Резюмета на научните трудове, участията в конференции и приложна дейност за периода 2021-2025 г.

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№	Заглавие, автори и резюме
1	**REQUIREMENTS FOR NEAR-SURFACE REMOTE SENSING DATA ACQUISITION AND PROCESSING AS AN ALTERNATIVE TO TRADITIONAL IN-SITU PHENOLOGY OBSERVATIONS OF CROPS IN BULGARIA** Dessislava **Ganeva**, Milen Chanev, Lachezar Filchev Space Research and Technology Institute – Bulgarian Academy of Sciences e-mail: dganeva@space.bas.bg; m_apiaster@abv.bg; lachezarhf@space.bas.bg **Keywords**: PhenoCams, phenology, agriculture **Abstract**: PhenoCams networks have been operating for more than a decade over vegetated areas to estimate phenology. They apply digital repeat photography that continuously capture images of a given area with an RGB or/and near-infrared enabled cameras. For the first time in Bulgaria, as part of Pheno-Sense project, a PhenoCam will be installed and connected to the PhenoCam cooperative network (https://phenocam.sr.unh.edu/webcam/) that archives and distributes imagery and derived data products from digital cameras deployed at research sites across North America and around the world. The goal of this research is to identify the requirements for near-surface remote sensing data acquisition and processing as an alternative to traditional in-situ phenology observations for crops in Bulgaria.
2	**ДОБРИ ПРАКТИКИ И ПРЕПОРЪКИ ЗА ОПЕРАТИВНИТЕ УСЛУГИ „КОПЕРНИК" НА ЕС ЗА НАБЛЮДЕНИЕ НА ЗЕМЯТА ОТ КОСМОСА, С ЦЕЛ ИНТЕГРИРАНЕТО ИМ В БЪЛГАРСКОТО РАСТЕНИЕВЪДСТВО** Десислава **Ганева**, Лъчезар Филчев, Златомир Димитров Институт за космически изследвания и технологии – Българска академия на науките e-mail: dganeva@space.bas.bg; lachezarhf@space.bas.bg; zlatomir.dimitrov@space.bas.bg **Ключови думи:** данни и услуги на програма „Коперник", растениевъдство, наблюдение на Земята **Резюме:** Разгледани са сайтовете и услугите предоставящи данните: 1) Copernicus hub; 2) RUS; 3) DIAS. Предложени са добри практики и препоръки за използването им в българското растениевъдство. Също така са разгледани услугите на програма „Коперник" започвайки с Atmosphere (CAMS); Land (CLMS) – (глобален, паневропейски, и локален компонент); Глобален компонент; Общоевропейски компонент; Местен

компонент; Климатични промени - Climate Change (C3S); бедствия и аварии - Emergency (EMS) – и по-специално наводнения, суша. След всяка услуга са изведени предложения и препоръки/добри практики.

3

ДОБРИ ПРАКТИКИ ЗА СИНХРОНИЗИРАНЕ НА ХИПЕРСПЕКТРАЛНИ ДАННИ ОТ КОСМИЧЕСКИ СЕНЗОРИ ЗА МОНИТОРИНГ НА ЕКОБИОЛОГИЧНИЯ СТАТУС НА РАЗЛИЧНИ КУЛТУРИ И КОМБИНИРАНЕТО ИМ С ДРУГИ ДАННИ ЗА ЦЕЛИТЕ НА РАСТИТЕЛНАТА ФЕНОМИКА

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Ключови думи: хиперспектрални (спектрометрични) данни, екобиологичен статус, състояние на посеви, наблюдение на земята

Резюме: Разгледано е използването на хиперспектрални данни за определяне на параметри на посев и посев/почва. В доклада са дадени данни за хиперспектралните спътникови мисии, които са достъпни за използване в българското растениевъдство, както и някои съвременни приложения на хиперспектралните данни в растениевъдството. В заключение са изведени предложения и препоръки, и е направен опит за предлагане на методика за определяне на тестови полета и наземни изследвания синхронизирани с дистанционни наблюдения на посевите. За тази цел е използван международният опит на програми и проекти като METEOC, VALERIE, и SPARC (Barax).

4

COMBINED USE OF HYPERSPECTRAL DATA FROM SPACE SENSORS WITH ANCILLARY DATA TO MONITOR THE CROPS STATUS FOR FOOD SECURITY ADDRESSING UN SDS

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Keywords: *Hyperspectral Data, Space Sensors, In-Situ, Crops Status, Food Security, UN SDG*

Summary: Hyperspectral satellite data, like all satellite remote survey data, must be calibrated and validated prior to their direct use in practice. This process is regulated at international level by the Calibration and Validation (CalVal) Group of the Earth Observation Satellites (EOS) Committee (CEOS, 2021). The VALERI project (Baret et al. 2000), which aims to validate products derived from medium-resolution satellite sensors, describes in detail a methodology for synchronizing satellite data with ground-based research data. A source of much information are the initiatives "Metrology for Earth Observation and Climate Observation – METEOC" (METEOC, 2021) and "ESA SPectra bARrax Campaign (SPARC)" from 2003-2004 (ESA SPARC, 2021). A major problem in the collection of terrestrial hyperspectral information is the absorption effects caused by various gas and dust constituents in the atmosphere, but especially the content of water vapor, which make significant parts of the spectrum unusable. For this purpose, inverse spectrum modelling based on physico-mathematical models of the atmosphere or of the reflective characteristic at leaf or crown level shall be used. After continuous and consistent collection (sufficient set of field hyperspectral data) ground spectrometric information, the data with sufficient reliability can be used and the error rate of the interpretation of spectral reflective characteristics may be lowered. There is no small problem in data processing and synchronisation is differences in the ground and satellite sensor – in particular the width of spectral channels – which does not always coincide due to the different engineering solutions of the different sensors brought into orbit. This requires the frequent use of aircraft analogues of these sensors, which are common practice in the countries of Western Europe, the US and Canada. It is on these aircraft analogues that instruments are largely calibrated before being put into orbit and then taken into orbit. Field spectrometric campaigns with spectrometers are mandatory in case aircraft ones cannot be organized. The combination of field, airborne and satellite hyperspectral data with other terrestrial data for plant phenomics purposes shall take place only after the initial calibration and validation of the former. When certifying spectral reflectors for each channel, signal stability, and correction factors for converting digital values into reflective characteristics – which sometimes takes years – data from hyperspectral missions can be used confidently, provided that they are checked periodically. Qualitative and quantitative methods (Homolová et al. 2013) shall be used to determine the parameters of the seed. Qualitative uses a classification with rules to determine each pixel in a relevant class. The quantitative ones are divided into three large groups: empirical (Homolová et al. 2013), physical (Hatfield et al. 2008; Baret and Buis, 2008) or hybrid (Verrelst et al. 2015). Empirical, in turn, is divided into two subgroups: those that use parametric functions with one variable, which is usually vegetative indices (VI), and non-parametric algorithms that use all available spectral information. In Bulgaria, non-parametric algorithms for determining parameters of winter wheat and canola crops (Ganeva et al. 2019; Ganeva and Roumenina, 2018;

	Ganeva, 2018) give good results. Particular attention to the synchronisation of hyperspectral satellite data with ground-based survey data should be given to the choice of test fields and the survey methodology.
5	**Evaluation of Phenocam phenology of barley** Dessislava **Ganeva***a, Milen Chaneva,b, Lachezar Filcheva, Georgi Jeleva, Darina Valchevab aSpace Research and Technology Institute – Bulgarian Academy of Sciences, acad. Georgi Bonchev str. bl.1, 1113 Sofia, Bulgaria; bInstitute of Agriculture Karnobat – Agriculture Academy, Industrialna str. №1, 8400 Karnobat, Bulgaria **Keywords:** Harmonized Landsat-8 and Sentinel-2, In-situ phenophases, Land Surface Phenology, Phenocam, Phenological indicators, Time series analysis **ABSTRACT:** Phenocams that capture images of a given area in the RGB or near-infrared (NIR) spectrum have been used for more than a decade to estimate phenology in natural landscapes and crop fields. The aim of our study is to estimate phenological parameters, start (SOS) and end (EOS) of season, for barley, from RGB and NIR Phenocam and compare them with in-situ observations from two sites, one with growing season 2014/2015 and the other with growing season 2021/2022. Time series of Phenocam Green Chromatic Coordinate (GCC) and Normalized Difference Vegetation Index (NDVI) were computed then scaled to Harmonized Landsat-8 and Sentinel-2 surface (HLS), available for both sites, and Sentinel-2 (S2), available for only one site, datasets. The HLS and S2 datasets were gap filled with classical and machine learning methods before the scaling. Phenological parameters were extracted from the scaled GCC and NDVI Phenocam data and from the gap filled HLS and S2 datasets. Our preliminary results show that the SOS can be modelled with one day difference compared with the in-situ observed with the scaled Phenocam NDVI and a week difference compared with the in-situ observed with gap filled HLS and S2 datasets with both vegetation indices.
6	**MODELLING BARLEY BIOMASS FROM PHENOCAM TIME SERIES WITH MULTI-OUTPUT GAUSSIAN PROCESSES** Asst. Prof. Dr. Dessislava **Ganeva[1]** , Milen Chanev[1,2], Prof. Dr. Darina Valcheva[2], Prof. Dr. Lachezar Filchev[1], Prof. Dr. Georgi Jelev[1] [1] Space Research and Technology Institute – Bulgarian Academy of Sciences, Sofia, Bulgaria [2] Institute of Agriculture Karnobat – Agriculture Academy, Karnobat, Bulgaria **Keywords:** biomass, machine learning, multi-output Gaussian processes, Phenocams **Abstract:** Biomass is monitored in many agricultural studies because it is closely related to the growth of the crop. The technique of digital repeat photography that continuously capture images of a given area with an RGB or near-infrared enabled cameras, Phenocams, has been used for more than a decade mainly to estimate phenology. Studies have found a relationship between Phenocam data and above-ground dry biomass. In this context we investigate the modeling of barley fresh above and underground biomass with Green chromatic coordinate (Gcc) colour index, extracted from Phenocam data, and multi-output Gaussian processes (MOGP). We take advantage of the available very high temporal resolution data from the phenocam to predict the biomass. The MOGP models take into account the relationships among output variables learning a cross-domain kernel function able to transfer information between time series. Our results suggest that MOGP model is able to successfully predict the variables simultaneously in regions where no training samples are available by intrinsically exploiting the relationships between the considered output variables.
7	**Phenotypic Traits Estimation and Preliminary Yield Assessment in Different Phenophases of Wheat Breeding Experiment Based on UAV Multispectral Images** Dessislava **Ganeva** 1,* , Eugenia Roumenina 1, Petar Dimitrov 1 , Alexander Gikov 1, Georgi Jelev 1, Rangel Dragov 2, Violeta Bozhanova 2 and Krasimira Taneva 2 1 Space Research and Technology Institute, Bulgarian Academy of Sciences, 1113 Sofia, Bulgaria; roumenina@space.bas.bg (E.R.); petar.dimitrov@space.bas.bg (P.D.); gikov@space.bas.bg (A.G.); jelev@space.bas.bg (G.J.) 2 Field Crops Institute, Agricultural Academy, 6200 Chirpan, Bulgaria; dragov1@abv.bg (R.D.); bozhanova@agriacad.bg (V.B.); krasimira.taneva@abv.bg (K.T.) * Correspondence: dganeva@space.bas.bg; Tel.: +35-988-5301-496 **Keywords**: biophysical variables retrieval; machine learning; multispectral imagery; phenotyping; remotely sensed phenotypic traits; unmanned aerial vehicles; winter durum wheat; yield assessment **Abstract**: The utility of unmanned aerial vehicles (UAV) imagery in retrieving phenotypic data to support plant breeding research has been a topic of increasing interest in recent years. The advantages of image-based phenotyping

are related to the high spatial and temporal resolution of the retrieved data and the non-destructive and rapid method of data acquisition. This study trains parametric and nonparametric regression models to retrieve leaf area index (LAI), fraction of absorbed photosynthetically active radiation (fAPAR), fractional vegetation cover (fCover), leaf chlorophyll content (LCC), canopy chlorophyll content (CCC), and grain yield (GY) of winter durum wheat breeding experiment from four-bands UAV images. A ground dataset, collected during two field campaigns and complemented with data from a previous study, is used for model development. The dataset is split at random into two parts, one for training and one for testing the models. The tested parametric models use the vegetation index formula and parametric functions. The tested nonparametric models are partial least squares regression (PLSR), random forest regression (RFR), support vector regression (SVR), kernel ridge regression (KRR), and Gaussian processes regression (GPR). The retrieved biophysical variables, along with traditional phenotypic traits (plant height, yield, and tillering), are analysed for the detection of genetic diversity, proximity, and similarity in the studied genotypes. Analysis of variance (ANOVA), Duncan's multiple range test, correlation analysis, and principal component analysis (PCA) are performed with the phenotypic traits. The parametric and nonparametric models show close results for GY retrieval, with parametric models indicating slightly higher accuracy (R2 = 0.49; RMSE = 0.58 kg/plot; rRMSE = 6.1%). However, the nonparametric model, GPR, computes per-pixel uncertainty estimation, making it more appealing for operational use. Furthermore, our results demonstrate that grain filling was better than the flowering phenological stage to predict GY. The nonparametric models show better results for biophysical variables retrieval, with GPR presenting the highest prediction performance. Nonetheless, robust models are found only for LAI (R2 = 0.48; RMSE = 0.64; rRMSE = 13.5%) and LCC (R2 = 0.49; RMSE = 31.57 mg m^{-2}; rRMSE = 6.4%) and therefore these are the only remotely sensed phenotypic traits included in the statistical analysis for preliminary assessment of wheat productivity. The results from ANOVA and PCA illustrate that the retrieved remotely sensed phenotypic traits are a valuable addition to the traditional phenotypic traits for plant breeding studies. We believe that these preliminary results could speed up crop improvement programs; however, stronger interdisciplinary research is still needed, as well as uncertainty estimation of the remotely sensed phenotypic traits.

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In-situ start and end of growing season dates of major European crop types from France and Bulgaria at a field level

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Keywords: Winter crop, Summer crop, Cover crop, BBCH, Phenology

Abstract: Crop phenology data offer crucial information for crop yield estimation, agricultural management, and assessment of agroecosystems. Such information becomes more important in the context of increasing year-to-year

	climatic variability. The dataset provides in-situ crop phenology data (first leaves emergence and harvest date) of major European crops (wheat, corn, sunflower, rapeseed) from seventeen field study sites in Bulgaria and two in France. Additional information such as the sowing date, area of each site, coordinates, method and equipment used for phenophase data estimation, and photos of the France sites are also provided. The georeferenced ground-truth dataset provides a solid base for a better understanding of crop growth and can be used to validate the retrieval of phenological stages from remote sensing data
9	**Remotely Sensed Phenotypic Traits for Heritability Estimates and Grain Yield Prediction of Barley Using Multispectral Imaging from UAVs** Dessislava **Ganeva** 1,* , Eugenia Roumenina 1, Petar Dimitrov 1 , Alexander Gikov 1, Georgi Jelev 1, Boryana Dyulgenova 2 , Darina Valcheva 2 and Violeta Bozhanova 3 1 Space Research and Technology Institute, Bulgarian Academy of Sciences, 1113 Sofia, Bulgaria; roumenina@space.bas.bg (E.R.); petar.dimitrov@space.bas.bg (P.D.); gikov@space.bas.bg (A.G.); gjelev@space.bas.bg (G.J.) 2 Institute of Agriculture, Agriculture Academy, 8400 Karnobat, Bulgaria; bdyulgerova@abv.bg (B.D.); darinadv@abv.bg (D.V.) 3 Field Crops Institute, Agricultural Academy, 6200 Chirpan, Bulgaria; bozhanova@agriacad.bg * Correspondence: dganeva@space.bas.bg; Tel.: +359-88-530-14-96 **Keywords**: barley; grain yield prediction; heritability; multispectral images; phenotypic traits; UAV **Abstract**: This study tested the potential of parametric and nonparametric regression modeling utilizing multispectral data from two different unoccupied aerial vehicles (UAVs) as a tool for the prediction of and indirect selection of grain yield (GY) in barley breeding experiments. The coefficient of determination (R2) of the nonparametric models for GY prediction ranged between 0.33 and 0.61 depending on the UAV and flight date, where the highest value was achieved with the DJI Phantom 4 Multispectral (P4M) image from 26 May (milk ripening). The parametric models performed worse than the nonparametric ones for GY prediction. Independent of the retrieval method and UAV, GY retrieval was more accurate in milk ripening than dough ripening. The leaf area index (LAI), fraction of absorbed photosynthetically active radiation (fAPAR), fraction vegetation cover (fCover), and leaf chlorophyll content (LCC) were modeled at milk ripening using nonparametric models with the P4M images. A significant effect of the genotype was found for the estimated biophysical variables, which was referred to as remotely sensed phenotypic traits (RSPTs). Measured GY heritability was lower, with a few exceptions, compared to the RSPTs, indicating that GY was more environmentally influenced than the RSPTs. The moderate to strong genetic correlation of the RSPTs to GY in the present study indicated their potential utility as an indirect selection approach to identify high-yield genotypes of winter barley.
10	**Chapter 20 - A novel approach for training nonparametric statistical models to retrieve rapeseed fresh above-ground biomass using in situ and Sentinel-2 data** Dessislava **Ganeva** **Keywords:** Nonparametric regression, biomass retrieval, Sentinel-2, in situ data **Abstract:** Training nonparametric statistical models with in situ data can be challenging due to the cost and time involved in obtaining measurements. To enhance the performance of these models, it is suggested to pair one in situ measurement with several dates of remote sensing (RS) data, particularly if the RS data have a high temporal resolution during the period when the plant is not undergoing development. To illustrate this approach, six different methods were evaluated, including regularized least squares linear regression (RLR), support vector regression (SVR), random forests regression (RFR), Gaussian processes regression (GPR), kernel ridge regression (KRR), and neural networks (NN), for retrieving rapeseed fresh above-ground biomass from Sentinel-2 data. Among these methods, GPR emerged as the best performing model, as evidenced by improvements in all the studied goodness-of-fit metrics.
11	**Enhancing Pléiades-based crop mapping with multi-temporal and texture information** Petar Dimitrov a,*, Eugenia Roumenina a, Dessislava **Ganeva** a, Alexander Gikov a, Ilina Kamenova a, Violeta Bozhanova b a Space Research and Technology Institute, Bulgarian Academy of Sciences, Academic G. Bonchev St., Blok 1, 1113, Sofia, Bulgaria b Agricultural Academy, 30 Suhodolska St., 1373, Sofia, Bulgaria **Keywords:** VHR, Random forest, GLCM, Vegetation indices, IACS

Abstract: Accurate crop mapping using satellite imagery is crucial for improving the monitoring of agricultural landscapes. Very high resolution (VHR) satellite imagery offers unique capabilities in this respect, allowing for even small fields to be discerned and image texture analysis to be performed. Additionally, satellite imagery has greater efficiency than unmanned aerial vehicles due to its extensive coverage. Moreover, the operation flexibility of VHR satellites means that timely image acquisition is possible several times during the growing season. This study investigates the potential of VHR Pléiades images and the random forest classifier for accurate crop mapping. Four images acquired on April 9th, May 12th, May 31st, and June 20th were used to test 16 classification scenarios, including single-date and multi-temporal combinations of spectral bands, texture features, and vegetation Indices (VIs). The classification using the spectral bands from all four images achieved the highest overall accuracy, 93.9% and 96.3% at field and pixel levels, respectively. The bitemporal classifications had lower accuracy. Nevertheless, the combination of the May 12th and June 20th spectral bands had 90% accuracy, which indicated that two images may be sufficient for reliable mapping if the periods with phenological differences between crops are considered. Adding texture features to the spectral bands significantly enhanced the accuracy (up to 8%) of single-date classifications, making it highly recommended when only one image is available. However, the impact of texture was more pronounced on the later dates. It showed the most marked benefit for vineyards and alfalfa, with minimal or no improvement observed for other classes like winter barley. An additional increase in overall accuracy was achieved in three of the four dates by supplementing the spectral and texture bands with VIs. This study highlights the importance of considering image acquisition dates and crop types when designing satellite-based crop mapping strategies for optimal accuracy.

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Winter Durum Wheat Disease Severity Detection with Field Spectroscopy in Phenotyping Experiment at Leaf and Canopy Level

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Keywords: disease severity; hyperspectral data; leaf spectroscopy; field spectroscopy; rust; winter durum wheat

Abstract: Accurate disease severity assessment is critical for plant breeders, as it directly impacts crop yield. While hyperspectral remote sensing has shown promise for disease severity assessment in breeding experiments, most studies have focused on either leaf or canopy levels, neglecting the valuable insights gained from a combined approach. Moreover, many studies have centered on experiments involving a single disease and a few genotypes. However, this approach needs to accurately represent the challenges encountered in field conditions, where multiple diseases could occur simultaneously. To address these gaps, our current study analyses a combination of diseases, yellow rust, brown rust, and yellow leaf spots, collectively evaluated as the percentage of the diseased leaf area relative to the total leaf area (DA) at both leaf and canopy levels, using hyperspectral data from an ASD field spectrometer. We quantitatively estimate overall disease severity across fifty-two winter durum wheat genotypes categorized into early (medium milk) and late (late milk) groups based on the phenophase. Chlorophyll content (CC) within each group is studied concerning infection response, and a correlation analysis is conducted for each group with nine vegetation indices (VI) known for their sensitivity to rust and leaf spot infection in wheat. Subsequent parametric (linear and polynomial) and nonparametric (partial least squares and kernel ridge) regression analyses were performed using all available spectral bands. We found a significant reduction in Leaf CC (>30%) in the late group and Canopy CC (<10%) for both groups. YROI and LRDSI_1 are the VIs that exhibited notable and strong negative correlations with Leaf CC in the late group, with a Pearson coefficient of −0.73 and −0.72, respectively. Interestingly, spectral signatures between the early and late disease groups at both leaf and canopy levels exhibit opposite trends. The regression analysis showed we could retrieve leaf CC only for the late group, with R2 of 0.63 and 0.42 for the cross-validation and test datasets, respectively. Canopy CC retrieval required separate models for each group: the late group achieved R2 of 0.61 and 0.37 (cross-validation and test), while the early group achieved R2 of 0.48 and 0.50. Similar trends were observed for canopy DA, with separate models for early and late groups achieving comparable R2 values of 0.53 and 0.51 (cross-validation) and 0.35 and 0.36 (test), respectively. All of our models had medium accuracy and tended to overfit. In this study, we analyzed the spectral response mechanism

	associated with durum wheat diseases, offering a novel crop disease severity assessment approach. Additionally, our findings serve as a foundation for detecting resistant wheat varieties, which is the most economical and environmentally friendly management strategy for wheat leaf diseases on a large scale in the future.
13	**Preharvest Durum Wheat Yield, Protein Content, and Protein Yield Estimation Using Unmanned Aerial Vehicle Imagery and Pléiades Satellite Data in Field Breeding Experiments** Dessislava **Ganeva** 1,* , Eugenia Roumenina 1, Petar Dimitrov 1 , Alexander Gikov 1, Violeta Bozhanova 2 , Rangel Dragov 2, Georgi Jelev 1 and Krasimira Taneva 2 1 Space Research and Technology Institute, Bulgarian Academy of Sciences, 1113 Sofia, Bulgaria; roumenina@space.bas.bg (E.R.); petar.dimitrov@space.bas.bg (P.D.); gikov@space.bas.bg (A.G.); gjelev@space.bas.bg (G.J.) 2 Field Crops Institute, Agricultural Academy, 6200 Chirpan, Bulgaria; bozhanova@agriacad.bg (V.B.); dragov1@abv.bg (R.D.); krasimira.taneva@abv.bg (K.T.) * Correspondence: dganeva@space.bas.bg; Tel.: +359-885-301-496 **Keywords:** feature selection; Gaussian process regression; pan-sharpened satellite imagery; phenotyping; time series **Abstract:** Unmanned aerial vehicles (UAVs) are extensively used to gather remote sensing data, offering high image resolution and swift data acquisition despite being labor-intensive. In contrast, satellite-based remote sensing, providing sub-meter spatial resolution and frequent revisit times, could serve as an alternative data source for phenotyping. In this study, we separately evaluated pan-sharpened Pléiades satellite imagery (50 cm) and UAV imagery (2.5 cm) to phenotype durum wheat in small-plot (12 m × 1.10 m) breeding trials. The Gaussian process regression (GPR) algorithm, which provides predictions with uncertainty estimates, was trained with spectral bands and a selected set of vegetation indexes (VIs) as independent variables. Grain protein content (GPC) was better predicted with Pléiades data at the growth stage of 20% of inflorescence emerged but with only moderate accuracy (validation R2: 0.58). The grain yield (GY) and protein yield (PY) were better predicted using UAV data at the late milk and watery ripe growth stages, respectively (validation: R2 0.67 and 0.62, respectively). The cumulative VIs (the sum of VIs over the available images within the growing season) did not increase the accuracy of the models for either sensor. When mapping the estimated parameters, the spatial resolution of Pléiades revealed certain limitations. Nevertheless, our findings regarding GPC suggested that the usefulness of pan-sharpened Pléiades images for phenotyping should not be dismissed and warrants further exploration, particularly for breeding experiments with larger plot sizes.
14	**OPTICAL REMOTE SENSING IN PRECISION FIELD PLANT BREEDING. A REVIEW** Dessislava **Ganeva** Space Research and Technology Institute – Bulgarian Academy of Sciences e-mail: dganeva@space.bas.bg **Keywords:** Plant Phenotyping, Phenomic traits, Phenotypic traits **Abstract:** Remote sensing in precision plant breeding involves using advanced technologies, such as drones, satellites, and sensors, to collect detailed data on plant traits and environmental conditions. These tools capture information on crop health, growth, stress responses, and other vital parameters through non-destructive methods like multispectral and hyperspectral imaging. This data helps plant breeders make informed decisions on selecting and developing crops with desirable traits, improving breeding efficiency, and accelerating the development of resilient, high-yield varieties tailored to specific environments. The equipment and characteristics of remote sensing used to date, as well as directions for the future development of these studies.
15	**Reviews and syntheses: Remotely sensed optical time series for monitoring vegetation productivity** Lammert Kooistra1,, Katja Berger2,, Benjamin Brede3, Lukas Valentin Graf4,5, Helge Aasen4,5, Jean-Louis Roujean6, Miriam Machwitz7, Martin Schlerf7, Clement Atzberger8, Egor Prikaziuk9, Dessislava **Ganeva**10, Enrico Tomelleri11, Holly Croft12,13, Pablo Reyes Muñoz2, Virginia Garcia Millan14, Roshanak Darvishzadeh9, Gerbrand Koren15, Ittai Herrmann16, Offer Rozenstein17, Santiago Belda18, Miina Rautiainen19, Stein Rune Karlsen20, Cláudio Figueira Silva21, Sofia Cerasoli21, Jon Pierre8, Emine Tanır Kayıkçı22, Andrej Halabuk23, Esra Tunc Gormus22, Frank Fluit1, Zhanzhang Cai24, Marlena Kycko25, Thomas Udelhoven26, and Jochem Verrelst2 1Laboratory of Geo-Information Science and Remote Sensing, Wageningen University & Research, Droevendaalsesteeg 3, 6708 PB Wageningen, the Netherlands

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Abstract. Vegetation productivity is a critical indicator of global ecosystem health and is impacted by human activities and climate change. A wide range of optical sensing platforms, from ground-based to airborne and satellite, provide spatially continuous information on terrestrial vegetation status and functioning. As optical Earth observation (EO) data are usually routinely acquired, vegetation can be monitored repeatedly over time, reflecting seasonal vegetation patterns and trends in vegetation productivity metrics. Such metrics include gross primary productivity, net primary productivity, biomass, or yield. To summarize current knowledge, in this paper we systematically reviewed time series (TS) literature for assessing state-of-the-art vegetation productivity monitoring approaches for different ecosystems based on optical remote sensing (RS) data. As the integration of solar-induced fluorescence (SIF) data in vegetation productivity processing chains has emerged as a promising source, we also include this relatively recent sensor modality. We define three methodological categories to derive productivity metrics from remotely sensed TS of vegetation indices or quantitative traits: (i) trend analysis and anomaly detection, (ii) land surface phenology, and (iii) integration and assimilation of TS-derived metrics into statistical and process-based dynamic vegetation models (DVMs). Although the majority of used TS data streams originate from data acquired from satellite platforms, TS data from aircraft and unoccupied aerial vehicles have found their way into productivity monitoring studies. To facilitate

	processing, we provide a list of common toolboxes for inferring productivity metrics and information from TS data. We further discuss validation strategies of the RS data derived productivity metrics: (1) using insitu measured data, such as yield; (2) sensor networks of distinct sensors, including spectroradiometers, flux towers, or phenological cameras; and (3) inter-comparison of different productivity metrics. Finally, we address current challenges and propose a conceptual framework for productivity metrics derivation, including fully integrated DVMs and radiative transfer models here labelled as "Digital Twin". This novel framework meets the requirements of multiple ecosystems and enables both an improved understanding of vegetation temporal dynamics in response to climate and environmental drivers and enhances the accuracy of vegetation productivity monitoring.
16	**Uncertainty Budget for a Traceable Operational Radiometric Calibration of Field Spectroradiometers, Calibration of the Heliosphere** Mike Werfeli , Andreas Hueni *, Member, IEEE*, Dessislava **Ganeva**, Giulia Ghielmetti, and Laura Mihai *, Member, IEEE* **Keywords:** Calibration, radiometry, spectroscopy, uncertainty. **Abstract:** To measure the distinct interaction of the Earth's materials with solar electromagnetic radiation, field spectroradiometers are commonly utilized. These are used to validate spectroradiometers deployed on various platforms through comparison exercises. Following metrology standards, the inclusion of uncertainties is required. Thus, field spectroradiometers need to be calibrated regularly against traceable radiance sources. In this article, we present a laboratory radiometric calibration protocol for the calibration of a heliosphere integrating sphere to make it traceable to the International System of Units as well as to establish an uncertainty budget. We adopted a transfer radiometer approach including four spectroradiometers that were calibrated at the Deutsches Zentrum für Luft und Raumfahrt Radiometric Standard facility before transferring that calibration to the heliosphere. After considering various sources of uncertainty by employing an uncertainty tree diagram approach, we arrive at an overall propagated uncertainty of approximately 1.5%. In future publications, we will present how to extend the traceability to other attenuations provided by the heliosphere. Its application to the calibration of a field spectroradiometer will be the focus of a future publication.
17	**Evaluation and improvement of Copernicus HR-VPP product for crop phenology monitoring** Egor Prikaziuk a ,∗, Cláudio F. Silva b, Gerbrand Koren c, Zhanzhang Cai d, Katja Berger e, Santiago Belda f, Lukas Valentin Graf g, Enrico Tomelleri h, Jochem Verrelst i, Joel Segarra j, Dessislava **Ganeva** k a Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, Enschede, 7500 AE, The Netherlands b Forest Research Centre (CEF) and Associated Laboratory TERRA, School of Agriculture, University of Lisbon, Tapada da Ajuda, Lisbon, 1349-017, Portugal c Copernicus Institute of Sustainable Development, Utrecht University, Princetonlaan 8a, Utrecht, 3584 CB, The Netherlands d Department of Physical Geography and Ecosystem Science, Lund University, Solvegatan 12, Lund, S-223 62, Sweden e GFZ Helmholtz Centre for Geosciences, Potsdam, 14473, Germany f Department of Applied Mathematics, Universidad de Alicante, Carretera San Vicente del Raspeig, Alicante, 03690, Spain g Crop Science, Institute of Agricultural Science, ETH Zurich, Zurich, 8092, Switzerland h Faculty of Agricultural, Environmental and Food Sciences, Free University of Bolzano, Bozen-Bolzano, 39100, Italy i Image Processing Laboratory (IPL), University of Valencia, Paterna, 46980, Spain j Department of Evolutionary Biology, Ecology and Environmental Sciences, Faculty of Biology, University of Barcelona, Barcelona, 08028, Spain k Space Research and Technology Institute, Bulgarian Academy of Sciences, Sofia, 1113, Bulgaria **Keywords:** Phenology, Crop, Sentinel-2, Copernicus Land Monitoring Service (CLMS), High-resolution Vegetation Phenology and Productivity (HR-VPP) **Abstract:** Monitoring agricultural land with optical remote sensing offers a valuable tool for estimating crop yield and supporting decision-making for food security. Cropland phenology indicators, such as the start of season (SOS), the end of season (EOS), and the number of growing seasons per year, provide essential information for land managers. While established toolboxes like TIMESAT have been extracting phenological metrics from coarse remote sensing data for two decades, agricultural monitoring applications demand continuous time series of high-resolution data, made possible by the European Union's Copernicus Sentinel-2 since 2015. Recently, the Copernicus Land Monitoring

	Service (CLMS) released the pan-European High-Resolution Vegetation Phenology and Productivity (HR-VPP) product suite. We conducted the first comprehensive validation of the analysis-ready SOS and EOS metrics from the VPP dataset of the HR-VPP product over a large set of agricultural fields spanning 10 countries, 14 crop types and 164 growing seasons. Our results demonstrate that the VPP product of the HR-VPP dataset correlates well with the sowing ($r2$ = 0.75) and harvesting ($r2$ = 0.56) dates observed in situ. The biases differ between spring (SOS bias: 59 days, EOS bias: 3 days) and winter (SOS bias: 136 days, EOS bias: –44 days) crops, likely due to the suppression of the autumn vegetation signal in the plant phenology index (PPI) by a solar zenith angle-dependent gain factor. We show that other indicators from the HR-VPP Vegetation Indices (VIs) product and re-parameterization of TIMESAT or DATimeS toolboxes are more suitable for winter crop phenology monitoring. This study calls for researchers and practitioners to carefully evaluate the performance of analysis-ready products to ensure their suitability for specific applications, ultimately promoting informed decision-making in agricultural management and food security endeavours.
18	**Exploring Sentinel-1 and Sentinel-2 time series sensitivity to rice height** Saygin Abdikan: *Department of Geomatics Engineering, Hacettepe University,* Ankara, Türkiye, Aliihsan Sekertekin: *Department of Architecture and Town, Planning Igdir University,* Igdir, Türkiye Milen Chanev: *Department Remote Sensing and GIS, Space Research and Technology Institute - Bulgarian Academy Of Sciences,* Sofia, Bulgaria Mustafa Tolga Esetlili: *Department of Soil Science and Plant Nutrition, Ege University,* Izmir, Türkiye Dessislava **Ganeva**: *Department Remote Sensing and GIS, Space Research and Technology Institute - Bulgarian Academy Of Sciences,* Sofia, Bulgaria Zlatomir Dimitrov: *Department Remote Sensing and GIS, Space Research and Technology Institute - Bulgarian Academy Of Sciences,* Sofia, Bulgaria Lachezar Filchev: *Department Remote Sensing and GIS, Space Research and Technology Institute - Bulgarian Academy Of Sciences,* Sofia, Bulgaria Fusun Balik Sanli: *Department of Geomatic Engineering, Yildiz Technical University,* Istanbul, Türkiye Omer Gokberk Narin: *Department of Geomatics Engineering, Afyon Kocatepe University,* Afyon, Türkiye Caglar Bayik: *Department of Geomatics Engineering, Zonguldak Bulent Ecevit University,* Zonguldak, Türkiye Mustafa Ustuner: *Department of Geomatics Engineering, Artvin Coruh University,* Artvin, Türkiye Yusuf Kurucu: *Department of Soil Science and Plant Nutrition, Ege University,* Izmir, Türkiye ***Keywords:*** paddy rice, crop phenophase, Sentinel-1, Sentinel-2, remote sensing **Abstract*:*** The rice plant is one of the most widely consumed crops globally, and its height is a key indicator of growth. This study explored the relationship between rice plant height, measured in situ in Bulgaria and Тъrkiye, and multi-temporal data from Sentinel-1 and Sentinel-2 satellites to develop models for height estimation. The strongest correlation was observed when integrating the Radar Vegetation Index (RVI) and the Normalized Difference Vegetation Index (NDVI), yielding a correlation coefficient of r = 0.69. Additionally, using VV polarization in a multi-linear regression analysis resulted in the lowest error rate, with a root mean square error (RMSE) of 14.14 cm. The findings suggest that combining synthetic aperture radar (SAR) and optical data holds significant potential for accurately estimating rice plant height**.**
19	**"Земеделски територии"** в Подраздел "Приложение на геоинформационните технологии в България. Моноторинг на околната среда, основан на геоинформационните технологии" в раздел "Геоинформационни технологии" на монография "География на България", Том 1 "Физическа география. Геоинформационни технологии" *Евгения Руменина, Десислава **Ганева**, Александър Гиков, Петър Димитров, Лъчезар Филчев, Георги Желев* *Институт за космически изследвания и технологии при Българската академия на науките* *Кореспондиращ автор: Е. Руменина, eroumenina@gmail.com* **Резюме:** Внедряването на съвременни геоинформационни технологии в земеделието през последните години направи възможно решаването на проблема с информационното обслужване на селското стопанство и прехода към „интелигентно земеделие“. Тези технологии са пряко свързани с разработване на спътникови продукти и услуги за оперативен мониторинг на посеви от земеделски култури, които са важна съставна част от съвременната селскостопанска практика. Това е една от активно развиващите се, със стратегическо значение, области на съвременните приложни дистанционни изследвания. Неразделна част от новата

	космическа политика (2021—2027г.) на Европейския съюз (ЕС) е развитието на програмата „Коперник" [https://www.copernicus.eu/bg/za-programata-kopernik] за наблюдение на Земята и в частност на земеделските територии в подкрепа на изпълнението на Общата селскостопанска политика (ОСП). За повишаване на ефективността и точността при предоставяне на тези продукти и услуги, включително и за България, се изисква да се отчитат специфичните климатични условия, при които се отглежда съответната култура и прилаганите земеделски практики. Тяхното използване в нашата страна е залегнало в „Стратегията за цифровизация на земеделието и селските райони на Република България", приета с Решение № 247 на Министерския съвет от 02.05.2019 г. На тази база технологиите за дистанционно наблюдение на Земята за земеделски приложения в България се развива в следните области: 1) Научни и научно-приложни изследвания; 2) Администриране и контрол на схемите за субсидиране на площ в рамките на Европейския фонд за гарантиране на земеделието (ЕФГЗ) и 3) Разработване на мобилни приложения
20	**Патент за изобретение № 67632 B1** **Интегрирана система за дистанционен и наземен мониторинг на селекционни опитни полета** Изобретатели: Евгения Кирилова Руменина, Виолета Златева Божанова, Рангел Георгиев Драгов, Десислава Ганчева **Ганева-Кирякова**, Георги Николаев Желев, Александър Георгиев Гиков, Петър Кирилов Димитров, Лъчезар Христов Филчев