees	27	3	1844.6	1.0
Shrubs	69	1.2	2534.2	1.4
Grass	-	15	84621.7	47.0
Buildings	13	2.5	2123.9	1.2
Other	-	-	15346.6	8.5

As can be seen from the table, the largest area is occupied by meadow vegetation, represented by grass (47% of the territory). To a lesser extent, the class of low trees is represented, which occupies 1% of the territory area.

Besides traditional methods of estimations, methods of subtracting DTM from DEM were used, resulting in a canopy height model (CHM), which contains information about local height of each object above terrain. Obtained raster can be used as an additional tool in determining vegetation heights, classification, area estimations and volume. Similarly, the difference between the summer DSM and winter DTM is obtained (Figure 4).

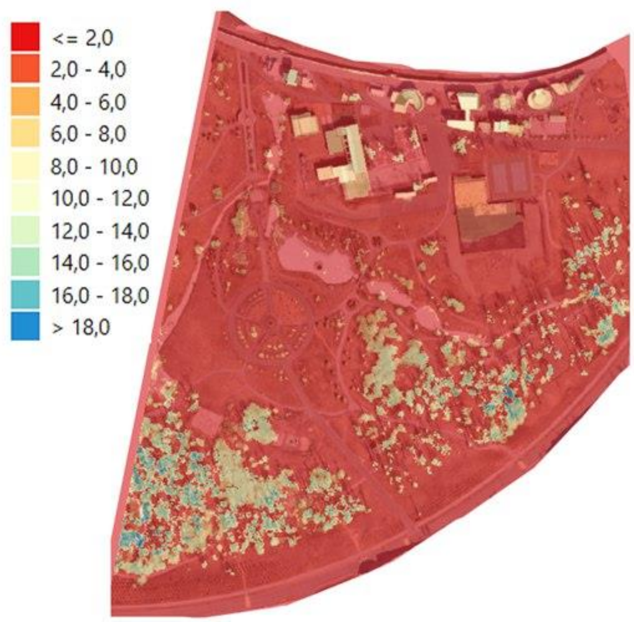

Figure 4.
Canopy height model, m.

According to the results presented in Figure 4 the average height of trees was 12-14 m, maximum detected height 20 meters, as confirmed by the TLS. According to CHM,. most of the polygon surface area has above ground elevation in the range of 10-30 cm, which is comparable to the height of grass cover in summer according to the ground survey data. The method of subtracting DTM from DEM has the potential to be applicable for estimating average parameters per site. Ground scanning data should be used to obtain accurate estimates.

Based on the results of data processing, generalized maps were compiled based on the classification of the area by the content of biomass and carbon reserves (Figure 5).

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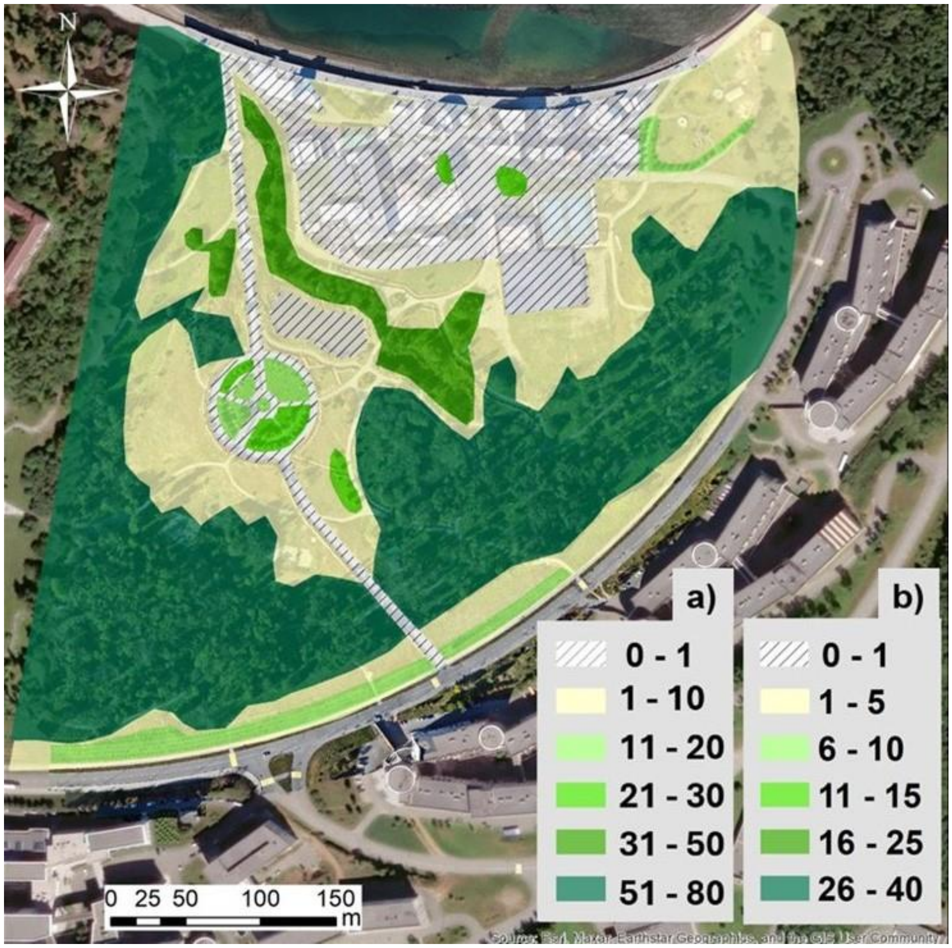

Figure 5.
Result of classification of an area by vegetation types, AGB (t/ha): (a), and carbon stock (t/ha) (b) presented.

Figure 5 shows that AGB (51-80 /ha) and carbon stocks (26-40 t/ha) were concentrated in the forest zone. The bay is located in the north of the study area, it is natural that the biomass and carbon content will decrease in presence of a large number of buildings. Meadow vegetation makes up a significant part of the site but has the lowest levels of biomass (1-10 t/ha) and carbon (1-5 t/ha). The average levels of biomass (11-50 t/ha) and carbon (6-25t/ha) belong to the classes of tall grass, shrubs and low trees, which occupy a smaller part of the entire area.

4. Conclusion

Remote monitoring of Far Eastern Carbon Polygon at Ajax bay, with usage of a UAV based multispectral camera on and TLS, aerial photography was refined by using ground-based point cloud, semi-automatic forest taxation and classification of objects on polygon, revelation of seasonal indicators of vegetation cover dynamics, preliminary estimation of biomass and carbon reserves on FECP. A detailed cartographic basis has been prepared for further work with spatial data. The possibilities of aerial and ground surveys in relation to the carbon landfill site have been studied.

The authors plan to continue remote monitoring of DWP in the winter, spring, summer and autumn seasons to study changes in vegetation cover and other indicators that help in the study of greenhouse gases.

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Transparency:
The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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