SUMMING UP THE ABILITIES OF MODERN AIRBORNE LIDARs FOR FOREST MAPPING

Ilya A. Rylsky, Vladimir S. Tikunov
World Data Centre for Geography ICSU-WDS, Faculty of Geography,
Lomonosov Moscow State University
rilskiy@mail.ru
tikunov@geogr.msu.su

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ABSTRACT

Currently, the primary data collection method for the study of forests is multispectral satellite survey. Digital aerial images are mainly used for forest inventory. However, now the widely used air laser scanning has not found the application for forest research. The main reasons: high cost, lack of methodology, low awareness of the method by researchers.

Progress in laser scanning field allowed greatly increase productivity of systems, among which are a number of devices that are comparable with aerial systems in capability. The cost of obtaining data in these systems can also be compared with space segment data.

The use of this survey type in common with aerial images allowed quickly and accurately obtains a number of vegetation characteristics which inaccessible to obtain with space images or classical aerial photography. For using these possibilities, it takes to develop of calculation methods for the new information. Such an experience is already available: in 2012-2013 was conducted research for "Roslesinforg" dedicated to exploring the possibilities of forest inventory by laser scanning data.

Taking into account the hardware equipment features and additional sensors are invited to intensify efforts to implement this method in practice of geographical forest research along with practical problems solution.

1. Current situation on the market of remote sensing data

At present the multispectral satellite imagery and digital aerial photography are the main sources of the data for forest mapping. Digital aerial photography is generally used for forest inventorying. But the airborne laser scanning using LIDARs (further we will use just the term "LIDAR") is not very widespread for this purposes in Russia. The main reasons of this were: the high price, the lack of methodology, proved on Russian types of landscapes, lack of the people who know something about LIDARs.

But is this method really expensive?

Let us compare the price of the new satellite imagery with 0.5 m pixel (or GSD – ground sample distance), made according to our own order, with the price of RGB digital aerial photography. We can see, that satellite imagery will cost us about 20 $ per 1 km^2, and aerial survey with 0.1-0.2 m GSD (including operations of photo-triangulation and photogrammetric network adjustments) will cost us about 42-65 $

per 1 km^2. The final price of aerial imagery varies from the actual place of surveying, while satellite imagery prices are independent. It is easy to see, that aerial photography is 2-3 times more expensive, but offers 2.5-5 times more detailed data.

From the end of 2014 it is also possible to purchase 0.3 m GSD satellite imagery, and in March 2015 the final price for this type of data in Russia is about 60 $ (prices for WorldView3 data). But the big demand for this type of data and the lack of satellites with comparable characteristics will not allow the common users to use this data very widely next 1-2 years, though 0.3 m GSD space imagery can be very concurrent with aerial imagery with the same GSD in terms of prices and operability.

In conclusion, it is obvious that any type of remote sensing data with GSD greater than 30 cm costs 42-60 $, and allows us to produce GIS data equal to 1:2000-1:5000 scale. This data is suitable for production digital elevation models with normally 0.3-0.6 elevation error (1 sigma) in open spaces and it is not suitable for production of any elevation model in forest regions.

2. Current satiation in airborne laser scanning: productivity, speed, and precision.

The progress in airborne laser scanning during last 15 years is impressive. In 2000 the swath width was about 300 meters and the average point distance (analog of GSD in imagery) from 1.5-3 m, in 2015 the swath width is up to 3000-5000 m while average point distance now is up to 0.2-0.4 m. (Schwarz, 2010; Medvedev, 2007).

For example, top level aerial system like Riegl Q1560 allows working from the altitude 2800 m, making 800 000 laser measurements per second. If we use the aerial vehicle with the cruise speed about 90 knots (like Antonov-2, or Mi8, or Cessna), than we can achieve the density of 4 points per 1 m^2, or average point distance about 0.5 m and average elevation error about 0.1-0.12 m. This is enough for 1:1000 scale mapping. This data allows us to produce DEM (digital elevation model) in open spaces, in forest, and to measure the relative altitude of the vegetation. With such conditions it is possible to survey about 450 km^2 per hour.

In case of use faster vehicle it is possible to achieve following volumes:

- Speed 140 knots, altitude 4000 meters, area per hour – about 1000 km^2, density – 2 points/m^2, average point distance – 0.7 m, suitable for 1:2000 mapping in any kind of terrain;
- Speed 200 knots, altitude 4000 meters, area per hour – about 1000 km^2, density – 0.7 points/m^2, average point distance – 1.2 m, suitable for 1:5000 mapping in any kind of terrain.

So far, in Russia the average cost of 1:1000-1:5000 LIDAR data acquisition (including flight costs and additional costs of any kinds) can be about 30-60 $ per km2, depending of time, region and level of detail.

In addition it must be figured, that during the laser scanning, the normal aerial imagery using mid-size cameras is collected (NIR or RGB modes are available).

From altitudes mentioned before the GSD of these images can vary from 0.25 to 0.35 m. Normally, the big-frame aerial cameras are not strictly needed to be used during the laser survey flight.

It is quite obvious, that efficiency of these systems is equal or greater than the efficiency of normal aerial imagery, because it allows us to collect real 3D data about relief and vegetation, without any problems with forests or grass, and the prices are equal or lower than prices of aerial or satellite imagery. The precision of the data (and elevation errors) are also several times better.

3. **What for the LIDAR data can be used**

LIDAR data with the density of 4 points/m^2 (suitable for 1:1000) allow us to detect directly in 3D (using information about the form of the canopy without spectral information) the type of the tree and its height over the relief. Data with density of 2 points per m^2 (is suitable for 1:2000) are also enough for forest inventory and monitoring of the vegetation (Kumar, 2014). Data, equal to 1:5000 (0.5-1.0 points/m^2) is suitable for proving the results of forest growth models (Pinto, 2014; Blashke, 2004).

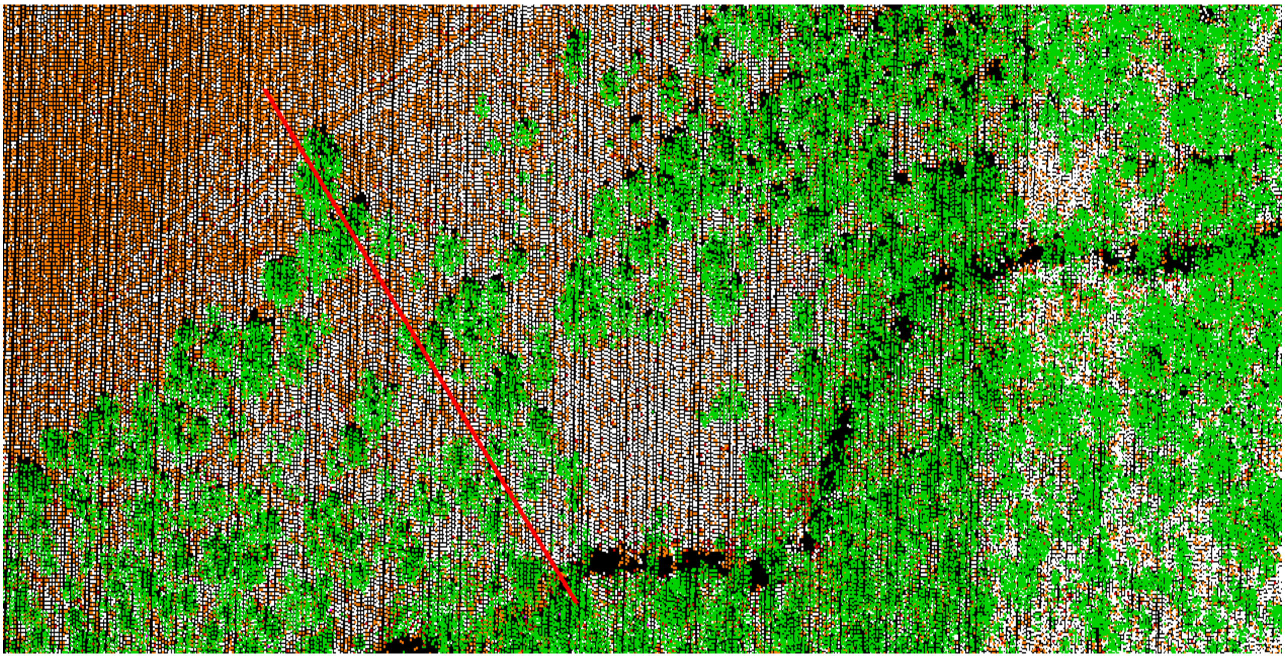

Figure 1. Example of airborne LIDAR data, density is about 4 points/m^2.
Red line is the axis of profile (see Fig. 2, below)

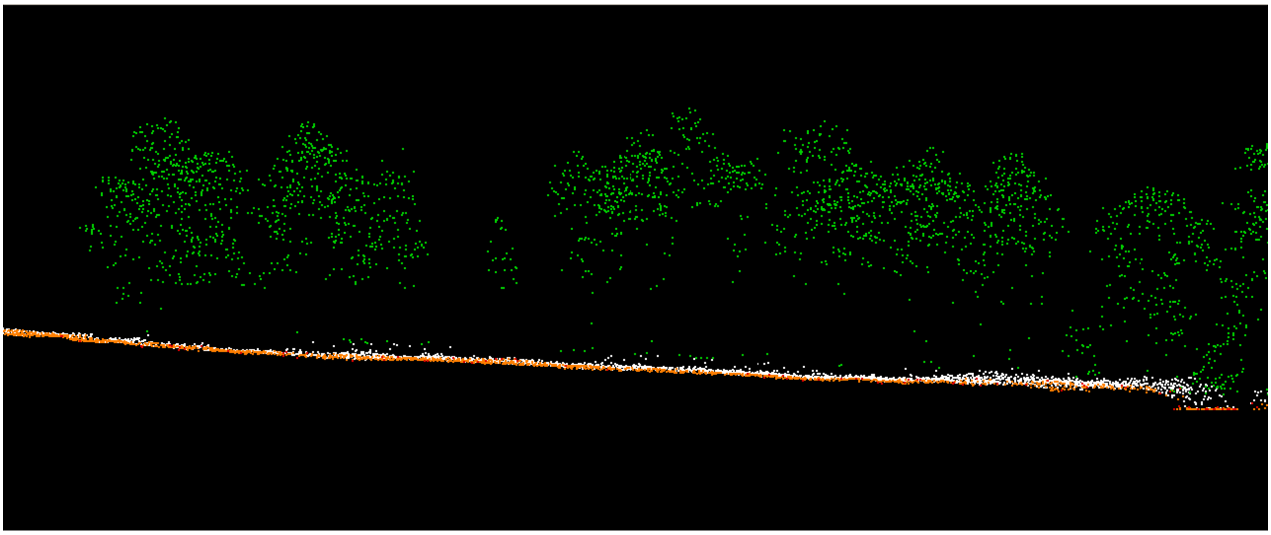

Figure 2. Profile along the red line through the LIDAR data.
Green points – the upper parts of canopies, yellow and white – the surface of the relief – even under the canopies.

In modern remote sensing there are no any other methods except airborne laser scanning, that allow us to detect in 3D the visible surface of canopies and mostly invisible surface of the relief simultaneously (Lang, Tiede, 2006). It is obvious, that optical sensors are suitable only for detection of objects, which are open to see. The radars, using longer wavelength, can give us the information of the relief under the trees, but the trees become transparent. Also the radars of these wavelengths do not provide very precise 3D data (up to several meters of elevation error). As compared with mentioned above, the airborne LIDAR provide 3D data of both surfaces simultaneously, and the precision of the data is much better - about 10 cm.

These features allow us to use this method for achieving the geometric parameters of EACH tree of the main story of the forest (Tiede, 2006). The most important parameters are the diameter and relative height of the canopy; this information, aggregated together with the information about the type of vegetation and local factors of growth, allow us to solve definite tasks. There can be building the model of growth for the whole region, searching for intra-zonal landscapes or specific conditions of vegetation, search of extra old or extra high trees, ecological research and so on. Also very important task of calculation of the actual lumber volume can be successfully solved. This approach is widespread in Scandinavian countries, well known by their careful attitude to the environment (Holmgren, 2004).

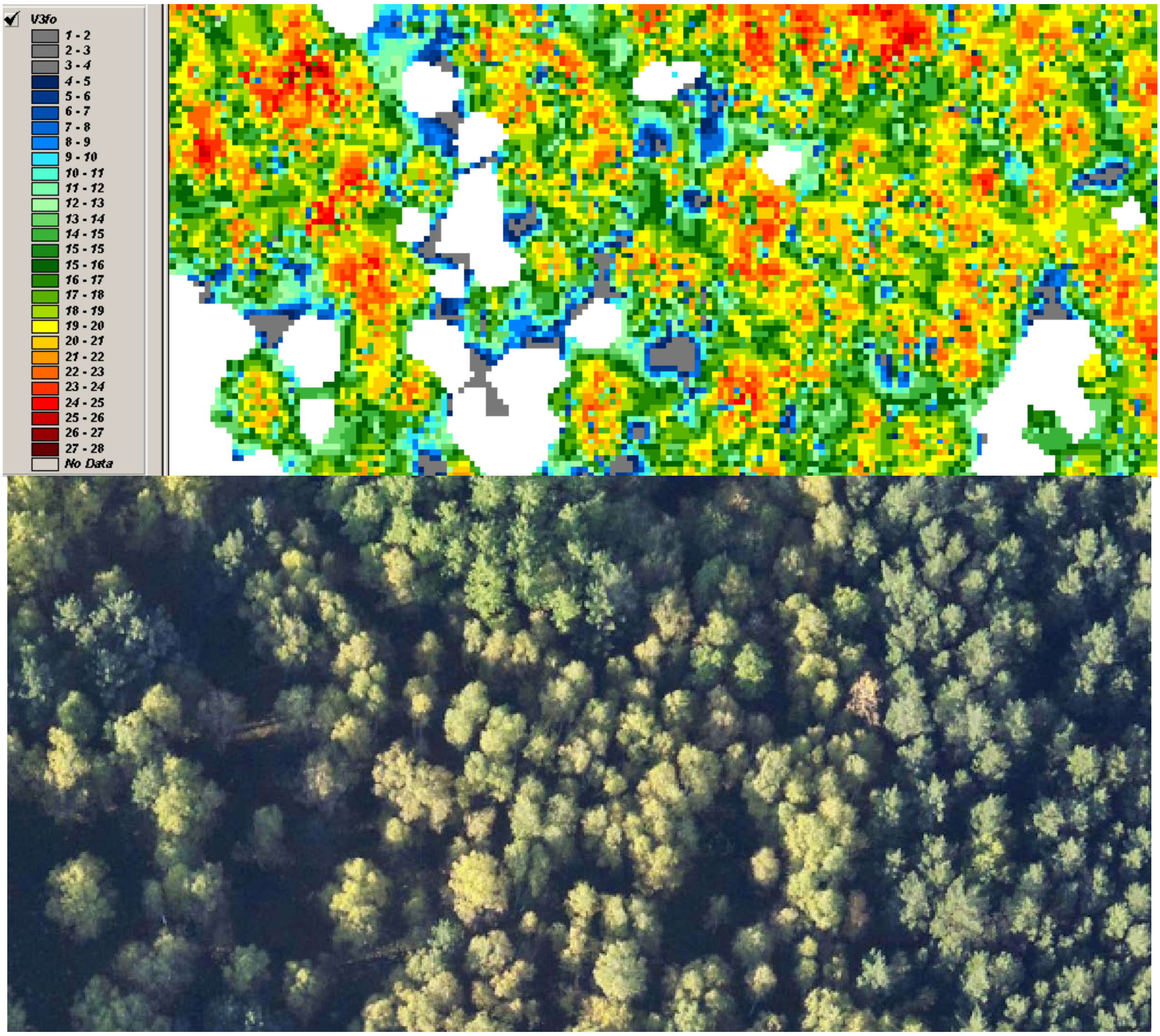

Figure 3. Digital elevation model of relative heights of canopies (upper picture) and common digital imagery (below).

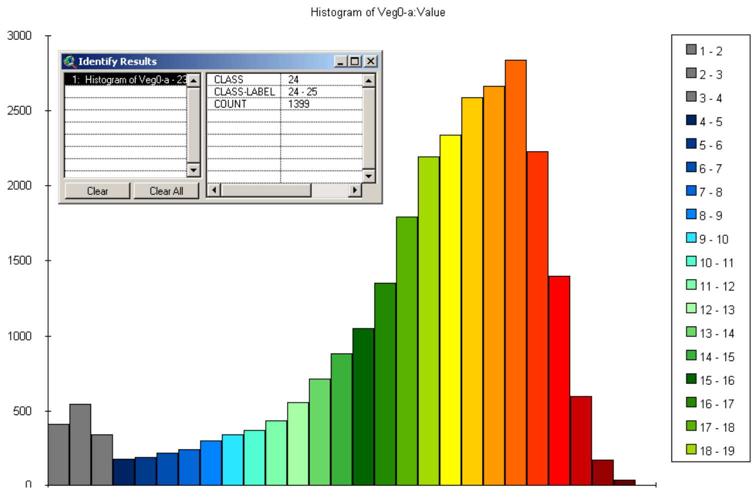

Figure 4. Histogram of distribution of the single trees according to their heights within previously mapped contour of the forest, defined by the experts as "homogenious". Done using 4 point/m^2 airborne laser scanning.

But the most interesting scientific results can be achieved using the airborne LIDAR simultaneously with the multiband high-resolution space imagery. The most valuable spectral range is between 630 and 2300 nanometer wavelength. (Burnett, 2003; TIEDE, 2004). Here are several examples:

1. For precise datasets and detailed research and mapping: (1:5000-1:25000) – 0.5 m GSD data from WorldView2 with 8 spectral channels (including 3 infrared channels); or 0.3 m GSD data from WorldView3 with 10 spectral channels (including 8 infrared channels)
2. For big territories and mid-scale mapping (1:50 000-1:100 000) – 15m GSD Landsat 8 (4 infrared channels), or 30 m Hyperion (220 channels).

Figure 5. Example of usage WorldView2 infrared data for correction of zonal borders during forest inventorying according to the type of forest. This data is to be used later (together with the airborne LIDAR data) to renew statistics.

Multispectral satellite imagery, used together with the LIDAR, can be very important for depicting the slight, but sometimes critical changes in the forest structure (detection of pathological sickness). But the direct application of high resolution multispectral data (and its spectral analysis) needs to solve several problems. These problems can be solved easily using the airborne LIDAR data:

- Texture and shadow analysis using 3D LIDAR data (Tiede, 2004);
- Correct topographic normalization of spectral data (to eliminate the influence of the relief over the spectral data) including the micro-relief of the visible surface of the forest;
- Collection of 3D characteristics of trees and other objects using LIDAR data for supervised classification of satellite data (Wehr, 2003);
- Application of extremely detailed and precise DEM or DTM and relative vegetation height information in automated mapping systems and/or knowledge bases, based upon Euclidian or Neural logics (Tiede, 2005; Dorren, 2004)

3D laser data can be especially valuable in regions, which are under the impact of climate change, which can dramatically change the speed of forest growth or even the whole landscape structure -especially in northern, semi-arid and intra-zonal regions (Tiede, 2006; Kuemmerle, 2010).

4. Implementation of the method and current experience

In Russia the method of airborne laser scanning became very common in map-making and precise geodetic projects during last 10 years. The biggest national corporations – like TransNeft, Gazprom and Russian Railroads produced in 2007-2010 their own corporate standards of surveying using LIDAR. But in Russian forest industry and ecological researches the method is not widespread at all.

First attempts to investigate the abilities of the airborne laser scanning method in forest inventorying were made under the authority of Geokosmos company (Medvedev, 2007) in collaboration with the V.N. Sukachev Institute of Forest of the Siberian Branch of Russian Academy of Sciences (Krasnoyarsk). Due to the deterioration of the economic situation in the country and financial crisis of 2008-2009, there were now researches till 2012. In 2012-2013, on behalf of Russian Forest Information Organization (RosLesInforg) and together with such companies like Arkon (Moscow) and Proektstroy (Omsk), several researches were performed. The researches were focused on the definition of equations, which allow us to estimate the volume of lumber without any field activity. Also the methodology of airborne laser scanning and data processing was improved, according to the task mentioned above (Rylskiy, 2013).

Tree specie	Growth class	Equation	η	F	S	σ
Cedar	III	$Dmean=3.270+1.772Hmean-0.003Hmean^2-12.485P+1.157P^2$	0.96	16.96	6.38	2.52
	IV	$Dmean= 1.335+1.982Hmean-0.011Hmean^2-7.299P-1.031P^2$	0.96	16.23	6.85	2.62
Pine	II	$Dmean=4.791+0.749Hmean+0.022Hmean^2-4.616P-1.353P^2$	0.97	17.14	4.33	2.08
	III	$Dmean= 6.843+0.556Hmean+0.026Hmean^2 – 7.475P+1.169P^2$	0.97	18.46	4.64	2.15
	IV	$Dmean=5.419+0.744Hcp+0.025Hcp^2-5.050P+0.086P^2$	0.98	12.15	3.72	1.93
Larix	III	$Dmean=8.799+0.109Hmean+0.049Hmean^2-10.685P+1.062P^2$	0.97	16.94	5.91	2.43
	IV	$Dmean=9.917+0.219Hmean+0.046Hmean^2-13.338P+3.270P^2$	0.97	16.80	6.24	2.50
Spruce	III	$Dmean=1.789+1.574Hmean-0.013Hmean^2-4.167P+2.160P^2$	0.96	15.63	7.40	2.72
	IV	$Dmean=4.137+1.346Hmean-3.432P-2.167P^2$	0.96	16.19	7.08	2.65
Silver fir	III	$Dmean=5.388+0.899Hmean+0.008Hcp^2-0.803P-5.091P^2$	0.96	16.28	6.93	2.63
	IV	$Dmean=8.187+0.688Hmean+0.015Hmean^2-2.008P-3.709P^2$	0.97	16.18	6.80	2.61
Birch	I-III	$Dmean=3.949+0.546Hmean+0.022Hmean^2-2.674P-0.903P^2$	0.96	16.23	6.89	2.62
Aspen	I-III	$Dmean=15.464-0.811Hmean+0.054Hmean^2+9.000P-10.272P^2$	0.98	21.87	3.83	1.96

Tablet 1. Equations, describing dependency of diameter, height and relative tree coverage for different species of trees in southern parts of Krasnoyarsk Region, calculated for usage of the airborne LIDAR data together with satellite imagery data. Equations calculation is based upon comparison of the laser data measurements and field approval. Dmean – mean log diameter; Hmean – mean height of the tree; P – relative coverage (from 0 to 1); η - correlation; F – Fisher criteria; S - dispersion; σ - mean square error

The test region covered by surveys has the area of approximately 17 000 hectares. The results of lumber volume estimation, produced using the laser and satellite data were compared with the field researches and results, that can be achieved using previous methods (based upon growth models (Herold, 2001). The final result included a kind of prototype of methodology, suitable (with corrections according to the local peculiarities) for the national forest industry.

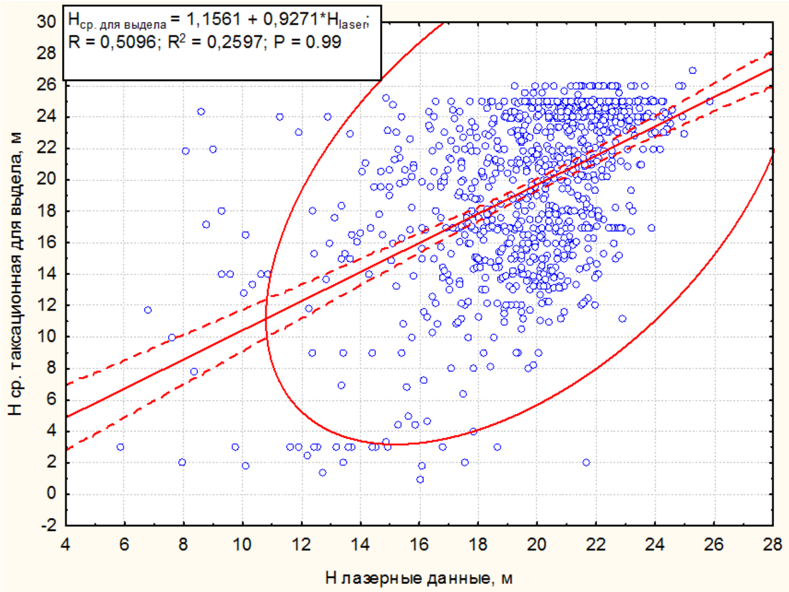

Figure 6. Dependency between mean heights of the trees, defined manually in the field (Y axis) and using the LIDAR data (X axis). Diagram belt using 978 semi-homogeneous regions.

During the research mentioned above, the airborne laser systems (like Riegl Q1560 mentioned above) were not produced yet, so the price of the survey shown during the LIDAR survey was comparably high. Now the development of the technology allows us to continue the implementation of the LIDARs if forest researches with greater efficiency and several times lower prices.

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