Tailored downstream applications/products– from Copernicus to coastal and inland water monitoring

Framework Partnership Agreement for Copernicus User Uptake

Co-funded by the European Union

Tarkka Syke

UNIVERSITY OF TARTU Tartu Observatory

Suomen ympäristökeskus
Finlands miljöcentral
Finnish Environment Institute

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Introduction

Finnish Environment Institutes (Syke) water related Earth observation activities

Finnish Environment Institute (Syke) under the Finnish Ministry of the Environment, is a governmental research institute, and a center for environmental expertise. Syke's research focuses on monitoring the changes in the environment and seeks ways to control these changes. Syke conducts research on a wide range of fields, from environmental policy, state of natural environment, climate change, marine and freshwater environments, to the cryosphere. A strong focus is on multi-disciplinary work and providing information, skills, and services to achieving sustainable development in Finland and globally. The information produced in research and operational services are provided to users, ranging from researchers in environmental administration and universities to governmental and municipal authorities as well as common citizens.

Syke's Earth observation activities on water areas are related to collecting information/observations on water quality, surface water temperature, floods, and ice-cover. The focus is on providing up-to-date information on topical phenomena, such as the extent of flooded areas during the melting period in the springtime. This is the time when seasonal snow, ice, and frost melt, typically creating floods over certain areas. In addition to flooding, incoming water from drainage basins also deliver material from land to water during the melting period in spring. For this reason, this project has focused on improving the availability of high-resolution data of turbidity over estuaries, and an index providing visual interpretation of areas under floods. In addition to these, the project improved high-resolution observations of surface water temperature and temporal aggregates of daily water surface temperatures with 100-meter and 1 km spatial resolution, respectively.

Syke's EO personnel have more than 20 years of experience in developing methods and providing satellite observations operationally over the northernmost Baltic Sea area. This includes water quality research, method development and daily monitoring, weekly algae bloom information for public and press. In EO related research and development projects, focus is on increasing our knowledge on environment by developing new methods or algorithms to better estimate water quality, detect human impact from natural changes, or follow the consequences of eutrophication or climate change. Methods that are robust enough are operationalized; calculation is automated, quality-assured, and observations are delivered via Syke's open EO-service Tarkka (tarkka.syke.fi).

Earth observation activities are mostly centralized in two units: Quality of information unit and Digital services. Quality of information coordinates and develops environmental monitoring at Syke's level, develops services and methods that support research and monitoring, promotes open science, and develops the processing pipelines of research information. For more information, please email eotuki@syke.fi.

TO water related Earth observation activities

Tartu Observatory (TO) is an Estonian space centre focused on research and development in remote sensing, space technology, cosmology and astronomy. It is an institute under the **University of Tartu**, founded in 1632, making it one of the oldest universities in Northeastern Europe.

The **TO's Department of Remote Sensing** has working groups dedicated to the remote sensing of water, vegetation and atmosphere. The focus is on the radiation measurements, *in situ* field sampling, radiative transfer modeling, calibration, validation, theoretical studies and practical applications.

TO has a long-term experience in collecting *in situ* field data which has been used for the validation of historic and operational satellite sensors. These analyses help to determine the suitability of various water quality products and to develop more suitable algorithms for regional conditions, if needed. This project aims to advance algorithms for characterizing phytoplankton bloom dynamics and enhance the EO data-based algorithms for water color, transparency and coloured dissolved organic matter.

Tarkka

Tarkka is a web application providing users with tools for visualizing satellite observations, monitoring station measurements, citizen observations, and modelled data as maps and statistical timeseries. The datasets are updated daily. Some datasets and advanced functionalities are only available for authenticated users, but datasets belonging to the Syke open data policy are openly available.

Tarkka comprises the following functional sections:

- Front page highlights current events in Finland and the Baltic Sea region
- Map viewer provides tools for browsing the time-dependent datasets both as map visualizations and as timeseries graphs
- Gallery provides tools for browsing quality assured (curated) satellite observations on pre-defined regions
- Analysis page (for advanced users), provides tools for creating free-form reports for datamining tasks

The datasets included in the Tarkka service are produced both by the continuous environmental monitoring programme and by specific projects.

Tarkka is a bilingual service (Finnish and English) and is owned and maintained by Syke.

For more information, please email eotuki@syke.fi.

Access, Delivery

- Almost all data is open-access
- Finland and Baltic Sea region

Specifications

- 17 satellites
- Resolution: 10 m – 1 km
- Frequence: daily data from year 2002

Data

- Satellites
- Monitoring stations
- Automated stations
- Transects, Alg@line
- Citizen observartions
- GIS-datasets
- Basemaps

Themes

- Water quality
- Blue-green algae
- Seasonal
- Lake ice service
- Land cover
- Project themes

Limitations

- Some parts are limited for national professional use
- Main focus on the Baltic sea area and Finland

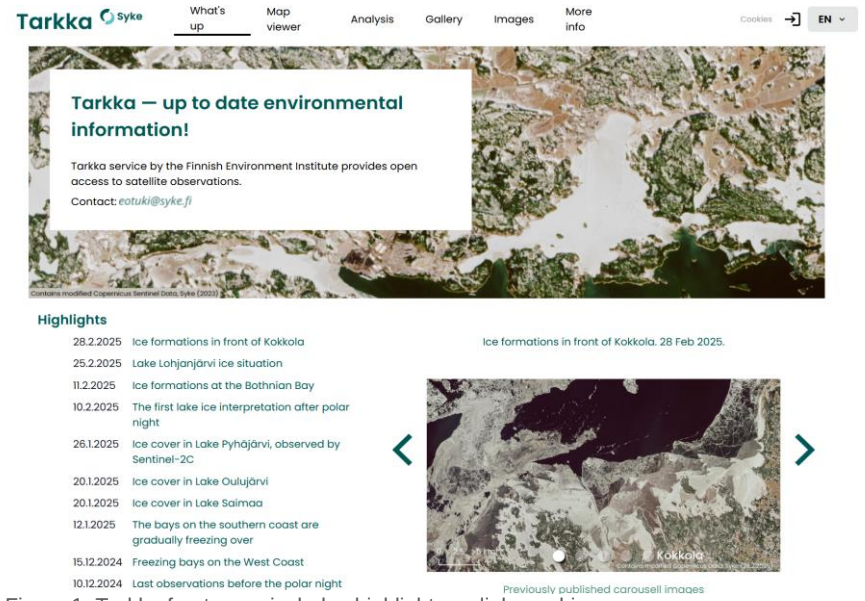

Figure 1. Tarkka front page includes highlights as links and images.

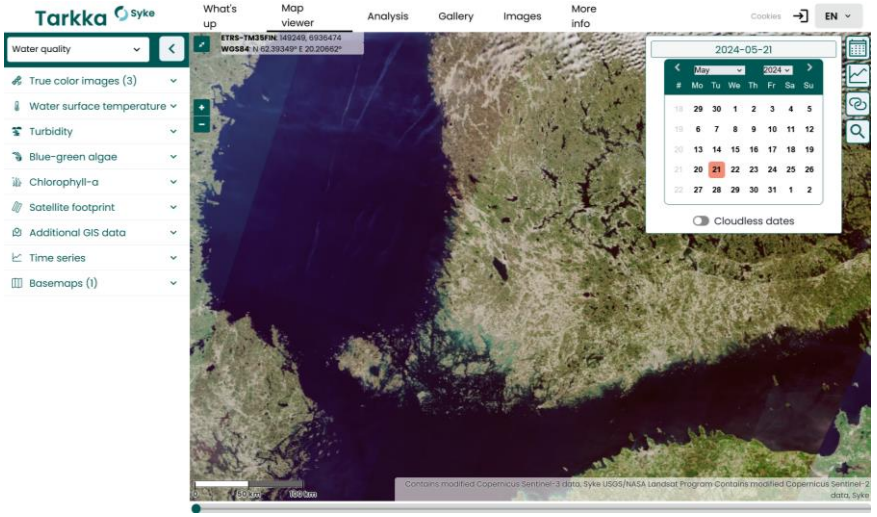

Figure 2. In Tarkka Map viewer you can browse various datasets including true color satellite data.

Links:

- Tarkka.syke.fi
- Syke's Metadata service: https://ckan.ymparisto.fi/

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National Satellite Data Centre ESTHub

ESTHub is a national satellite data centre, which allows users to search and download Copernicus programme data. ESTHub also offers a hosted data processing service to governmental institutions.

ESTHub gathers Sentinel and Landsat 8 data for the Estonian area of interest and provides a fast download service.

For Sentinel 1 and 2, but also for Landsat 8, ESTHub has data about 200 km beyond state borders (Figure 1), for Sentinel 3 the area of interest covers the Baltic Sea and its surrounding area (Figure 2).

ESTHub

Access to the Services

Satiladu

ESTHub Satellite Data Portal

ESTHub Processing Platform

Contact

For questions and concerns, please contact esthub@maaruum.ee

Figure 1. Region for Sentinel 1, 2 and Landsat 8 data retrieval.

Figure 2. Region for Sentinel 3 data retrieval.

Links:

ESTHub: esthub.maaruum.ee/eng/esthub-p26.html

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Turbidity 20m resolution

The expertise to produce high-resolution (20m) turbidity exists and can be utilized in the following projects. Data can be produced on-demand and for selected dates and regions. The interpretation is based on the MSI (Multi-spectral Instrument) of the Sentinel-2 satellite series of the EU Copernicus program starting from year 2016. Production workflow is based on the 60m resolution turbidity product the Syke provides in Tarkka service (tarkka.syke.fi).

Turbidity maps often show natural variation, such as soil brought into the coastal waters by rivers or resuspension caused by strong winds, which raises more turbid water from the bottom to the surface. Data is also useful for detection of dredging events. Example to change in turbidity in coastal waters on Finland is in Figure 1 and Figure 2.

Use cases

- River impact areas
- Dredging
- Small lakes

Access, Delivery

- Produced based on requests

Specifications

- Sentinel-2 A/B/C, MSI
- 20m
- Value range 0-60 FNU
- Every 3-5 days max

Limitations

- Not available under cloud cover
- For requested dates and small areas only

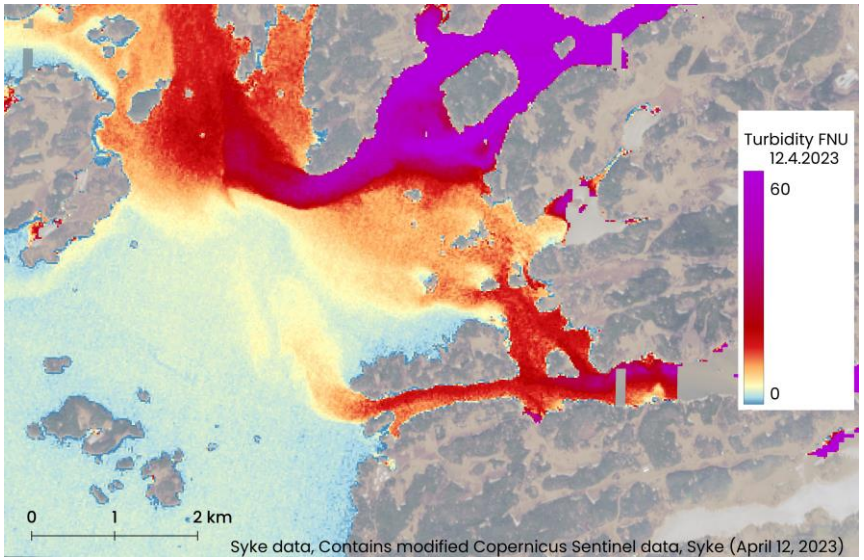

Figure 1. Turbidity in 20m resolution in Finnish coast April 12, 2023.

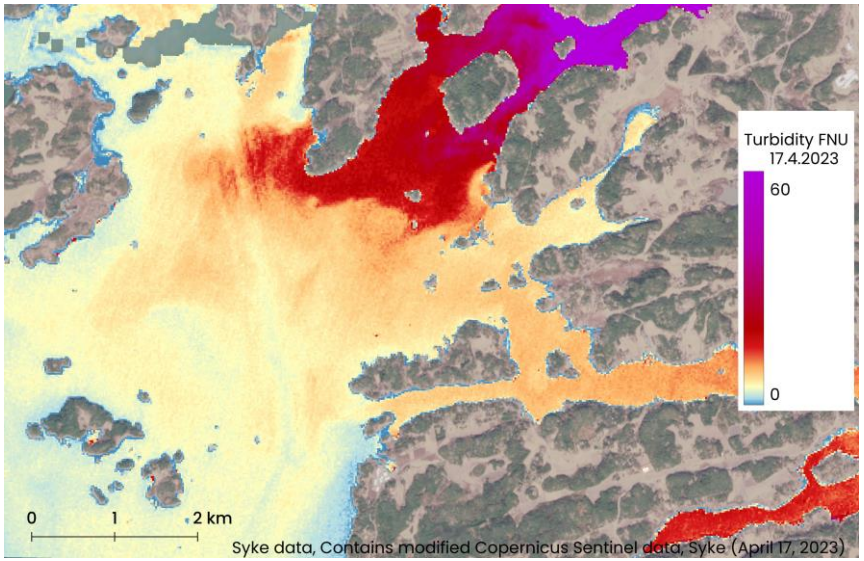

Figure 2.Turbidity in 20m resolution in Finnish coast April 17, 2023.

Links:

- **Tarkka:** Tarkka.Syke.fi
- **Syke Metadata portal**: Daily turbidity of the Baltic Sea and Finnish lakes (Sentinel-2 MSI) 2016–

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Flood area estimation for river and lake flooding with Normalized Difference Water Index, NDWI

Normalized Difference Water Index (NDWI) represents the liquid water content of land surface and water bodies. The NDWI-index is used to distinguish open water features, i.e., floods, from Earth observation data as shown in the Figure 1. In Figure 1 the spring-flood of River Tornio in Western Lapland is clearly distinguishable on the NDWI dataset. The NDWI can be used, for example, by flood experts in environmental organizations. In addition, the NDWI dataset provides a valuable supplement to the SAR imagery for flood monitoring purposes, since NDWI has higher spatial resolution. NDWI and SAR data are accessible in the Syke's Tarkka-service (tarkka.syke.fi), under the *Landcover-> Wetness* and *SAR observations* categories.

The dataset covers the full Sentinel-2 mission from 2016 onwards for the Baltic Sea basin. The NDWI-images are obtained from the Sentinel-Hub API through an automated process, resulting the data to be accessible in the Tarkka-service on daily basis depending on the Sentinel-2 overpasses and cloud coverage. The average temporal resolution of NDWI-images in Finland is approximately every 3 days. However, the NDWI is not applicable during cloudy days, which might lead to a longer period without observations.

Use cases

- Detecting water bodies
- Flood area estimation
- Drought monitoring

Access, Delivery

- Tarkka.syke.fi -> Landcover -> Wetness
- Available from the previous day

Specifications

- Sentinel-2 A/B/C, MSI
- Spatial resolution 10 m
- Value range –1 to 1:
  - >0: water surface
  - <=0: non water surface
- Computed every day with temporal resolution of ~3 days.

Limitations

- Not available under cloud cover
- Sensitive to build structures-> can lead to overestimation of water bodies
- Automatic, no manual validation

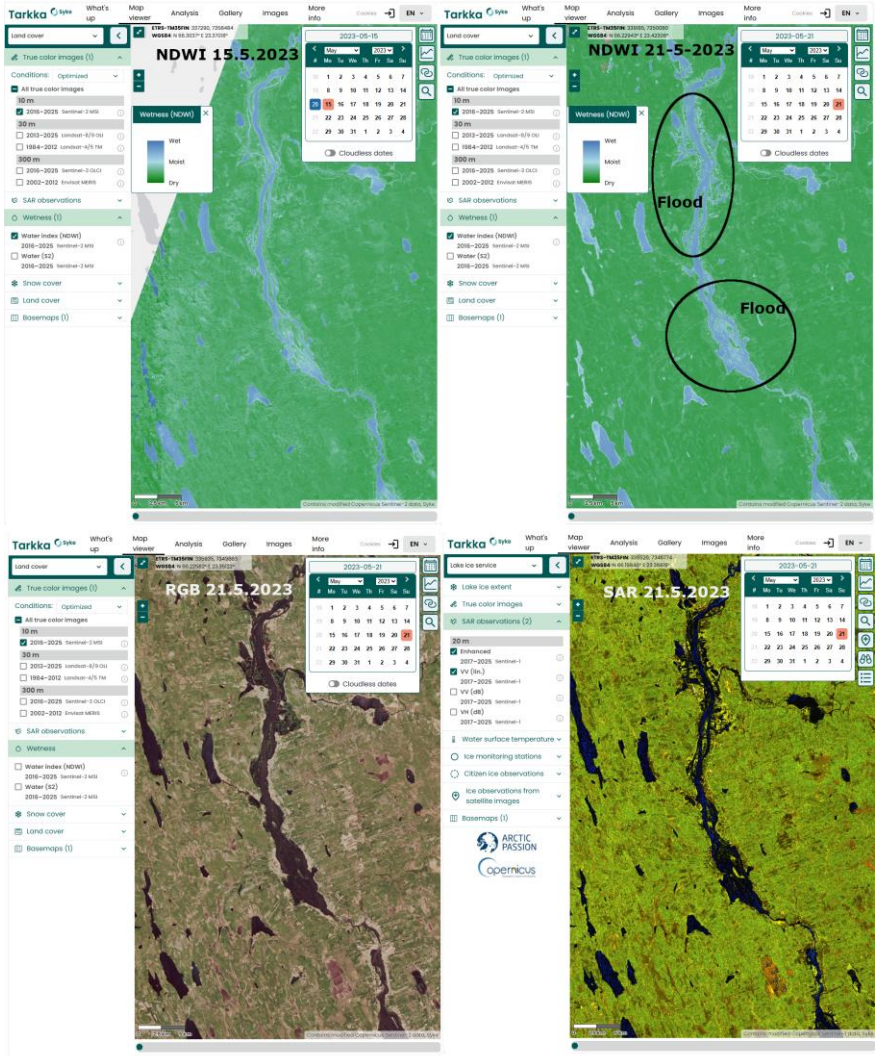

Figure 1. Spring-flooding of the River Tornio at Western Lapland during May 2023. The extended blue areas alongside the Tornio River represent expanding water bodies, i.e., flooding. The top figures present the NDWI-index before and during spring flooding, which is visible on the circled areas on the right figure. Below are true color image (left) and SAR (right) during the flooding period.

Links:

- **Tarkka:** Tarkka.syke.fi
- **Syke Metadata potal:** Daily water index NDWI for Finland (Sentinel-2) 2016– (ymparisto.fi)

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High-resolution water temperature

The high-resolution water surface temperature (WST) observations (100 m) from the Landsat-8 and Landsat-9 satellites enable monitoring of lakes and coastal waters where medium-resolution Sentinel-3 SLSTR instrument (1 km) is not applicable. Coastal water areas are typically more diverse and productive marine ecosystems compared to open seas. Similarly, coastal marine ecosystems tend to be more vulnerable to marine heatwaves and variation in water temperature, affecting the fisheries and marine habitants. Hence, accurate monitoring of WST in coastal waters is essential for researching and modelling the marine biodiversity and ecosystems in the coastal waters.

These temperatures are derived from the Thermal Infrared Sensors (TIRS) on Landsat-8 and the TIRS-2 on Landsat-9. The automatically processed data undergoes calibration, atmospheric correction, and manual quality control procedures by Syke. The satellite observations have been validated with in-situ measurements of near-surface water temperatures for selected monitoring stations and have very high accurance. The Landsat satellites observe the entire Earth every 8 days. Due to swath overlap, this corresponds to around three observations per week in Finland for each water body (depending on cloud cover).

The dataset can be accessed in Syke's Tarkka-service and as an OGC-compliant WCS and WMS-interfaces.

Use cases

- Monitoring of WST on coastal waters and lakes
- A dataset to support modelling and research on marine ecosystems
- Fishery management

Access, delivery

- Available at Tarkka.Syke.fi

Specifications

- Landsat 8/9, TIRS-instrument
- 100m
- Value range 0 –30 C°
- Frequency:
  - ~3 observations per week

Limitations

- Not available under cloud cover or during rain
- Narrow spatial coverage due to narrow swath width compared to medium resolution instruments

Links:

- **Tarkka:** Tarkka.Syke.fi
- **Syke Metadata portal**: Daily high resolution water surface temperature of Finnish coast and lakes (Landsat-8/9,100 m) (ymparisto.fi)
- Thermal Infrared Sensor (TIRS) | Landsat Science (nasa.gov)
- TIRS Requirements | Landsat Science (nasa.gov)

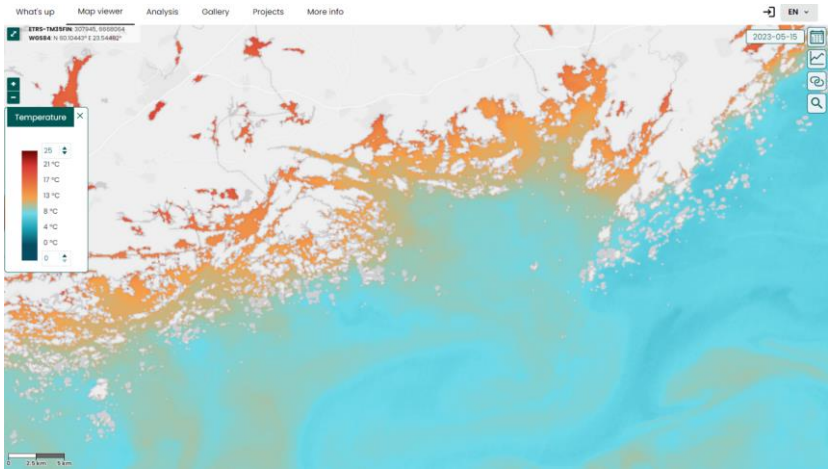

Figure 1. Temperature in Finnish coast May 15, 2023.

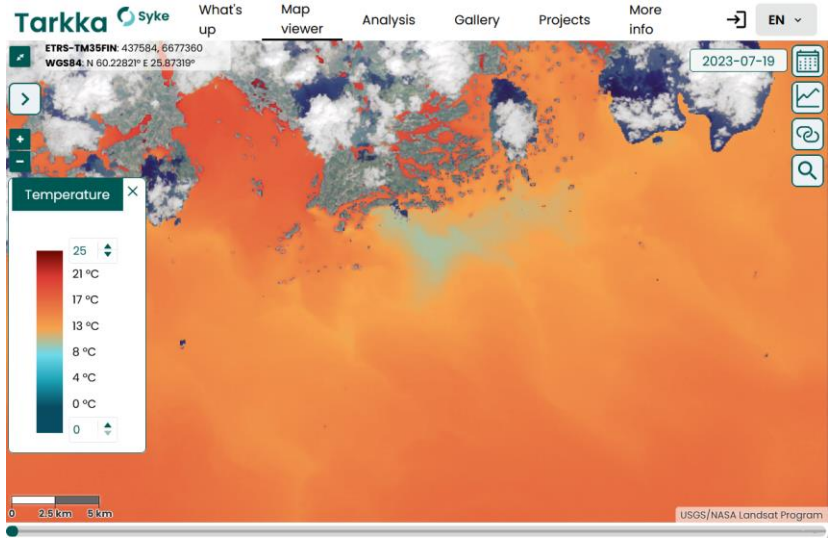

Figure 2. Temperature in Finnish coast July 7, 2023.

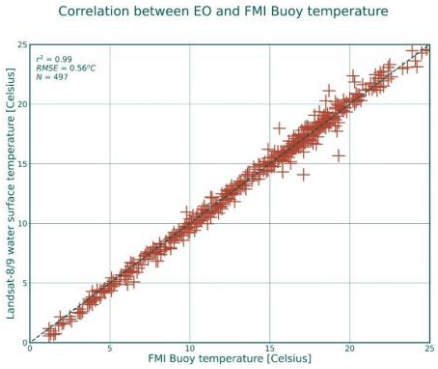

Figure 3. Correlation between EO and Finnish Meteorological Institute FMI Buoy.

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Temporal aggregates of medium-resolution water surface temperature

Satellite observations are used to monitor the water surface temperature (WST). The Finnish Environment Institute (Syke) provides seasonal (monthly, summer, and annual) aggregates from daily satellite observations. The aggregates provide a non-cloudy overview of the WST in the Baltic sea and large Finnish lakes during the chosen period of interest. Some use cases for the WST aggregates

- monitoring WST monthly, annually, or during growing season
- providing quick overview of spatial WST anomalies in the Baltic Sea, such as upwelling areas
- A supportive dataset for climate change research when the temporal coverage of the dataset extends and covers a longer time-period

The observations are obtained with Copernicus Programme's Sentinel-3 satellite series Sea and Land Surface Temperature Radiometer (SLSTR) instrument, which is a medium resolution instrument of ~1 kilometer. The SLSTR instrument measures thermal radiation during nighttime in the Baltic Sea water areas. SLSTR provides solid temporal coverage over large areas, such as the Baltic Sea.

Use cases

- Quick overview of seasonal variations of the minimum, maximum, and median water surface temperatures.
- Can be used in climate change and oceanography research

Access, Delivery

- Available at Tarkka.Syke.fi

Specifications

- Sentinel-3 A/B, SLSTR
- Resolution 1 km
- Value range 0 – 30 C°
- Frequency:
  - Daily SLSTR observations
  - Aggregates processed monthly/summer/annually

Limitations

- Data not available under cloud cover
- Medium spatial resolution is un-optimal for precise monitoring of coastal areas and smaller lakes

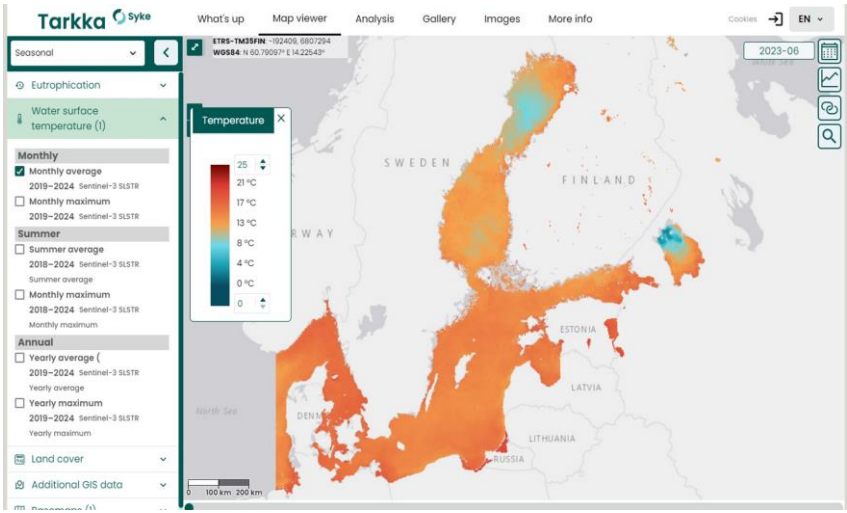

Figure1. Average monthly water surface temperature in June 2023. Syke dataset, contains modified Copernicus data, 6/2023.

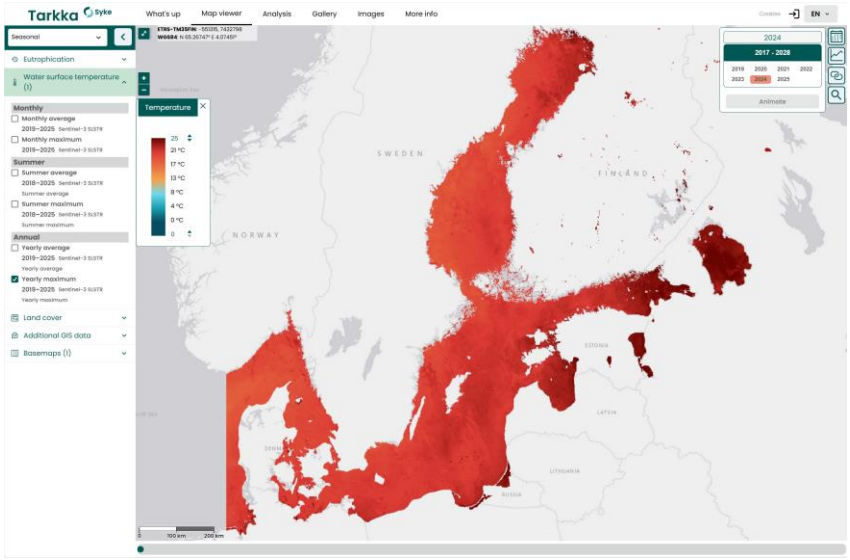

Figure 2. Yearly maximum water surface temperature in 2024. Syke dataset, contains modified Copernicus data, 2024.

Links:

- **Tarkka:** Tarkka.Syke.fi
- **Syke Metadata portal:** Aggregates of water surface temperature of the Baltic Sea and Finnish lakes (Sentinel-3 SLSTR) 2019–
- **Copernicus.eu: SLSTR Applications**

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Temporal aggregates of high-resolution water surface temperature

Satellite observations are used to monitor the water surface temperature (WST) at the Finnish lakes and coastal areas of the Baltic Sea. High-resolution WST dataset is based on observations of Landsat-8 The Thermal Infrared Sensor (TIRS) instrument and Landsat-9 TIRS-2 instrument. Both instruments are high-resolution instruments with a spatial resolution of 100 meters. The high-resolution data is useful for monitoring the small lakes and coastal areas, such as lagoons. However, the high resolution is obtained via narrow swath width which restricts the revisit time of the satellites leading to fewer observations from the same area.

The high-resolution WST aggregate datasets provide seasonal, detailed information of growth conditions for coastal and lake aquatic ecosystems (fish, vegetation etc.). The aggregate dataset can be used in modelling of the ecosystems, analyzing heatwaves and WST anomalies, and research in general. High-resolution instruments enable observations close to coast while providing robust spatial coverage in contrast to in-situ measurements and medium resolution satellite instruments. The aggregates were tested for multiple seasonal periods (weekly, bi-weekly, monthly, summer, annual). A 3-year summer-period aggregate was found to be the most suitable dataset with multiple enough observations (growing season from beginning of June to the end of September, 2022-2024).

Use cases

- Detailed quick overview of water surface temperature at lakes and coast over chosen temporal period.
- Determining the growth conditions of aquatic vegetation on the lakes and coastal waters.

Access, delivery

- Aggregates not available for public

Specifications

- Landsat 8/9, TIRS-instrument
- 100m
- Value range 0 –30 C°
- Frequency:
  - ~3 observations per week
  - Processed into 3-year summertime aggregate

Limitations

- Data not available under cloud cover
- Narrow swath width reduces the coverage of observations from the same area, which are needed for functional aggregate.

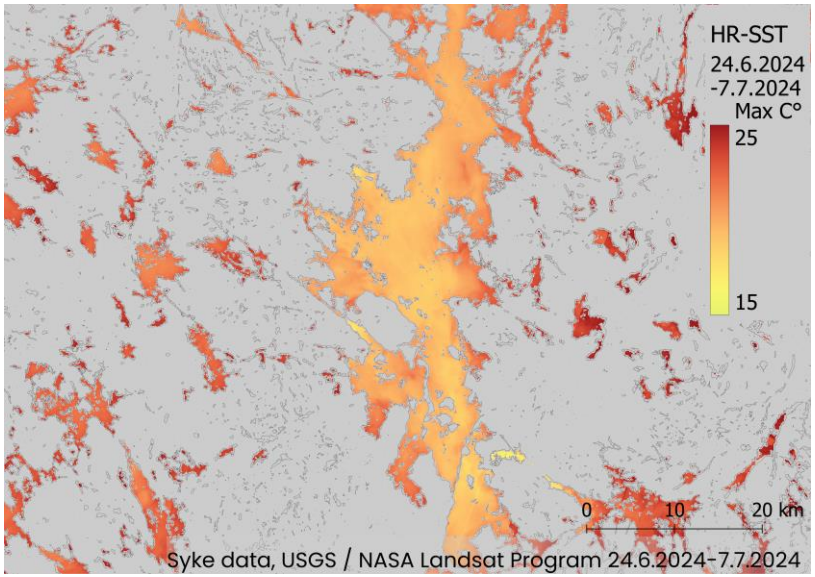

Figure 1. High resolution water surface temperature (max C°) 2-week aggregate, Southern Finland. Tarkka.syke.fi

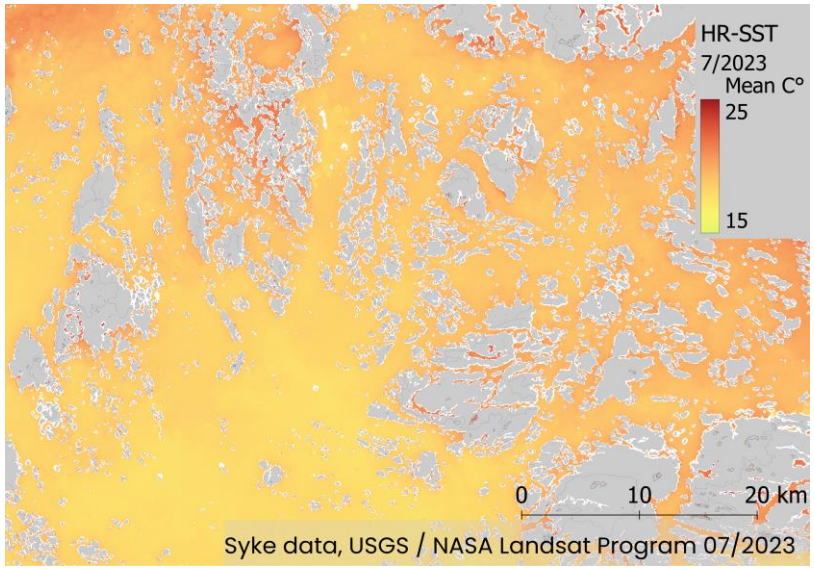

Figure 2. High resolution water surface temperature (mean C°) monthly aggregate, Archipelago Sea. Tarkka.syke.fi

Links:

- **Syke Metadata portal:** Daily high resolution water surface temperature of Finnish coast and lakes (Landsat-8/9, 100 m) (ymparisto.fi)
- Thermal Infrared Sensor (TIRS) | Landsat Science (nasa.gov)
- TIRS Requirements | Landsat Science (nasa.gov)

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Water colour product

This product is based on Sentinel 3/OLCI data.

This product allows to give a spatial estimation of water colour. Figure 1. Hue angle product over Estonia in 2023 from May to July applied on Sentinel 3 Ocean Color and Land Instrument (S3 OLCI). We can see higher Hue angle more in spring and in the beginning of the summer.

National monitoring measures the color of water once a month in Lake Peipsi in different stations over the lake. Satellite data gives spatial coverage (S3 OLCI every 1-2 days) depending on the cloud coverage. Traditional monitoring is measuring water yellowness in Pt-Co scale (mg/l) (Figure 2.), which is inversely correlated with Hue angle (degrees). Hue angle relates to optically active parameters, such as transparency (Secchi Disc Depth) and a_{CDOM}, which gives the possibility to use Hue angle for deriving other parameters.

Valid range

- Hue angle 16-230 degrees corresponds to color 10-230 mg/l Pt

Delivery methods & service options

- Sentinel 3/ OLCI data can be retrieved from ESTHub portal

Limitations

- Not available under cloud cover or during rain
- Depends on accuracy of atmospheric correction
- Higher uncertainties along the coastline
- Information only about the surface

Spatial Resolution

- 300 m

Frequency

- Potentially daily

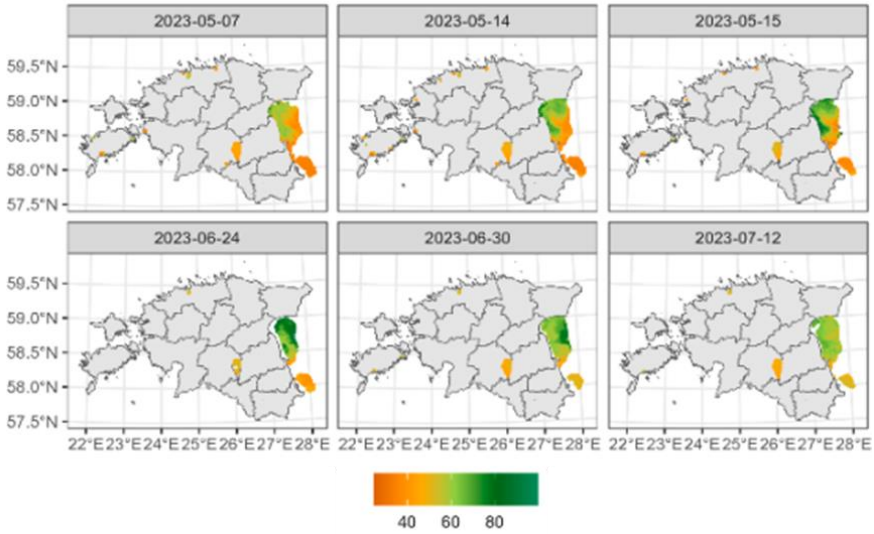

Figure 1. Water colour product over Estonia

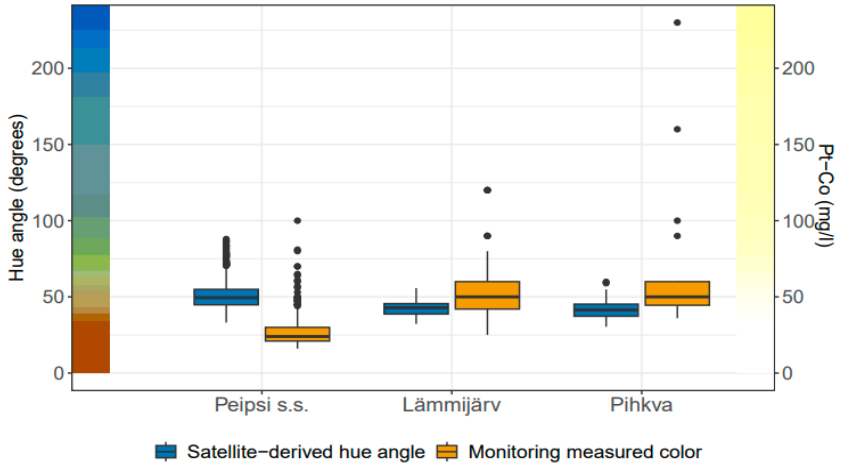

Figure 2. Water colour from Hue angle and from monitoring data about various lake parts of L. Peipsi

Links:

ESTHub: esthub.maaruum.ee/eng/esthub-p26.html

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Water transparency and a_{CDOM} product

This product is based on Sentinel 3/OLCI data.

These products allow to estimate transparency and a_{CDOM} (absorption by Coloured Dissolved Organic Material) values from the Hue angle. Transparency is measured using Secchi Disc Depth and a_{CDOM} is an absorption of colored dissolved organic matter measured at 442 nm.

As lakes are not homogeneous bodies, therefore Copernicus products can be used to analyze spatio-temporal changes more frequently than relying on sparse *in situ* measurements.

Moreover, calculating transparency and a_{CDOM} from water colour (i.e. Hue angle), gives an advantages over traditional band ratio algorithms, where only a few bands are used.

Higher transparency is visible in Lake Peipsi northern part, especially in June (Figure 1.). There are also lover a_{CDOM} concentrations (Figure 2.)

Transparency and a_{CDOM} timeseries of 2023 from May to September by selected monitoring stations in different parts of L. Peipsi (Figure 3). Red dots indicate *in situ* measurements, while black dots indicate satellite-derived parameters value.

Use cases

- Overview of transparency in various waterbodies
- Seasonal and spatial dynamics of transparency and a_{CDOM}

Access, delivery

Sentinel 3/OLCI data is available in ESTHub

Limitations

- Not available under cloud cover and rain
- Depends on accuracy of atmospheric correction
- Higher uncertainties along the coastline
- Information only about the surface

Frequency

Potentially daily

Algorithm training range

- Transparency 0.4-5.4 m
- a_{CDOM} (442) 1.1 - 17.2 m^{-1}

Spatial Resolution

- 300 m

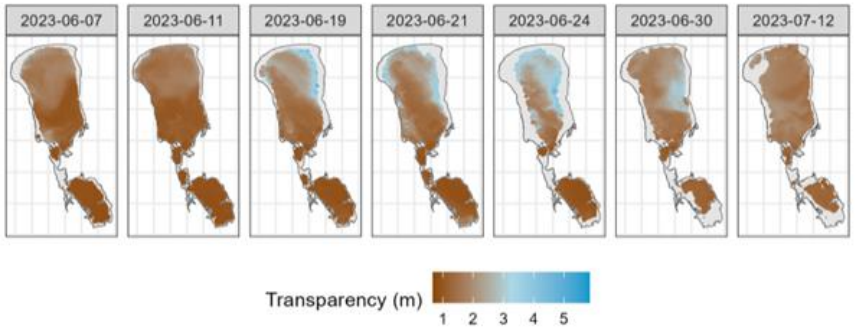

Figure 1. Transparency in Lake Peipsi during spring and summer 2023.

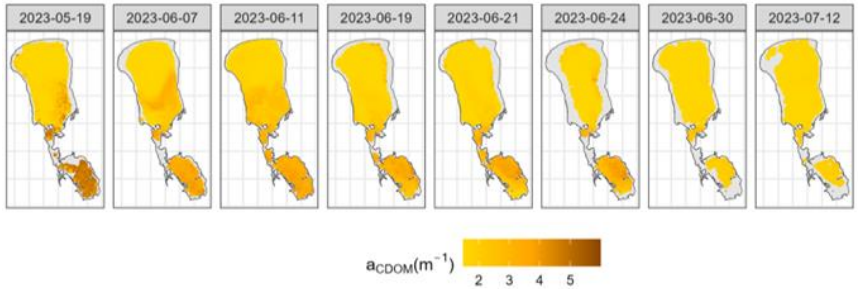

Figure 2. a_{CDOM} in L. Peipsi during spring and summer, 2023.

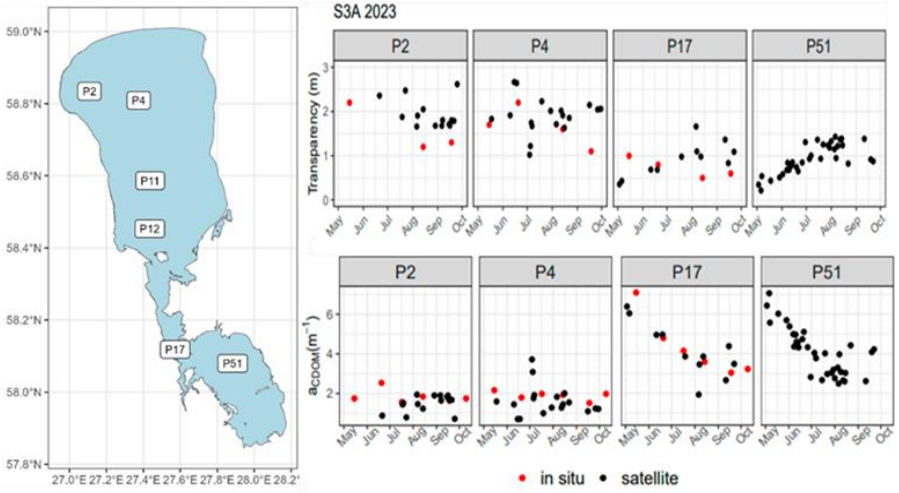

Figure 3. Examples of seasonal dynamics of transparency and a_{CDOM} in monitoring points in L. Peipsi.

Links:

ESTHub: esthub.maaruum.ee/eng/esthub-p26.html

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Bloom product for large Lake Peipsi

Initially based on Sentinel 3/OLCI data, but applicable to other satellites.

This product allows to quantify the bloom parameters based on Chlorophyll a concentration. As cyanobacterial surface blooms have a patchy nature, Earth Observation methods give a possibility to look at changes in the entire waterbody. Initiation, duration and spatial extent of surface blooms can be followed and quantified.

An example:

Figure 1A. Bloom product generation for the year 2019,

B- Maximal bloom coverage (% of the lake total area), 2019 is brought out.

C- Duration of the bloom in different lake parts during 2003-2011 and 2016-2022. Whiskers indicate the period with cloud cover, when the bloom presence/absence was undetectable.

Valid range

- Training range for Chl a regional algorithm 5-150 mg/m^3

Delivery methods & service options

- Sentinel 3/OLCI data can be retrieved from ESTHub portal

Limitations

- Not available under cloud cover or during rain
- Information only about water surface

Spatial Resolution

- 300 m for Sentinel 3/OLCI and ENVISAT/MERIS

Frequency

- Averaged over 2 weeks do assure data availability

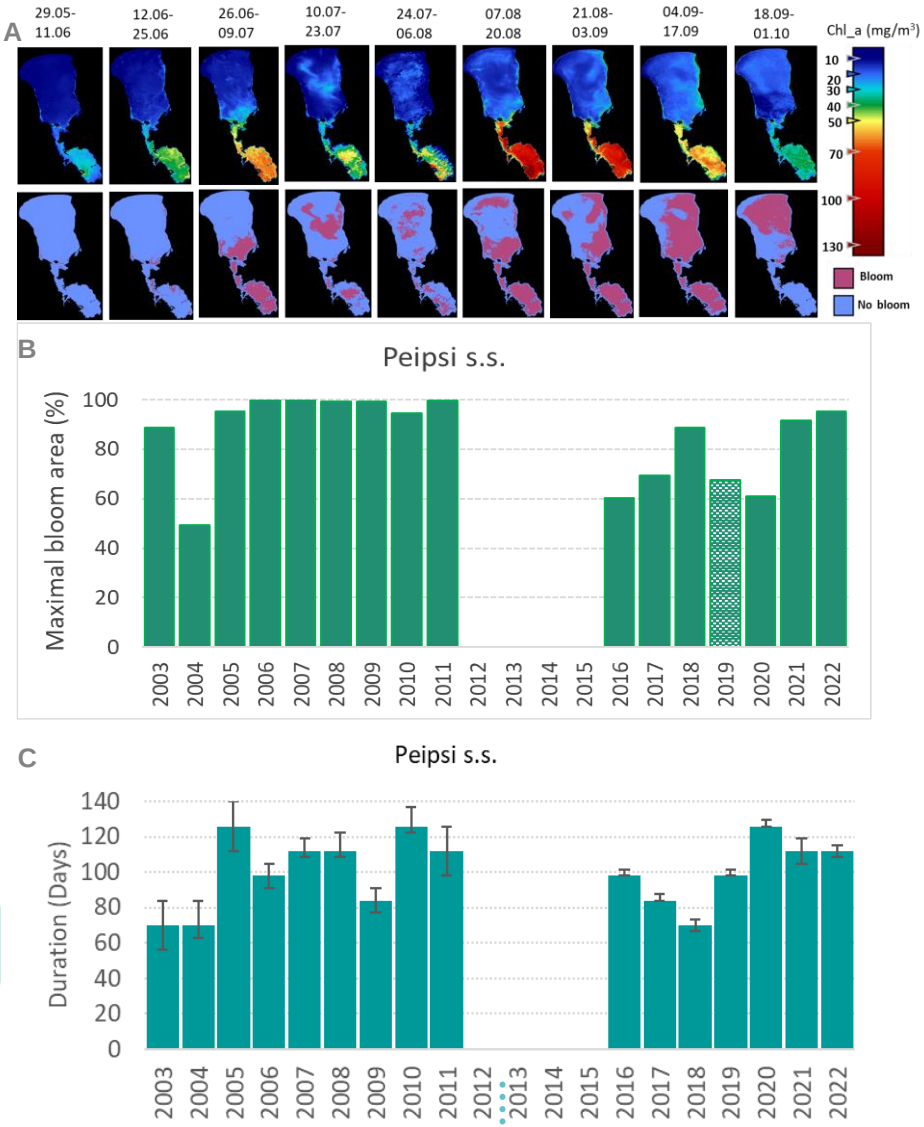

Figure 1. Usage examples of the bloom product.

Links:

ESTHub: esthub.maaruum.ee/eng/esthub-p26.html

Teaching materials about bloom mapping, using ESTHub and SeNtinel Application Platform (SNAP 9.0.0.):

- In English (fpcup.net/resources/resource-details/mapping-phytoplankton-blooms-from-copernicus-data-651)
- In Estonian (fpcup.net/resources/resource-details/mapping-phytoplankton-blooms-from-copernicus-data-1-748)

Lake-part specific criteria for bloom initiation

Lake part	Long-term median + 5%
Peipsi s.s.	18 µg/L
Lämmijärv	35.7 µg/L
Lake Pihkva	46.6 µg/L

Framework Partnership Agreement for Copernicus User Uptake
Co-funded by the European Union
UNIVERSITY OF TARTU Tartu Observatory

Links

- Finnish Environment Institute (Syke): syke.fi
- Tarkka.syke.fi: tarkka.syke.fi
- Syke Metadata portal: ckan.ymparisto.fi/
- Tartu Ülikool: ut.ee/en
- Tartu Observatory: ut.ee/en/tartu-observatory
- ESTHub: esthub.maaruum.ee/eng/esthub-p26.html