Copernicus-enabled assessment of the impact of war on Ukrainian agriculture

#EUSpace

EUSPA
European Union Agency for the Space Programme

TERMS OF USE AND DISCLAIMERS

Authorised use and scope of use

Cover image: False colour image of agricultural areas in Southern Ukraine. Contains modified Copernicus Sentinel data (2020), processed by EUSPA.

DOCUMENT CHANGE RECORD

REASON FOR CHANGE	ISSUE	REVISION	DATE
First version of the document	1	0	December 2023

EXECUTIVE SUMMARY

The European Union (EU) Agency for the Space Programme (EUSPA) launched the EUSpace4Ukraine initiative in April 2022 in response to the war in Ukraine. The objective is to **support innovation and uptake of EU Space Programme solutions by humanitarian aid actors working in Ukraine**, with this white paper on Copernicus enabled impact assessment as one of three demonstrators within the initiative.

As part of the EU Space Programme, the Copernicus Programme is based upon the EU Sentinels and third party Earth Observation (EO) satellites, in-situ (non-space based) data, and data-derived products available via the Copernicus Services. **EO data in general and Copernicus in particular can be utilised for a variety of use cases** across many different market segments, including agriculture.

Ukraine is one of the world's top agricultural producers, with ca. 30% of the global production of sunflower oil, meal and seeds, for example. Among rural households, 49% of the food supply comes from own production, indicating the importance of agriculture also domestically. **Agricultural activities have been disrupted in many regions due to the war**, including access to agricultural labour and operational materials, damaged or destroyed assets and changes to demand and trade opportunities.

In order to quantify the effects of disruptions, Sentinel data was used to estimate cropland extent prior to and during the intensification of the war (2022). The **total cropland area in 2022 compared to the 2017-2021 mean across all crops decreased by ~7% (nearly 2 million ha)**, while the most affected crops (wheat / barley, sunflower and corn) experienced up to ~13% drop in cropland extent. Spatial **correlations of decrease in cropland extent with areas of war indicate a potential direct causation**.

However, additional smaller variations and a lack of correlation for some less important crops suggest that other factors are at play too. These may be linked to **indirect effects of the war on people and economy** (including an estimated €37 Bn in damages and losses linked to agricultural activities from 2022-2023 that has been **derived from EO and other insights**), as well as weather and other variables.

Copernicus can yield **insights in terms of the war in Ukraine that reach beyond agriculture**, including air quality analyses and damage mapping. Furthermore, innovative **European service & infrastructure providers provide value add by building capabilities and services that facilitate end-user uptake**. Such end-users include **NGOs and humanitarian organisations that can benefit from the insights**, such as for demining operations, analysing food security, and much more.

Current and future EU EO capabilities can thus have a lasting impact on ensuring the safety of people in Ukraine and further afield, facilitate implementation of strategies to alleviate the impacts of the war, and pave a path towards rebuilding people's lives and supporting economic recovery.

Acknowledgements: This white paper and accompanying StoryMap have been produced in the framework of the EUSpace4Ukraine initiative ran by EUSPA. Several entities have significantly contributed to their development. We gratefully thank the following individuals / entities and acknowledge their contributions:

- Prof. Nataliia Kussul (National Technical University of Ukraine 'Igor Sikorsky Kyiv Polytechnic Institute') and her team for providing data, technical insights and text contributions.
- Guido Lemoine from the European Commission's Joint Research Centre for his feedback on the analysis and report.
- The World Bank and Joint Research Centre for contributing to Prof. Kussul's impact analysis by providing methodology such as econometric analyses.
- Horizon 2020, the National Research Foundation of Ukraine, and the Alexander von Humboldt Foundation for providing financial support to fund Prof. Kussul's research in general and linked projects, as well as providing stipends/salaries for Prof. Kussul and her team.
- CloudFerro S.A., EarthDaily Analytics, ICEYE, ITF Enhancing Human Security, Kermap & Vista Geowissenschaftliche Fernerkundung GmbH for technical insights, figures, data and review.

КОРОТКИЙ ПІДСУМОК

Агентство Європейського Союзу (ЄС) з Космічної Програми (EUSPA) запустило ініціативу EUSpace4Ukraine у квітні 2022 року у відповідь на війну в Україні. Метою цієї публікації про оцінку впливу війни на сільськогосподарський сектор за допомогою програми Copernicus, як одного із трьох демонстраторів у рамках ініціативи, є **підтримка та впровадження інновацій Космічної Програми ЄС для гуманітарного сектору, працюючого в Україні**.

У рамках Космічної Програми ЄС, Програма Copernicus базується на супутниках Європейського Союзу Sentinel, супутниках третьої сторони для спостереження за Землею, даних *in situ* (отриманих не з космосу) та продуктах на основі даних, доступних через Служби Copernicus. **Дані спостереження за Землею загалом, і Copernicus зокрема, можна використовувати в багатьох випадках** в різних сегментах ринку, включаючи сільське господарство.

Україна є одним з найбільших виробників сільськогосподарської продукції у світі, з приблизно 30% глобального виробництва соняшникової олії, жому та насіння, наприклад. Серед сільських господарств, 49% продовольчого постачання забезпечується власним виробництвом, що свідчить про важливість сільського господарства також в межах країни. **Сільськогосподарські діяльності були порушені в багатьох регіонах через війну**, включаючи доступ до сільськогосподарської робочої сили та матеріалів, пошкоджені або зруйновані активи та зміни в попиті та торговельних можливостях.

Для оцінки наслідків порушень сільськогосподарської діяльності були використані дані Sentinel для визначення площі сільськогосподарських угідь до та під час інтенсифікації війни (2022 рік). **Загальна площа сільськогосподарських угідь у 2022 році, порівняно з середнім значенням 2017-2021 років для всіх культур, зменшилася на приблизно 7% (майже 2 млн га)**, тоді як найбільше постраждалі культури (пшениця / ячмінь, соняшник та кукурудза) зазнали зменшення площі сільськогосподарських угідь до 13%. **Просторова кореляція зменшення площі сільськогосподарських угідь з областями війни свідчить про потенційну пряму причинно-наслідкову залежність**.

Однак додаткові незначні варіації та відсутність кореляції для деяких менш важливих культур свідчать про те, що й інші фактори мають вплив. Це може бути пов'язано з **непрямими наслідками війни на людей та економіку** (у тому числі оціненими збитками та втратами у розмірі 37 млрд євро, пов'язаними з сільськогосподарською діяльністю з 2022 по 2023 рік, які були **отримані на основі даних космічного спостереження та інших даних**), а також погодних умов та інших факторів.

Copernicus також може надавати **інформацію, пов'язану з війною в Україні, яка виходить за рамки сільського господарства**, включаючи аналіз якості повітря та картографування пошкоджень. Крім того, інноваційні **Європейські постачальники послуг та інфраструктури створюють додану вартість, розвиваючи можливості та послуги, які полегшують їх використання кінцевими користувачами**. До таких кінцевих користувачів належать **громадські та гуманітарні організації, які можуть отримати вигоду від отриманих даних**, наприклад, для операцій з розмінування, аналізу продовольчої безпеки та багато іншого.

Таким чином, **нинішні і майбутні можливості ЄС зі спостереження за Землею можуть мати тривалий вплив на забезпечення безпеки людей в Україні** і за її межами, сприяти впровадженню стратегій, спрямованих на пом'якшення наслідків війни, і прокласти шлях до відновлення життя людей і підтримки економічного відновлення.

Подяки: Ця публікація та StoryMap, що її супроводжує, були підготовлені в рамках ініціативи EUSpace4Ukraine, якою керує Європейське Агентство EUSPA. Певні організації зробили значний внесок у їхню розробку. Ми висловлюємо вдячність наступним особам/організаціям та визнаємо їхній внесок:

- Професору Наталії Куссуль (Національний Технічний Університет України "Київський Політехнічний Інститут імені Ігоря Сікорського") та її команді за надані дані, технічні ідеї та текстові матеріали.
- Гвідо Лемуану з Об'єднаного Дослідницького Центру Європейської Комісії за його коментарі щодо аналізу та звіту.
- Світовому Банку (the World Bank) та Об'єднаному Дослідницькому Центру (the Joint Research Centre) за внесок в аналіз професора Куссуль шляхом надання методології, зокрема, економетричного аналізу.
- Horizon 2020, Національному Фонду Наукових Досліджень України та Фонду Олександра фон Гумбольдта за надання фінансової підтримки для фінансування досліджень професора Куссуль в цілому та пов'язаних з ними проектів, а також надання стипендій/заробітної плати професору Куссуль та її команді.
- CloudFerro S.A., EarthDaily Analytics, ICEYE, ITF Enhancing Human Security, Kermap & Vista Geowissenschaftliche Fernerkundung GmbH за технічну інформацію, графіки, данні та відгуки.

LIST OF ABBREVIATIONS & ACRONYMS

API	Application Programming Interface
CAMS	Copernicus Atmosphere Monitoring Service
CCM	Copernicus Contributing Missions
CEMS	Copernicus Emergency Management Service
CHIME	Copernicus Hyperspectral Imaging Mission
CLMS	Copernicus Land Monitoring Service
CGLS	Copernicus Global Land Service
EGNOS	European Geostationary Navigation Overlay Service
EO	Earth Observation
EU	European Union
EUSPA	European Union Agency for the Space Programme
GNSS	Global Navigation Satellite Systems
GOVSATCOM	Governmental Satellite Communications
HPCM	High-Priority Candidate Mission
IRIS²	Infrastructure for Resilience, Interconnectivity & Security by Satellite
JRC	Joint Research Centre
NDVI	Normalised Difference Vegetation Index
NGO	Non-governmental organisation
PNT	Positioning, Navigation, and Timing
R&D	Research and Development
ROSE-L	Radar Observing System for Europe in L-band
SAR	Synthetic Aperture Radar
SatCom	Satellite Communications
SSA	Space Situational Awareness
SUFC	Support Ukrainian Farmers Coalition
SWIR	Short-wave infrared
TROPOMI	TROPOspheric Monitoring Instrument
UN	United Nations
UNDP	United Nations Development Programme
UNHCR	United Nations High Commissioner for Refugees
US	United States
UXO	Unexploded Ordnance
VNIR	Visible / Near-Infrared

TABLE OF CONTENTS

LIST OF FIGURES

1 INTRODUCTION

1.1 EUSPA and the EU Space Programme

The European Union Agency for the Space Programme (EUSPA) is the **agency in charge of implementing the European Union (EU) Space Programme with the aim of providing reliable, safe and secure space-related services to users**. EUSPA's mission is to be the user-oriented operational Agency of the EU Space Programme, contributing to sustainable growth, security and safety of the European Union. In the execution of its mission, EUSPA counts on strong partnerships with the European Commission, European Parliament, Member States, European Space Agency, and private actors across the EU.

The EU Space Programme consists of various components, including **Earth Observation** (EO - Copernicus), **Global Navigation Satellite Systems** (GNSS – Galileo and EGNOS), **Space Situational Awareness** (SSA) and (governmental) **Satellite Communications** / connectivity (SatCom – GOVSATCOM and soon IRIS^2) as its main parts. All of these elements can provide extremely useful insights and applications, for example for regions where ground access can be difficult or impossible to achieve.

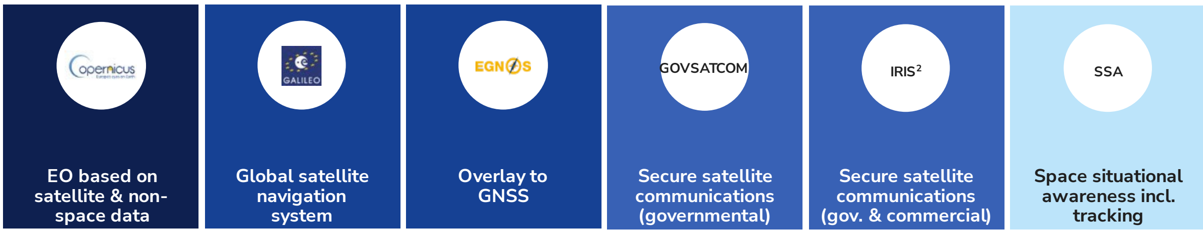


Figure 1: Overview of EU Space Programme.

Particularly relevant for this analysis, the Copernicus Programme provides a combination of EO data from six Sentinel satellite missions, Copernicus Contributing Missions (CCMs) and in-situ data. Additionally, capabilities will be bolstered in the future through six planned High-Priority Candidate Missions (HPCMs). Across the multitude of sensors and capabilities, the current and future satellites are able to provide data across a **variety of spectral wavelengths** (optical, radar, radio frequency), **monitoring various terrestrial domains** (land, coastal and marine areas, atmosphere), with a **range of spatial and temporal resolutions and coverage**. Furthermore, the satellite capabilities are complemented by in-situ (non-space based) sensors as well as the Copernicus Services, which provide data derived products for specific topics or domains (e.g., Copernicus Land Monitoring Service - CLMS or Copernicus Emergency Management Service - CEMS).

Depending on the parameters above, there are manifold applications for EO, including, for example, crop yield forecasting, soil condition and biomass monitoring and precision irrigation for agriculture, and many others.

EUSPA has thus defined 17 market segments for which it **implements specific, targeted EO and GNSS initiatives to link space to user needs**. The market segments range from rural and environmental applications (e.g., agriculture, fisheries, environmental monitoring) through infrastructure and key industries (e.g., energy and raw materials, road and automotive, rail) to governmental applications (e.g., emergency management and humanitarian aid).

Key messages:

- The European Union Agency for the Space Programme (EUSPA) provides reliable, safe and secure space-related services to users.
- European satellite Earth Observation (EO) capabilities can support a range of applications and market segments, including agriculture.

Figure 2: Overview of 17 EUSPA market segments.

1.2 EUSpace4Ukraine initiative

One such activity is the EUSpace4Ukraine initiative, launched by EUSPA in April 2022 in response to the war in Ukraine in order to **support innovation and uptake of EU Space Programme solutions by humanitarian aid actors working in Ukraine**.

Figure 3: A residential building in Chernihiv, destroyed by war activities in March 2022. Photo by Anzhela Bets on Unsplash.

The **war in Ukraine**, which intensified in 2022, has had **far-reaching consequences for the country and the wider international community**. There is now **widespread damage to Ukrainian infrastructure**, particularly in southern and eastern regions. **Massive economic effects have been felt globally** mainly due to difficulties with Ukrainian exports, causing issues with global food and energy supply chains and corresponding price increases to mostly unprecedented levels. **Europe is seeing the largest refugee crisis since World War II**, with over 6 million refugees from Ukraine recorded globally, the vast majority finding refuge in countries neighbouring Ukraine as well as Germany[1].

The EUSPA **EUSpace4Ukraine initiative** provides critical activities with the objective of **mobilising the EU Space innovation community and connecting them with users to alleviate the impacts of the war.** In particular, innovators with **technological**

[1] *UNHCR Operational Data Portal - Ukraine Refugee Situation*. (2023, August 15). Retrieved from https://data2.unhcr.org/en/situations/ukraine (accessed 21/06/2023)

solutions enabled by EU space capabilities (EO, GNSS, SatCom) are linked to non-governmental organisations (NGOs) to enhance humanitarian support for the Ukrainian people. An EUSpace4Ukraine platform aims to match the innovators with NGOs and other helpers through the EUSpace4Ukraine Network, sowed the seeds for new technological solutions that can support NGOs via a dedicated hackathon, and enabled a series of three demonstrators to be developed.

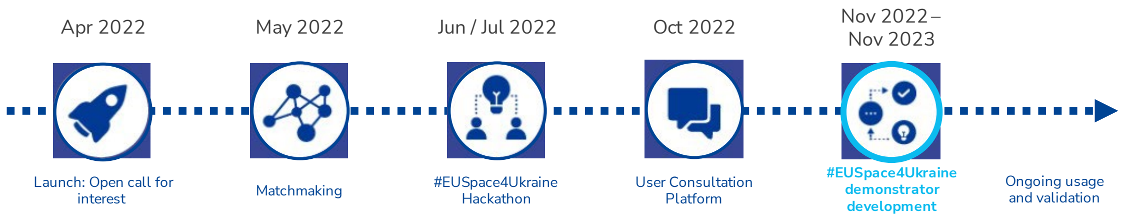


Figure 4: Timeline of EUSpace4Ukraine initiative.

The three demonstrators are:

- **Galileo-powered drones for search-and-rescue operations:** Hands-on training and validation of the use of drones enabled by EGNSS for rapid and safe search & rescue operations by NGOs, including Red Cross Ukraine.
- **Up-to-date maps for fieldwork navigation:** A highly tailored geospatial platform to provide up-to-date maps derived from satellite data to facilitate efficient on-the-ground logistics for humanitarian aid for NGOs.
- **Copernicus enabled assessment of impact of war on Ukrainian agriculture** (this white paper and its accompanying [online StoryMap]): An overview of opportunities linked to utilising EO capabilities to assess the impacts of the war on Ukrainian agriculture, and other, linked applications, as shown in the subsequent sections.

Figure 5: Demonstrator day between EUSPA, Red Cross Ukraine & supporting organisations showcasing EU-space enabled drone capabilities for search & rescue.

Key messages:

- The EUSPA EUSpace4Ukraine Network supports innovation and uptake of EU Space Programme solutions by humanitarian aid workers in Ukraine.
- The three EUSpace4Ukraine demonstrators include this white paper, Galileo-powered drones and a geospatial platform for up-to-date maps to be used by NGOs such as Red Cross in Ukraine.

2 IMPACT OF WAR ON UKRAINIAN AGRICULTURE

2.1 Agricultural sector in Ukraine

Prior to the war, Ukraine was one of the **world's top agricultural producers**, particularly considering oil seeds / grains but also corn, wheat, barley, rapeseed, rice, soybean and millet. A large portion of the production was exported, making the country the top global exporter for sunflower oil and meal. For example, in 2021 ca. **30% of the global production of sunflower oil, meal and seeds came from Ukraine**[2]. The biggest export markets for Ukraine for these products were India, the EU, China and Turkey, and 90% of agricultural export was facilitated via Black Sea ports[3] (which are heavily affected by the war).

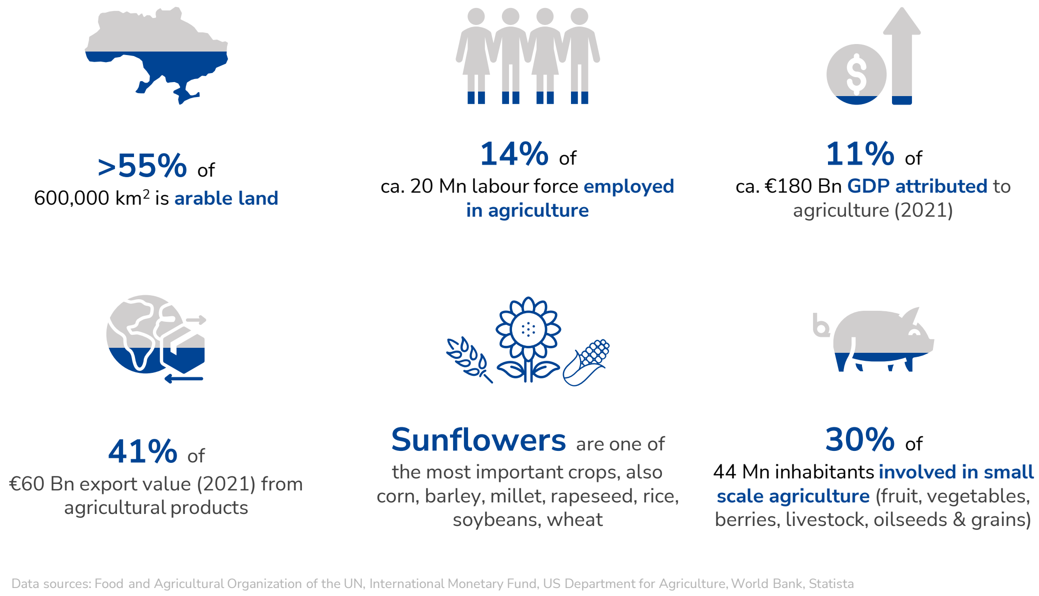


Figure 6: Agriculture as an important contributor to Ukrainian pre-war economy.

Agriculture is not only important from an economic and export point of view, but also to **sustain individual livelihoods in Ukraine particularly in rural areas**. Of the ~44 million inhabitants[4] prior to the war, **13 million people were involved in small-scale agricultural production**, with fruit, vegetables, berries and livestock generally slightly more important than oil seeds and *grains*[5]. *A 2022 survey has shown that at the* national average, 49% of food for rural households comes from own production[5].

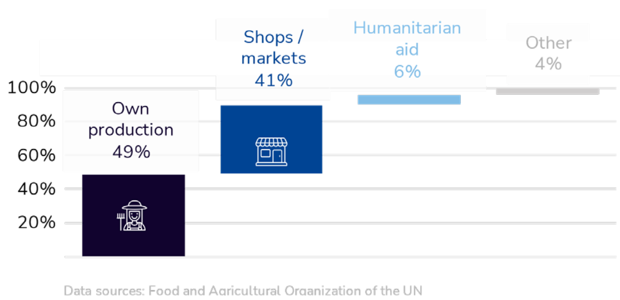


Figure 7: Recent survey data shows own production as the main food source for rural households.

---

[2] Foreign Agricultural Service, US Department of Agriculture. (2022). Ukraine Agricultural Production and Trade, April 2022.

[3] World Bank; Government of Ukraine; European Union; United Nations. (2022). Ukraine Rapid Damage and Needs Assessment: February 2022 - February 2023. Washington, DC: World Bank Group. Retrieved from http://documents.worldbank.org/curated/en/099184503212328877/P1801740d1177f03c0ab180057556615497

[4] The World Bank - Data. (2023, August 15). Retrieved from https://data.worldbank.org/indicator/SP.POP.TOTL?locations=UA

[5] UN Food and Agricultural Organization. (2022). Ukraine: Impact of the war on agriculture and rural livelihoods in Ukraine – Findings of a nation-wide rural household survey, December 2022. Rome. Retrieved from https://doi.org/10.4060/cc3311en

Dictated by regional differences in climate and topography, among other factors, there are **regional trends in terms of most important crops** (Figure 8).

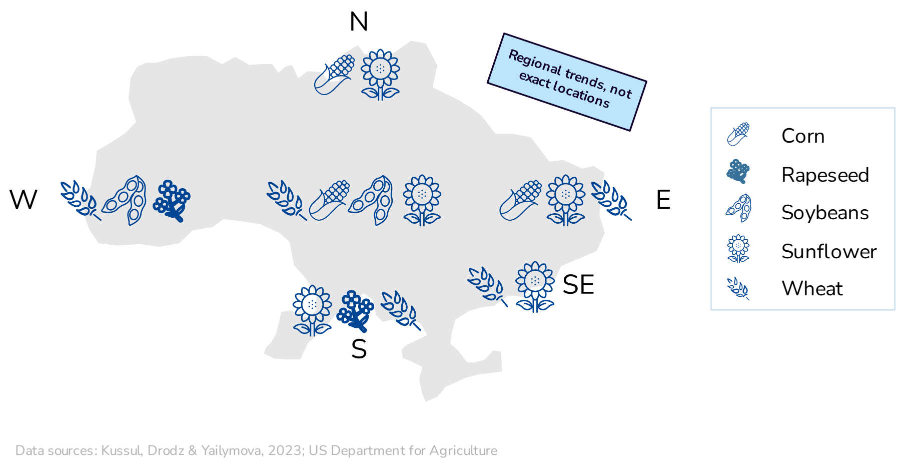


Figure 8: Regional differences in prevalence of common crops in Ukraine.

2.2 Disruption of agricultural activities

The war has had a **multitude of effects on agricultural activities**, which can be categorised into four groups (with some overlap / grey areas in between):

1. **Labour & people:** Lack of staff for operations including harvest, lack of veterinary & maintenance expertise, both linked to dangerous working conditions (e.g., due to active fighting or military occupation), restricted movement and displacement of people;
2. **Operational materials:** Damage to vehicles or other equipment, difficulty accessing fuel, spare parts, tools, seeds, fertilisers, medication, animal feed etc., disruption of operational utilities (power, water), looting;
3. **Assets:** Damage to or destruction of assets (including soil contamination or degradation due to changed physical, chemical and biological characteristics impacted by war activities, and the need for re-cultivation of agricultural land, as well as killed or slaughtered livestock), disrupted access to agricultural areas & processing facilities (e.g., due to damages to transport infrastructure, roadblocks, flooding, military occupation, mines or active fighting);
4. **Demand & trade:** Disrupted access to ports and trade routes, lower or higher demand depending on refugee movements and internally displaced people.

As such, **changes to agricultural output compared to times of peace** or less widespread conflict can be expected. The following section presents a **detailed summary of EO derived estimates of changes in cultivated areas** for some of the most important crops. **Observed changes are likely linked to impacts from all of the aforementioned categories**.

Key messages:

- Ukraine is one of the world's top agricultural producers, with ca 30% of global production of sunflower oil, meal and seeds, among others.
- Agriculture is also important to sustain individual livelihoods in Ukraine with 49% of food for rural households coming from own production.
- War can disrupt labour and access to operational materials, damage or destroy assets and cause changes to demand and trade opportunities for agriculture.

2.3 Quantitative impact analysis leveraging Copernicus

EO data can be utilised to estimate agricultural parameters from space, either where ground-based estimates are difficult or as a complement to ground-based data to enable larger spatial or temporal coverage. Data from different Sentinel satellites can be useful for different purposes.

Sentinel-1 Synthetic Aperture Radar (SAR) data utilises radio waves and their reflections off the Earth's surface to characterise the ground. Out of the original Sentinel-1 satellite pair, the remaining Sentinel-1A (Sentinel-1B stopped functioning in December 2021) collects SAR data from circa 693 km altitude regardless of day light and weather conditions with a 12 day revisit rate. Sentinel-1A provides down to 5 m resolution and a swath width of up to 410 km (a wider swath mode implies coarser resolution). With suitable algorithms and sometimes based on validation in the field, this data can be used to **classify which crops grow in which areas**, gathering insights across entire regions or even countries.

The **Sentinel-2 mission** consists of a pair of satellites that orbit the Earth 180° apart from each other at 786 km above the surface (on average). On board, a **multi-spectral camera collects optical imagery** in 13 spectral bands ranging from visible / near-infrared (VNIR) to short-wave-infrared (SWIR). A 290 km swath offers between 10-60 m spatial resolution on the ground, with a 2-10 day revisit rate (depending on latitude). **Sentinel-2 imagery can also be used for crop classification** based on different spectral characteristics and their variation through time, as well as to determine **different indicators relevant for agriculture**.

In particular, a metric called **normalised difference vegetation index (NDVI) is widely used as a measure of vegetation "greenness"** (Figure 9, Figure 10) and can be used to derive estimates of vegetation, type, density, and changes in plant health. NDVI is calculated based on the amount of reflected radiation captured in two different frequency bands within the light spectrum received by optical satellites such as Sentinel-2 and Sentinel-3 . This calculation can be done independently by interested parties based on raw satellite imagery, or is available as a ready-to-use product (e.g., derived from Sentinel-3 or other missions)as part of standard higher level processing.

Whereas the **crop classification based on Sentinel-1 data is possible even in cloudy conditions, NDVI can only be obtained from cloud-free images**. For some purposes, tools exist to **"remove" cloud coverage from optical satellite imagery by utilising artificial intelligence and machine learning**. In other instances, thanks to a circa 2-10 day revisit rate of Sentinel-2, monthly composites can be created that utilise imagery from different dates for different parts of the same region to ensure full coverage without the impact of clouds.

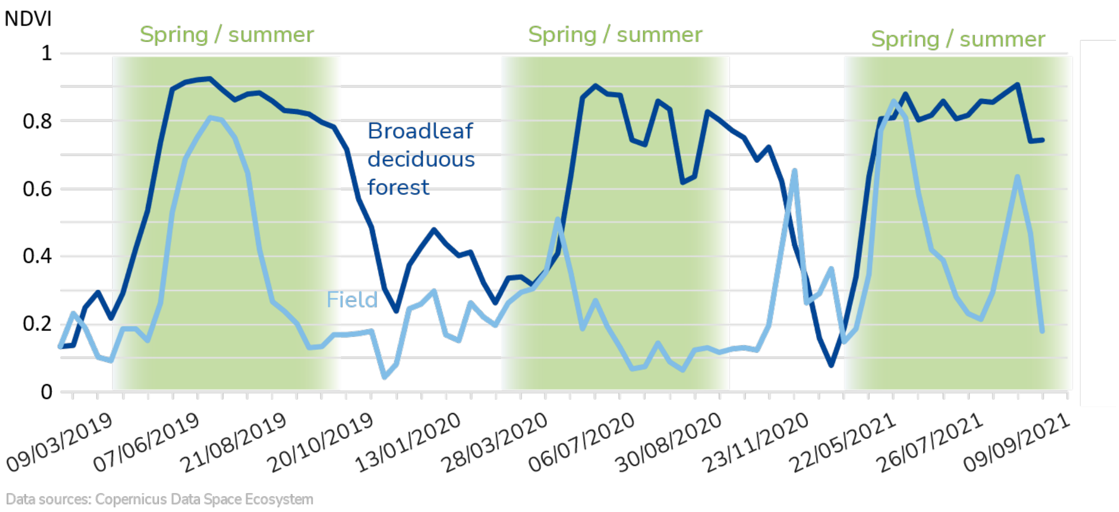


Figure 9: Smoothed example timeseries of NDVI estimates (where higher values indicate greener vegetation) from Sentinel-2 from 2019-2021 show seasonal variations.

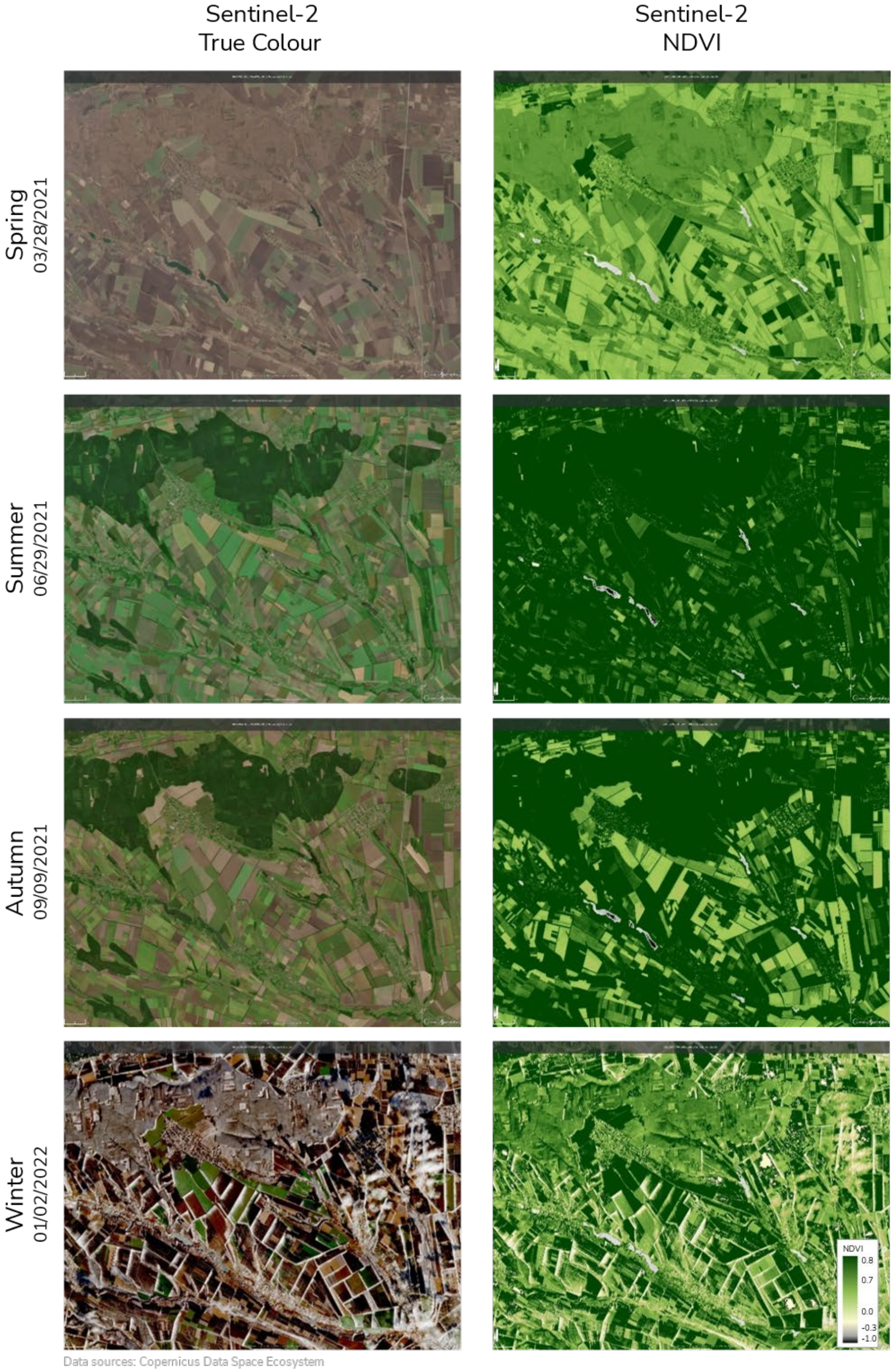


Figure 10: Seasonal changes in true colour imagery and NDVI estimates from Sentinel-2. Credit: European Union, contains modified Copernicus Sentinel data 2021-2022, processed with EO browser.

In a study with funding contributions from the European Commission through the joint World Bank / EU project "Supporting Transparent Land Governance in Ukraine"[6], results from **machine learning applied to crop classification and NDVI measurements** across pre-determined parts of Ukraine **combined with ground-truthed "training" data** that pre-dates the war were utilised to **estimate cropland extent for different crops before and during war time**[7]. The data was derived from a combination of Sentinel-1 and Sentinel-2 imagery.

Scan the QR code above to explore the data shown below in our interactive StoryMap online.

Looking at some of the most important crops (in order of cropland extent from larger to smaller: wheat & barley, sunflower, corn), a **decrease in crop land from pre-war conditions to war conditions** can be observed (Figure 11). The **total cropland area in 2022 compared to the 2017-2021 mean across all crops decreased by ~7% (nearly 2 million ha)**, while the most affected crops (wheat / barley, sunflower and corn) experienced up to ~13% drop in cropland extent (ca. 1 million ha less for wheat/barley and sunflower and 0.5 million ha less for corn). Interestingly, the less significant crops soybeans and rapeseed saw a slight increase in cropland in 2022 compared to the previous years.

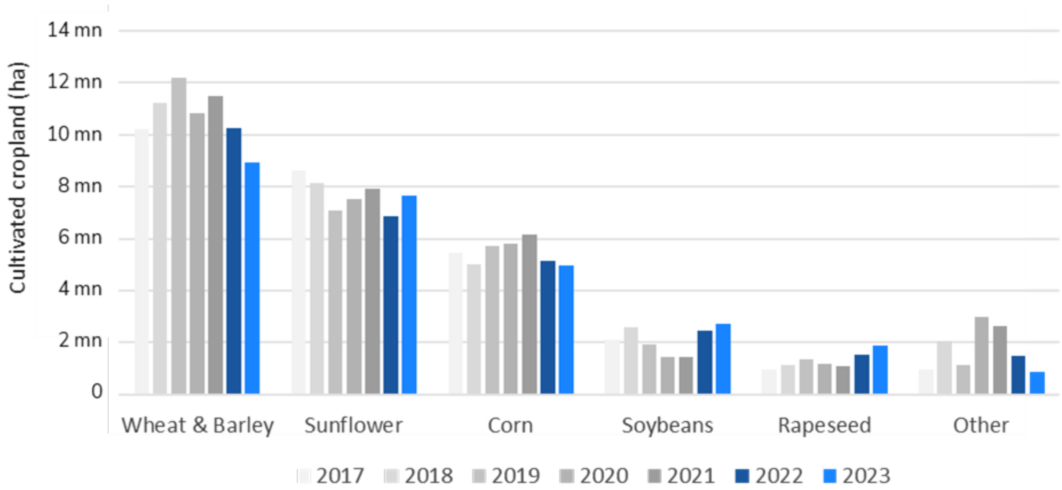


Figure 11: Comparison of cultivated land by crop in Ukraine for 2017-2021 (grey) vs. 2022 shows war-time cropland decrease for important crops, particularly when comparing to the previous 3 years. 2023 numbers are initial, unpublished estimates with a similar trend for wheat / barley and corn.

Furthermore, and not unexpectedly, regional differences can be observed. For the two most important crop groups (wheat/barley and sunflower – Figure 12 and Figure 13), the **strongest reduction in cropland can be seen in the Eastern and Southeastern regions – which are strongly affected by the war**. For example, wheat & barley cropland dropped by ~43% (~0.4 million ha) and ~32% (~0.3 million ha) for Crimea and the oblast around Kherson, respectively.

[6] ENI/2017/387-093 and ENI/2020/418-654

[7] Kussul, N., Drozd, S., & Yailymova, H. (2023). Forecast of Yield of Major Crops in Ukraine in War Conditions 2022 Based on MODIS and Sentinel-2 Satellite Data. Proceedings of the 11th International Conference on Applied Innovations in IT, (ICAIIT).

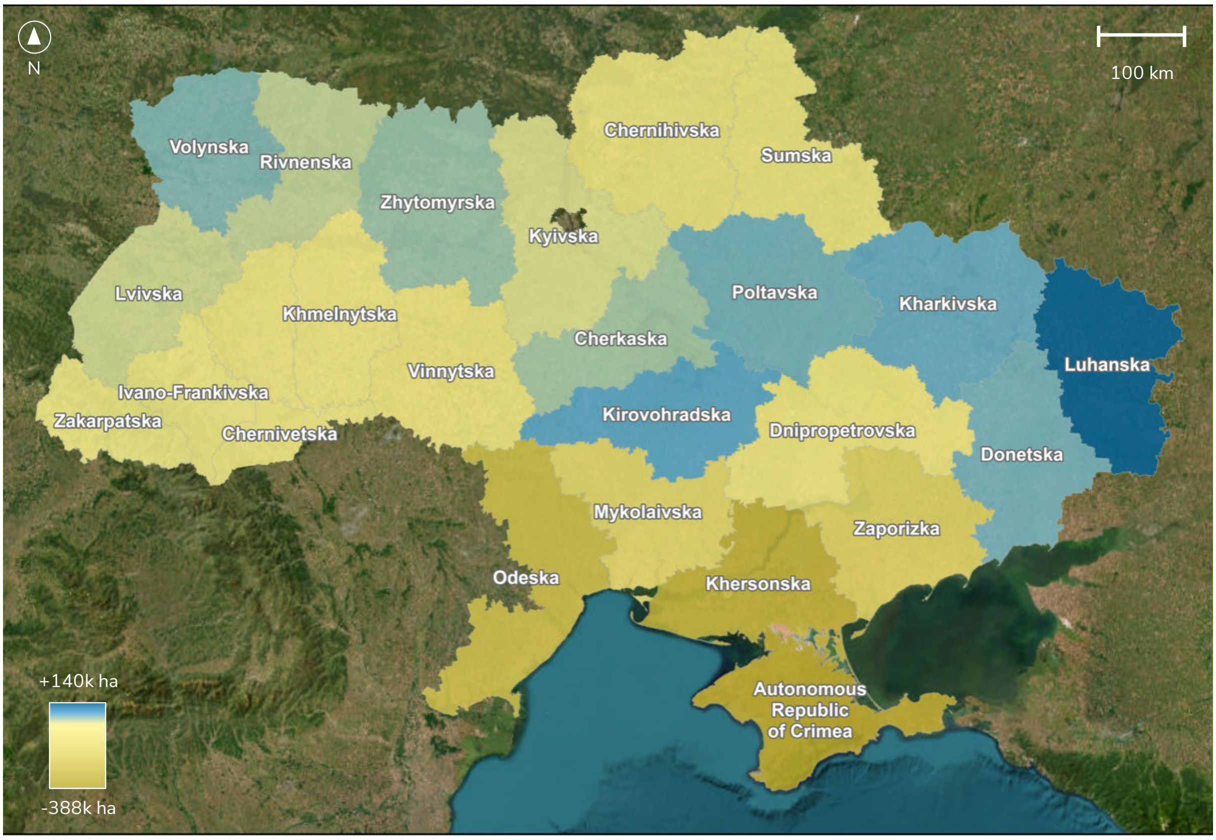


Figure 12: Difference between 2022 and 2017-2021 average cropland for wheat & barley.

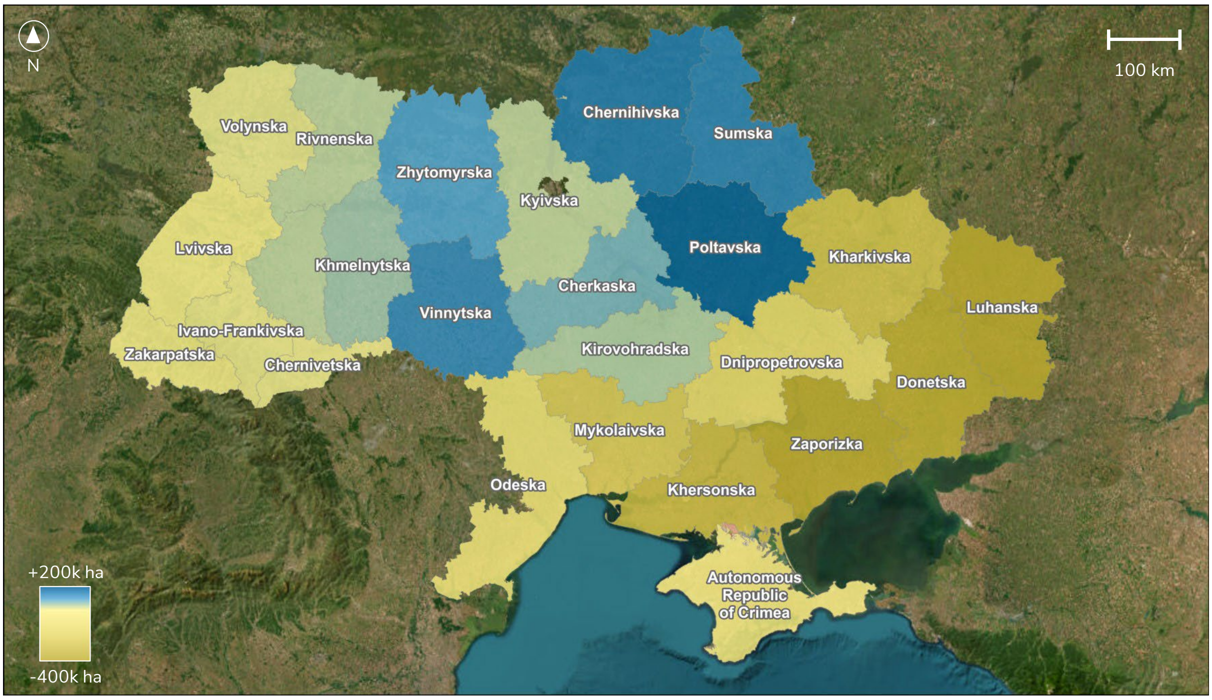


Figure 13: Difference between 2022 and 2017-2021 average cropland for sunflowers.

This correlation between regional concentration of decreased extent of cultivated land and war activities is also reflected in the total cropland difference across all crops (Figure 14).

Some of the crops with overall lower footprints (e.g., rapeseed, Figure 15) **show regional trends that do not strongly mirror direct localisation of war activities, suggesting that other factors are at play**. These may include war-related, indirect impacts (e.g., supply chain issues, economic circumstances) as discussed in the following section, but also influences from year-on-year climatic differences, individual weather events and more.

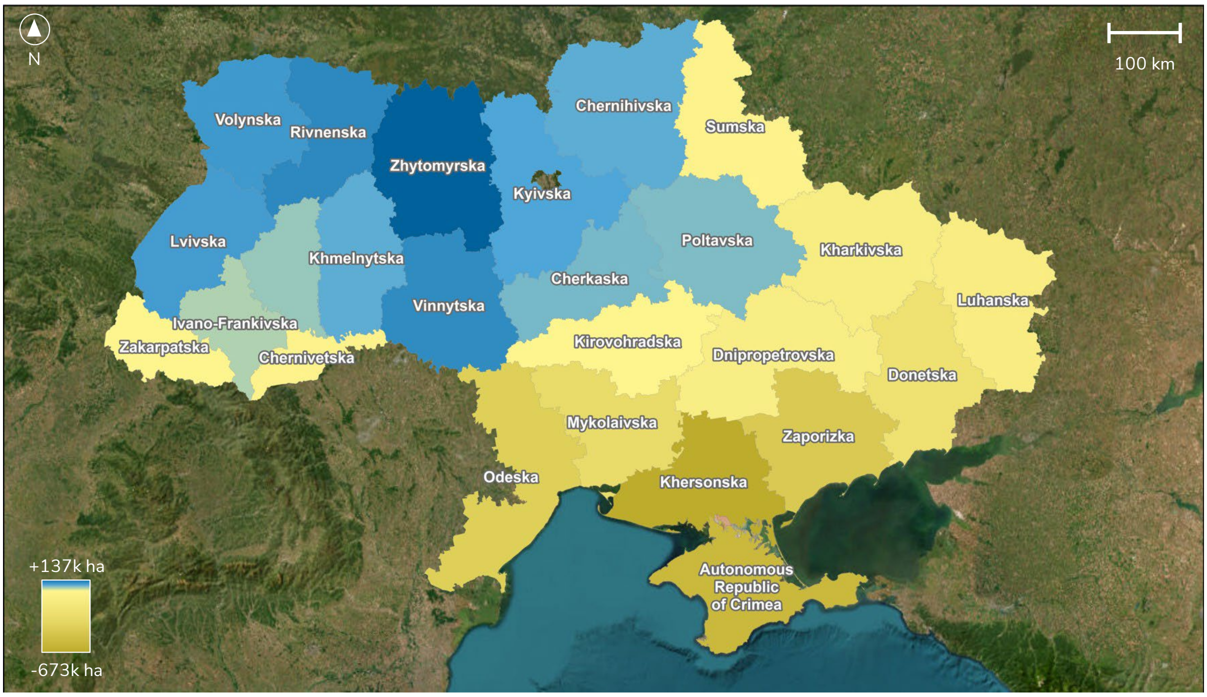


Figure 14: Difference between 2022 and 2017-2021 average cropland, all crops.

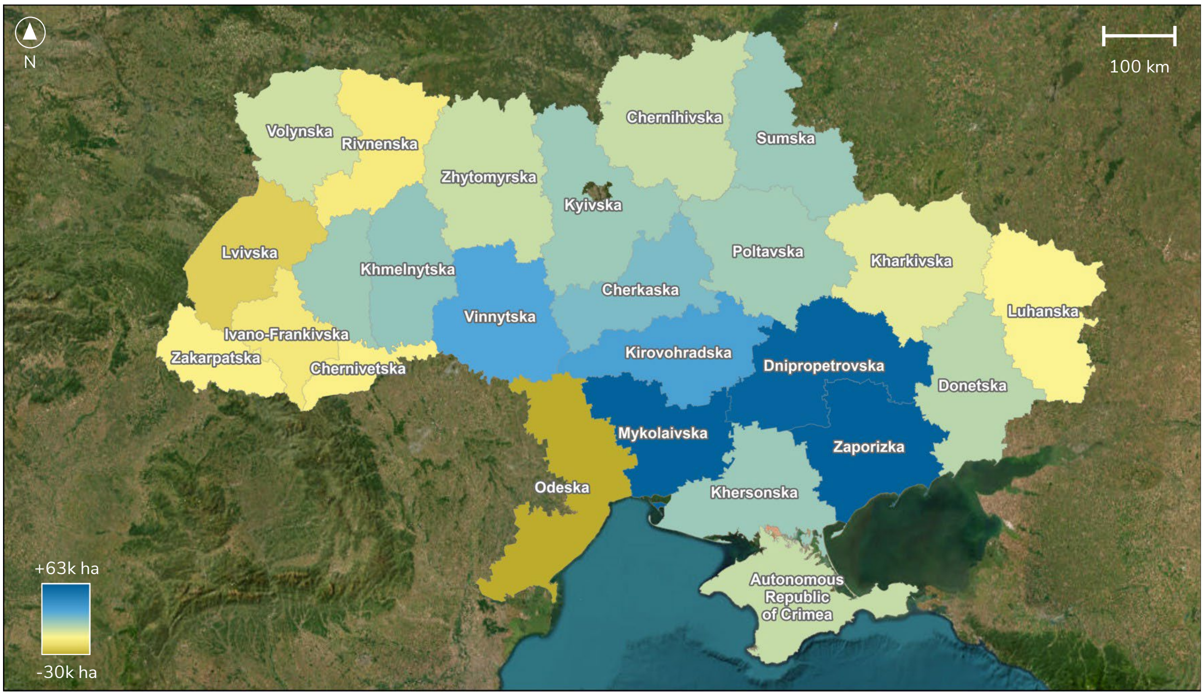


Figure 15: Difference between 2022 and 2017-2021 average cropland for rapeseed.

Initial data from 2023 including Copernicus observations indicate a similar drecrease in cropland extent for wheat/barley and corn in 2023 compared to the preceding 5-year average, with some recovery of cropland extent for sunflower, rapeseed and soybean [8] (also Figure 11). Copernicus capabilities – as an important enabler of the analysis above – will continue to contribute to assessing the impacts of the war in Ukraine.

Key messages:

- Copernicus Sentinel-1 and 2 data can be used to map cropland extent and Sentinel-2 / Sentinel-3 data can help to assess variations via NDVI (vegetation "greenness").
- For important crops (wheat/barley, sunflower, corn), total extent of cropland in Ukraine as derived from Copernicus data decreased by up to ~13% in 2022 compared to previous years, with strongest changes seen in regions affected by the war.

2.4 Implications for people and the economy

The drop in agricultural production for several crops and the regional trends derived from Copernicus data suggest that the **war directly affects farming and agricultural activities**. However, **smaller regional variations and different regional trends for different crops may also be linked to other, indirect impacts and non-war related variables**. Furthermore, long-term effects – e.g., due to soil contamination – are not studied in the present analysis.

Recent analysis of Copernicus and other EO data suggests that only 14% of estimated yield loss can be attributed to the direct effects of the war, while the remainder is linked to the wider (war-influenced) economic context[9]. Vice versa, beyond the **direct disruption of agricultural activities due to war, there are ripple effects of the situation within the agricultural sector for people and the wider economy both on a local and a global level**.

In general,these ripple effects can be grouped into 3 main categories: **Monetary, Supply & demand, and Coping strategies**, with further short- and long-term consequences in terms of **mental and physical health** (e.g., stress, malnutrition) as well as further **economic effects** (e.g., reduced purchasing power).

Category	Effect	Extent
Monetary	Lack of income	Local
	Increasing production costs*	Regional
	Fluctuations and unpredictability of food prices**	Global
Supply & Demand	Crop oversupply / spoilt crops due to disrupted trade routes and lack of adequate storage	Local
	Lack of food security / not enough supply** (e.g., concentrations of internal refugees)	Global
	Disruption of supply chains**	Global
Coping Strategies	Financial mitigating strategies (sell assets, reduce expenditure, spend savings, borrow money)	Local
	Change in farming practices or priority areas (e.g., from wheat to oilseed crops)	Local

* Main impacts observed locally / regionally, while global increases more linked to rising energy costs (no direct link to Ukrainian agriculture)
** Global effects somewhat limited to affected crops / products, whereas local / regional effects may be broader

[8] JRC. (September 2023). MARS Bulletin - Global outlook: Crop Monitoring European neighbourhood Ukraine.

[9] Deininger, K., Ayalew Ali, D., Kussul, N., Shelestov, A., Lemoine, G., & Yailymova, H. (2023, February). Quantifying war-induced crop losses in Ukraine in near real time to strengthen local and global food security. Food Policy, 115(102418). Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0306919223000167

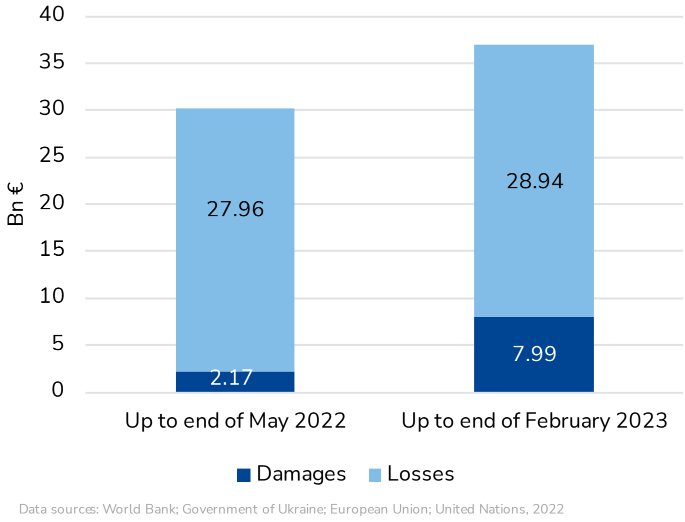


Figure 16: Estimates of damages & losses in the Ukrainian agriculture due to war.

Copernicus as well as other EO and more general space capabilities such as **GNSS can help to assess some of these effects**. For example, EO can help to identify field-level changes from one crop to another; GNSS applications can support assessments of the disruption of trade routes. **Observing other effects**, e.g., increased production costs or food prices, are **beyond the reach or mandate of space capabilities**.

Household survey-based estimates by the UN Food and Agricultural Organization from December 2022 indicate a total of nearly €2.2 billion in damages (e.g., lost animals, destroyed assets accounting for 37% of the total) and losses (e.g., reduced production value, increased costs) to rural households during the first 6 months of the war alone[10]. More recent estimates for the wider agricultural ecosystem by the World Bank (which were supported by EO data including Copernicus) indicate a **total of over €37 billion worth of damages and losses linked to agricultural activities by the end of February 2023**[11] (Figure 16).

With war activities continuing at the time of writing, these estimates are likely only scratching the surface of the real magnitude of the impact. For example, more recent military activity that post-dates these economic analyses has resulted in the **collapse of a dam at the bottom of a large reservoir, severely disrupting agricultural areas up- and downstream**, as discussed in the case study overleaf.

Key messages:

- EO and other space capabilities can help assess impacts of disrupted agricultural activities on people and economy.
- Over €37 billion worth of damages and losses linked to agricultural activities have been estimated by the end of February 2023

[10] UN Food and Agricultural Organization. (2022). Ukraine: Impact of the war on agriculture and rural livelihoods in Ukraine – Findings of a nation-wide rural household survey, December 2022. Rome. Retrieved from https://doi.org/10.4060/cc3311en

[11] World Bank; Government of Ukraine; European Union; United Nations. (2022). Ukraine Rapid Damage and Needs Assessment: February 2022 - February 2023. Washington, DC: World Bank Group. Retrieved from http://documents.worldbank.org/curated/en/099184503212328877/P1801740d1177f03c0ab180057556615497

Case study: Impacts of Kakhovka dam collapse on agriculture

On 6th June 2023, the destruction **of the 1956-built Kakhovka dam** with the dam's ~18 km^3 upstream reservoir **resulted in flood waters being emptied from the Dnieper river into cities, villages and agricultural areas downstream with far-reaching humanitarian, environmental and economic impacts.**

The dam collapse was tracked by cloud-penetrating SAR satellites. **Copernicus, ICEYE** (a commercial SAR satellite operator and contributing mission to the Copernicus Programme) **and other EO data has been extremely useful to map the extent of the reservoir level decrease upstream and flooding downstream.**

Figure 17: Left image: Image before the dam breach; blue colour shows water, white colour shows land. Right image: ICEYE flood insights product after the dam breach; blue colours show extent and depth of flooding (darker blue = deeper water).

From an agriculture point of view, while the immediate consequence of flooded fields will certainly affect crop yield for the 2023 season, there are **significant further reaching implications**.

Draining flood waters have swept away **dislodged landmines that can now no longer be tracked and may endanger future agricultural activities.** Mud and other debris are **covering and contaminating fields and agricultural facilities** even once flood waters have receded, subsequently requiring **extensive clean-up efforts and recultivation**, which are complicated by ongoing military activities and Russian occupation of territories particularly South of the river.

In addition, the reservoir originally fed a series of **irrigation canals, with over 12,000 km length in total**, particularly critical for the agriculturally extremely important Kherson Oblast. Dropping reservoir water levels also imply **reduced or completed disrupted availability of water** in the canals, further complicating or prohibiting agricultural activities in corresponding areas.

Furthermore, the upstream Kakhovka Reservoir is experiencing drastically reduced water levels, resulting in large-scale fish die-offs with corresponding implications for fisheries and food chains.

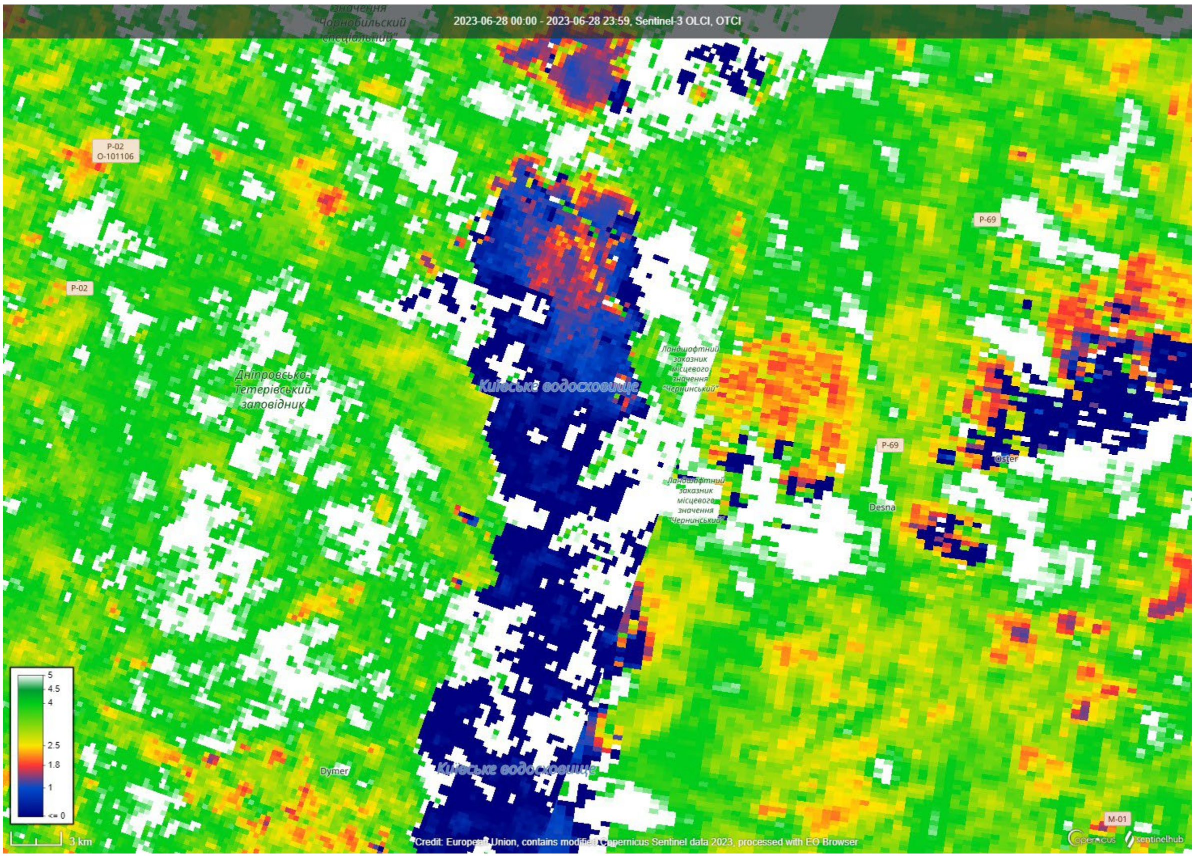
EO data and analysis such as that facilitated by Finnish ICEYE will be a valuable tool in order to map the extent of the affected areas and **estimate their economic impacts in order to efficiently and effectively direct international aid and mobilise solutions**.

3 BENEFITS OF COPERNICUS AND OTHER EARTH OBSERVATION DATA

3.1 EO data including Copernicus supported impact analyses

EO is a useful tool and can be applied by different types of entities involved in alleviating the impacts of the war. Understanding agricultural indicators as discussed is helpful in **assessing where to direct humanitarian aid while maintaining large scale spatial coverage without the need for extensive physical in-person assessments on the ground**.

EU Space data and in particular Copernicus Sentinel-1 and Sentinel-2 images were crucial to enable the impact analysis above. First and foremost, the fact that Copernicus data are governed by the principle of **free, full, open data access ensures maximum impact and reach of the missions,** particularly considering financial circumstances linked to war and humanitarian crises. Satellite EO data can **quickly capture insights across large areas** (regions, nations and cross-national focus areas) and **revisit** these at **regular intervals without the need to be on the ground**. A **combination of different sensors** (e.g., SAR from Sentinel-1 vs. optical from Sentinel-2) as well as data from the CCMs **ensures a variety of insights can be derived at adequate resolution depending on the use case**, and gives options for redundancy / validation as well as some level of **continuity and day / night as well as weather independence** in terms of data collection.



Data sources: Copernicus Data Space Ecosystem

Figure 18: Terrestrial chlorophyll index from Sentinel-3 can give insights into crop development. Credit: European Union, contains modified Copernicus Sentinel data 2023, processed with EO browser.

Other Copernicus information, such as Sentinel-3 optical data can be useful too. **Sentinel-3 captures a larger range of spectral bands compared to Sentinel-2 and has a higher revisit rate** (can monitor some parts of the world almost daily), but at lower ground resolution (300 m), and can also be used to derive NDVI and similar metrics linked to agricultural applications (e.g. global coverage vegetation products released in near real time).

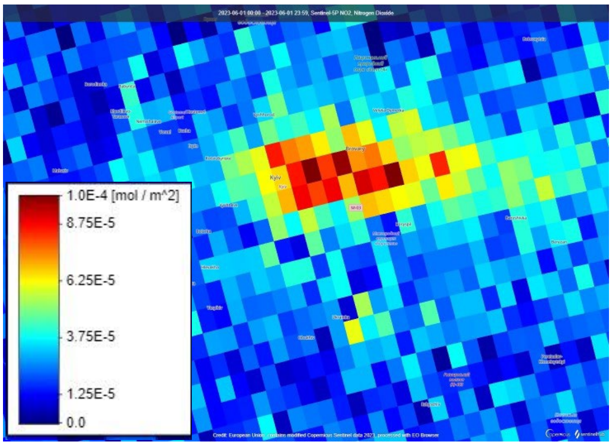
Similarly, **EO data in general can be utilised to identify areas of agricultural activity; categorise and monitor such activities; analyse variations over weekly, seasonal, annual and decadal timescales; detect changes in land use; determine agricultural parameters and estimate output**; as well as to **generate risk and recovery maps**; among others. Such insights support agricultural supply chains, policy makers and enforcing entities alike, as evidenced by the quote below.

"The precise estimation of the [Copernicus-derived] predicted yield per region enables detailed and assured planning of the harvest and crop storage. These insights will strengthen food security and the Ukrainian export potential." (Mariya Yaroshko – Deutsch-Ukrainischer Agrarpolitischer Dialog - German-Ukrainian agricultural policy dialogue – with regards to Vista Ypsilon EO product provision).

Future satellite missions will further expand these capabilities. The HPCMs or Copernicus Expansion Missions will include the **Copernicus Hyperspectral Imaging Mission (CHIME) to provide insights via a novel hyperspectral instrument** at additional wavelengths and with a spectral resolution that Sentinel-2 and 3 cannot achieve. These additional capabilities will enable **enhanced insights into crop and soil properties**, for example. Similarly, the HPCM **ROSE-L will utilise SAR at a different frequency** compared to Sentinel-1 in order **to penetrate vegetation, snow and ice and to give insights regarding soil moisture** and other parameters that will further improve our understanding of agricultural and enable precision farming, for example.

3.2 Copernicus capabilities beyond agriculture

The products and services enabled by Copernicus data are not just limited to agriculture, but have a much wider reach. When determining the **capability of an EO satellite system for a given application, the image resolution characteristics, overall spatial extent / swath width, revisit rate, and the regions of the electromagnetic spectrum and radiometric resolution** have to be considered.



Data sources: Copernicus Data Space Ecosystem

Figure 19: Atmospheric NO_2 measurements from Sentinel-5P showcase higher concentrations (yellow and red colours) near Kyiv. Credit: European Union, contains modified Copernicus Sentinel data 2023, processed with EO browser.

The **variety of sensors onboard** the Sentinels / CCMs (e.g., optical/radar, spectrometers, altimeters) combined with varying temporal and spatial resolutions allows for a large number of applications to benefit from the data, ranging from scientific research into the physical domains of the planet (land, ocean, atmosphere) through to emergency management / defense & security as well as commercial applications. Based on this, the six Copernicus Services provide a **value-add layer on top of the basic imagery**. In war situations, non-agricultural applications of Copernicus and other EO capabilities range from **measuring of environmental impacts of the war to monitoring infrastructure, or other activities from space.**

The **Sentinel-5 Precursor (Sentinel-5P) TROPOspheric Monitoring Instrument (TROPOMI) has been used to measure air**

pollution in various regions of Ukraine[12]. TROPOMI's measurements of nitrogen dioxide (NO_2) and carbon monoxide (CO) are two of the main gases measured when determining pollution levels linked to industrial activities, and are available e.g., through the Copernicus Atmospheric Monitoring Service (CAMS). Thanks to the very high temporal resolution (Sentinel-5P covers the territory of Ukraine daily), Copernicus observations could be directly compared to events on the ground. In this way, the **data retrieved from Copernicus has shown an elevated atmospheric pollution after missile hits and wildfires near the front-line**.

Additionally, Ukrainian researchers used different Copernicus services. For example, CAMS in combination with CLMS and specifically the Copernicus Global Land Service (CGLS) was utilised to **assess possible fire risks in Ukraine**.[13] The study served to create a detailed map with the potential zones most proned to having fire events in Ukraine, which can be useful to create risk assessments also linked to war.

To assess the damage linked to war in Kyiv, images from Sentinel-1, and Sentinel-2 before and after a potentially destructive event or episode were analysed[14]. The results of this study showed detection of structural damage closely aligned with the reference commercial images, particularly for larger buildings. These findings underscore the promising capabilities of **publicly accessible medium-resolution satellite imagery for swift, high-level damage mapping** and delivering initial reference data in the immediate aftermath of a disaster, with potential to not just apply to buildings but also to other infrastructure (e.g., roads).

Moreover, researchers have used **CEMS to create a realistic assessment of what might happen to buildings if the Kyiv hydroelectric plant had a breach**.[15] In this case, as the plant had already been targeted by rockets a model was built using data from CAMS to accurately reproduce the evolution of flows in a dam failure. The study showed how advanced numerical methods combined with data offered by **Copernicus can help to better predict the impact of potential hazards, enabling not just the assessment of impacts of past events but also preparing for future eventualities**.

Key messages:

- Copernicus capabilities through Sentinels and Copernicus expansion missions are useful to derive enhanced agricultural and environmental parameters (e.g, linked to crop and soil properties).
- Other example applications of assessing the impacts of war include air quality analyses and damage mapping.

[12] Savenets, M., Osadchyi, V., Komisar, K., Zhemera, N., & Oreshchenko, A., (2023). Remotely visible impacts on air quality after a year-round full-scale Russian invasion of Ukraine. Atmospheric Pollution Research, 14(11), doi: 10.1016/j.apr.2023.101912.

[13] Kussul, N.; Fedorov, O.; Yailymov, B.; Pidgorodetska, L.; Kolos, L.; Yailymova, H.; Shelestov, A. Fire Danger Assessment Using Moderate-Spatial Resolution Satellite Data. Fire 2023, 6, 72. https://doi.org/10.3390/fire6020072

[14] Aimaiti, Y.; Sanon, C.; Koch, M.; Baise, L.G.; Moaveni, B. War Related Building Damage Assessment in Kyiv, Ukraine, Using Sentinel-1 Radar and Sentinel-2 Optical Images. Remote Sens. 2022, 14, 6239. https://doi.org/10.3390/rs14246239

[15] Sánchez-Linares, C., Macías, J., and Castro Díaz, M. J.: HPC in Rapid Disaster Response: Numerical simulations for hazard assessment of a potential dam breach of the Kyiv cistern reservoir, Ukraine, Galileo Conference: Solid Earth and Geohazards in the Exascale Era, Barcelona, Spain, 23–26 May 2023, GC11-solidearth-18, https://doi.org/10.5194/egusphere-gc11-solidearth-18, 2023.

4 ENABLING ACTIONABLE INSIGHTS FROM SPACE

4.1 Enablers & innovators facilitate uptake of EO capabilities

Key agencies and innovators in Europe and on the global stage are supporting the utilisation and uptake of EO capabilities in order to improve assessment and mitigation of the impacts of war on the Ukrainian agricultural and other sectors.

Worldbank and other international organisations facilitate EO R&D and subsequent application

The World Bank and other international organisations **provide key foundations to enable the research and development (R&D) of EO applications**. For example, the World Bank provides **financial support and funding for projects that utilise EO data** to address development challenges, and offers **technical assistance and capacity building programmes** to help countries and institutions to effectively leverage EO technologies. The quantitative impact analysis presented above was supported by World Bank funding, and additionally strengthened by the availability of econometric analyses of the impact of war that helped to account for any non-war related drivers of observed variations of agricultural indicators (such as meteorological factors).

The Joint Research Centre (JRC) – the European Commission's science and knowledge service – **develops methods, tools and systems for use within agricultural monitoring, as well as relevant technical guidance**. The methodologies and corresponding output including crop yield forecasting contribute towards **policy management** (e.g., for the common agricultural policy) and inform the **development of aid activities** (e.g., related to potential crop shortages and implications for food security).

Similar organisations either facilitate R&D through project funding or by providing technical tools, methods and data. These efforts further contribute to innovation and ultimately enable commercialisation and corresponding **economic impacts of EO facilitated products and solutions**.

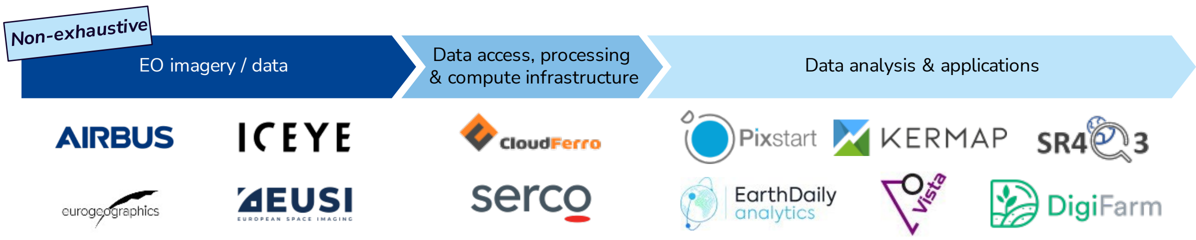


Figure 20: Overview of EUSpace4Ukraine network members linked to agricultural applications along the EO value chain.

CloudFerro provides EO data platforms and offers cloud computational services

Satellite data such as the datasets collected in the agriculture case study above needs to be processed. This can be achieved using the CREODIAS platform developed by **CloudFerro**. This **innovative cloud computing service provider** from Poland and contributor to the EUSpace4Ukraine initiative **supported the analysis above with computation resources** to **enable processing of the EO data** via bespoke machine learning algorithms. Furthermore, their eo4ua geoportal enables visualisation of Copernicus satellite data over Ukraine alongside processing results (e.g., agricultural field delineation or surface cover classification)**.** The CREODIAS platform is the first commercial element of the **new Copernicus Data Space Ecosystem, which became the main distribution hub for Copernicus data in Q4/2023.**

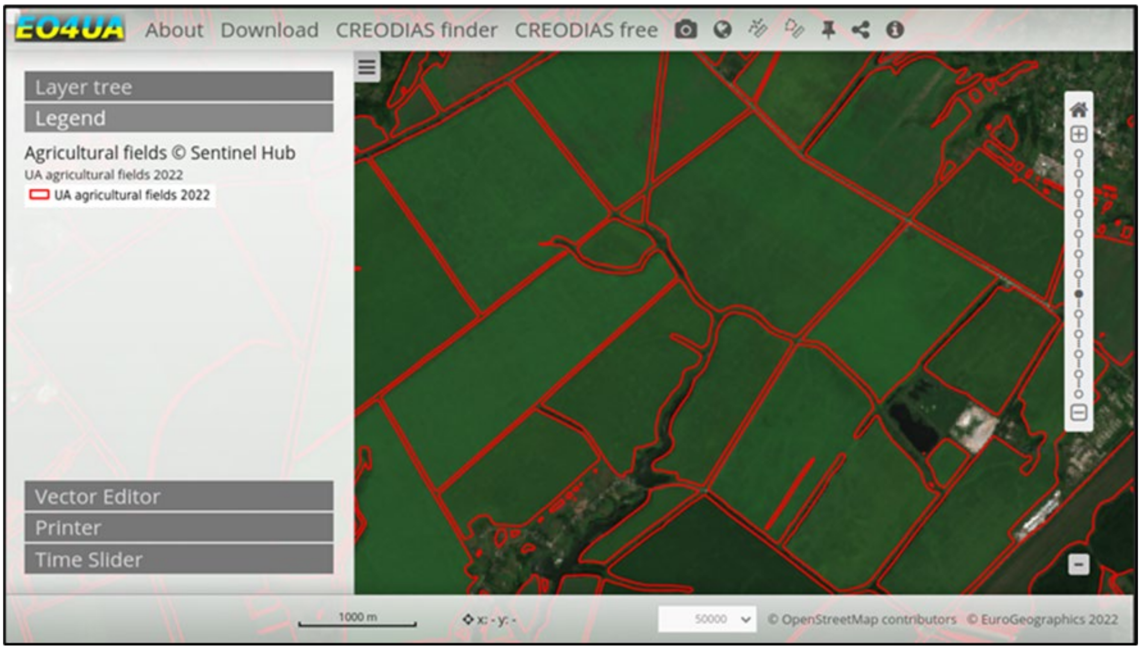


Figure 21: eo4ua geoportal shows visualisation of Sentinel Hub agricultural field delineation derive from Sentinel data.

ICEYE's SAR data provides additional insights for faster response and recovery

As a CCM, Finnish ICEYE operates a **satellite constellation that complements and contributes to the wealth of data** accumulated by the Copernicus Programme. Their small and agile SAR satellites can **revisit target areas 4-8 times per day** (in certain areas even every ~2 hours), enabling insights about short-term changes that would typically be difficult to capture particularly at larger regional scales.

SAR is weather independent and offers high-resolution imagery, with applications for direct observation and monitoring of natural disasters (e.g., wildfires or floods such as the Kakhovka dam collapse discussed above, which you can also explore in our online StoryMap here) supporting insurance and government, among others. The high revisit rate combined with the expertise of ICEYE's 24/7 global operations team allows for **near-real time detection and analysis of catastrophes, and enables rapid implementation of mitigating activities**, saving costs and potentially lives.

EarthDaily Analytics develops technologies to derive insights from EO data

The EU satellite supply chain also includes innovators who directly process EO data and derive significant metrics. Agribusiness experts EarthDaily Analytics and subsidiary EarthDaily Agro generate **agricultural insights that enable precision agriculture and farming, commodities trading and logistics, as well as crop insurance and financial risk mitigation**, among others.

Their EarthDaily Agro <geosys/> platform is utilising Copernicus Sentinel-2 (as well as Sentinel-1 and 3) and other EO data to inform initiatives in support of Ukrainian farmers including damage assessment and provide insights into critical supply chains affected by the war, for example for crops (you can explore some of their data in our online StoryMap here). By harnessing the power of EO, EarthDaily are actively monitoring crop health around the world and **detect early warning signs of production distress, so that organisations can proactively take action**.

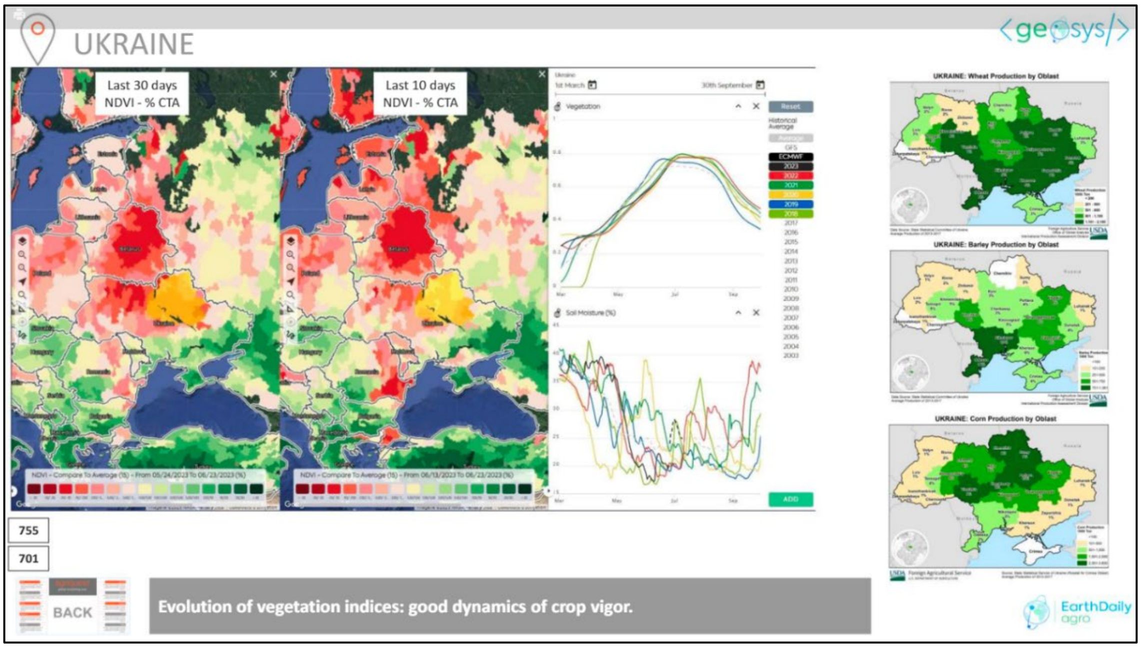


Figure 22: NDVI dashboard extracted from EarthDaily Agro's <geosys/> platform, showcasing agricultural parameters for Ukraine.

EarthDaily is also leading two initiatives for Ukrainian farmers: Farmerhood, which is inspired by a simple yet powerful principle — farmers helping farmers, and the Support Ukrainian Farmers Coalition (SUFC) providing material support to the Ukrainian Agricultural industry in conjunction with over 50 diverse farmers, NGOs, industry and governmental partners.

Kermap leverages Copernicus data for crop analytics

Similarly, French start-up Kermap have developed their Nimbo solution to facilitate **access to geospatial intelligence with a wealth of agricultural and environmental indicators derived from Copernicus** data via artificial intelligence algorithms. Through their analysis, advanced analytics on vegetation cover type and duration, heterogeneity, soil moisture, etc. are automatically estimated and delivered via visualisation platforms or API (you can explore some of their data in our online StoryMap here). With field level resolution but large scale coverage, they can enable applications ranging from **assessment of local needs to support planning and logistics all the way through obtaining regional or national market estimates**.

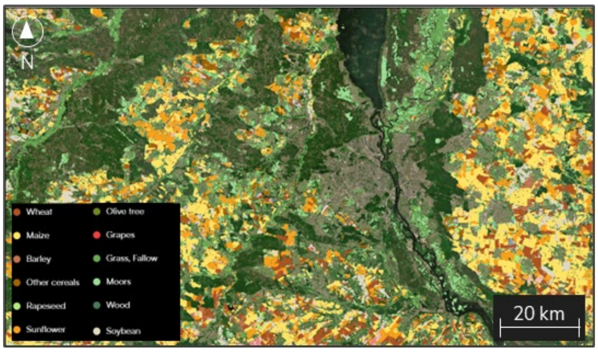


Figure 23: Example Sentinel-2-derived crop classification (only selected crops shown in legend) from Kermap Nimbo Platform.

Key message:

EU innovators are important to enable end-user Copernicus applications (e.g, by providing processing infrastructure, environmental metrics or graphical, easy-to-use web applications)

If your organisation can contribute and would like to be part of the EUSpace4Ukraine network, please get in touch via euspace4ukraine@euspa.europa.eu.

4.2 End-users utilise EO insights to inform activities

Various stakeholders and end-users within the humanitarian aid community can utilise unbiased EO derived insights to inform strategic definition of their own activities without the need to gather large amounts of data on the ground, and thus improve efficiency and implementation. Identifying locations of decreased agricultural output can enable **food charities** (e.g., the World Food Programme) to **gain insights into areas most likely needing humanitarian aid, and facilitate long-term planning of predicted availability of different crops, associated shortages and alternative sources**. Such efforts improve food security local to affected conflict zones, but also on a more regional / international level (e.g., considering common trade routes and predicted shortages).

ITF benefits from insights for de-mining activities

As an example on the user side, **Slovenian ITF Enhancing Human Security is a humanitarian, non-profit organisation specialising in the removal of landmines and unexploded ordnances** (UXOs) in the immediate aftermath of armed conflicts but also in the longer term.

Figure 24: ITF team clearing battle areas from UXOs / mines in Northeast Syria. Photo by Arne Hodalič.

Because **localised decreased agricultural output may imply inaccessibility of agricultural areas** due to mines and UXOs, EO derived estimates can serve as proxy for the need for support through organizations such as ITF, who might **utilise the insights in some cases to determine optimal deployment strategies** and decide where to direct help and when. EO datasets such as those presented in Section 2 (including field-level resolution not shown here) with **derived agricultural metrics thus provide a valuable resource to support efforts of reducing the risk of injury or death of agricultural workers and striving for long-term economic recovery by making agricultural areas safe.**

Space data helps UNDP in building sustainable food and agricultural commodity systems

Other international actors also rely on EO and more broadly space data. For example, the **United Nations Development Programme (UNDP) utlises EO insights for landscape mapping to improve understanding of regional land use** and system dynamics. EO can be used to identify the areas of strongest impact of development initiatives linked to land use or agriculture, including small or large scale estimation of yield and other indicators, and **monitoring contributes to food security**.

Similarly, EO provides an independent view on agricultural activities from space, **supporting initiatives to tackle fraud** (e.g., fraudsters claiming to be unable to continue their agricultural operations and asking for international aid). Well-designed applications utilising space capabilities can also support farming practices and improve uptake of digital or information and communications technology.

More broadly, space data supports **measuring success towards implementation of UN Sustainable Development Goals and other policy frameworks**.

Key message:

Humanitarian organisations and NGOs can benefit from utilising EU Space data and insights for clearing of war affected areas, analysing land use, ensuring food security and more.

5 CONCLUSIONS AND OUTLOOK

The analyses presented in this white paper, as part of the EUSpace4Ukraine initiative by EUSPA, has shown that **Copernicus data can help to make detailed assessments with regards to the impacts of war** on agriculture. **Decreased extent of cropland for important crops after the beginning of intensified war in 2022 can be measured with Copernicus EO capabilities and spatial and temporal correlation suggests that war directly affects agricultural activities**. Additionally, Copernicus can be useful to assess indirect effects of war on agriculture and other sectors, for example, through satellite insights on trade routes and infrastructure.

EU innovators provide expertise, infrastructure, products and services for Copernicus and general EO / satellite data derived applications. Insights from these applications can **help humanitarian organisations and NGOs to inform their activities and operations for improved efficiency and timeliness as well as detailed insights at potentially reduced risk and / or cost**.

Copernicus data are **free, open, and accessible to all, facilitating integration into a broad set of applications** – ranging from complementary insights to stand-alone EO products or services. There is plenty of scope for **future innovation based on Copernicus EO data in existing and potential new markets**.

Particularly, **combining EO with in-situ (ground data)** where / when possible as well as complementing with **EU capabilities for PNT (Galileo, EGNOS) and communications such as GOVSATCOM and future IRIS[2]** can enable a multitude of applications. For example, the analysis presented here, utilising EO data together with in-situ verification enabled crop classification and subsequent identification of areas with reduced agricultural outputs. If done at field level resolution, this analysis can help to identify key areas in need of humanitarian aid and remediation of agricultural assets. For this purpose, GNSS enabled drones can support on-the-ground surveying of specific areas, and overall in-country operations can be supported by satellite connectivity when terrestrial communications infrastructure has been damaged or destroyed.

EU EO capabilities including Copernicus can thus have a lasting impact on ensuring the safety of people in Ukraine and further afield, facilitate implementation of strategies to alleviate the impacts of the war, and pave a path towards rebuilding people's lives and supporting economic recovery.

LIST OF REFERENCES

Aimaiti, Y., Sanon, C., Sanon, C., Sanon, C., & Sanon, C. (2022). War Related Building Damage Assessment in Kyiv, Ukraine, Using Sentinel-1 Radar and Sentinel-2 Optical Images. *Remote Sensing, 14*(24). doi:10.3390/rs14246239

Copernicus Global Land Service. (2023, August 15). Retrieved from https://land.copernicus.eu/global/products/ndvi

Deininger, K., Ayalew Ali, D., Kussul, N., Shelestov, A., Lemoine, G., & Yailymova, H. (2023, February). Quantifying war-induced crop losses in Ukraine in near real time to strengthen local and global food security. *Food Policy, 115*(102418). Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0306919223000167

Foreign Agricultural Service, US Department of Agriculture. (2022). *Ukraine Agricultural Production and Trade, April 2022.*

JRC. (September 2023). *MARS Bulletin - Global outlook: Crop Monitoring European neighbourhood Ukraine.*

Kussul, N., Drozd, S., & Yailymova, H. (2023). Forecast of Yield of Major Crops in Ukraine in War Conditions 2022 Based on MODIS and Sentinel-2 Satellite Data. *Proceedings of the 11th International Conference on Applied Innovations in IT, (ICAIIT).*

Kussul, N., Fedorov, O., Yailymov, B., Pidgorodetska, L., Kolos, L., Yailymova, H., & Shelestov, A. (2023). Fire Danger Assessment Using Moderate-Spatial Resolution. *Fire, 6*(72). doi:10.3390/fire6020072

Sánchez-Linares, C., Macías, J., & Díaz, M. J. (2023). HPC in Rapid Disaster Response: Numerical simulations for hazard assessment of a potential dam breach of the Kyiv cistern reservoir, Ukraine. *Galileo Conference: Solid Earth and Geohazards in the Exascale Era.* doi:10.5194/egusphere-gc11-solidearth-18

Savenets, M., Osadchyi, V., Komisar, K., Zhemera, N., & Oreshchenko, A. (2023). Remotely visible impacts on air quality after a year-round full-scale Russian invasion of Ukraine. *Atmospheric Pollution Research, 14*(11). doi:10.1016/j.apr.2023.101912

The World Bank - Data. (2023, August 15). Retrieved from https://data.worldbank.org/indicator/SP.POP.TOTL?locations=UA

UN Food and Agricultural Organization. (2022). *Ukraine: Impact of the war on agriculture and rural livelihoods in Ukraine – Findings of a nation-wide rural household survey, December 2022.* Rome. Retrieved from https://doi.org/10.4060/cc3311en

UNHCR Operational Data Portal - Ukraine Refugee Situation. (2023, August 15). Retrieved from https://data2.unhcr.org/en/situations/ukraine (accessed 21/06/2023)

World Bank; Government of Ukraine; European Union; United Nations. (2022). *Ukraine Rapid Damage and Needs Assessment: February 2022 - February 2023.* Washington, DC: World Bank Group. Retrieved from http://documents.worldbank.org/curated/en/099184503212328877/P1801740d1177f03c0ab180057556615497

EUSPA European Union Agency for the Space Programme

LINKING SPACE TO USER NEEDS

www.euspa.europa.eu

@EU4Space

@EU4Space

EUSPA

@space4eu

EUSPA

#EUSpace