An Open Platform for RGB Composite Analysis and Validation: RGB_DIGI

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Abstract

In this paper we present an open platform which consists of a free automated digital image processing tool, a camera network portal where digital images are available freely, operational monitoring system and Cal / Val activities producing near real time results for comparison of satellite-derived products with webcam derived and in-situ data. We proposed a concept of RGB-based data platform which may provide some progresses to existing challenges of applications of digital imagery technologies. We provided a quick analysis from a set of webcam images and discuss their capabilities on capturing climate proxies in 10 years’ time.

1. Introduction

The currently available information on ecosystem parameters is insufficient in terms of both temporal and spatial coverage to serve the needs of meteorology, hydrology and climate monitoring. Integrated and automatized use of satellite and in situ data for Essential Climate Variable (ECV) retrieval is nonexistent. Low cost and robust in-situ instruments would be able to cover the satellite footprints.

Dynamic climatological proxies are needed to follow diurnal variations of the ECVs such as snow cover, especially water retention in snow and the evolution of snow layer structure due to melt/freeze events for advancing the understanding of vegetation phenology and thus the hydrological cycle and carbon exchange in cold regions.

A RGB composite imagery consists of three colours of light (red, blue and green). True colour (natural colour) RGB composite imagery uses visible light bands red, green and blue resulting in a natural coloured as seen it naturally by the human eye. On the other hand, when a RGB composite imagery is created by the bands outside of the visible spectrum it is called as false color RGB composite imagery. The RGB composite imageries are commonly used in the applications of remote sensing. For instance, the Sentinel-2 based true colour RGB (bands 4, 3 and 2) images are used in products of land monitoring, maritime monitoring, emergency management and security. The Sentinel-2 based false colour (urban) RGB (bands 12, 11 and 4) images are used to visualize urbanized areas (vegetation, urbanised areas, soils, sands, minerals, snow, ice, and detecting natural hazards such as flooded areas, wildfires, calderas of the volcanoes). more clearly (SentiWiki).

Applications of digital imagery technologies such as time-lapse photography, drones and citizen science observations expand rapidly due to their efficient and low-cost availability for effective monitoring of the environment. There is an increased need and great opportunities on digital imagery to impact science and society. RGB imaging of digital cameras is simple, accessible and cost effective for vast and diverse applications in the monitoring of environment such as phenological applications (Graham 2009 ; Davidson, 2022 ; Parilli-Ocampo, 2024 ; Sonnentag, 2012 ; Alberton,2017, Katal, 2022) and cryospheric applications (Bernard, 2013 ; Garvelmann, 2013 ; Arslan, 2017) etc. There are also many other applications and among them like monitoring of suspended sediment in coastal construction areas (Noh, 2024), ice detection on rotor blades of wind turbines (Kreutz, 2020) etc.

Validation is very critical in terms of verifying the performance of the satellite-derived products. Ground observations (in-situ data) are not always available, costly, or very limited. Due to this limitation, they are not spatially or temporally good enough for validation of the satellite-derived products. Digital images from simple cameras can be an important source of a validation data (Piazzi, 2019).

2. RGB_DIGI Platform

The concept of the RGB_DIGI platform is provided in Figure 1. The main objective of the RGB_DIGI platform is to develop an open platform which enables RGB composite analysis to estimate the ECVs for applications such as hydrological and Numerical Weather Prediction (NWP) and climate services.

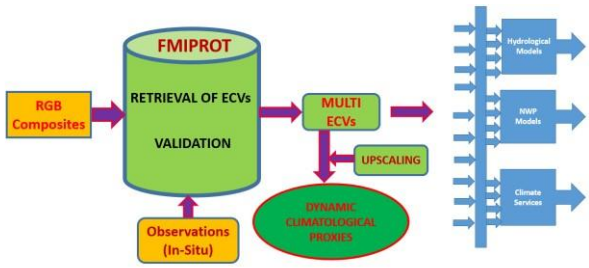


Figure 1. The concept of the RGB_DIGI platform.

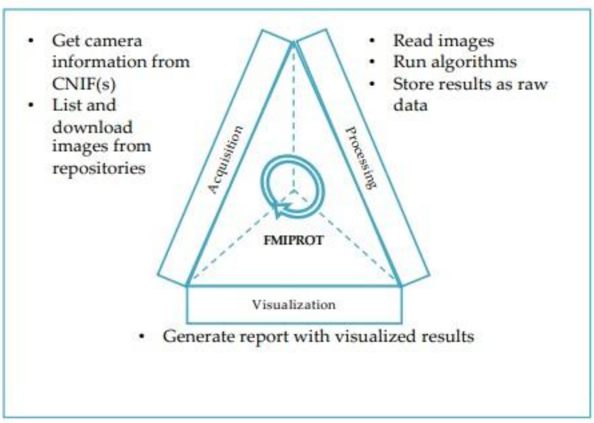
In our current platform, we provide processing tool for images, camera network portals and operational monitoring and validation services for snow and vegetation phenology.

2.1 FMIPROT

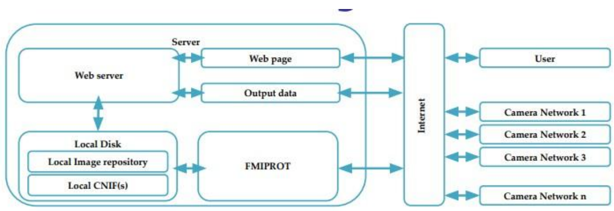
FMI Image Processing Toolbox (FMIPROT) (Tanis, 2018) is a software designed to process digital image series from cameras and camera networks. It can acquire and process images from multiple camera networks on a single platform by adding connection information of the image repositories. It provides a graphical user interface (GUI) to set up configurations and parameters to be used in the acquisition and processing of the images. The analysis can be run either using the GUI or via command line interface (CLI) with a single action that triggers a processing chain. The toolbox performs necessary tasks to acquire images from image repositories of the camera networks, process them and generate HTML reports with interactive plots along for visualization of the output data.

The design allows using the toolbox with a job scheduler to run analysis for creating operational monitoring systems. The software was developed under the EU Life+ MONIMET project which was an ambitious project spearheaded by scientists in Finland to increase turnover of climate data by implementing a network of webcams in Finland’s boreal forest and wetland environments (MONIMET). The main activity of the MONIMET was implementing a new innovative approach to in situ monitoring and mapping of climate change indicators that have an influence on the mitigation potential and vulnerability estimates of boreal forests and peatlands. The approach was based on a combination of different information sources describing phenology, CO_2 and CH_4 exchange, land cover, snow evolution and albedo. The information sources include in situ observations and Earth Observation (EO) (satellite) data, as well as ancillary data supporting vulnerability assessments. Dedicated high resolution regional models were applied to describe climate and land surface fluxes of carbon and water by different ecosystems. The software later was improved under ESA QA4EO-IDEAS project. The FMIPROT has following functions:

- Image acquisition from multiple camera networks
- Storing scenario conditions as files
- Generating reports for scenario options and analyses results
- Multiple scenarios
- Multiple analyses in each scenario
- Mask/ROI creation by selection with GUI
- Filtering images according to different means of thresholds
- Downloading and handling images
- Quantitative image archive check
- Expandable algorithms by plugin system
- Customizable Plotting/Mapping of results
- Configuring settings and running analysis from command line interface
- Windows and Linux support.

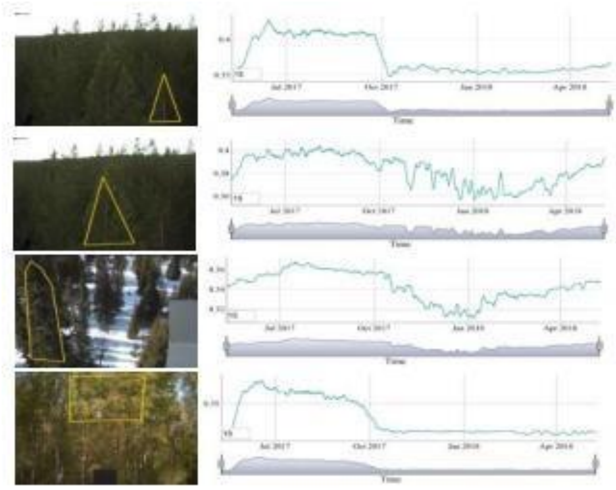


(a)



(b)

(c)



(d)

Figure 2. The system concept of the FMIPROT: (a) functions of the FMIPROT, (b) system of the FMIPROT, (c) user interface of the FMIPROT and (d) an example of postprocessing of the FMIPROT.

The FMIPROT has following processing algorithms:

1-Color Fraction Extraction: Calculates red fraction index, green fraction index, blue fraction index, brightness, luminance, red channel mean, red channel median, red channel standard deviation, green channel mean, green channel median, green channel standard deviation, blue channel mean, blue channel median, and blue channel standard deviation. **2**-Vegetation Indices: Calculates red fraction index, green fraction index, green-red vegetation index, green excess index.

3-Custom Color Index: Calculates an index from a mathematical formula entered by the user using average values of red, green and blue channels in ROIs. The formula supports sums, differences, multiplication, and division and operation priority by using parentheses.

4-Snow cover fraction: Calculates the fraction of snow-covered pixels using georectification of the image and classification of pixels into snow and no-snow. Also provides the fraction without the georectification.

5-Snow depth: Calculates snow depth from the objects in the field (e.g. snow sticks) by finding the intersection with the snow surface.

6-Timelapse animation: Creates a time-lapse video file out of available images from the cameras.

7-Georectification: Creates orthoimages and weight masks by orthorectifying camera images. (Not applicable for too many images, only for testing purposes.)

The FMIPROT has already been used in many studies(Linkosalmi, 2016; Arslan, 2017; Bongio, 2021; Heiskanen, 2021; Linkosalmi, 2022; Gerin, 2023; Tanis, 2023)

2.2 Camera Network Portal

The camera network portal aims to list existing camera networks and provide information and links on how to reach the data. All data belongs to their rightful owners as indicated in their webpages and/or publications.

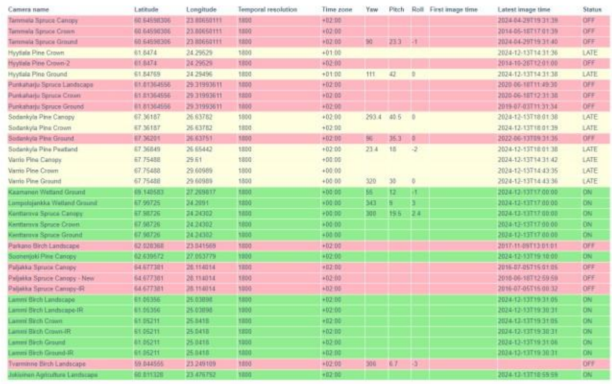
If the communication protocols of the webcams are supported by the FMIPROT, their CNIFs (camera network information file) are provided so the data can be used in FMIPROT. CNIFs also provide available metadata collected from publications and webpages to be used in this website for visualization purposes (e.g. marking on maps) and for camera specification and geolocation dependent processing (e.g. georectification).

We also created our camera network, MONIMET, is a network of digital surveillance cameras for automated monitoring of phenological activity of vegetation and snow cover in the boreal ecosystems of Finland. Cameras were mounted at 14 sites, each site having 1-3 cameras (Peltoniemi, 2018).

Image datasets can be found under the Zenodo community 'Phenological time lapse images and data from MONIMET EU Life+ project (LIFE12 ENV/FI/000409).' Datasets in Zenodo are updated every year. For access to the data by the FMIPROT over direct FTP (only for operational monitoring), the MONIMET project team can be contacted with the information implying your purpose and duration of your study.

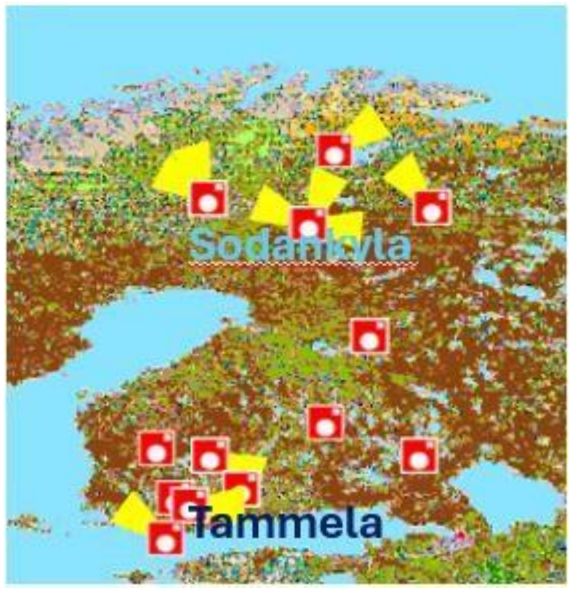
MONIMET imagery data downloaded from Zenodo repositories can be processed using the FMIPROT. Also, another camera network can be added and process in the FMIPROT. A tutorial for that is available in the FMIPROT webpage. It only takes a few minutes to add the cameras to FMIPROT and start processing. There are 34 cameras are listed in the MONIMET camera network (some cameras may not be present or active) in Figure 3.

The analysis is presented from two sites, Tammela and Sodankyla which are highlighted in the Figure 3(b).

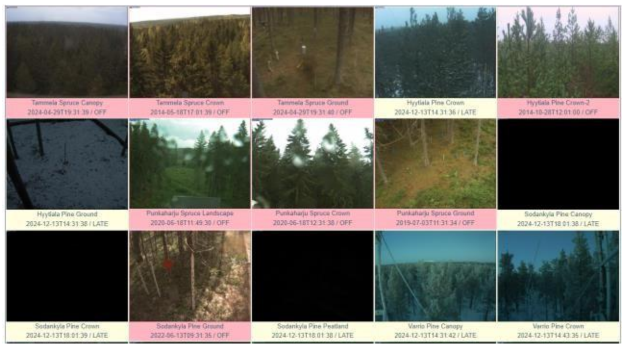


Camera name	Latitude	Longitude	Temporal resolution	Time zone	Yaw	Pitch	Roll	First image time	Latest image time	Status
Tammela Spruce Canopy	60.64598306	23.80650111	1800	+02:00					2024-04-29T19:31:39	OFF
Tammela Spruce Crown	60.64598306	23.80650111	1800	+02:00					2014-05-18T17:01:39	OFF
Tammela Spruce Ground	60.64598306	23.80650111	1800	+02:00	90	23.3	-1		2024-04-29T19:31:40	OFF
Hyytiala Pine Crown	61.8474	24.29529	1800	+01:00					2024-12-13T14:31:36	LATE
Hyytiala Pine Crown-2	61.8474	24.29529	1800	+02:00					2014-10-28T12:01:00	OFF
Hyytiala Pine Ground	61.84769	24.29496	1800	+01:00	111	42	0		2024-12-13T14:31:38	LATE
Punkaharju Spruce Landscape	61.81364556	29.31993611	1800	+02:00					2020-06-18T11:49:30	OFF
Punkaharju Spruce Crown	61.81364556	29.31993611	1800	+02:00					2020-06-18T12:31:38	OFF
Punkaharju Spruce Ground	61.81364556	29.31993611	1800	+02:00					2019-07-03T11:31:34	OFF
Sodankyla Pine Canopy	67.36187	26.63782	1800	+02:00	293.4	40.5	0		2024-12-13T18:01:38	LATE
Sodankyla Pine Crown	67.36187	26.63782	1800	+02:00					2024-12-13T18:01:39	LATE
Sodankyla Pine Ground	67.36201	26.63751	1800	+02:00	96	35.3	0		2022-06-13T09:31:35	OFF
Sodankyla Pine Peatland	67.36849	26.65442	1800	+02:00	23.4	18	-2		2024-12-13T18:01:38	LATE
Varrio Pine Canopy	67.75488	29.61	1800	+00:00					2024-12-13T14:31:42	LATE
Varrio Pine Crown	67.75488	29.60989	1800	+00:00					2024-12-13T14:43:35	LATE
Varrio Pine Ground	67.75488	29.60989	1800	+00:00	320	30	0		2024-12-13T14:43:36	LATE
Kaamanen Wetland Ground	69.140583	27.269817	1800	+00:00	55	12	-1		2024-12-13T17:00:00	ON
Lompolojankka Wetland Ground	67.99725	24.2091	1800	+00:00	343	9	3		2024-12-13T17:00:00	ON
Kenttarova Spruce Canopy	67.98726	24.24302	1800	+00:00	300	19.5	2.4		2024-12-13T17:00:00	ON
Kenttarova Spruce Crown	67.98726	24.24302	1800	+00:00					2024-12-13T17:00:00	ON
Kenttarova Spruce Ground	67.98726	24.24302	1800	+00:00					2024-12-13T17:00:00	ON
Parkano Birch Landscape	62.028368	23.041569	1800	+02:00					2017-11-09T13:01:01	OFF
Soonenjoki Pine Canopy	62.639572	27.053779	1800	+02:00					2024-12-13T19:10:00	ON
Paljakka Spruce Canopy	64.677381	28.114014	1800	+02:00					2016-07-05T15:01:05	OFF
Paljakka Spruce Canopy - New	64.677381	28.114014	1800	+02:00					2018-06-18T12:59:59	OFF
Paljakka Spruce Canopy-IR	64.677381	28.114014	1800	+02:00					2016-07-05T15:00:32	OFF
Lammi Birch Landscape	61.05356	25.03898	1800	+02:00					2024-12-13T19:31:05	ON
Lammi Birch Landscape-IR	61.05356	25.03898	1800	+02:00					2024-12-13T19:30:31	ON
Lammi Birch Crown	61.05211	25.0418	1800	+02:00					2024-12-13T19:31:05	ON
Lammi Birch Crown-IR	61.05211	25.0418	1800	+02:00					2024-12-13T19:30:31	ON
Lammi Birch Ground	61.05211	25.0418	1800	+02:00					2024-12-13T19:31:06	ON
Lammi Birch Ground-IR	61.05211	25.0418	1800	+02:00					2024-12-13T19:30:31	ON
Tvarminne Birch Landscape	59.844555	23.249109	1800	+02:00	300	6.7	-3			OFF
Jokioinen Agriculture Landscape	60.811328	23.476752	1800	+02:00					2024-12-13T18:55:59	ON

(a)



(b)



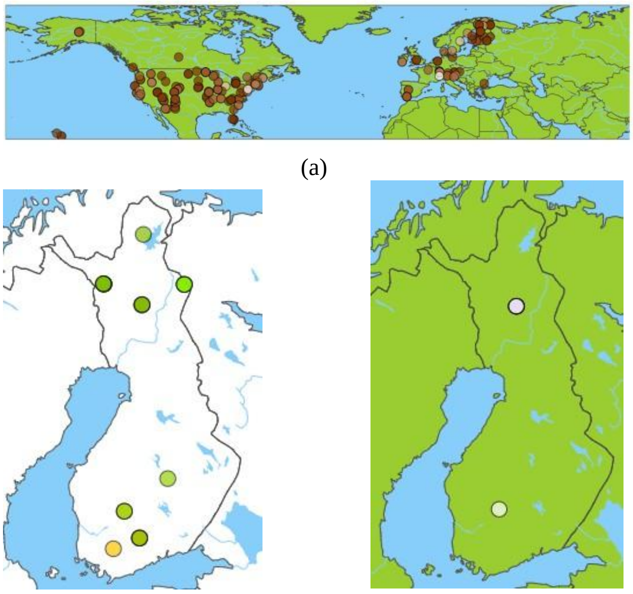
(c)

Figure 3. The MONIMET camera network: (a) list of the cameras, (b) locations of the cameras in Finland, (c) the camera images.

2.3 Operational Monitoring

Multiple sets of setups are running in FMIPROT server regularly producing near real time results for operational monitoring of snow cover and vegetation.

Visualized results, the setup reports (processing options) and output data can be accessed in the platform. The output data are available for snow cover, snow depth and vegetation indices, using input data from 444 cameras in 6 camera networks (MONIMET, University of Eastern Finland, The PhenoCam Network, Finnish airport cameras, Finnish automatic weather station (AWS) cameras and LUMIKE (SPICE) Cameras in Finland (Figure 4).



(a)

(b) (c)

Figure 4. Locations of cameras used in operational monitoring: (a) snow cover fraction, (b) vegetation indices and (c) snow depth.

2.4 Cal / Val Activities

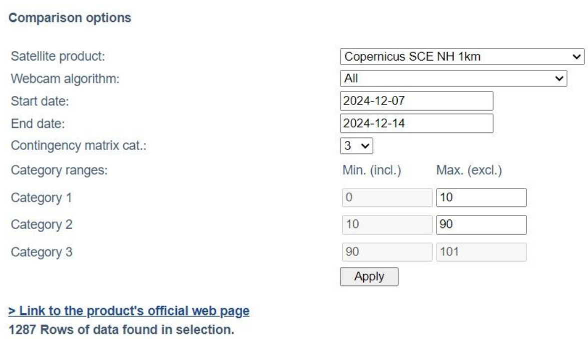
Multiple sets of comparisons are running in the server regularly, producing near real time results for comparison of satellite products with webcam derived and in-situ data. Current CAL /VAL activities are shown in Figure 5.

In the comparison of satellite derived products with webcam derived database comparisons, fractional snow cover (FSC) / snow cover extent (SCE) and binary snow cover values from satellite derived snow products are compared with FSC values derived from webcam images, which are available in the operational monitoring processing chains. Webcam derived data is fetched from the FMIPROT Download data API. "Snow cover fraction" parameter is calculated are included in the comparison. If the satellite product already provides binary snow cover information, class values are converted to 0 and 100 before the categorization, i.e. there are always only two categories for those products. If the webcam derived data contains ROI Geolocation information, ROI is used for the selection of satellite product pixels. If ROI is not provided, camera location is used. For the "Point" type ROIs and camera locations, single pixel which corresponds to that point is used for each webcam derived data point. For the "Polygon" type ROIs, all the pixels whom their cell area intersects with the ROI are used, for each webcam derived data point. After collecting all data pairs, their median value for each day and camera location (all the points in ROI together) are calculated. Invalid values (nan, cloud, dark etc.) are discarded. "N points" in the plots corresponds to the number of data pairs for those each location for each day. "N days" in maps correspond to the number of days which has valid data for each location. RMSE Maps show RMSE values calculated from all the (daily median) data pairs for each location. RMSE from 0 to 100 is coloured from green to red. Scatter Plots show daily value (median) pairs for each location. Different locations are coloured differently. Maps and plots will only be visible if there is any valid data in comparison. For example, there may be no valid data in winter days due to the camera data corresponds to the low sun zenith angle (polar night) pixels. An example is provided in the Figure 6. Cal/Val includes some satellite products of Copernicus Land Monitoring Service (CLMS) snow products and EUMETSAT H SAF snow products.

Group	Name
Satellite vs Webcam	Copernicus High Resolution Snow Cover Pan European 20m Resolution
Satellite vs Webcam	Copernicus High Resolution Snow Cover Pan European Gap-Filled 60m Resolution
Satellite vs Webcam	Copernicus Snow Cover Extent Northern Hemisphere 1km Resolution
Satellite vs Webcam	Copernicus Snow Cover Pan European 500m Resolution
Satellite vs Webcam	EUMETSAT HSAF H12 Effective snow cover by VIS/IR radiometry Pan-Europe
Satellite vs Webcam	EUMETSAT HSAF H34 Snow detection (snow mask) by VIS/IR radiometry covering full MSG Disk
Satellite vs Webcam	EUMETSAT HSAF H35 Effective snow cover by VIS/IR radiometry Northern Hemisphere
Satellite vs Webcam	EUMETSAT HSAF H43 (Unoperational) Snow extent (snow mask) by VIS/NIR of MTG FCI
Satellite vs Insitu	Copernicus High Resolution Snow Cover Pan European 20m Resolution
Satellite vs Insitu	Copernicus High Resolution Snow Cover Pan European Gap-Filled 60m Resolution
Satellite vs Insitu	Copernicus Snow Cover Extent Northern Hemisphere 1km Resolution
Satellite vs Insitu	Copernicus Snow Cover Pan European 500m Resolution
Satellite vs Insitu	EUMETSAT HSAF H12 Effective snow cover by VIS/IR radiometry Pan-Europe
Satellite vs Insitu	EUMETSAT HSAF H34 Snow detection (snow mask) by VIS/IR radiometry covering full MSG Disk
Satellite vs Insitu	EUMETSAT HSAF H35 Effective snow cover by VIS/IR radiometry Northern Hemisphere
Satellite vs Insitu	EUMETSAT HSAF H43 (Unoperational) Snow extent (snow mask) by VIS/NIR of MTG FCI
Last run is on time	Running now

Next run is late or missing

Figure 5. CAL /VAL activities.

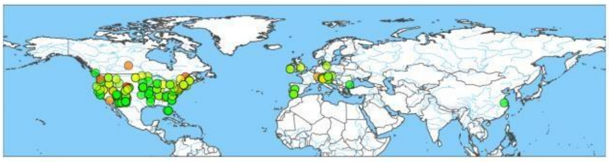


(a)

RMSE	#Points
32.12	1287

/////Webcam ///// Satellite/////	Category 1	Category 2	Category 3	Total	Commission errors
Category 1	837	193	22	1052	0.20
Category 2	36	47	16	99	0.53
Category 3	32	63	41	136	0.70
Total	905	303	79	1287	0.28
Accuracy	**0.92**	**0.16**	**0.52**	**0.72**	

(b)



(c)

Figure 6. FMI ARK SAT QA Portal: (a) comparison options, (b) RMSE and number of points in comparison and (c) RMSE map.

In the comparison of satellite derived products with in-situ snow depth data, FSC (SCE) and binary snow cover values from satellite products are compared with snow depth (SD) values from in-situ measurements, which are available through FMI open data. After collecting all data pairs, binary snow cover information (snow covered or snow free) is determined from FSC values by using FSC and SD thresholds. If the product already provides binary snow cover information, class values are converted to 0 and 100 before the thresholding. These thresholds can be changed from the "Comparison options" menu. Invalid values (nan, cloud, dark etc.) are discarded. 'N days' in maps corresponds to the number of days which has valid data for each location. Accuracy Maps show accuracy values calculated using data pairs for each location in contingency tables. Accuracy from 0% to 100% is coloured from red to green. False Alarm Rate Maps show false alarm rate values calculated using data pairs for each location in contingency tables. False alarm rates (FAR) from 0% to 100% is coloured green to red. If FAR cannot be calculated, the data location is shown in white colour. Maps and plots will only be visible if there is any valid data in comparison. For example, there may be no valid data in winter days due to the camera data corresponds to the low sun zenith angle (polar night) pixels.

An example is provided in the Figure 7. Cal/Val includes some satellite products of Copernicus Land Monitoring Service (CLMS) snow products and EUMETSAT H SAF snow products.

Comparison options

Satellite product:	Copernicus HRSI Pan-EU 20m
Satellite prod. threshold (%):	50
Insitu data threshold (cm):	2
Start date:	2024-12-07
End date:	2024-12-14
Min. points per location:	2 ☑ Auto

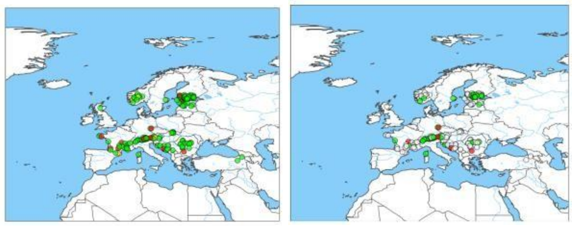
Apply

> Link to the product's official web page
171 Rows of data found in selection.

(a)

Hit	Miss	Fal. Alarm	Corr. Neg.	#Points	ACC	FAR	POD	POFD
99	14	5	53	171	0.89	0.05	0.88	0.09

(b)



(c) (d)

Figure 7. FMI ARK SAT QA Portal: (a) comparison options, (b) accuracy and number of points in comparison (c) accuracy map and (d) false alarm rate map.

2.5 Analysis

Here we present some analysis from the webcams located in two operational monitoring sites. We selected one site from south, Tammela and the other site from north, Sodankylä to see climate proxies if any. Figure 8 shows 10 years of FSC analysis from two sites between 2014 and 2024. Here 2014 means August 2014 – August 2015 and 2015 means August 2015- August 2016 etc. Unfortunately, we did not have data for August 2022-August 2023 and August 2023-August 2024 for Sodankylä site. The presented data in Figure 8 are not validated. They are estimated values from the images directly. There is no post-processing, filtering or smoothing, i.e. the plots include values from each image. We can see clearly seasons-start / -end trends and variations in 10 years.

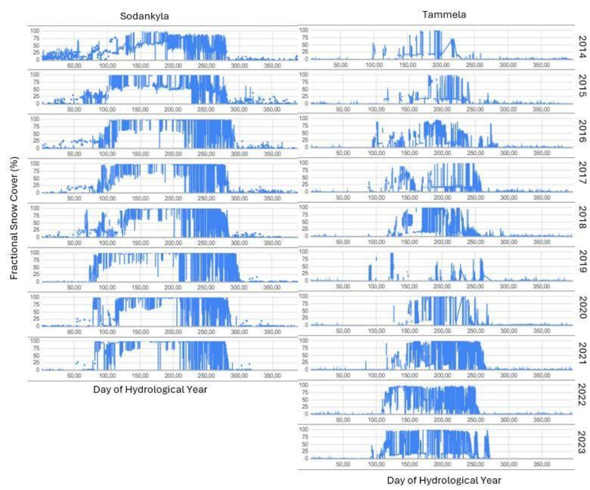


Figure 8. Fractional Snow Cover (%) unvalidated estimations in Tammela and Sodankyla operational monitoring sites during 2014 -2024.

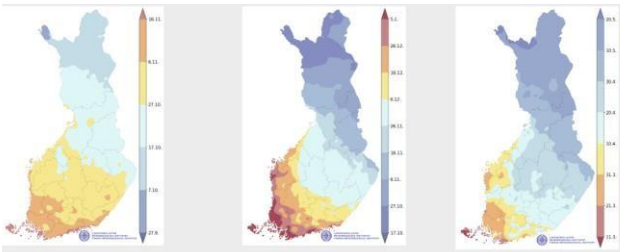
In Table 1 we estimated unvalidated approximate dates for start and end snow seasons for two operational monitoring sites. We consider start snow season about 20 % and more FSC calculated and end snow season about less than 20 % FSC calculated. These dates are rough estimations and surely should be validated with visual inspections of the images or in-situ snow data.

YEARS	SODANKYLA		TAMMELA	
	Start of Snow Season	End of Snow Season	Start of Snow Season	End of Snow Season
2014–2015	03.08.2014	07.05.2015	06.11.2014	11.03.2015
2015–2016	21.08.2015	08.05.2016	20.11.2015	08.03.2016

2016–2017	29.08.2016	23.05.2017	27.11.2016	01.05.2017
2017–2018	08.09.2017	10.05.2018	21.11.2017	15.04.2018
2018–2019	20.09.2018	10.05.2019	26.11.2018	06.04.2019
2019–2020	12.10.2019	26.05.2020	30.11.2019	18.04.2020
2020–2021	05.10.2020	13.05.2021	22.12.2020	20.04.2021
2021–2022	04.10.2021	10.05.2022	23.11.2021	21.04.2022
2022–2023			16.11.2022	11.042023
2023–2024			14.11.2023	27.04.2024

Table 1. Estimated snow season start and end dates for Sodankyla and Tammela.

In Figure 9, map on the left shows the typical timing of the first intact snow cover for the reference period 1991-2020, while the map in the middle and on the right shows the typical timing of the onset and end of permanent snow cover for the reference period 1991-2020 (Finnish Meteorological Institute (FMI)).



(a) (b) (c)

Figure 9. Snow statistics on timing in Finland during 19912020 for: (a) first snow cover (b) onset snow cover (c) end of snow cover.

Estimated dates using camera images provided in Table 1 are quite comparable with the dates given in Figure 9.

According to statistics from the Finnish Meteorological Institute, 2014 was the second warmest year in Finland's measurement history, after 1938. 2018 was 1-2 degrees warmer than normal. Based on more than 100 years of statistics, such a warm year occurs on average once every 10-15 years. Winter, or December-February, was 1-3 degrees milder than normal in most parts of the country. In 2019, winter precipitation was slightly above normal in the south and north. Snowfall was also slightly above average. According to preliminary statistics from the Finnish Meteorological Institute, the average temperature in Finland in 2020 was a record high of around 4.8 degrees Celsius.

High-level findings from the analysis by just looking at the Figure 8 and the Table 1 are in line with the statistics. In 2020, snow arrived quite late in Tammela, 22.12.2020. We can also see less snow cover in Tammela 2019 (August 2018 -August 2019) in Figure 8. We notice higher winter precipitation in 2019 looking at the Tammela 2018 (August 2018-August 2019) as we see high percentage long period of snow cover in Figure 8. Tammela 2014 in the Figure 8 also reflects warm year as there are not much snow cover. We will continue our analysis with adding other operational monitoring sites and vegetation indices estimated from the images.

3. Challenges and Expected Progresses

Challenges can be categorized as (1) lack of harmonisation in data management (data collection, data storage, data access), (2) lack of harmonised protocols and guidelines (ground truth, image acquisition and geometry, image processing and guidelines in sensor (like camera, drone) set up, sensor design and implementation, repositories, quality check procedures, and application of RGB-based methodologies, algorithms, and tools), (3) limited awareness and understanding of RGB-based automated methodologies, algorithms, tools, and their application.

By proposing RGB_DIGI platform, our expected progress is as follows:

1. Established interoperability at the data level from different sources like time-lapse cameras, drones, citizen science observations and spaced-based observations.
2. Improved trusted RGB imagery data repositories in FAIR (Findable, Accessible, Interoperable and Reusable) data principles for improving environment monitoring.
3. An open access catalogue of RGB-based algorithms for environmental parameters.
4. Developed systems and interfaces for crowdsourced digital imagery.
5. Automated workflow and tools on digital imagery process from different sources.
6. Enhanced use of digital imagery and its derived products in a wide range of applications such as phenology, natural hazard, cryosphere, marine, biosphere and atmosphere etc.

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References

Alberton, B., Torres, R.D.S., Cancian, L.F., Borges, B.D., Almeida, J., Mariano, G.C., dos Santos, J., Morellato, L.P.C., 2017. Introducing digital cameras to monitor plant phenology in the tropics: applications for conservation. *Perspectives in Ecology and Conservation*, 15. doi.org/10.1016/j.pecon.2017.06.004.

Arslan, A.N., Tanis, C.M., Metsämäki, S., Aurela, M., Böttcher, K., Linkosalmi, M., Peltoniemi, M., 2017. Automated webcam monitoring of fractional snow cover in northern boreal conditions. *Geosciences*, 7(3), 55. doi.org/10.3390/geosciences7030055.

Bernard, É., Friedt, J.M., Tolle, F., Griselin, M., Martin, G., Laffly, D., Marlin, C., 2013. Monitoring seasonal snow dynamics using ground based high resolution photography (Austre Lovénbreen, Svalbard, 79 N). *ISPRS Journal of Photogrammetry and Remote Sensing*, 75. doi.org/10.1016/j.isprsjprs.2012.11.001.

Bongio, M., Arslan, A.N., Tanis, C.M., and De Michele, C., 2012. Snow depth time series retrieval by time-lapse photography: Finnish and Italian case studies. *The Cryosphere*, 15, 369–387. doi.org/10.5194/tc-15-369-2021.

Davidson, C., Jaganathan, V., Sivakumar, A.N., Czarnecki, J.M.P., Chowdhary, G., 2022. NDVI/NDRE prediction from standard RGB aerial imagery using deep learning. *Computers and Electronics in Agriculture*, 203. doi.org/10.1016/j.compag.2022.107396.

Finnish Meteorological Institute (FMI), https://www.ilmatieteenlaitos.fi/lumitilastot (accessed on 22.12.2024).

FMIPROT, https://fmiprot.fmi.fi/ (accessed on 13.12.2024).

Garvelmann, J., Pohl, S., Weiler, M. 2013. From observation to the quantification of snow processes with a timelapse camera network. *Hydrol. Earth Syst. Sci.*, 17. doi.org/10.5194/hess-17-1415-2013.

Graham, E.A., Yuen, E.M., Robertson, G.F., Kaiser, W.J., Hamilton, M.P., Rundel, P.W., 2009. Budburst and leaf area expansion measured with a novel mobile camera system and simple color thresholding. *Environmental and Experimental Botany*, 65(2-3), 238-244. doi.org/10.1016/j.envexpbot.2008.09.013.

Gerin, S., Vekuri, H., Liimatainen, M., Tuovinen, J.P., Kekkonen, J., Kulmala, L., Laurila, T., Linkosalmi, M., Liski, J., Joki-Tokola, E., Lohila, A., 2023. Two contrasting years of continuous N2O and CO2 fluxes on a shallow-peated drained agricultural boreal peatland. *Agricultural and Forest Meteorology*, 341, 109630, doi.org/10.1016/j.agrformet.2023.109630.

Heiskanen, L., Tuovinen, J.P., Räsänen, A., Virtanen, T., Juutinen, S., Lohila, A., Penttilä, T., Linkosalmi, M., Mikola, J., Laurila, T., Aurela, M., 2021. Carbon dioxide and methane exchange of a patterned subarctic fen during two contrasting growing seasons. *Biogeosciences*, 18(3), 873-896. doi.org/10.5194/bg-18-873-2021.

Katal, N. Michael, R., Patrick, M., Jana W., 2022. Deep Learning in Plant Phenological Research: A Systematic Literature Review. *Front. Plant Sci.*, 13. doi.org/10.3389/fpls.2022.805738.

Kreutz, M., Alla, A.A., Eisenstadt, A., Freitag, M. and Thoben, K.D., 2020. Ice detection on rotor blades of wind turbines using RGB images and convolutional neural networks. *Procedia CIRP*, 93. doi.org/10.1016/j.procir.2020.04.107.

Linkosalmi, M., Aurela, M., Tuovinen, J.-P., Peltoniemi, M., Tanis, C.M., Arslan, A.N., Kolari, P., Böttcher, K., Aalto, T., Rainne, J., Hatakka, J., Laurila, T., 2016. Digital photography for assessing the link between vegetation phenology and CO2 exchange in two contrasting northern ecosystems. *Geosci. Instrum. Method. Data Syst.*, 5, 417–426. doi.org/10.5194/gi-5-417-2016.

Linkosalmi, M., Tuovinen, J.-P., Nevalainen, O., Peltoniemi, M., Taniş, C.M., Arslan, A.N., Rainne, J., Lohila, A., Laurila, T., Aurela, M., 2022. Tracking vegetation phenology of pristine northern boreal peatlands by combining digital photography with CO2 flux and remote sensing data. *Biogeosciences*, 19, 4747–4765. doi.org/10.5194/bg-194747-2022.

MONIMET, https://monimet.fmi.fi/ (accessed on 13.12.2024).

Noh, H., Kwon, S., Park, Y.S., Woo, S.B., 2024. Application of RGB UAV imagery to sea surface suspended sediment concentration monitoring in coastal construction site. *Applied Ocean Research*, 145, 7. doi.org/10.1016/j.apor.2024.103940.

Peltoniemi, M., Aurela, M., Böttcher, K., Kolari, P., Loehr, J., Karhu, J., Linkosalmi, M., Tanis, C.M., Tuovinen, J.-P., Arslan, A.N., 2018. Webcam network and image database for studies of phenological changes of vegetation and snow cover in Finland, image time series from 2014 to 2016. *Earth Syst. Sci. Data*, 10, 173–184. doi.org/10.5194/essd-10-173-2018.

Piazzi, G., Tanis, C.M., Kuter, S., Simsek, B., Puca, S., Toniazzo, A., Takala, M., Akyürek, Z., Gabellani, S., Arslan, A.N., 2019. Cross-country assessment of H-SAF snow products by Sentinel-2 imagery validated against in-situ observations and webcam photography. *Geosciences*, 9(3), 129. doi.org/10.3390/geosciences9030129.

Parilli-Ocampo, V., Monsalve, M.O., Cerón-Muñoz, M., Galeano-Vasco, L., Medina-Sierra, M., 2024. Use of RGB Images in Field Conditions to Evaluate the Quality of Pastures in Farms in Antioquia: A Methodology. *Agricultural Sciences*. IntechOpen. doi.org/10.5772/intechopen.114198.

SentiWiki, https://sentiwiki.copernicus.eu/web/ (accessed on 13.12.2024).

Sonnentag, O., Hufkens, K., Teshera-Sterne, C., Young, A.M., Friedl, M., Braswell, B.H., Milliman, T., O’Keefe, J., Richardson, A.D., 2012. Digital repeat photography for phenological research in forest ecosystems. *Agricultural and Forest Meteorology*, 152. doi.org/10.1016/j.agrformet.2011.09.009.

Tanis, C.M., Peltoniemi, M., Linkosalmi, M., Aurela, M., Böttcher, K., Manninen, T., Arslan, A.N., 2018. A system for acquisition, processing and visualization of image time series from multiple camera networks. *Data*, 3(3), 23. doi.org/10.3390/data3030023.

Tanis, C.M., Lindgren, E., Frey, A., Latva, L., Arslan, A.N., Luojus, K., 2023. Use of Webcams in Support of Operational Snow Monitoring. *Geosciences*, 13(3), 92. doi.org/10.3390/geosciences13030092.