ESA STUDY – PROGRESS REPORT 4

ESA Contract No:	SUBJECT:	INSTITUTE:
4000117034/16/NL/NDe	**SURGE**: Simulating the cooling effect of urban greenery based on solar radiation modelling and a new generation of ESA sensors	Pavol Jozef Šafárik University in Košice, Institute of Geography

ESA Contract No: 4000117034/16/NL/NDe	No. of Volumes: 1 This is Volume No: 1	INSTITUTE'S REFERENCE: SURGE_PR4

ABSTRACT (Executive Summary of the Project):

The aim of this feasibility study is to assess the applicability of the Sentinel-2A multispectral satellite imagery for approximating the dynamics of solar radiation transmittance of urban greenery leading to its cooling effects via modelling the spatial distribution of solar radiation in a complex urban environment represented by a 3-D city model. The main technical objective of the project is to define the relationship between a high-resolution 3-D geometry of urban greenery and vegetation metrics in selected periods throughout the year. The study will be used to evaluate the proposed approach in the development of a toolbox enabling urban planners and researchers to mitigate heat risk based on solar radiation modelling and Sentinel-2A multispectral data.

The work described in this report was done under ESA PECS Contract. Responsibility for the contents resides in the author or organisation that prepared it.

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Simulating the cooling effect of urban greenery based on solar radiation modelling and a new generation of ESA sensors (acronym SURGE)

Progress Report 4

1. Introduction

The objective of the progress report is to provide all actors with actual information concerning the status of the project "Simulating the cooling effect of urban greenery based on solar radiation modelling and a new generation of ESA sensors (acronym SURGE)" from 01/12/2017 to 31/05/2018. This report is number as the 4th since the materials presented during the meeting in Bratislava 19 December 2017 were accepted by the ESA representatives instead of Progress Report 3.

The aim of this project: This project will serve as a preparatory study to assess the applicability of the multispectral satellite imagery for approximating the dynamics of solar radiation transmittance of urban greenery to assess the cooling effects of the greenery via modelling the spatial distribution of solar radiation in a complex urban environment represented by a 3-D city model.

The main technical objectives: The main technical objective of the project is to define the relationship between 3-D geometry of urban greenery and vegetation metrics in selected periods throughout the year. The imagery to be acquired by the new generation of ESA Sentinel 2-A satellite sensors will be used to derive the vegetation metrics and it will be downscaled to higher resolution datasets. The final outcome of this study will be in the proof-of-concept which identifies critical functions and characteristics of the proposed approach. This study can be used in the future to develop a toolbox enabling urban planners and researchers to mitigate heat risk based on solar radiation modelling and Sentinel-2A multispectral data for urban greenery parameterization.

2. Highlight Summary

During the last 6 months since December 2017, we have achieved the following results:

1. The work in WP2 was focused on analysis of the Sentinel 2 multispectral imagery, identification of suitable vegetation metrics and defining the relationship of these metrics in respect to the geometrical properties of the laser scanning point cloud time series.
2. Deliverable 4: *Report on derivation of satellite based vegetation metrics and downscaling to high-resolution data* was elaborated and submitted to ESA in April 2018.
3. The work in WP3 has been started and partial results were achieved in integrating urban greenery into solar radiation modelling based on gridded digital surface models and terrestrial laser scanning data.
4. The work in WP4 has been started in defining the roadmap for implementation of the findings in a toolbox for improved urban climate modelling.
5. Partial results of the SURGE project became published in a scientific journal and presented on international conference GIS Ostrava 2018 in Ostrava, Czech Republic.

The work progress has been delayed by 4 months with respect to the original plan for issues related to submission of Deliverable 2 and payments. The original schedule was modified after consulting with ESA and the final deadline of the project was set to 30 September 2018.

3. Work Summary Status (during the reporting period)

Work package	Activities	Responsible Person	Status
WP1: Study management	1.1. Meetings of the project team	Jaroslav Hofierka	On-going
WP2: Data, methods and architecture of the system	2.1. Generated 3D city model (D1)	Michal Gallay	Finished
	2.2. Generation of 3D time series of urban greenery	Ján Kaňuk	Finished
	2.3. Gathering of Sentinel 2A imagery	Michal Gallay	Finished
	2.4. Urban greenery field mapping	Alena Petrvalská (Gessert)	Finished
WP3: Testing, Validation and Viability of the System/Model	3.1. Modification and validation of the v.sun solar radiation model	Jaroslav Hofierka	On-going
WP4: Roadmap for further Implementation	4.1. Roadmap for the urban greenery cooling toolbox	Jaroslav Hofierka	On-going

4. Detailed Progress of Work

3.1 **WP1 – Study management**

Over the last 6 months (since December 2017), we had 2 meetings of the project team. The most important meeting was held in Bratislava 19 December 2017 where we were invited by ESA and by the Ministry of Education, Science, Research and Sport of Slovak Republic. The materials presented on this occasion were accepted as the Progress Report 3. We have explained the reasons of delay in the work progress and presented the achieved results to the ESA Contract Officers (Sandy Courtois, Kay Van Der Made) and to the Ministry Officer (Jana Rovňanová). Based on the presented results and explanations at meeting the remaining payment by ESA was transferred in January 2018 and the work plan was modified as stated in Section 9 (Planning).

A regular meeting of the project team was held on 9 March 2017 when we discussed details of the D4 report on vegetation metrics and deliverables. The WP leaders discussed the planned presentations of the ongoing results of the project in the GIS Ostrava 2018 conference in Ostrava in March 2018. Besides this, the project leader had regular meetings with the WP2, WP3 leader discussing the ongoing activities as well as various management and financial issues. Informal meetings were held during the reporting period to manage the activities within WP2 and outline the work for starting WP3, WP4.

Progress meeting of the team is going to be held in June 2018 in Košice, where the work plan for the final period is to be discussed in relation to WP3 and WP4.

3.2 **WP2 – Data, methods and architecture of the system**

Overall, this WP involved the technical steps (tasks):

1. State-of-the-art review
2. Selecting the study area
3. Generating a high-resolution 3-D city model of the study area
4. Generating time series of high-resolution 3-D urban greenery for the study area
5. Gathering and analysing time series of Sentinel 2A multispectral imagery
6. Preparing inputs for solar radiation modelling

The tasks 1. - 5. were finished by December 2017 within the third reporting period. The work in the current reporting period concentrated on the analysis of the spatial datasets assembled during the previous reporting periods. The activity was related to *Task 6: Preparing input 3-D data for solar radiation modelling*. As a result of the work the Deliverable 4 (D4) "*Report on derivation of satellite based vegetation metrics and downscaling to high-resolution data*" was elaborated and submitted to ESA on 5 April 2018. The achieved results of the reported period are briefly summarized and illustrated below.

- The input data used for the analysis involved: time-series of Sentinel 2A MSI data, airborne photogrammetry data, airborne laser scanning data, time-series of terrestrial laser scanning data.
- The data were pre-processed to analyse the relation of the selected vegetation metrics derived from lidar datasets and Sentinel 2A imagery. The pre-processing involved resampling to the spatial resolution match the spatial resolution of the compared datasets, spatial clipping of the layers to match the four small study sites (Fig. 1).
- Four indices were derived from the Sentinel 2 imagery: normalized vegetation index (NDVI), enhanced vegetation index (EVI), enhanced vegetation index (EVI2) which avoids the use of blue band, soil adjusted vegetation index (SAVI) (Fig. 2).
- Three metrics were derived from laser scanning data canopy: canopy density, canopy cover, estimated leaf area index.
- The indices based on Sentinel 2 imagery were found to be strongly correlated, therefore just the NDVI was used further steps (Fig. 3).
- Linear regression models (ordinary least squares) were defined between time-series of NDVI from the Sentinel 2 data and corresponding point cloud metrics derived from time–series of terrestrial laser scanning (TLS) data. The relationship between the estimated leaf area index of TLS and Sentinel 2 NDVI seemed to most suitable with medium to strong correlation (Fig. 4, 5).
- Generation of geodatabase on the tree vegetation of the four small observed sites (Fig. 1) was created and analysed (Fig. 6, 7).

The results opened more issues and questions to address than were answered. One of the most important is whether and how the response of the defined linear models can be improved and if a more suitable set of vegetation metric can be identified for relating the information of Sentinel 2 with 3D geometry. The reliability of the prediction of the vegetation transmittance from the Sentinel 2 data based on the reported findings will be tested in the following steps within the contract under WP3, which concerns developing the algorithmic structure for solar radiation modelling with implementation of vegetation transmittance under WP3. We will concentrate on downscaling the information content of Sentinel 2 multispectral imagery based on higher resolution layers of land cover and normalized canopy height. The higher resolution layers ae derived from aerial orthoimagery and airborne lidar point cloud.

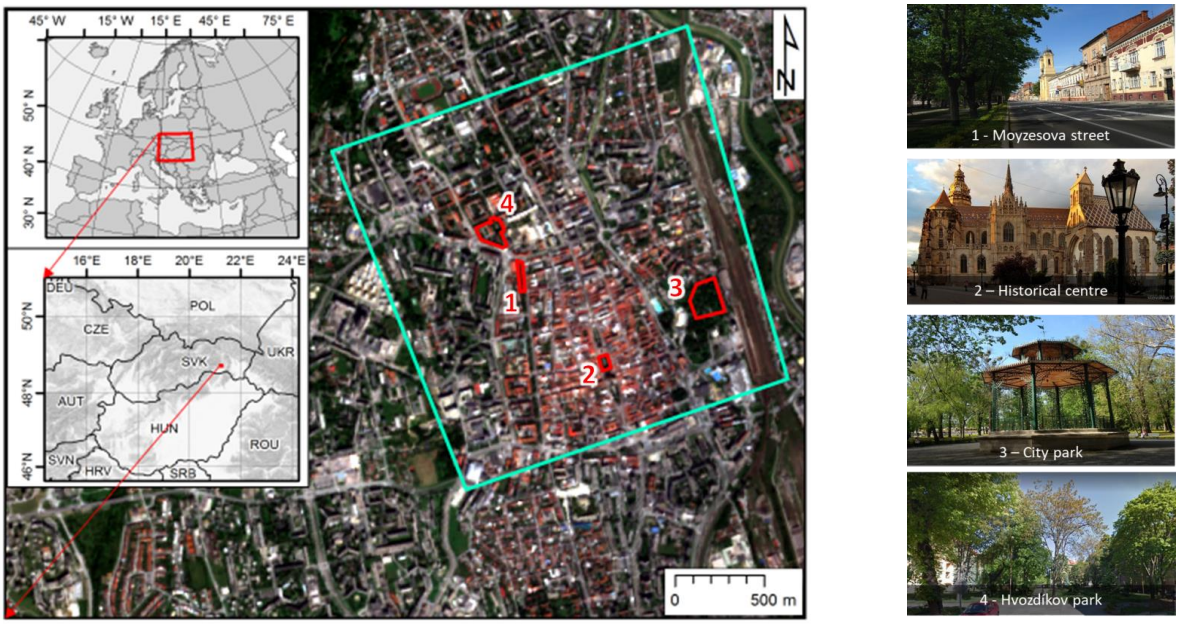


Figure 1. Location of the study area in the Košice City, Slovakia. The cyan line outlines the area subject to airborne lidar and photogrammetric mapping in a single mission, time series of the Sentinel 2 image coverage. The red outline delineates four sites selected for repeated terrestrial laser scanning of urban vegetation. The background maps are © Copernicus, Sentinel 2A image acquired on 7 September 2016.

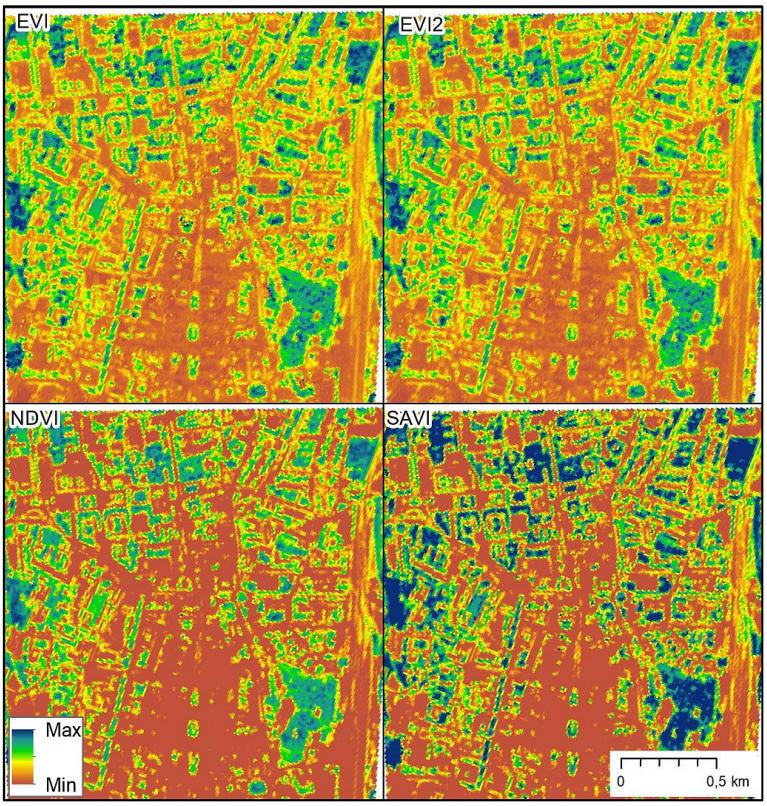


Figure 2. Four vegetation indices derived from Sentinel 2A data acquired on 8 August 2016.

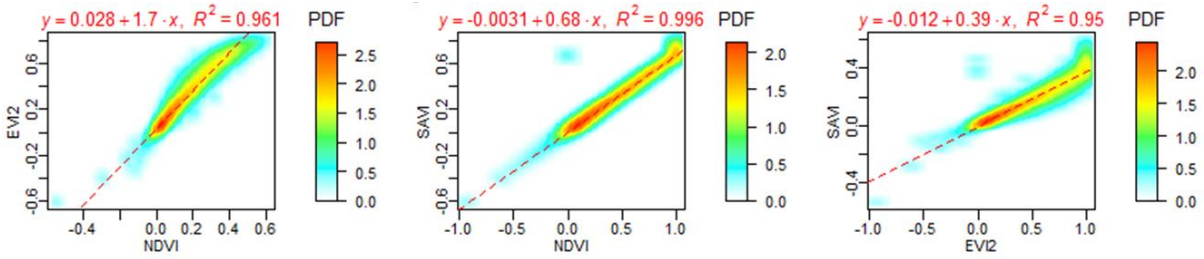


Figure 3. Smoothed scatterplots and linear regression model for combinations of vegetation indices NDVI, EVI2, SAVI derived for the extent of the study area (Fig. 1, cyan outline) at 10 m spatial resolution from imagery of Sentinel 2A. Date of sensing: Sentinel 2: 8 August 2016.

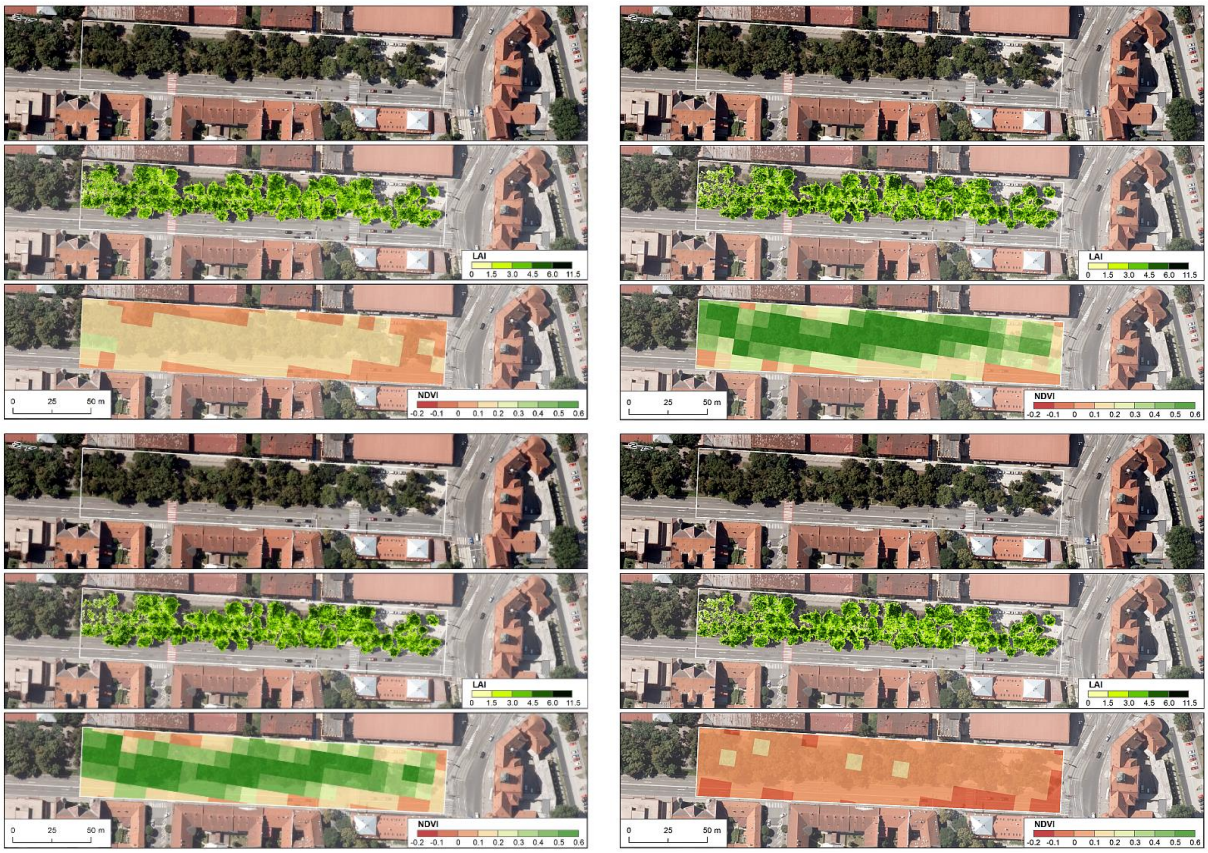


Figure 4. LAI_e per 0.1 m cell size from TLS data and Sentinel 2A NDVI for 10 m cell size r the site of Moyzesova street. Data acquisition: 7 April 2016 (top left), 26 July 2016 (top right), 27 August 2016 (bottom right), 23 November 2016 (bottom right).

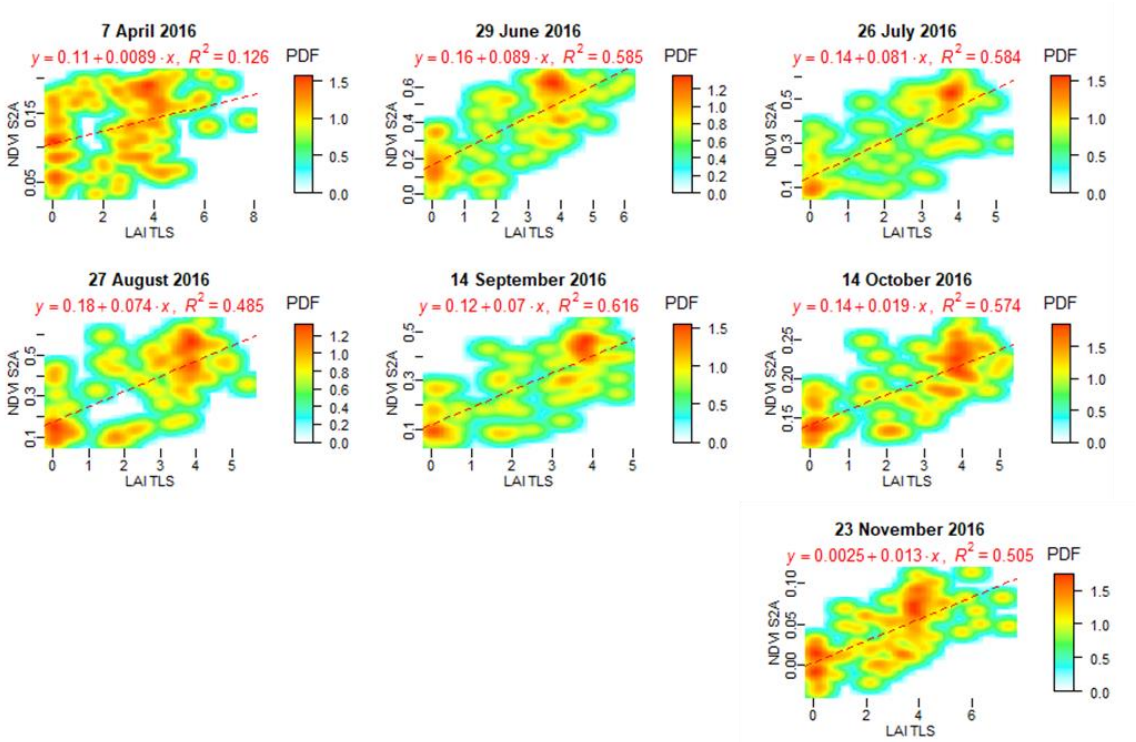


Figure 5. Smoothed scatterplots of Sentinel 2A NDVI and LAI_e canopy density calculated at 0.1 m grid cell size for the site of Moyzesova street.

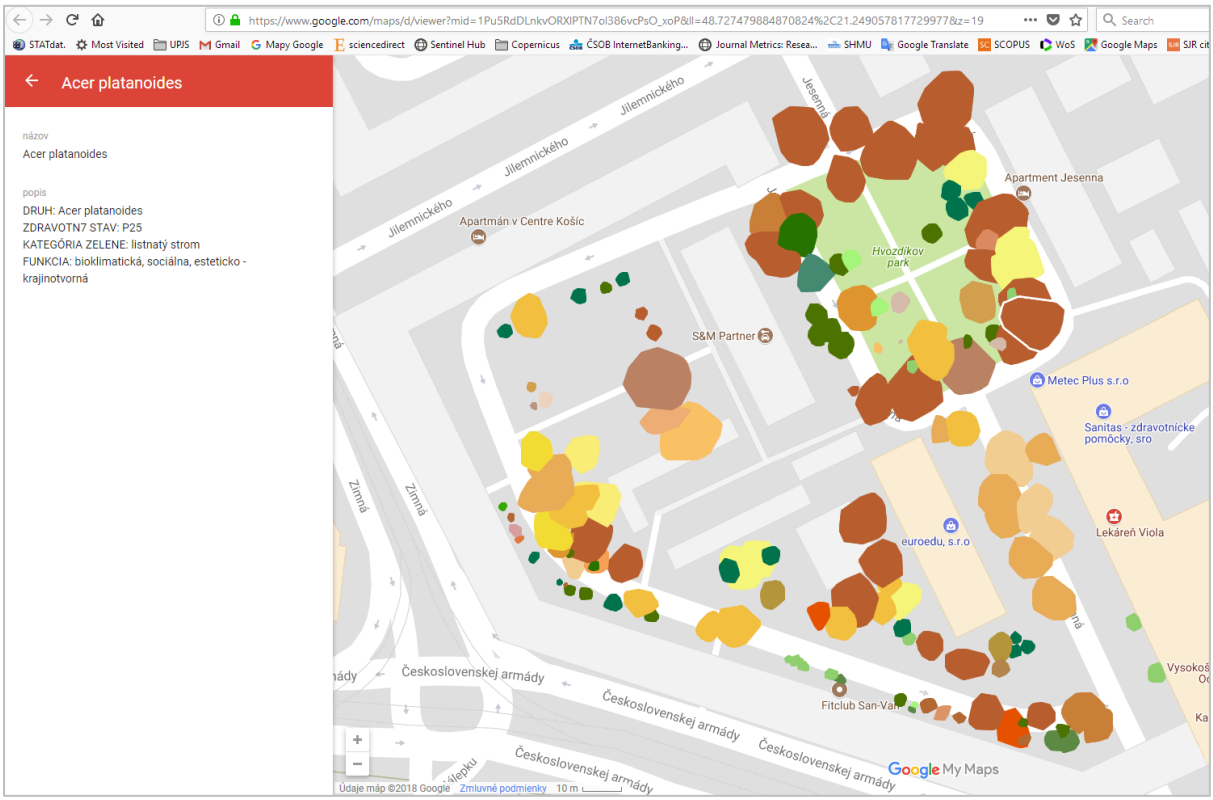


Figure 6. A screen-shot of the online web map showing the spatial distribution and attributes of the tree and shrub vegetation of the site of Hvozdíkov park in Košice based on field survey. https://drive.google.com/open?id=1Pu5RdDLnkvORXlPTN7ol386vcPsO_xoP&usp=sharing

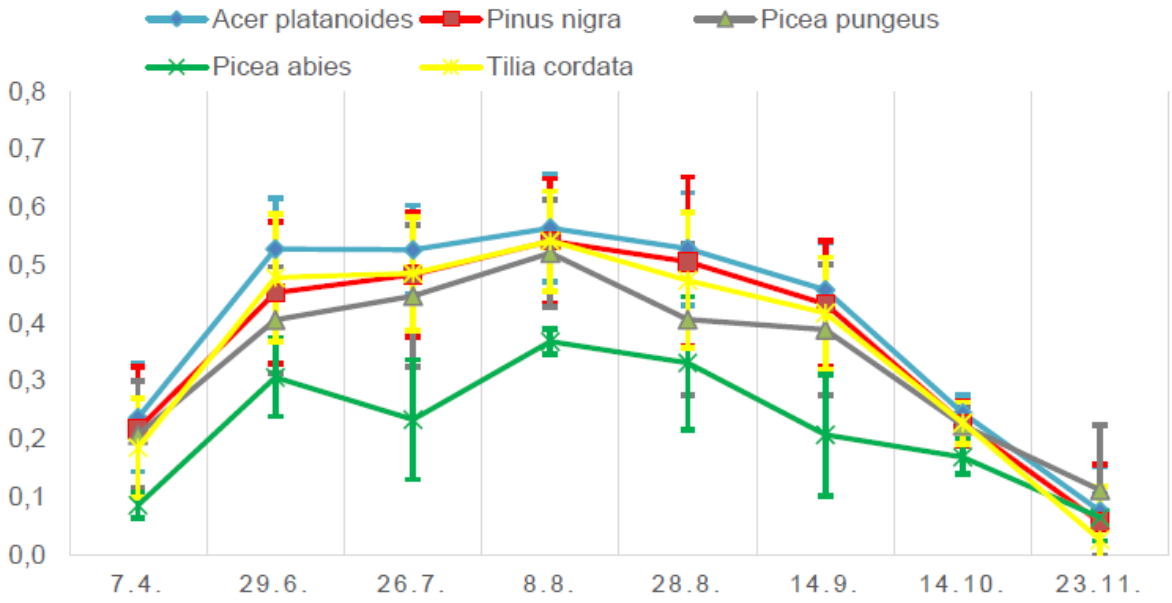


Figure 7. Sentinel 2 based NDVI (y axis) of five most abundant tree species in Hvozdíkov park (Fig.6) throughout the year of 2016.

3.3 **WP3 – Testing, Validation and Viability of the System/Model**

The work on WP3 has been started in December 2017 based on the preliminary results of the WP2, especially the Report of Deliverable 4. The achieved partial results were presented at the conference GIS Ostrava 2018 conference in contributions Kaňuk et. al (2018). Figure 6 demonstrates the preliminary tests which involved raster (grid) based solar irradiation modelling in GRASS GIS r.sun module. A binary layer of tree canopy was derived from TLS point cloud and used to attenuate the solar irradiation coming to the terrain surface under the tree canopy. In the next steps, we aim to replace the TLS based binary layer with a layer derived from Sentinel 2 imagery. Our plan is to use the vegetation metrics derived of Sentinel 2 and TLS data and defined linear models in modelling the attenuation of solar radiation by urban greenery (trees). This approach will be validated in respect to the solar modelling based on higher resolution TLS-based tree canopy cover. Some preliminary modelling with 3D vector trees from TLS data time-series were presented in Hofierka et al. (2017).

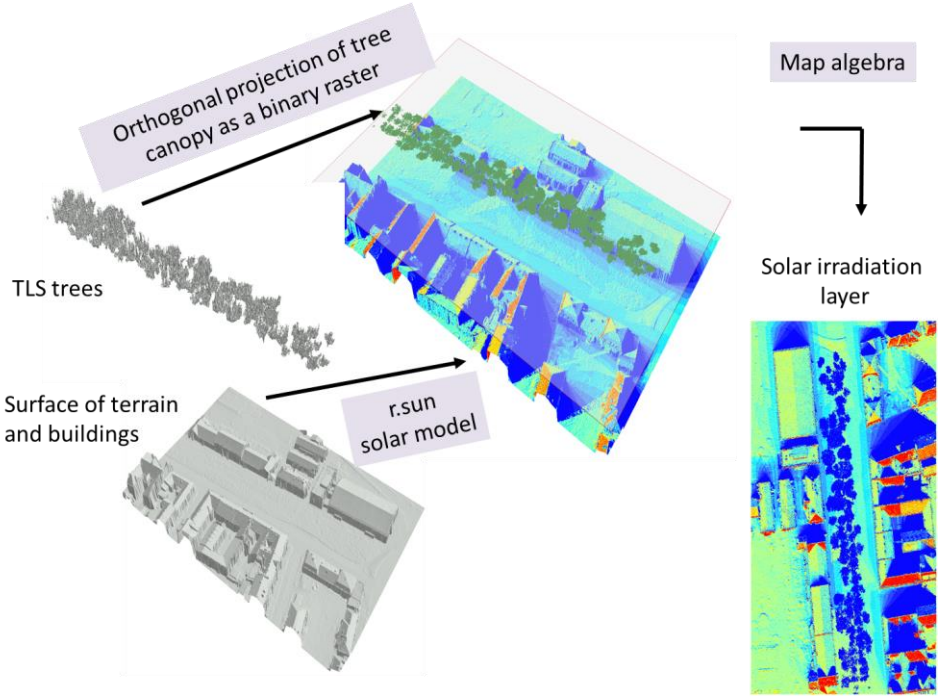


Figure 6. The principle of using rasterized tree canopy layer from TLS data for uniform attenuation of solar irradiation modelling on the surface of terrain and buildings. Example from the site of Moyzesova street.

3.4 **WP4: Roadmap for further Implementation**

The work on WP4 has been started in May 2018 based on the preliminary results of the WP3.

4 Problems, Issues and Risk Areas

We can confirm that the work progresses normally according to the modified plan accepted by ESA (Section 9) during the fourth 6 months period (12/2017 – 05/2018). We do not expect any other reasons for new problems to arise given that the submitted D4 will be accepted by ESA.

5 Meetings

Meeting Name	Description/ Purpose	Location	Planned Date	Actual Date	Attendees
Kick-off meeting	Kick-off meeting of the team	Kosice	2 June 2016	2 June 2016	Pavol Jozef Safarik University
Regular team meeting	Presentation of progress and discussion of planning and problems	Kosice	7 September 2016	7 September 2016	Pavol Jozef Safarik University
Regular team meeting	Presentation of progress and discussion of planning and problems	Kosice	23 January 2017	23 January 2017	Pavol Jozef Safarik University
Progress meeting	Progress meeting	Kosice	June 2017	10 May 2017	Pavol Jozef Safarik University
Progress meeting	Progress meeting	Bratislava	December 2017	19 December 2017	P.J.Safarik University, ESA representatives, Slovak Ministry of Education.
Regular team meeting	Presentation of progress and discussion of planning and problems	Kosice	March 2018	9 March 2018	Pavol Jozef Safarik University
Progress meeting of the team	Presentation of progress and discussion of planning and problems	Kosice	June 2018		Pavol Jozef Safarik University
Final meeting	Final meeting	Kosice	September 2018		Pavol Jozef Safarik University

6 Deliverables Status

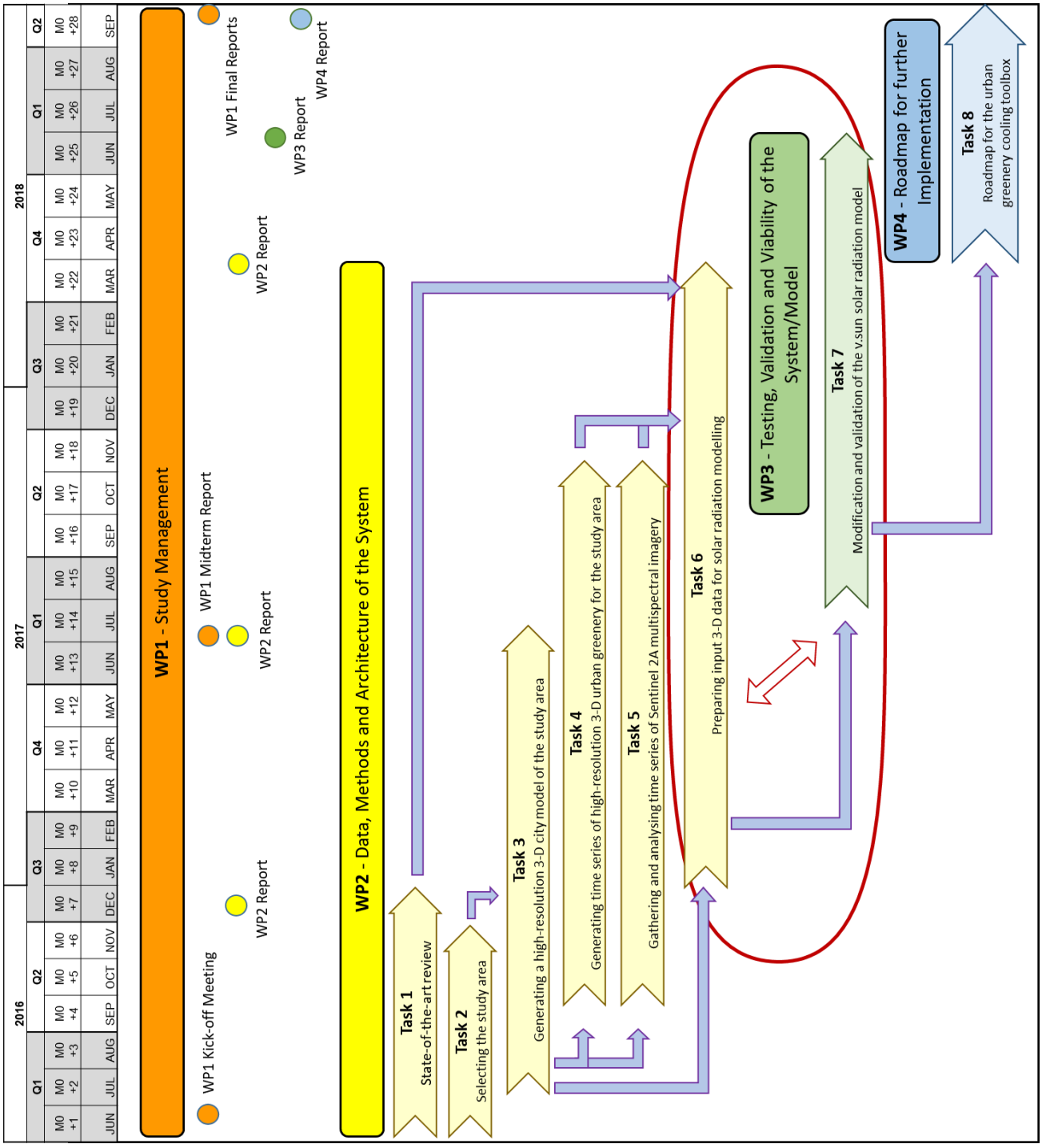
Deliverable Identifier	Title/ Description	Original Delivery Date	Planned Delivery Date	Associated Milestone	Status
D1	Report on the reviewed applicability of multiscpetral satellite imagery for derivation of vegetation transmittance	Nov-2016	Nov-2016	Milestone 1	Finished
D2	Generated 3-D city model	May-2017	May-2017	Milestone 2	Finished
D3	Midterm report	May-2017	May-2017	Milestone 2	Submitted
D4	Report on derivation of satellite based vegetation metrics and downscaling to high-resolution data	Nov-2017	April 2018	Milestone 2	Submitted
D5	Report on definition of algorithmic structure of the toolbox	Feb-2018	June 2018	Milestone 3	Planned
D6	Roadmap report on implementation of the toolbox	May-2018	September 2018	Milestone 3	Planned
TDP	Technical data package (containing all approved technical notes)	May-2018	September 2018	Final Review	Planned
FPR	Final Project Report	May-2018	September 2018	Final Review	Planned
ESR	Executive Summary	May-2018	September 2018	Final Review	Planned

7 Milestone Payment Plan: Status

ID	Description	Amount	Contractual date	Actual/ Expected Date	Status
MP1	Advance payment: Offset against MS1	17500	Upon signature of the Contract by both Parties	xxx	Paid
MP2	Progress (MS1): Upon successful completion and delivery of D1 & D2 under WP2 and acceptance of all related deliverables	12500	June 2017	June 2017	Paid in January 2018
MP3	Progress (MS2): Upon successful completion and delivery of D4 under WP2 and acceptance of all related deliverables	12450	December 2017	June 2018	Due after acceptance of D4
MP4	Final Settlement (MS3): Upon the Agency's acceptance of all deliverables items due under the Contract and the Contractor's fulfilment of all other contractual obligations including submission of the Contract Closure Documentation	7491	June 2018	September 2018	Not yet Due

8 Planning

The original plan was revised submitted to ESA on 2 March 2018. The proposed change was accepted by ESA (ref. ESA-IPL-PTS-SC-ah-FAX-2018-088) with the postponement of the deliverables dates to the following: MS2 to March 2018, MS3 to September 2018, Final delivery to 28 September 2018.



9 Action Item – Status List

NA

10 Any other Business

Besides maintaining the project website, two activities towards public promotion of the project were undertaken. GIS Ostrava 2018 was held in Ostrava in 23 March 2018, where Dr. Ján Kaňuk presented the paper published in conference proceedings in Slovak language:

KAŇUK, J., GALLAY, M., HOFIERKA, 2018. Refinement of the solar cadastre by integrating a time series of urban greenery models. In: Inspektor, T., Horák, J., Růžička, J. (Eds.) Symposium GIS Ostrava 2017, Geoinformatika v pohybu, 22. - 24. března 2017. VŠB - Technická univerzita Ostrava, ISBN 978-80-248-4029-1, ISSN 1213-239X. Available on:

http://gisak.vsb.cz/GIS_Ostrava/GIS_Ova_2018/sbornik/papers/gis20175a5bc0efa66e6.pdf

A case study of the urban heat island in Košice was elaborated by Michal Gallay and his doctoral student Katarína Onačillová:

ONAČILLOVÁ, K., GALLAY, M. (2018).Spatio-temporal analysis of surface urban heat island based on LANDSAT ETM+ and OLI/TIRS imagery in the city of Košice, Slovakia. *Carpathian Journal of Earth and Environmental Sciences*, 13(2), 395 - 408.

The methodical approach of mapping urban greenery as a time-series of high resolution terrestrial lidar data was presented at the 3D geoinfo conference in Melbourne Australia:

HOFIERKA, J., GALLAY, M., KAŇUK, J., ŠUPINSKÝ, J., ŠAŠAK, J. (2017). High-resolution urban greenery mapping for micro-climate modelling based on 3D city models. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (ISPRS Archives), XLII-4/W7, 7-12.

The public presentations are made available as PDFs at https://esa-surge.science.upjs.sk/index.php/results .

11 Reasons for slippage and/or

The original plan had to be modified and the planned work postponed for the process of acceptance of the D1 and D2, D3 as the MS1 taking longer than we and ESA expected. For this reason, the payment of the remaining 12,500 EUR was delayed, which caused slippage in the plan for not having sufficient resources and more importantly uncertain perspective on when the MS1 and invoice will be accepted. Fortunately, this issue was discussed and explained at the meeting with the ESA representatives in Bratislava on 19 December 2017. The MS1 remaining payment was transferred to our Institution in January and the work can progress normally. The proposed plan of the postponed work was accepted by ESA (Section 9).

Despite, the mentioned uncertainty in money transfer in the second half of 2017, we have worked on the D4 and D5 and we presented the research at relevant conferences and workshops (3D geoinfo in Melbourne, GIS Ostrava 2017 in the Czech Republic, and at the Copernicus User Forum in Prague). Also the research article Onačillová & Gallay (2018) on urban heat island in Košice got published.