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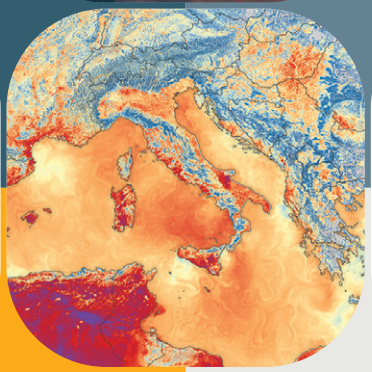
EARTH OBSERVATION HANDBOOK 2026

SATELLITE EARTH OBSERVATIONS IN SUPPORT OF ADAPTATION & RESILIENCE







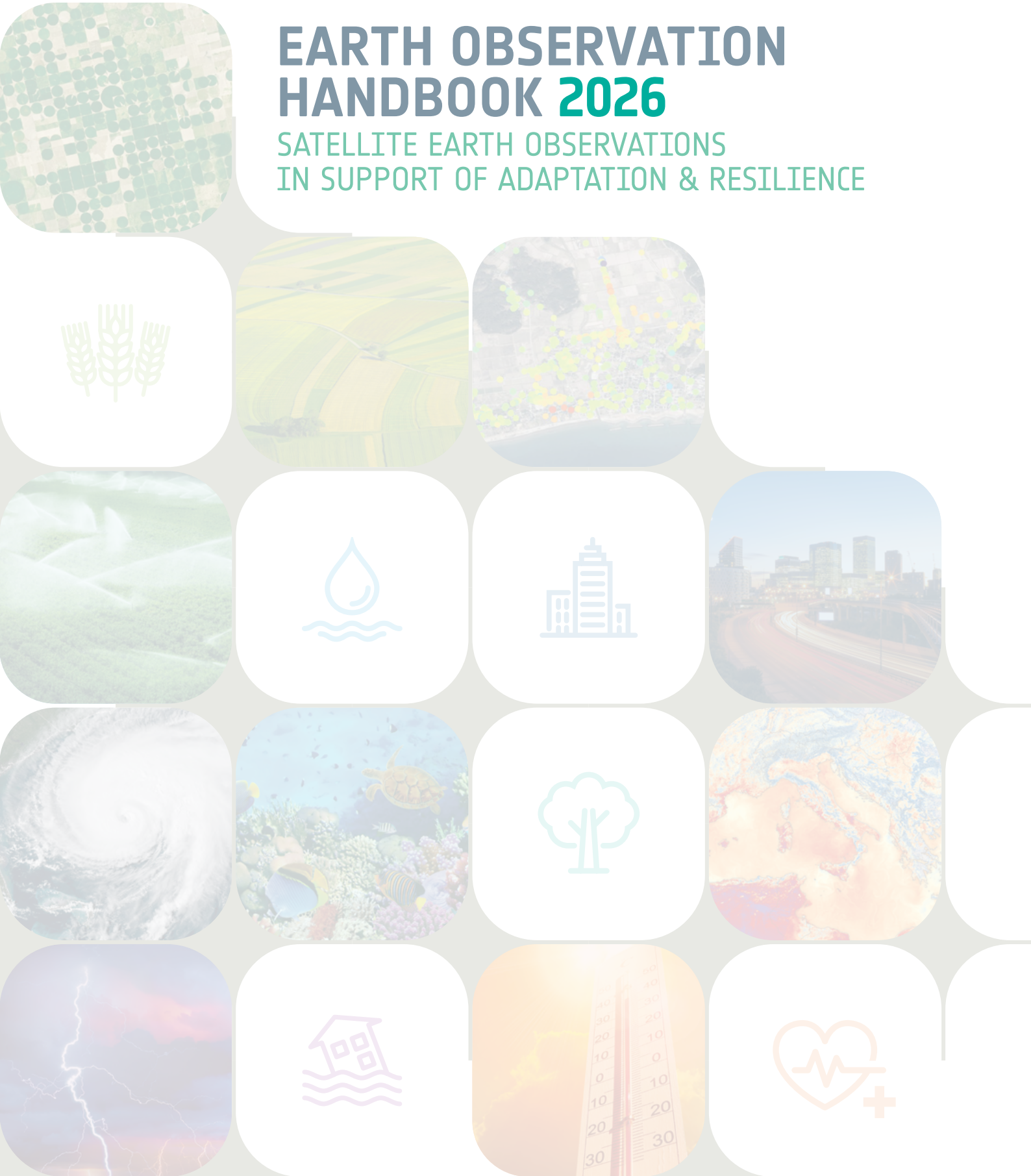


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FOREWORD

As climate change accelerates and risk landscapes evolve in unprecedented ways, the imperative to understand, anticipate and reduce disaster risk has never been greater. Because disaster risk is inherently dynamic, static maps and assessments are no longer sufficient. Earth observation satellites offer a powerful lens on our changing world, enabling near real-time monitoring of hazards such as wildfires, cyclones and floods as they evolve. In doing so, they deepen our understanding of risks and potential impacts on communities, economies and critical infrastructure.

This transformative capability makes satellite data critical to enhancing early warning and early action, as called for in the Early Warnings for All initiative. When combined with ground-based and airborne observations, local knowledge and forward-looking projections, they can support long-term disaster risk reduction and climate adaptation planning, while helping to mobilise the resources needed to act at scale. During implementation, they can also track the progress of large-scale interventions such as reforestation programmes and the strengthening of coastal defences.

I welcome the 2026 edition of the Earth Observation Handbook, with its focus on resilience and adaptation, and commend the Committee on Earth Observation Satellites for its leadership in expanding access to satellite data.

With less than four years remaining to achieve the ambitions of the Sendai Framework for Disaster Risk Reduction, I encourage disaster risk management agencies, as well as all stakeholders, to draw on this handbook to better leverage satellite Earth observations in their work.

By harnessing space-based technologies to bridge knowledge gaps on the ground, we can help countries anticipate hazards before they become disasters, thereby saving lives and livelihoods and advancing Resilience for All.



Kamal Kishore

Special Representative of the United Nations Secretary-General for Disaster Risk Reduction, and Head of the United Nations Office for Disaster Risk Reduction (UNDRR)

As the Committee on Earth Observation Satellites (CEOS), we are pleased to introduce this 2026 Earth Observation Handbook on Adaptation and Resilience.

CEOS was established to strengthen international coordination of civil space-based Earth observation activities and to promote the accessibility and effective use of satellite data worldwide. That mission is especially important in the context of adaptation and resilience. No single agency, mission or observing system can meet the full range of information needs required to understand and respond to climate risk. Through cooperation across agencies and with partner organisations, we work to ensure that satellite observations are better coordinated, more accessible and more responsive to societal needs.

Adaptation and resilience present a particularly important challenge for the Earth observation community. Unlike applications focused on a single variable or sector, adaptation requires integrated information across hazards, exposure, vulnerability, ecosystems, infrastructure and human systems. It also requires data that can support the full adaptation cycle: risk assessment, planning, implementation, monitoring and evaluation. Satellite observations, used alongside in-situ, modelled and socio-economic data, are increasingly central to this task.

This Handbook demonstrates the breadth of ways in which Earth observation can support adaptation and resilience, from drought and flood monitoring to agricultural planning, coastal management, urban heat assessment, ecosystem conservation and climate services. It also underscores a critical point: Earth observation delivers its full value only when data is translated into actionable information and integrated within decision-making and operational workflows. Delivering this depends not only on satellite capability, but also on data access, analytical tools, strong institutional partnerships, user engagement and sustained capacity-building.

Across CEOS, we are contributing to this effort through coordinated missions, open data policies, analysis-ready data, thematic initiatives, capacity development activities and partnerships with user communities and international frameworks such as the Group on Earth Observations (GEO). Our shared challenge is not simply to observe the planet, but to ensure that observations help societies anticipate risk, reduce vulnerability and build resilience.

We commend all those who contributed to this Handbook and see it as an important example of how the global Earth observation community can support practical action on one of the defining challenges of our time.



Simonetta Cheli

Director of Earth Observation Programmes
European Space Agency (ESA)



Alex Held

CSIRO Chief Scientist Earth Observation and AquaWatch.
CEOS Chair for 2026

PART I



01

Introduction

The Committee on Earth Observation Satellites (CEOS) Earth Observation (EO) Handbook has a long and proud history highlighting the role of satellite EO in support of society's greatest challenges and opportunities. This 2026 edition focuses on the central role of satellite EO in helping society address adaptation and resilience at all scales in the face of varied and increasing hazards and risk conditions.

The role of satellite EO in adaptation and resilience can be understood through the hazards, environmental changes, and risk drivers which need to be measured, monitored, and addressed. *Hazards* encompass a wide range of processes, singular and chronic phenomena, and human activities that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. These include biological, climatic, environmental, geophysical, hydrometeorological, and technological hazards, many of which are increasing in frequency, intensity, or complexity. Risk emerges through the interaction of hazards, exposure, and vulnerability, each of which is shaped by environmental, social, economic, and institutional conditions. Multi-hazard events may involve compounding or cascading impacts, such as a landslide which then results in a toxic waste spill or increased fuel loads for wildfires. Many contemporary risks emerge not from isolated hazards alone, but from the interaction of pressures across interconnected systems.

EO allows for long-term measurement and monitoring of hazards and their drivers. For example, observational records indicate that global mean near surface temperature has increased by approximately 1.26°C above pre-industrial levels (1850–1900 baseline). This magnitude of warming is associated with measurable changes in climate-related hazards, including more frequent and intense heat events, shifts in precipitation patterns, increased likelihood of heavy rainfall episodes in many regions, and accelerating sea-level rise driven primarily by thermal expansion and cryospheric melt. These changes interact with existing social, environmental, and economic vulnerabilities, reinforcing the need for EO-informed adaptation and resilience planning.

Other examples of hazards and their drivers that can be measured by EO include: development and urbanisation patterns that may alter land use and cause heat island effects; water stress and drought leading to salinisation, subsidence, and resource conflicts; economic changes such as inflation eroding community resilience; biodiversity loss disrupting ecosystem services; and constraints on mobility that reduce adaptive capacity, particularly during geohazards. Every hazard that becomes a disaster highlights the need for informed adaptation, resilience planning and risk management in our society.

Adaptation is the process of adjustment to actual or expected hazards, including evolving climatic conditions and associated impacts, in order to moderate harm or exploit beneficial opportunities. Adaptation involves a wide range of reactive and proactive actions aimed at lowering risk by reducing exposure and vulnerability to hazards and increasing adaptive capacity. The transboundary and cascading nature of risks increasingly demands effective adaptation at multiple scales, including the global level.

Resilience refers to the capacity of systems - natural, built, economic, and social - to withstand disturbances, maintain essential functions, and

recover efficiently under conditions of stress, uncertainty, and environmental and climatic change. In the context of rising hazard risk, resilience encompasses absorptive capacity (withstanding shocks), adaptive capacity (adjusting to evolving conditions), and, where necessary, transformative capacity (reconfiguring systems to remain viable over the long term). While adaptation often targets specific hazards or sectors, resilience strengthens the underlying robustness and flexibility of interconnected systems across local, national, and global scales.

The 2026 EO Handbook seeks to provide a broad understanding of the importance of satellite EO for all stakeholders in these processes. EO is uniquely suited to support adaptation and resilience because risk is inherently spatial and dynamic. Satellite EO data provide consistent, repeatable, and globally comparable measurements of key environmental variables across local to planetary scales, including surface temperature, atmospheric and soil moisture, vegetation condition, land deformation, surface water extent, sea level, smoke, volcanic ash, land use and land use change including urban expansion. This synoptic perspective enables objective risk assessment, early warning, long-term trend analysis, and performance monitoring of adaptation interventions. Crucially, EO data transcend administrative boundaries, supporting coordinated responses to transboundary and cascading risks, while its continuity and standardisation allow decision-makers to track change over time and evaluate whether resilience-building measures are delivering measurable outcomes.

The Handbook also provides practical examples and pointers for further investigation so that the potential of the data available from our EO satellites is fully realised. We hope to help the reader understand the power of the data, where to find it, and how to begin to learn to apply and benefit from it.

CEOS provides a broad framework for international coordination on space-borne EO missions. In 2026, CEOS membership comprises the majority of civil EO programmes internationally, amounting to 34 space agency Members, complemented by a further 32 Associate Members that include major data users and scientific bodies.

Part I of this Handbook explains the role of EO in support of adaptation and resilience, including in relation to relevant international frameworks:

- the various ways in which geospatial data, including EO, can support the different stages of the adaptation process;
- the role of CEOS as the coordination body for civil space agency EO programmes globally;
- other international activities advancing adaptation and resilience on all scales;
- some of the opportunities and challenges ahead for EO data to have maximum impact in support of society's needs in these areas.

Part II comprises a global case study atlas, featuring powerful stories from around the globe from diverse users and diverse usage of EO satellite data on all scales, in support of their adaptation and resilience challenges and ambitions. Each of these articles is intended to be a stand-alone narrative and they may be read in any order. It is hoped that readers might find inspiration and resources for further study relevant to their own information needs and obligations. The web version at eohandbook.com features a larger number of stories and more multimedia content to help convey these stories.

02



Adaptation and Resilience

2.1 Introduction

Adaptation and resilience can be understood through the lens of risk. This Handbook draws upon a risk framework to illustrate the value of EO for adaptation and resilience. Risk arises from the interaction between three elements: hazard, exposure, and vulnerability. Hazards - such as extreme heat, heavy precipitation, drought, tropical cyclones, and sea-level rise - become harmful when they intersect with exposed populations, infrastructure, economic assets, and ecosystems, and where underlying vulnerability limits the capacity to anticipate, cope, recover or adapt. Risk is the potential for adverse consequences for human or ecological systems, arising from the interaction of hazard, exposure, vulnerability, and societal responses.

This framing distinguishes between drivers of physical change and the socio-economic conditions that shape impacts. While the magnitude and frequency of certain hazards are projected to increase under sustained warming, exposure and vulnerability are shaped by policy choices, development pathways, and institutional capacity. Figure 2.1 summarises the widely adopted climate risk framework with the stages of the adaptation cycle, which can be applied to a multitude of hazards. Exposure reflects the presence of people, assets and ecosystems in harm's way; vulnerability captures the sensitivity and capacity of those systems to cope or adjust; and response to hazards will also impact and change risk. Adaptation seeks to influence this risk equation. By reducing exposure, lowering vulnerability, or strengthening adaptive capacity, decision-makers can reduce overall risk even where hazards intensify.

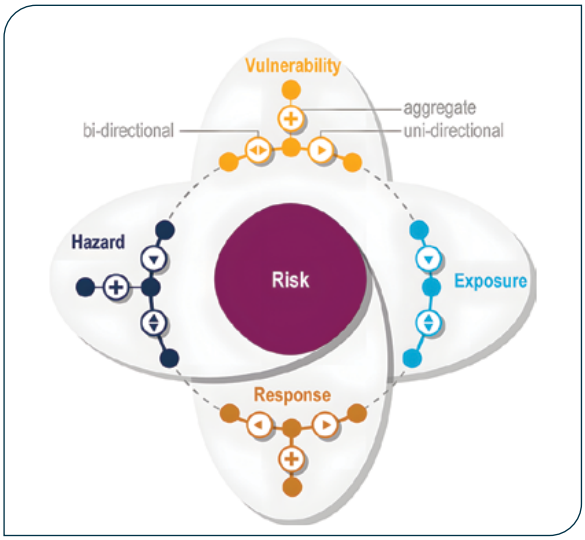


Fig. 2.1 A representation of a risk framework illustrating risk as arising from the interaction between hazard, exposure and vulnerability (Simpson et al., 2021; IPCC, 2022)

2.2 The Adaptation Cycle

International coordination efforts have recognised that effective adaptation depends on a continuous and structured process of decision-making. This process typically unfolds in four stages:

Impact, Vulnerability, and Risk Assessment: This stage establishes the evidence base. It involves identifying hazards, mapping exposure, assessing vulnerability, and evaluating current and future risks. The objective is to understand where and why impacts occur, and how they may evolve over time. This stage establishes the baseline from which adaptation decisions are made. It also provides the evidence required to prioritise sectors, regions, and communities at greatest risk.

Planning: Based on the risk assessment, authorities develop adaptation strategies, policies, and investment plans. This includes prioritising actions, allocating responsibilities,

integrating adaptation into sectoral policies, and aligning with national development goals. A number of countries have developed *National Adaptation Plans (NAPs)* in support of this stage.

Implementation: At this stage, planned measures are executed. This may include infrastructure upgrades, ecosystem restoration, regulatory reforms, social protection and early warning measures, or capacity-building initiatives. Implementation translates strategy into concrete risk-reducing action. Implementation capacity is often constrained by finance, governance fragmentation, institutional coordination, and data limitations.

Monitoring, Evaluation, and Learning: Adaptation is iterative. Monitoring tracks whether measures are being delivered and whether risks are changing. Evaluation assesses effectiveness and efficiency. Learning closes the loop and enables adjustment of strategies over time in response to new information, emerging risks, or unintended consequences.

In practice, these stages are not sequential or one-off. Risk conditions evolve as climatic hazards intensify, socio-economic patterns shift, and new information becomes available. As a result, adaptation is best understood as a continuous governance cycle. Risk assessment informs planning; implementation generates new data and experience; monitoring reveals emerging vulnerabilities; and learning feeds back into revised assessments and updated priorities. The quality of adaptation therefore depends not only on the strength of individual measures, but on the coherence and responsiveness of the overall decision-making system.

EXAMPLE THE NETHERLANDS DELTA PROGRAMME

To illustrate the real-world application of these adaptation cycle stages, consider the following example of the Netherlands Delta Programme. The Delta Programme protects the Netherlands against high water and flooding, ensures there is enough fresh water, and contributes to climate-resilient and water-robust planning for the country. The experience of the Netherlands illustrates how the adaptation cycle can operate in practice at national scale. Faced with long-term sea-level rise, river flooding, and storm surge risk, the country institutionalised a structured and iterative approach to climate adaptation through the Delta Programme.

Impact, Vulnerability, and Risk Assessment: The Netherlands has undertaken extensive hydrological modelling and flood risk mapping to assess present and future hazards, including sea-level rise scenarios and river discharge projections. Detailed exposure assessments quantify populations, economic assets and critical infrastructure located below sea level or in flood-prone areas. Vulnerability analysis considers dyke standards, drainage systems, and socio-economic sensitivity. This comprehensive risk assessment establishes long-term risk baselines extending to 2050 and 2100.

Planning: Based on this assessment, the Delta Programme developed adaptive pathways that identify sequences of measures under different climate scenarios. Planning integrates flood protection standards, spatial planning reforms, freshwater availability strategies, and nature-based solutions such as the "Room for the River" approach (reducing water levels by giving rivers more space to expand safely during high discharge events). The programme is embedded within national legislation, with a dedicated Delta Commissioner and long-term investment framework.

Implementation: Implementation includes reinforcement and heightening of dykes, construction of storm surge barriers, redesign of river landscapes to increase flood storage capacity, and spatial planning measures to reduce exposure in high-risk zones. Investments are phased over time so they can be adjusted as climate conditions change.

Monitoring, Evaluation, and Learning: The Delta Programme publishes annual reports to parliament assessing progress, risk developments, and emerging uncertainties. Hydrological monitoring systems track sea levels, river discharge, and subsidence. This continuous monitoring informs periodic reassessment of adaptation pathways, ensuring that measures remain proportionate to evolving risk.



Fig. 2.2 Oosterscheldekering: part of the Delta Works that protects the Netherlands against flooding (Attribution: Dietmar Rabich / Wikimedia Commons / "Vrouwenpolder (NL), Oosterscheldekering -- 2022 -- 5023" / CC BY-SA 4.0)



Fig. 2.3 Room for the River Nijmegen: the most complex project within the Room for the River programme. In addition to water management measures such as the creation of a bypass channel with inlets, dyke lengthening, and nature development, this unique project involved the construction of three new bridges. (Attribution: H+N+S Landscape Architects)

2.3 Resilience

The ultimate objective of the adaptation cycle is the enhancement of resilience: the capacity of communities, ecosystems, infrastructure systems, and economies to withstand shocks, absorb disturbances, recover from impacts, and, where necessary, transform in response to changing conditions. Resilience can emerge from the cumulative effect of adaptation decisions over time, if those decisions are well informed and not maladaptive. Where exposure is reduced, vulnerability lowered, and adaptive capacity strengthened, systems become more robust and better able to manage uncertainty.

Resilience is not simply resistance to disruption, nor does it imply avoiding all impacts. Rather, it reflects the ability of systems to maintain, or quickly regain, essential functions under stress and to reorganise effectively when conditions change. This may involve redundancy in critical infrastructure, diversity in livelihoods, institutional flexibility, strong social networks, and access to timely information. These characteristics enable systems to cope with variability while preserving core services and reducing the likelihood of cascading failures across sectors.

Resilience also has a temporal and structural dimension. Short-term coping capacity during extreme events differs from long-term adaptive capacity to manage gradual climatic shifts such as sea-level rise or increasing temperatures. As risks intensify, incremental measures may no longer suffice, and resilience may require more fundamental changes in land use, infrastructure

design, ecosystem management, or economic systems. In this sense, adaptation describes the actions taken to reduce risk, while resilience describes the condition that results – the sustained ability of systems to function, recover, and evolve under uncertainty and disruption.

In the example of the Netherlands Delta Programme, the country reduced the probability and consequences of catastrophic flooding. Resilience has been improved not only through physical protection, but through institutional continuity, long-term investment frameworks, and systematic monitoring that enables periodic reassessment of risk. EO has supported the resilience of the Delta Programme by providing long-term and spatially consistent observations of sea-level rise, land subsidence, river dynamics, land-use change and coastal conditions. These observations support ongoing risk assessment, infrastructure planning, and periodic reassessment of adaptation pathways as environmental and hazard conditions evolve.

03



The Role of Satellite EO

3.1 The Value of EO for Adaptation and Resilience

Satellite EO provides a unique capability to monitor environmental conditions relevant to adaptation and resilience consistently across national boundaries and over long time periods. Many of the variables that drive or identify hazards can be measured directly from space, enabling systematic observation of the Earth system at different scales.

Because satellite observations are collected using consistent measurement techniques across large geographic areas, they also enable the development of **globally comparable environmental indicators**. The key features of satellite EO in this context are:

Objectivity: Satellite-based measurements and derived data products follow strict quality standards. Products are generated using multiple instruments or sensors, and the data is centrally curated, calibrated, validated, and publicised.

Repeatability: The nature of satellite-based EO, where orbital position of the satellite and the field of view of the instrument are well controlled, means that they are repeatable and comparable over time and location.

Coverage: EO satellites have a range of configurations which enable them to provide local, national, regional to near-global coverage and measurements can be retrieved over remote and inaccessible areas which would otherwise be difficult to monitor through ground-based techniques.

Data continuity and long-term archive: The satellite era of data now spans several decades up to 60 years with some key variables being monitored by multiple sensors over space and time. Continuity of observations (across different satellite instruments) is an essential aspect of satellite missions despite being a non-trivial task to do. This allows the scientific community to gain expertise with the systems and to develop and refine approaches for environmental indicator methodologies with EO data. A long-term continuous, well maintained data archive is particularly important for chronic hazards, such as climate change, as it allows for quantifying trends in atmospheric and surface property changes at climatologically significant time scales in addition to observing variability at shorter time scales, thus establishing the baseline for monitoring change under historical and future adaptation measures.

Availability: EO data are collected by a large fleet of satellites operated by numerous national and intergovernmental space agencies and a rapidly growing number of privately owned constellations.

As of 2026, around 150 satellite missions are in active service provided by CEOS space agencies and many of these have free and open data archives for exploitation of their data. These datasets provide the basis for consistent and spatially comprehensive information that underpins scientific understanding of change and supports decision-making. This availability, continuity, and coverage of EO data is not only essential for monitoring resilience, but enhances the resilience of the observing system itself.

3.2 EO across the Adaptation Cycle

When integrated with models, ground observations and socio-economic data, satellite EO can be a powerful tool for informing adaptation and resilience decisions. Satellite EO supports multiple stages of **adaptation and resilience**. EO data contribute strongly to the **risk assessment stage**, where hazards, environmental trends, and exposure patterns must be understood. They also play an important role in **monitoring and evaluation**, where long-term environmental observations allow changes in climate conditions and ecosystem responses to be tracked over time. **Planning and implementation** decisions typically involve additional socio-economic and governance factors that cannot be observed directly from space, nevertheless satellite data provide an essential environmental evidence base that informs these decisions.

Figure 3.1 illustrates how EO data can support each stage of the adaptation cycle.

The relative contribution varies across stages: EO is particularly influential in the risk assessment and monitoring and evaluation phases, where environmental observations are fundamental to understanding hazards and tracking environmental change. In the planning and implementation stages, EO plays an important role by informing decision-support tools, spatial analysis, and early warning systems.

Impact and Risk Assessment

The first stage of the adaptation cycle focuses on understanding changing risks by analysing hazards, exposure, and vulnerability. Satellite observations provide key inputs to this process by enabling systematic monitoring of environmental variables relevant to hazards. Atmospheric and ocean observations support the monitoring of phenomena such as temperature extremes, precipitation patterns, tropical cyclones, and sea-level rise, while land surface observations provide information on soil moisture, vegetation health, snow cover, and water availability.

These datasets allow scientists and decision-makers to identify emerging risks and to assess how environmental conditions are evolving over time. For example, long-term satellite records of sea-level rise derived from radar altimetry missions provide essential information for coastal risk assessments, while satellite soil moisture observations contribute to drought

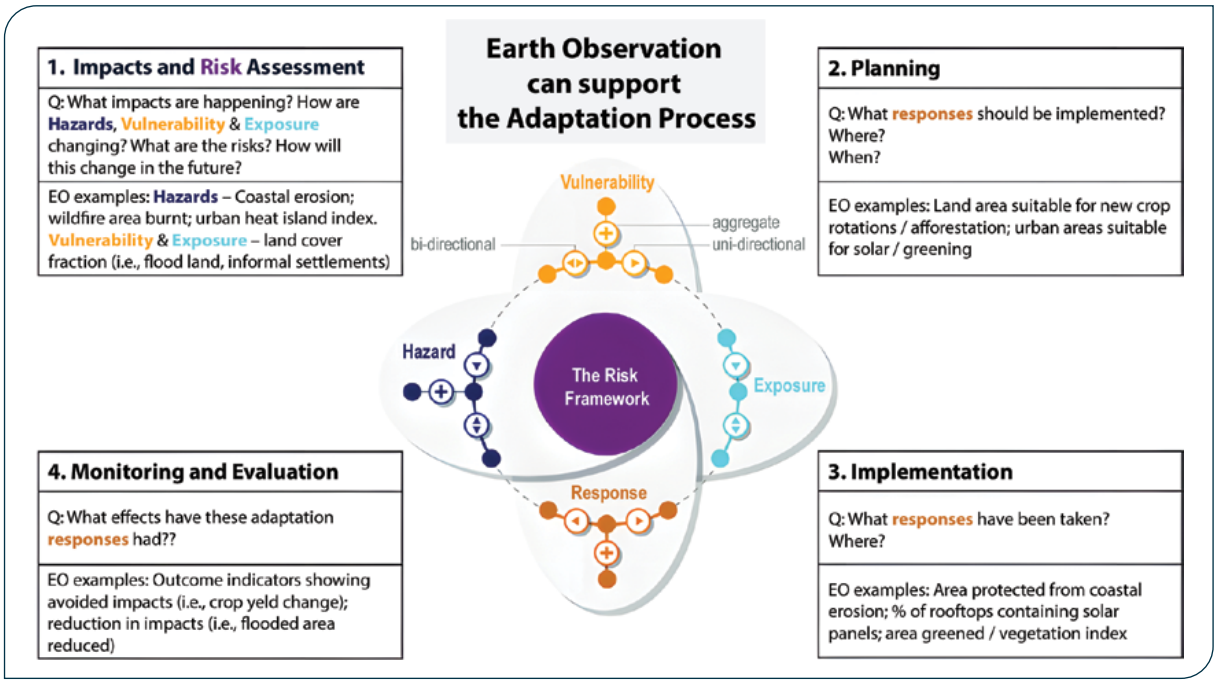
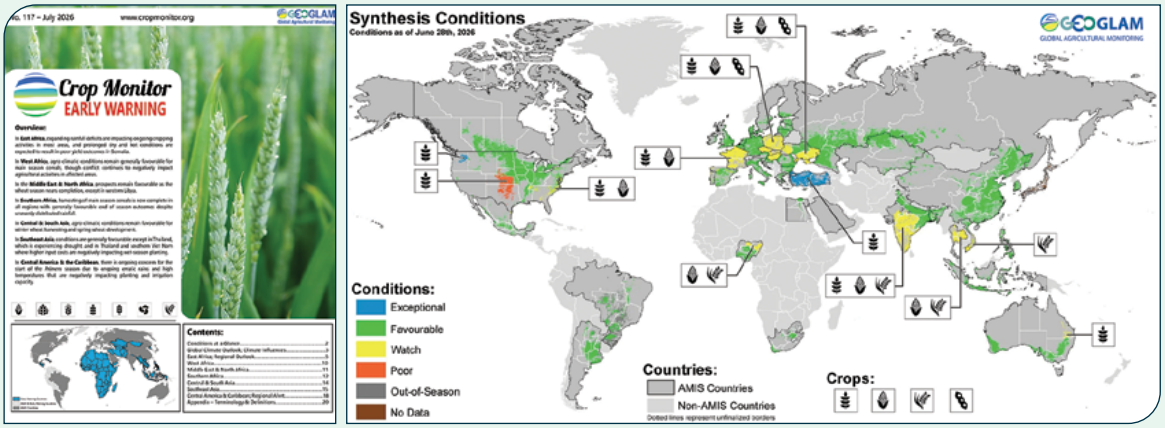


Fig. 3.1 An overview of the adaptation cycle and examples of the potential for EO to support at different stages (Connors et al, 2025)

EXAMPLE

GEOGLAM'S MONTHLY CROP MONITOR BULLETIN

GEOGLAM's Monthly Crop Monitor Bulletins detail in-season crop conditions and anticipated yield outcomes in the context of global food supply and production. Satellite soil moisture anomalies are used by GEOGLAM to confirm emerging drought conditions affecting crops. During the 2022 Horn of Africa drought, satellite-derived soil moisture anomalies were used to confirm severe agricultural drought conditions affecting sorghum and maize production. https://geoglam.org/



monitoring systems used, for example, in agricultural risk management. Products derived from missions such as NASA's Soil Moisture Active Passive (SMAP) satellite and ESA's Soil Moisture and Ocean Salinity (SMOS) mission provide near-global information on soil moisture conditions. These datasets are used by organisations including the Famine Early Warning Systems Network (FEWS NET), Group on Earth Observations Global Agricultural Monitoring (GEOGLAM) Crop Monitor, and national agricultural agencies to identify emerging drought conditions and anticipate impacts on crop production and food security. By providing spatially comprehensive observations across national territories and regions, EO data enable consistent mapping of hazard exposure and environmental change.

Planning

During the planning stage, governments and institutions translate risk assessments into strategies, policies, and investment plans. Satellite EO contributes to this stage primarily through spatial analysis and environmental monitoring, helping planners understand where adaptation measures may be most effective.

High-resolution satellite imagery allows planners to identify settlements, infrastructure networks, and agricultural areas located in hazard-prone zones such as floodplains or low-lying coastal regions. EO-derived land cover and land use datasets also help assess ecosystem conditions and identify areas where nature-based solutions – such as wetland restoration or improved land management – may reduce risk.

Satellite data are therefore frequently used within geospatial planning tools, environmental models, and climate risk maps that support national and regional adaptation planning processes, including the development of NAPs.

For coastal regions, one example is the use of satellite altimetry missions (including TOPEX/Poseidon, Jason-1/2/3, and the recent Sentinel-6 Michael Freilich mission) to produce multi-decadal records of global sea-level change to a high precision. These datasets (a long-term cooperation between the CEOS agencies CNES, ESA, EUMETSAT, NASA, and NOAA) have become a key evidence base for coastal adaptation planning, helping governments and researchers assess long-term trends in sea-level rise and evaluate future flood risks in

vulnerable coastal zones. For example, coastal monitoring programmes in countries such as the Netherlands, Bangladesh, and Australia incorporate satellite altimetry data alongside tide-gauge observations to inform flood risk assessments and coastal protection strategies. The Netherlands Delta Programme explained in Section 2 integrates satellite altimetry observations with tide-gauge records and hydrodynamic modelling in their *Sea Level Rise Knowledge Programme* to assess long-term sea-level trends and future coastal flood risk and to guide long-term investment in flood defences, spatial planning, and coastal management.

Implementation

Although implementation decisions often depend on institutional, financial, and governance factors, EO data can support the delivery of adaptation measures in several ways. Satellite observations contribute to operational monitoring systems, including flood monitoring, drought early warning, and wildfire detection services. These systems allow authorities to anticipate emerging hazards and respond more effectively. Radar satellites, for example, can map flood extent during extreme rainfall events even under cloud cover, while meteorological satellites continuously track the development and movement of severe weather systems. Such capabilities form an important component of early warning systems and disaster preparedness efforts.

Monitoring and Evaluation

The final stage of the adaptation cycle involves assessing whether adaptation and resilience measures are effective and how risks are evolving over time. Satellite observations are particularly valuable in this stage because they can be prepared in such a way that they provide long-term, consistent environmental records that allow changes in hazard drivers to be tracked over decades.

An important challenge in the monitoring and evaluation of adaptation actions is attribution – determining whether observed changes in environmental or societal outcomes can be linked to specific adaptation measures rather than to broader climatic or socio-economic trends. For many *Essential Climate Variables* (see below), satellite observations extend back

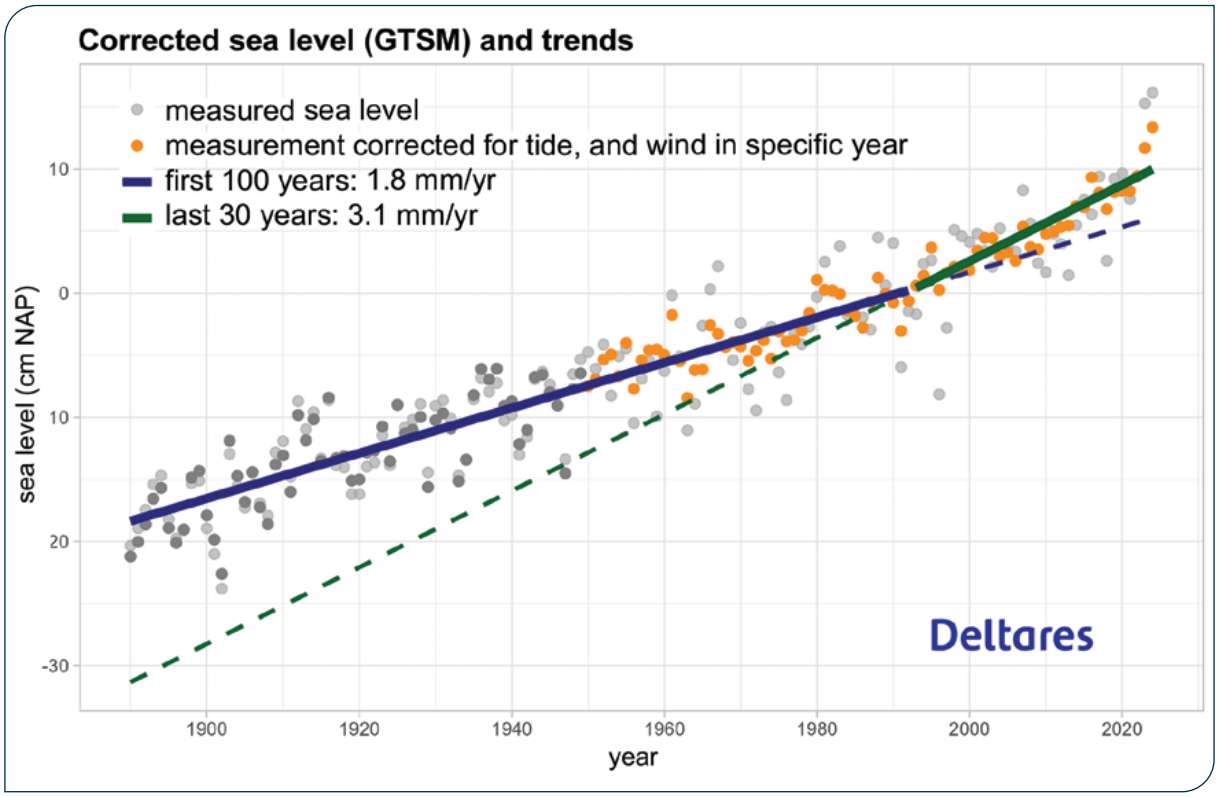


Fig. 3.2 Based on tide gauge monitoring data, the annual average water levels off the Dutch coast show a faster increase in recent years. The sea level rise from the early 1990s compares well to satellite observations. (Deltares Sea Level Monitor 2022)

decades, allowing trends in surface temperature, vegetation condition, water availability, and sea level to be analysed over long time periods. In many cases, adaptation actions aim to reduce exposure to hazards or mitigate environmental impacts, such as reducing flood risk, improving water management, or lowering heat stress in urban environments. To determine whether these measures are successful, environmental and societal conditions are compared before and after the intervention while accounting for broader variability.

Attribution of adaptation outcomes rarely relies on satellite data alone and involves in-situ measurements, socio-economic data, and modelling approaches in order to interpret observed changes and identify their underlying causes. For example, research examining the impacts of heat stress on human health may integrate satellite observations of land surface temperature and aerosol concentrations with ground-based measurements and demographic data to analyse relationships between environmental conditions and health outcomes. Such integrated approaches allow the assessment of both risk driver changes and the effects of adaptation measures.

3.3 Observables and Indicators for Adaptation and Resilience

One framework for identifying key observables is the *Essential Climate Variables (ECVs)* defined by the Global Climate Observing System (GCOS). These variables represent key components of the climate system required to inform all stages of the risk framework. Approximately two-thirds of the 55 ECVs can be observed using satellite instruments, including variables such as surface temperature, precipitation, sea level, soil moisture, vegetation condition, and land cover. These datasets provide consistent and spatially comprehensive information that underpins scientific understanding of our planet.

These observations can support the development of environmental indicators related to reducing risk and strengthening resilience. For example, long-term satellite measurements of vegetation productivity can reveal trends in ecosystem health, while observations of surface water extent can track changes in water availability or flood frequency. Unlike mitigation, where greenhouse gas emissions provide a clear quantitative metric, adaptation outcomes are often context-specific and influenced by multiple environmental and socio-economic factors. As a result, identifying robust indicators that can support national and global assessments of adaptation and resilience is a clear opportunity for EO observables.

Work is underway within the *Global Goal on Adaptation (GGA)* to identify indicators that can help track global progress. Many of the proposed indicators relate to environmental conditions linked to hazards and ecosystem health, including water availability, land degradation, coastal change, and agricultural productivity. Satellite EO datasets are increasingly recognised as a valuable source of information for monitoring such indicators, complementing national monitoring systems and helping to establish globally consistent reference points for environmental change. The development of these indicators presents an important opportunity to incorporate EO data and expertise into adaptation monitoring frameworks, where they can be combined with in-situ observations, socio-economic data, and modelling approaches to create a comprehensive understanding of adaptation outcomes. Incorporating EO-based indicators early in the process helps ensure that globally comparable datasets are available to all countries and reduces the difficulty of introducing EO methodologies at later stages.

Satellite EO has the potential to make an important contribution to resilience and adaptation efforts by providing consistent environmental datasets that can support indicator development. Observations of variables such as surface temperature, soil moisture, vegetation productivity, land cover change, surface water extent, and sea level can provide measurable indicators of environmental conditions that influence hazards and ecosystem responses. Because these datasets are generated

using consistent measurement approaches across regions and time periods, they offer a foundation for indicators that are comparable across countries and regions.

ADAPTATION DOMAIN	EXAMPLE EO-BASED INDICATOR	SATELLITE MISSIONS/ INSTRUMENTS / DATASETS	RELEVANCE FOR ADAPTATION
Drought and water resources	Soil moisture anomaly	SMAP, SMOS, Sentinel-1, MetOp	Early identification of agricultural drought and water stress; informs crop monitoring and drought preparedness systems such as GEOGLAM
Ecosystems and land degradation	Vegetation productivity (NDVI / vegetation condition index)	Sentinel-2, MODIS, Landsat	Tracking ecosystem health, land degradation, and drought impacts; supports monitoring of nature-based adaptation measures
Coastal risk	Global and regional sea-level trends	TOPEX/Poseidon, Jason series, Sentinel-6	Supporting coastal risk assessments and long-term planning for sea-level rise and storm surge impacts
Flood risk	Surface water extent and flood inundation	ALOS, Landsat, MODIS, geostationary missions like GOES, Meteosat and Himawari series	Rapid mapping of flood extent during extreme events; supporting disaster response and flood risk management
Heat risk in cities	Land surface temperature	MODIS, Landsat, Sentinel-3, geostationary missions like GOES, Meteosat and Himawari series	Identifying urban heat island effects and supporting monitoring of urban heat adaptation strategies
Cryosphere change	Glacier mass balance / snow cover extent	Sentinel-2, Landsat, ICESat-2	Indicating changes in mountain water resources and downstream flood risk

Table 3.1 Examples of EO-based indicators. Part II of this Handbook features a global case study atlas including many of these

FURTHER READING

Group on Earth Observations Work Programme: https://earthobservations.org/our-work/geo-work-programme

GEOGLAM (agriculture & drought monitoring): https://www.geoglam.org

UNFCCC NAP Central: https://napcentral.org

WMO Climate services and early warning: https://public.wmo.int/en/our-mandate/climate

GCOS ECVs: https://gcos.wmo.int/site/global-climate-observing-system-gcos/essential-climate-variables/about-essential-climate-variables

Earth observations for climate adaptation: tracking progress towards the Global Goal on Adaptation through satellite-derived indicators: https://doi.org/10.1038/s41612-025-01251-1

04



Key Institutions and Frameworks

4.1 Introduction

The previous section has illustrated the many ways in which satellite EO can support adaptation and resilience across the stages of the adaptation cycle. However, effective use of EO data depends not only on the availability of satellite measurements but also on the international systems that coordinate, curate, and disseminate these data. This section gives examples of organisations that play a role in organising EO activities, promoting open access to data, and translating observations into usable information for adaptation and resilience decision-makers.

Three organisations are particularly important in this context: the Committee on Earth Observation Satellites (CEOS), the Coordination Group on Meteorological Satellites (CGMS, for weather satellites specifically), and the Group on Earth Observations (GEO). Together they help coordinate the global, public EO ecosystem, linking satellite-operating space agencies, governments, research institutions, and international organisations. Through these collaborative frameworks, EO datasets, analytical tools, and thematic initiatives are made accessible to a wide range of users, from national governments and scientific institutions to development agencies and local practitioners. For readers seeking to explore the practical use of EO in support of adaptation and resilience, these organisations provide key entry points to the global community, resources, and data infrastructures that underpin many of the applications discussed throughout this Handbook.

Within the UN system, where many countries choose to coordinate on adaptation and resilience, there are entities who benefit from EO coordination such as the World Meteorological Organization (WMO) and the UN Environment Programme (UNEP), as well as the Sendai Framework for Disaster Risk Reduction that promotes improved understanding of disaster risk, strengthened preparedness, and the expansion of multi-hazard early warning systems. Countries party to the Global Goal on Adaptation (GGA) of the United Nations Framework Convention on Climate Change (UNFCCC) seek to provide a framework for assessing collective global progress in enhancing adaptive capacity, strengthening resilience, and reducing vulnerability to climate change. At the national level, these objectives are operationalised through instruments such as NAPs and, increasingly, through adaptation components embedded within *Nationally Determined Contributions (NDCs)*, which define country-specific priorities, actions, and reporting processes.

At the national, sub-national, and local scales, last mile adaptation and resilience decisions are made daily. From sizing a drainage ditch to approving new zoning, local governments, companies, and emergency managers are required to address a broad range of hazards and tradeoffs, often assisted by technologically savvy boundary organisations. EO usage at this scale is often combined with other information to identify solutions to improve adaptation and resilience. Boundary organisations and applied science intermediaries translate EO data into actionable products, such as localised flood extent maps, drought monitoring dashboards, urban heat assessments, and land-use change analytics, that align with local planning cycles and regulatory requirements. By integrating EO with socioeconomic, infrastructure, and hazard data, these groups help communities tailor resilience strategies to their specific vulnerabilities and long-term development

goals. Groups such as the Philippine Disaster Resilience Foundation or the European Climate Adaptation Platform (Climate-ADAPT) routinely integrate satellite-derived products for lifeline-infrastructure monitoring, business continuity planning, and localised emergency response coordination. At the municipal scale, cities like Semarang and Surabaya in Indonesia, eThekwini/Durban in South Africa, United Kingdom county- and city-level resilience hubs (e.g., in Bristol, Glasgow, and Manchester), and the Miami-Dade County Office of Resilience use EO-driven flood mapping, heat-vulnerability modeling, and land-use change monitoring to inform resilience decisions like zoning, infrastructure upgrades, and hazard-mitigation plans. Australian resilience and emergency-management agencies (such as the New South Wales Department of Climate Change, Energy, the Environment and Water) use EO for bushfire and flood-risk planning. University-based centres, such as the University of Nebraska's National Drought Mitigation Center, serve as applied research hubs that convert EO data into tools used by city planners, water managers, and emergency responders. These organisations bridge scientific capability and local decision processes, ensuring that satellite observations directly support resilience-building actions.

4.2 Institutions and Frameworks

Below are further details of institutions and frameworks important to integrating EO with adaptation and resilience planning. The Case Studies in Part II also highlight sub-national organisations and partners who facilitate on-the-ground, last mile solutions using a wide variety of case studies.

CEOS

The Committee on Earth Observation Satellites (CEOS, ceos.org) was created in 1984 in response to a recommendation by a Panel of Experts on Remote Sensing from Space, under the aegis of the G-7 Economic Summit of Industrialised Nations Working Group on Growth, Technology and Employment. This Panel recognised the multidisciplinary nature of space-based EO and the value of coordinating international EO efforts to benefit society.

CEOS was established to coordinate and harmonise EO to make it easier for the user community to access and use data, recognising that no single programme, agency, or nation can hope to satisfy all of the observational requirements that are necessary for improved understanding of the Earth System. Since its establishment, CEOS has provided a broad framework for international coordination on space-borne EO missions. In 2026, CEOS membership comprises every significant civil EO programme internationally, amounting to 34 space agency Members, complemented by a further 32 Associate Members that include major data use and scientific bodies.

CEOS has three primary objectives:

1. To optimise the benefits of space-based EO through cooperation of CEOS Agencies in mission planning and the development of compatible data products, formats, services, applications, and policies;

2. To aid both CEOS Agencies and the international user community by, among other things, serving as the focal point for international coordination of space-based EO activities, including the Group on Earth Observations, and entities related to global change;

3. To exchange policy and technical information to encourage complementarity and compatibility among space-based EO systems currently in service or development, and the data received from them, as well as address issues of common interest across the spectrum of EO satellite missions.

CEOS coordination is implemented through a range of thematic initiatives, working groups and virtual constellations that align satellite observations from multiple agencies to

address priority environmental domains. These collaborative structures support areas such as climate monitoring, disaster risk management, carbon cycle observations, land surface change, and water resources. CEOS also promotes interoperability of data systems, common calibration and validation practices, and improved access to EO data and information products. Through these mechanisms, CEOS helps ensure that observations from multiple national satellite programmes function as a coherent global observing system capable of supporting scientific understanding, operational services, and policy decision-making.

A number of CEOS initiatives and strategies are of special relevance to adaptation and resilience:

- The CEOS Global Stocktake (GST) Strategy and accompanying GST Portal featuring projects and datasets with guidance for users.
- The CEOS Working Group on Information Systems and Services (WGISS) supports data usability for adaptation and resilience applications through interoperability demonstrators and analysis ready data guidance.
- The CEOS/CGMS Essential Climate Variables (ECV) Inventory is a comprehensive, publicly accessible database of space-based Climate Data Records (CDRs) for ECVs. Updated annually by the Joint CEOS/CGMS Working Group on Climate, it covers existing and planned data, supporting gap analysis and monitoring to ensure consistent, long-term data availability.
- CEOS Working Group on Disasters activities play a critical role in disaster risk reduction and early warning systems. These cover coordination and pilot activities on hazards such as floods, wildfires, droughts, and volcanic activity, supporting improved understanding of disaster risk and enabling rapid situational awareness during emergencies. These capabilities contribute to international efforts under the Sendai Framework for Disaster Risk Reduction, which emphasises the importance of risk-informed decision-making, early warning systems, and strengthened disaster preparedness.

CGMS

The Coordination Group for Meteorological Satellites (CGMS, https://cgms-info.org) is the international forum that coordinates the activities of space agencies operating meteorological satellite systems. Established in 1972, CGMS brings together agencies responsible for both geostationary and polar-orbiting weather satellites to exchange technical information, harmonise operational practices, and ensure continuity of critical meteorological observations. Through this coordination, CGMS helps maintain the global network of weather satellites that underpin modern weather forecasting, climate monitoring, and environmental services. These satellites provide continuous observations of atmospheric conditions, cloud systems, precipitation, water- and land-surface temperature, and other variables essential for understanding and predicting weather and climate dynamics.

The operational observations coordinated through CGMS play a crucial role in disaster preparedness and early warning systems. Continuous satellite monitoring enables the detection and tracking of severe weather systems such as tropical cyclones, storms, and heavy rainfall events. Data from meteorological satellites also contribute to drought monitoring, flood forecasting, and wildfire risk assessment. In this way, the global meteorological satellite constellation coordinated through CGMS forms a key component of the international infrastructure supporting hazard monitoring, early warning, and disaster risk reduction efforts aligned with the Sendai Framework for Disaster Risk Reduction.

GEO

The Group on Earth Observations (GEO) is an intergovernmental partnership that connects governments, space agencies, scientific bodies, and user communities to improve the availability and use of EO for decision-making. In practice,

GEO's value lies in turning satellite, in situ, and modelled data into coordinated services, guidance, and capacity support that countries can apply in policy and implementation.

For adaptation and resilience, GEO has moved beyond general coordination into more targeted support for the NAP process. A notable example is its supplement to the UNFCCC NAP technical guidelines on agriculture and food security, launched in 2022. This guidance draws on GEO's agricultural community, especially GEOGLAM, and shows how EO can support crop and drought monitoring, land and water assessment, seasonal outlooks, and other information needs relevant to climate-resilient agriculture and food systems.

At the UNFCCC NAP Expo, GEO highlighted new sectoral guidance for coastal and ocean adaptation/coastal zone management, and GEO partners later developed a dedicated supplement in this area through GEO Blue Planet. GEO has also identified water resources management as a further priority for support.

WMO and EW4All

The World Meteorological Organization (WMO) plays a central coordinating role in the global meteorological enterprise, ensuring that satellite observations from international space agencies are transformed into actionable weather and climate services. WMO helps member states access the continuous, global EO coverage required to monitor rapidly evolving hazards, including tropical cyclones, floods, drought, wildfires, landslides, heatwaves, and coastal storm events.

A focus of WMO's current work is the Early Warnings for All (EW4All) initiative, a United Nations effort to ensure that every person on the planet is protected by life-saving early-warning systems by 2027. Satellite data form the observational backbone of this initiative and is showcased through a comprehensive satellite data product dashboard. Space-based sensors provide consistent global monitoring across the atmosphere, land, and oceans, offering critical inputs for hazard detection, impact-based forecasting, and real-time risk assessment.

WMO collaborates closely with CEOS, CGMS, and national space agencies to refine satellite-derived products and expand delivery systems that reduce vulnerability to emerging climate threats. This partnership framework, including from CEOS member agencies and working groups, emphasises the need to strengthen the satellite observing system, improve analysis-ready data standards, and align space-based products with EW4All priority hazards.

In addition to improving observational systems, WMO is engaged in capacity development, ensuring that national meteorological and hydrological services can transform satellite data into operational early warnings. Regional expert teams, such as the WMO Expert Team for Satellite Utilization in the West Pacific, are prioritising EW4All by training forecasters, expanding access to satellite-based hazard monitoring, and strengthening national forecasting chains in high-risk regions. CEOS and WMO are also jointly exploring ways to better coordinate product development and capacity-building activities that support EW4All and longer-term adaptation and resilience goals.

Together, these efforts illustrate how WMO and its partners are weaving satellite EO, ground-based observations, and modeling into a globally coordinated early-warning architecture. By aligning advanced space-based monitoring, national forecasting capabilities, and community-scale dissemination systems, the EW4All initiative aims to deliver more timely, accurate, and accessible warnings, strengthening resilience and adaptation around the globe.

UNFCCC and the Global Goal on Adaptation

A central element of the UNFCCC Paris Agreement (2015) is the *Global Goal on Adaptation (GGA)*, which aims to enhance adaptive capacity, strengthen resilience, and reduce vulnerability to climate change in the context of sustainable development by driving UNFCCC member country ambition. While mitigation progress can be assessed through greenhouse gas emissions inventories, measuring progress on adaptation presents a more complex challenge. Adaptation outcomes are often context-specific, vary across

sectors and regions, and involve both physical and socio-economic dimensions of risk reduction. For this reason, the GGA seeks to establish a framework through which collective progress on adaptation can be assessed at the global level while recognising national circumstances and diverse adaptation pathways.

A key challenge in this effort is the availability of reliable, comparable data across countries and regions. Adaptation outcomes often emerge over long timescales and may be influenced by multiple interacting factors, including socio-economic development, governance arrangements, and ecosystem conditions. For this reason, the GGA process places increasing emphasis on strengthening the information base that supports adaptation planning and reporting. This includes improving national monitoring systems, enhancing the integration of climate risk information into decision-making, and expanding access to environmental observations that allow hazards, exposure, and environmental change to be tracked consistently.

Satellite EO can play an important supporting role in this context. Many of the environmental variables relevant to climate risk – such as land cover change, vegetation condition, surface water extent, sea level, and surface temperature patterns – can be observed systematically from space. These observations provide globally consistent datasets that complement national monitoring systems and help establish shared reference points for assessing environmental change and emerging risks. As the GGA framework evolves, EO data are expected to contribute increasingly to the evidence base used to assess adaptation needs, monitor environmental trends, and inform indicators related to climate hazards and ecosystem conditions.

Progress on adaptation is also linked to the Global Stocktake established under the Paris Agreement. The Global Stocktake is conducted every five years to assess collective progress toward the long-term goals of the Agreement, including mitigation, adaptation, and means of implementation. The development of the GGA framework provides an important foundation for ensuring that adaptation progress can be assessed as part of this global review process. Over time, improved indicators, monitoring systems and observational datasets will help strengthen the ability of the Global Stocktake to evaluate how effectively the international community is reducing climate risks and building resilience.

Continued development of the GGA will depend on strengthening the links between observation systems, national adaptation planning processes, and international reporting mechanisms. As countries expand their NAPs and integrate climate resilience into development strategies, the demand for reliable environmental information is likely to grow. In this evolving landscape, coordinated EO systems and international collaboration on climate data will play an increasingly important role in supporting evidence-based adaptation and resilience planning worldwide.

National Adaptation Plans

NAPs are a key mechanism through which UNFCCC member countries identify medium- and long-term climate risks and integrate adaptation into national development planning. The NAP process generally follows a structured cycle that closely mirrors the broader adaptation framework. It begins with the assessment of climate hazards, exposure, and vulnerability, followed by the development of adaptation priorities and strategies. Governments then move to implementation through sectoral policies, investment programmes, and institutional reforms, while monitoring and evaluation systems are developed to track progress and inform future updates. Through this iterative process, NAPs aim to embed climate risk considerations within national planning systems, infrastructure, water management, agriculture, urban planning, and ecosystem conservation.

A key feature of NAPs is their emphasis on coordination across government ministries and levels of governance. Climate risks often span sectors and administrative boundaries, requiring collaboration between agencies responsible for environment, infrastructure, agriculture, health, and disaster management. NAPs therefore

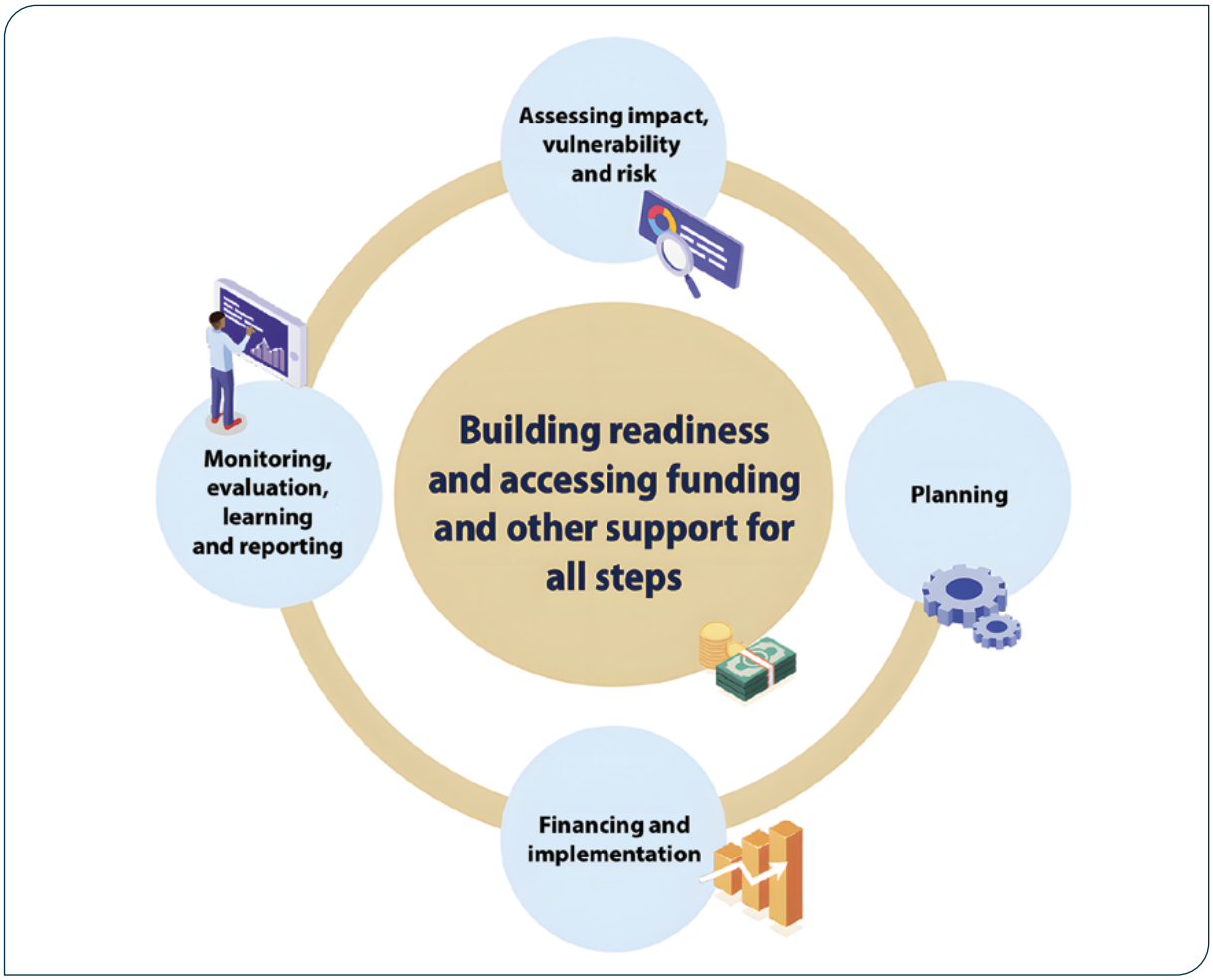


Fig. 4.1 Main modules of the NAP process (UNFCCC NAP Technical Guidelines)

help align adaptation measures with broader development goals and improve the coherence of national climate policies.

Reliable climate and environmental information is essential for effective NAP development and implementation. Satellite EO data can support many aspects of the process, including risk assessment, spatial planning, monitoring environmental change, and evaluating adaptation outcomes. By providing consistent observations of key environmental variables across national territories, EO datasets help strengthen the evidence base for adaptation priorities and investment decisions.

As of early 2026, approximately 75 developing countries had submitted NAPs to the UNFCCC, while more than 140 countries had initiated the process. This reflects the growing global effort to integrate adaptation into national development planning. These plans play an increasingly important role in informing international assessment of adaptation progress, providing national-level evidence and experience that contribute to the evolving framework for the GGA.



Fig. 4.2 National Adaptation Plans of Bangladesh and Kenya, some of the 75+ plans developed since 2015

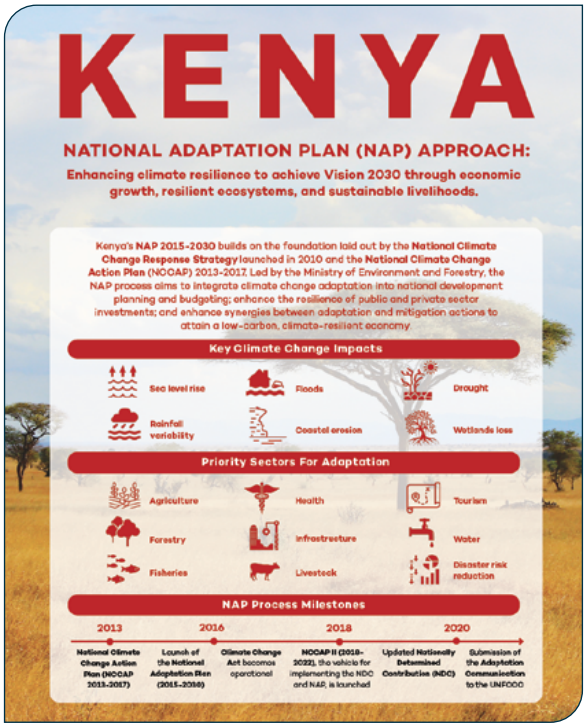


Fig. 4.3 Highlights of the Kenya NAP

Disaster Risk Reduction, Early Warning and the Sendai Framework

Climate adaptation is closely linked with disaster risk reduction, particularly in relation to extreme events whose frequency and intensity may be changing under a warming climate. A key international framework guiding these efforts is the *Sendai Framework for Disaster Risk Reduction*, adopted by United Nations member states in 2015. The Sendai Framework seeks to substantially reduce disaster risk and losses in lives, livelihoods, and infrastructure by strengthening risk understanding, improving governance arrangements, investing in resilience, and enhancing preparedness for effective response and recovery. Many of these priorities overlap directly with the objectives of climate adaptation, particularly where countries seek to anticipate and manage climate-related hazards such as floods, storms, droughts, heatwaves, and wildfires.

A central pillar of the Sendai Framework is the development of multi-hazard early warning systems that can provide timely information about emerging hazards and enable authorities and communities to take preventive action. Early warning systems typically integrate observations, forecasting models, risk information, and communication mechanisms to translate scientific data into actionable warnings. Satellite EO plays a key role in many of these systems by providing continuous monitoring of atmospheric and environmental conditions at regional and global scales. In addition to providing key observations for routine weather forecasting, meteorological satellites support the detection and tracking of severe weather systems such as tropical cyclones and major storm systems, while other EO systems monitor indicators relevant to drought, wildfire risk, flood conditions, and coastal hazards.

The same satellite observations that support early warning also contribute to longer-term understanding of hazard patterns and environmental change. By providing consistent observations across large areas and long time periods, EO datasets help identify emerging trends in climate extremes, assess the spatial extent of disasters and support post-event damage assessments. These capabilities allow governments and international organisations to better understand how risks are evolving and to refine both adaptation strategies and disaster preparedness measures. In this way, EOsystems form an important component of the global information infrastructure supporting disaster risk reduction, early warning, and resilience-building efforts aligned with the Sendai Framework.



Fig. 4.4 Sendai Framework priorities

CEOS Agency Programmes Supporting Adaptation and Resilience-From Global to Local

Across the international EO community, a number of agency-led programmes are translating satellite data into practical services that support climate adaptation and resilience. These initiatives focus not only on generating environmental information but also on ensuring that data are accessible, usable, and embedded within decision-making processes in governments, development organisations, and local institutions. Together they illustrate how space agencies are increasingly working with users to deliver operational climate information services. A number of examples for readers to explore further are presented below.

The Space for Climate Observatory (SCO) of CNES brings together space agencies, research institutions, and operational users to develop and implement projects addressing climate challenges. SCO projects apply satellite observations to areas such as coastal change, water resource management, agricultural monitoring, and urban climate risks. A key objective is to move beyond pilot demonstrations toward solutions that can be replicated and adopted operationally by public authorities and local communities. CNES has compiled an impressive project directory: https://www.spaceclimateobservatory.org/projects

ESA's Global Development Assistance (GDA) programme is implemented in partnership with international financial institutions to boost the sustainable adoption of EO services addressing development and climate challenges in regions such as Africa, Asia, and Latin America. Connecting European EO industry with development banks, international organisations, and government stakeholders, the programme co-develops EO-enabled applications in areas including climate adaptation and finance, water resource and environmental management, agricultural resilience, disaster risk reduction, clean energy, and public health, as well as transport and urban planning. A central aim is to facilitate the integration of satellite data from missions such as Copernicus into operational decision-making and impact finance processes as well as long-term policy planning in countries particularly exposed to climate risks.
https://gda.esa.int

NASA's Applied Remote Sensing Training Program (ARSET) focuses on building skills to use satellite information for environmental decision making. ARSET delivers online and in-person training to government agencies, NGOs, and technical specialists around the world, covering topics such as flood mapping, drought monitoring, wildfire risk, air quality, and agricultural monitoring. By strengthening technical skills and institutional capacity, the programme enables countries to integrate satellite data into routine environmental management and adaptation planning.
https://www.earthdata.nasa.gov/data/projects/arset

Services such as the **Copernicus Climate Change Service** provide authoritative climate datasets derived from the integration of satellite observations, in-situ measurements, and numerical modelling. These services deliver climate indicators, long-term reanalyses, and sector-specific information used for climate risk assessment, infrastructure planning, and national adaptation strategies. By providing consistent, open, and globally available climate data records, Copernicus plays a central role in supporting evidence-based climate policy and resilience planning.
https://climate.copernicus.eu

Sentinel Asia, led by JAXA in collaboration with partners across the Asia–Pacific region, provides satellite imagery and derived products to support emergency response and disaster management. The initiative enables rapid access to EO data during events such as floods, landslides, typhoons, and forest fires, while also supporting capacity building and the development of early-warning and preparedness capabilities among participating countries.
https://earth.jaxa.jp/en/application/disaster/sentinel-asia/index.html

Operational meteorological satellite systems also provide critical information for monitoring climate variability and extreme events. The **Satellite Application Facilities (SAF) coordinated by EUMETSAT** generate a wide range of environmental datasets derived from meteorological satellites. These include products related to precipitation, soil moisture, vegetation, surface radiation, and climate indicators. Facilities such as the Climate Monitoring SAF (CM SAF) and Hydrology SAF (H SAF) deliver operational data products widely used in climate monitoring, drought assessment, hydrological modelling, and early warning systems. EUMETSAT is also a major player in the Global Monitoring for Environment and Security (GMES) and Africa programme.
https://www.eumetsat.int/about-us/satellite-application-facilities-safs
http://gmes.au.int

The U.S. National Oceanic and Atmospheric Administration (NOAA) complements satellite missions with operational climate services that support adaptation and resilience. A key example is the **National Integrated Drought Information System (NIDIS)**, which integrates satellite observations, in-situ data, and modelling to provide early warning of drought conditions. NIDIS delivers accessible drought monitoring, forecasts, and decision-support tools used by governments, water managers, and agricultural stakeholders to anticipate impacts and plan responses.
https://www.drought.gov/about

FURTHER READING

Understanding the GGA: https://weadapt.org/wp-content/uploads/2025/02/UPDATED_TECHNICAL-BRIEFING_Understanding-the-Global-Goal-on-Adaptation.pdf

NAPs: https://unfccc.int/national-adaptation-plans

Sendai Framework for Disaster Risk Reduction: https://www.undrr.org/implementing-sendai-framework/what-sendai-framework

EW4ALL: https://earlywarningsforall.org/site/early-warnings-all

05



Future Challenges and Opportunities

5.1 Challenges for the Use of EO in Adaptation and Resilience

Part II of this Handbook illustrates the breadth of satellite EO applications for adaptation and resilience. However, significant challenges remain in translating these capabilities into sustained, decision-relevant services. These relate less to data availability than to usability, integration, institutional uptake, and long-term operationalisation. The challenges can be broadly grouped into three categories: translation from data to decisions; institutional and capacity constraints; and system-level integration and sustainability.

From Data Availability to Decision Relevance – The "Last-Mile" Challenge

One of the most persistent challenges lies in bridging the gap between the availability of EO data and its effective use in decision-making processes. While large volumes of satellite data are openly available and analytical platforms have lowered technical barriers to access, decision-makers require information that is tailored to specific policy questions, expressed in relevant metrics, and aligned with planning cycles and regulatory frameworks.

This "last-mile" challenge reflects the need to translate EO data into decision-relevant information products. In practice, this requires not only processing and interpretation, but also the integration of EO with complementary data sources, including in situ observations, socioeconomic data, local knowledge, and model outputs. It also requires alignment with policy and reporting frameworks, where indicators must correspond to institutional needs and decision contexts.

Without such integration and alignment, EO-derived information risks being underutilised or applied in isolation, limiting its practical relevance for adaptation planning and implementation. These challenges are explored further below in terms of institutional capacity, system interoperability, and long-term operationalisation.

Capacity and Institutional Constraints

In many countries, particularly in developing and climate-vulnerable regions, limitations in technical capacity, institutional structures, and resources constrain the effective use of EO. While global datasets are increasingly accessible, their interpretation and application require expertise in geospatial analysis, climate science, and sector-specific decision contexts. Institutional fragmentation can further limit uptake. Responsibilities for climate adaptation, environmental monitoring, disaster risk management, and sectoral planning are often distributed across multiple agencies with limited coordination. This can result in duplication of effort, inconsistent use of data, or underutilisation of available information.

Sustained capacity building is therefore essential, not only in terms of technical training, but also in developing institutional arrangements that support the integration of EO into routine decision-making processes. Short-term projects and training initiatives, while valuable, are often insufficient to establish lasting capability without long-term support and embedding within national systems.

EXAMPLE **KENYA'S NEW SPACE DATA INFORMATION CENTRE**

The Space Data Information Centre (SDIC) established under the ESA SPARKme project provides a useful example of the types of institutional and capacity-building measures needed to make EO data more usable for adaptation and resilience planning in developing countries. The project is establishing and operating an EO-focused data and information centre in Nairobi, designed to foster the utilisation of space data, expertise, and knowledge across multiple sectors including government, industry, and academia. By providing access to EO datasets, analytical tools, training programmes and value-added information products, the centre seeks to catalyse the development of new services and decision-support capabilities based on satellite data.

Initiatives such as the SDIC address several of the key barriers that often limit the effective use of EO data in developing-country contexts. While large volumes of satellite data are now openly available, the ability to translate these data into actionable information frequently depends on local technical capacity, data processing infrastructure, and sustained training. The SDIC model combines data access with human capacity development, offering technical training for students, public officials, and practitioners while supporting the development of locally relevant applications. By strengthening regional expertise and fostering partnerships between space agencies, research institutions, and local users, such centres help bridge the gap between global EO capabilities and the practical information needs of adaptation and resilience decision-makers. Over time, centres of this kind can contribute to building sustainable national and regional ecosystems for EO-based services, enabling countries to integrate satellite-derived information more effectively into climate risk assessment, planning, and monitoring processes.

The SDIC model illustrates how sustained institutional infrastructure – not just data provision – is critical to embedding EO within national adaptation systems.

Integration with Other Data Sources

EO provides a powerful perspective on environmental conditions, but effective application depends on combining it with other data sources. Technical challenges arise from differences in spatial and temporal resolution, data formats, and methodological approaches, which can complicate data fusion and analysis. Addressing these challenges requires interoperable systems, standardised workflows, and approaches that enable consistent integration across datasets, enhancing the data's resilience.

Crucially, integration must extend beyond observational datasets to include climate projections and scenario-based information on future change. While EO provides robust baselines and observed trends in hazards, exposure, and environmental conditions, adaptation planning requires an understanding of how these risks are expected to evolve or change over time. This involves combining EO-derived information with outputs from climate models, downscaled projections, and impact models to assess changes in the frequency and intensity of hazards such as floods, droughts, heatwaves, and sea-level rise.

The integration of EO with projection-based datasets enables a transition from retrospective analysis to forward-looking risk assessment, supporting the design of adaptation measures that are robust under a range of future scenarios. Without this connection, there is a risk that EO-based analyses remain anchored in historical conditions and do not fully capture the scale and dynamics of future climate risk.

Integrated indicator frameworks and methodological approaches that combine EO with other sources of evidence are essential for monitoring and evaluating adaptation effectiveness, which is inherently challenging. Adaptation involves complex, context-specific

changes in vulnerability, exposure, and resilience. EO can contribute valuable information on environmental changes but linking these observations directly to specific adaptation interventions is not straightforward. Establishing baselines, defining appropriate indicators, and accounting for confounding factors all present methodological difficulties. As a result, there remains a gap between what EO can measure and what is required to assess the effectiveness of adaptation actions.

Fragmentation of Services and Lack of Interoperability

The EO landscape is characterised by a wide range of missions, programmes, platforms, and service providers operating at global, regional, and national scales. Users may face multiple platforms providing similar datasets or services, often with differing interfaces, standards, and levels of support. This can create confusion, increase transaction costs, and hinder adoption, particularly for non-expert users.

Interoperability between systems remains uneven, and the lack of standardised workflows can make it difficult to integrate EO products into existing decision-support systems. Beyond interoperability itself, there is also a growing need for practical integration and aggregation of datasets, services, and analytical outputs across platforms and sectors. Users often require consolidated, decision-ready information rather than access to multiple separate EO products that must be combined independently. Greater coordination across agencies and initiatives, adoption of common standards, and user-oriented service design will therefore be important not only for improving interoperability, but also for enabling seamless integration of EO with climate, socioeconomic, infrastructure, and hazard data into coherent operational services.

Sustained Funding and Operationalisation

In Part II of this Handbook, we have sought to prioritise services available on a sustained basis, but a significant proportion of EO applications for adaptation and resilience are developed through research projects, pilot initiatives, or time-limited programmes. While these efforts demonstrate the potential of EO, they do not always transition into sustained operational services. Adaptation requires long-term, reliable information services that can support planning, implementation, and monitoring over extended timeframes. This, in turn, requires stable funding, institutional ownership, and integration into national and regional systems. The transition from pilot to operations is therefore a critical challenge. Without mechanisms to sustain and scale successful applications, there is a risk that valuable innovations remain isolated and do not achieve broader impact.

Alignment with International and Domestic Needs

International and domestic frameworks and investments increasingly emphasise measurable indicators of progress. A key challenge is ensuring that EO capabilities are considered early in the design of such frameworks as well as ensuring new EO capabilities are planned to deliver on societal observation needs. Where this is achieved, EO can support consistent and scalable indicators; where it is not, opportunities to leverage satellite data may be constrained and more difficult to introduce retrospectively.

Ensuring Access and Usability

While EO data are increasingly open, access alone does not guarantee usability. Differences in infrastructure, connectivity, technical capacity, and institutional support can create disparities in the ability of countries and communities to benefit from EO. Addressing these disparities requires attention not only to data provision, but also to the design of services, tools, and capacity-building initiatives that are responsive to user needs. Co-development approaches, in which users are actively involved in the design and implementation of EO applications, have shown promise in improving relevance and uptake. Ensuring equitable access to EO-enabled services is therefore both a technical and a governance challenge, with implications for the effectiveness and fairness of adaptation efforts globally.

Looking Ahead

Addressing these challenges will require coordinated efforts across the EO community,

national governments, international organisations, and user communities. Technical advances alone will not be sufficient; progress will depend equally on institutional innovation, sustained investment, and the development of user-oriented services. In this context, the role of organisations such as CEOS, GEO, and partner agencies is critical in promoting coordination, fostering capacity development, and supporting the transition from data provision to decision support. As adaptation and resilience become increasingly critical for countries and communities, ensuring that EO can effectively contribute to these efforts will remain a central priority.

5.2 Opportunities for the Use of EO in Adaptation and Resilience

Some of the above challenges are significant but some of the trends apparent around the use of satellite EO data suggest there is ample cause for optimism that some of these may be overcome. These opportunities lie not only in improved observations, but also in the ability to translate data into consistent, decision-relevant information and to embed EO within policy frameworks, operational systems, and user-driven services.

A Global, Consistent Evidence Base for Adaptation

One of the most distinctive contributions of EO is its ability to provide globally consistent, repeated observations of the Earth system. This enables the development of comparable datasets across countries and regions, supporting assessments of exposure, vulnerability, and environmental change.

Such consistency is particularly valuable in the context of global policy frameworks (see Section 4), where there is a growing need for indicators that can support the assessment of collective progress. EO-derived datasets offer a unique opportunity to underpin a subset of indicators with consistent methodologies, enabling comparability across national contexts while reducing reporting burdens. Long-term satellite records, including those associated with ECVs, further strengthen this role by providing the temporal depth required to establish baselines, detect trends, and monitor slow-onset changes such as sea-level rise, land degradation, and shifts in vegetation patterns.

Advancing Indicator Frameworks and Monitoring Systems

The increasing availability of EO data creates new opportunities to support indicator frameworks for adaptation and resilience. EO can contribute consistent measurements of hazards, exposure, and environmental conditions, complementing socioeconomic and institutional indicators.

A key opportunity lies in designing indicators that explicitly incorporate EO from the outset, enabling scalable and comparable monitoring systems. Where combined with other data sources, EO can support more comprehensive assessments of risk and resilience.

Scalable Analytics and Reduced Technical Barriers

The emergence of cloud-based platforms and Analysis-Ready Data (ARD) represents a major shift in the accessibility and usability of EO. Cloud-native infrastructures allow users to access, process, and analyse large volumes of satellite data without the need for significant local storage or computing capacity, reducing barriers to entry and enabling more efficient workflows.

In parallel, ARD products – pre-processed to a standard suitable for immediate analysis – remove the need for complex steps such as radiometric and geometric correction. Together, these developments allow users to focus on generating insights rather than managing data processing pipelines.

These advances support reproducibility, standardisation, and scalability, enabling applications to be deployed consistently across regions and institutions. As a result, EO is increasingly able to move from specialist use toward broader operational adoption in areas such as agriculture, water management, and disaster risk assessment.



Fig. 5.1 CEOS Analysis Ready Data has simplified data use for multiple product types (ceos.org/ard)

Enhanced Early Warning and Risk Monitoring Systems

EO is playing an increasingly important role in multi-hazard early warning systems, providing timely information on extreme weather, floods, droughts, wildfires, and coastal hazards. Advances in satellite capabilities, combined with improved data processing and dissemination, enable near-real-time monitoring at regional and global scales. These capabilities align closely with international initiatives such as the EW4All initiative and the Sendai Framework for Disaster Risk Reduction, both of which emphasise the importance of timely, accessible, and actionable information.

EO can support not only hazard detection, but also the monitoring of exposure and vulnerability, contributing to more comprehensive risk assessments. This creates opportunities to move from reactive responses to more anticipatory approaches, supporting preparedness and risk-informed decision-making.

User-Driven Services and Integration into Decision-Making

There is a growing shift from data provision toward user-driven services that are co-designed with stakeholders. Programmes such as the Global Development Assistance (GDA) initiative and the Space for Climate Observatory (SCO) have demonstrated the value of engaging users throughout the development process to ensure relevance and uptake.

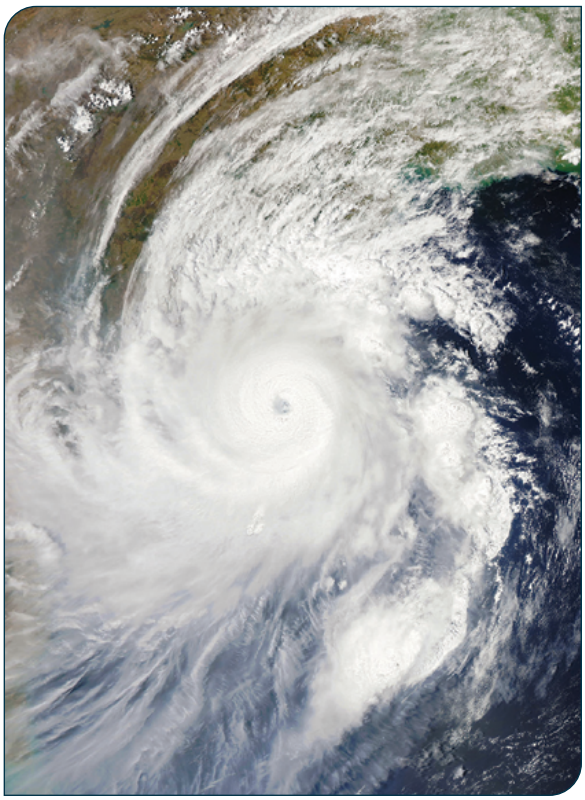


Fig. 5.2 Satellite imagery of Cyclone Fani making landfall in India on 3 May 2019

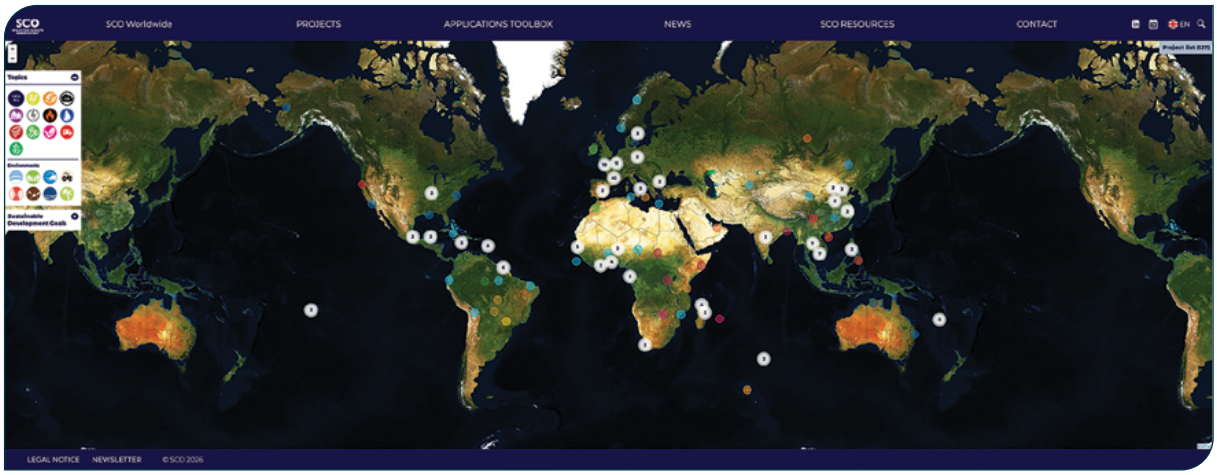


Fig. 5.3 The Space for Climate Observatory (SCO) features 118 projects in its programme (https://www.spaceclimateobservatory.org/projects)

EO is increasingly being integrated into national adaptation planning processes, climate services, and sectoral decision-making frameworks. NAPs provide a key entry point for embedding EO within structured planning systems, linking risk assessment, planning, implementation, and monitoring.

This shift toward co-designed and institutionally embedded services represents an important step from demonstration projects toward sustained, operational use of EO in adaptation and resilience.

Expanding Private Sector and Downstream Innovation

The EO ecosystem is increasingly supported by a dynamic private sector that is translating satellite data into actionable products and services. These include applications in agriculture, insurance, infrastructure, urban planning, and environmental management. Private sector involvement can drive innovation, improve service delivery, and expand the range of available applications. It can also contribute to the sustainability of EO services by creating viable business models that complement public-sector provision. Partnerships between public and private actors offer opportunities to combine strengths, leveraging public data and infrastructure with private-sector agility and user engagement.

Toward Operational, Scalable Impact

Taken together, these developments point toward a transition from a focus on data provision to the delivery of operational, scalable services that support adaptation and resilience. Advances in cloud computing, analysis-ready data, and user-driven service design are reducing barriers to use, while the growing integration of EO into policy frameworks is increasing demand for consistent and reliable information. Realising this potential will require continued attention to usability, capacity development, and institutional integration. However, the trajectory is clear: EO is increasingly well positioned to serve as a foundational component of the information systems that underpin adaptation and resilience in a changing climate.

PART II

GLOBAL CASE STUDY ATLAS

Part II: Global Case Study Atlas

Part II comprises a global case study atlas, featuring powerful stories from around the globe from diverse users and diverse usage of EO satellite data on all scales, in support of their adaptation and resilience challenges and ambitions. Each of these articles is intended to be a stand-alone narrative and they may be read in any order. It is hoped that readers might find inspiration and resources for further study relevant to their own information needs and obligations.

Each case study is labelled according to thematic area or areas, using the following legend:

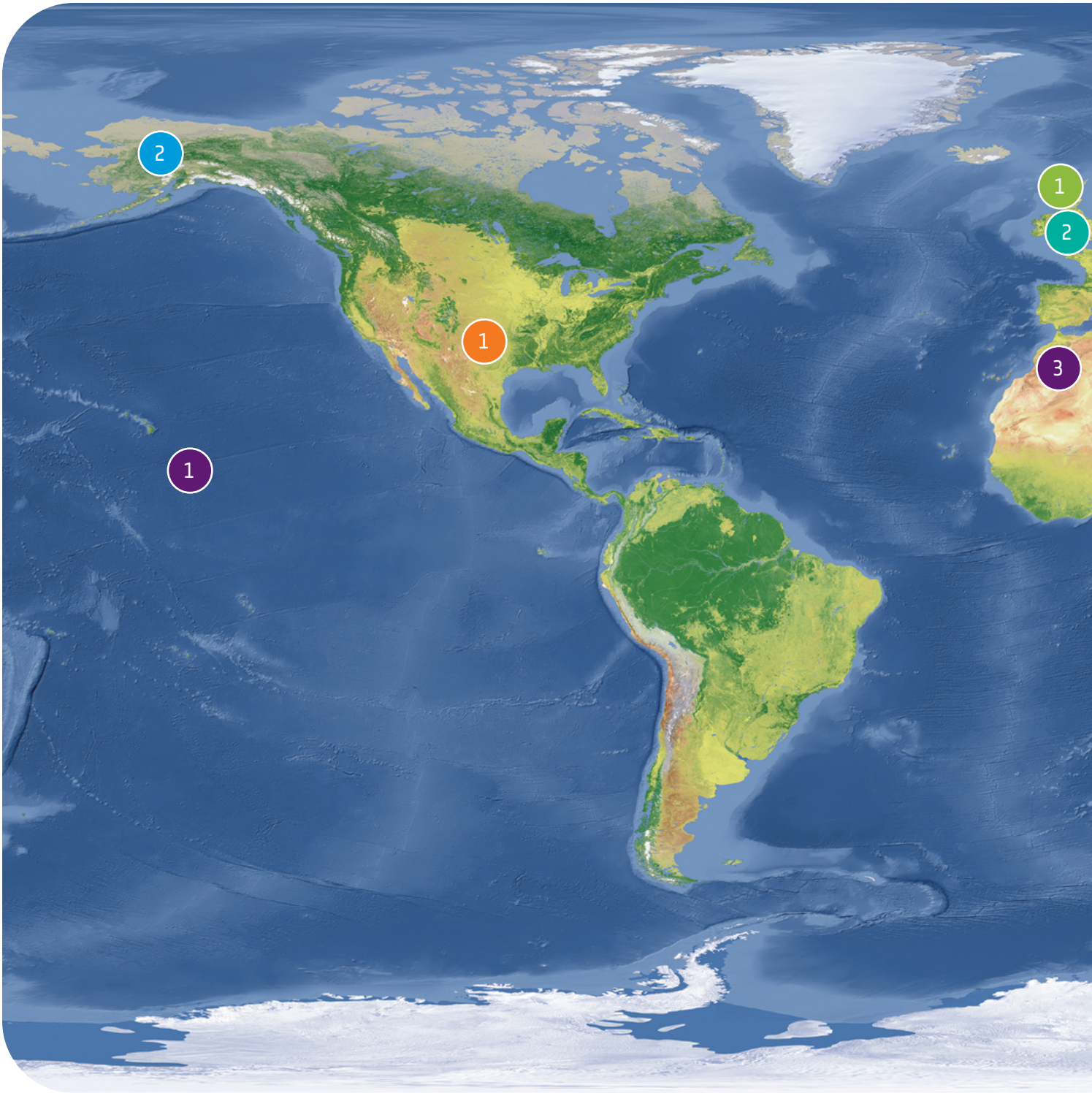
Agriculture
Disasters
Economic security & infrastructure
Ecosystems
Health and well-being
Water

Case studies are further categorised by geography, meaning the area where the projects or programmes are focused. In some cases, the scope of the service is global and the geography may indicate a typical example, or the origins of the service providers.

The emphasis in the stories is on the human dimension and impact of the EO satellite data in solving challenges for clearly identified user groups. In each case, contacts and further reading links are provided to help readers wishing to explore in more detail.

The table below provides an index to search for case studies of particular interest or for a given category. The geographic distribution is summarised in the graphic. The web version at eohandbook.com features a larger number of stories and with more multimedia content to help convey these stories.

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AGRICULTURE

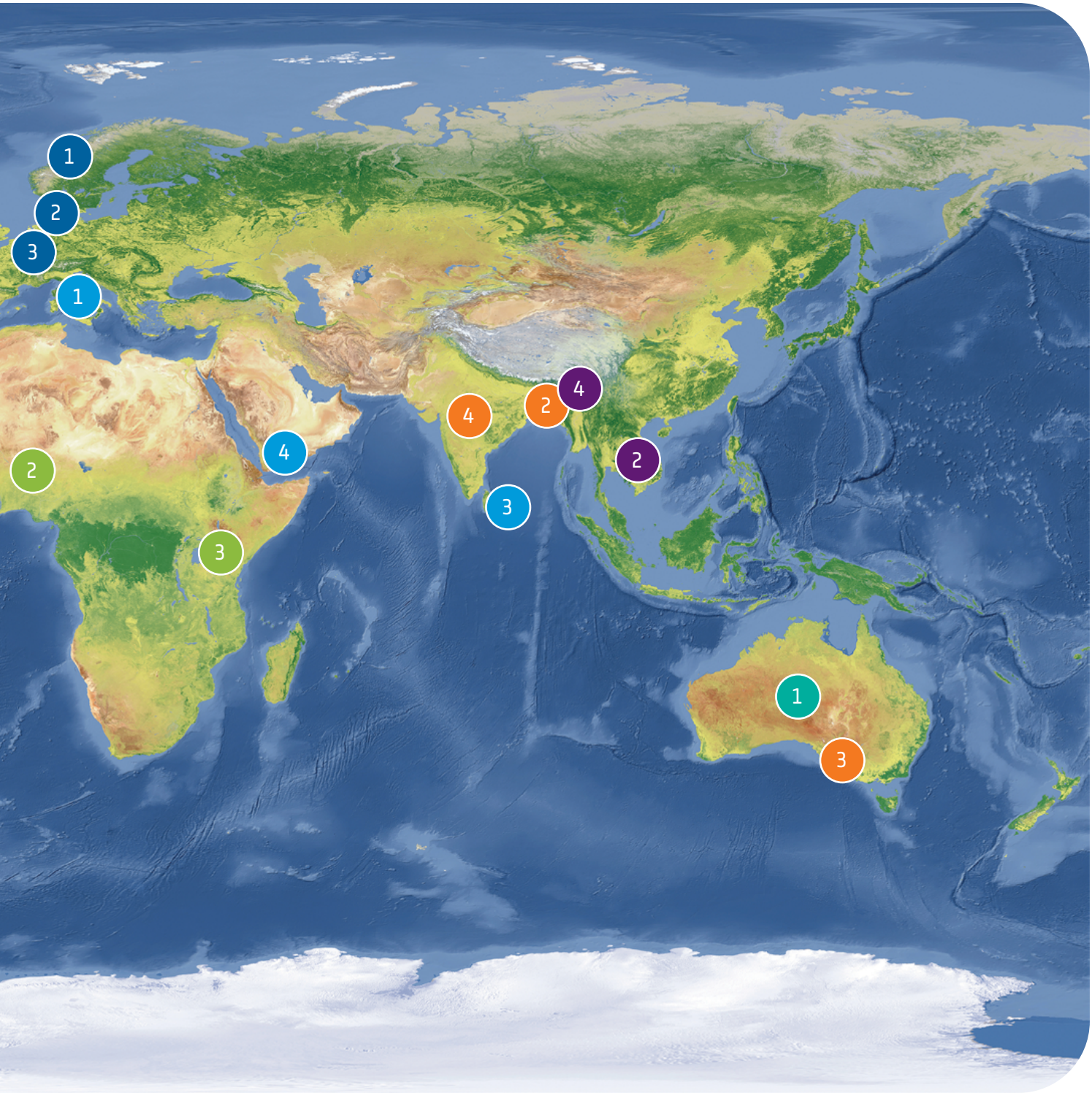
DISASTERS

ECONOMIC SECURITY & INFRASTRUCTURE

ECOSYSTEMS

HEALTH & WELL-BEING

WATER


1
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AGRICULTURE

CASE STUDIES



01

REGION: EUROPE



Grassland Modelling for Improved Utilisation

Summary

Grass is the most widely grown crop in the United Kingdom and globally, forming the foundation of livestock farming systems and rural economies. Yet managing grass growth remains one of the most time-consuming and uncertain aspects of farm management. Farmers traditionally rely on manual measurements, walking fields and recording grass height using plate meters. This process is labour-intensive, inconsistent, and often deprioritised during busy periods.

The Grassland Modelling for Improved Utilisation project, funded by Innovate UK, set out to demonstrate how Earth observation (EO) data could transform this process. By combining satellite radar imagery (C-Band SAR), atmospheric modelling, and machine learning algorithms, the project developed a system capable of measuring and predicting grass growth automatically across farms. The technology provides sub-weekly updates on pasture conditions and predicts grass growth up to two weeks in advance, enabling farmers to make informed grazing and feed management decisions.

A key innovation of the project was the mixed use of radar satellite data, which can operate reliably in cloudy conditions, and atmospheric based prediction models. This allows for proactive monitoring of grassland conditions regardless of the weather, providing farmers with consistent, timely information. EO data and atmospheric observations are combined with mechanistic models to produce an ensemble field-scale prediction supporting day-to-day farm management.

Trials conducted on farms in England demonstrated that the system could significantly improve decision-making and operational efficiency. Farmers reported time savings, reduced reliance on manual measurements, and improved confidence in managing grazing rotations. The technology enabled more precise use of fertilisers and feed resources, reducing costs while improving environmental sustainability.

The outputs of this project are now being commercialised into a service for farmers. Validation activities have recently begun in Ireland and across the EU, enabling access for a wider farming community and increasing the project's real-world impact.

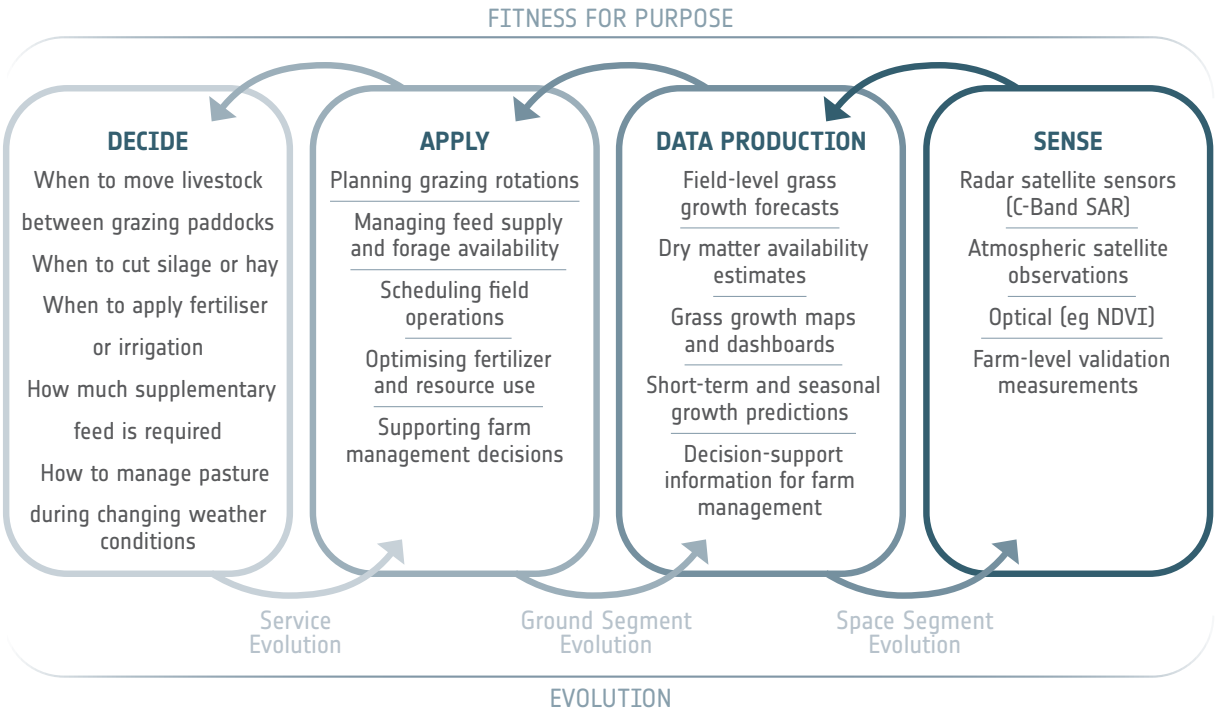
Decision-Making Context and Needs

Grass management is central to livestock farming, underpinning animal productivity while also delivering environmental benefits beyond agriculture through improved soil health, enhanced biodiversity, and carbon sequestration in grassland ecosystems.

Farmers who actively manage grass typically rely on traditional methods that involve manually walking fields and measuring grass height with a plate meter. This approach is unreliable, time-consuming and difficult to maintain consistently during busy periods, highlighting the need for more efficient solutions. As a result, farmers may miss opportunities to optimise grazing schedules or manage feed supplies effectively.

At the same time, farmers face increasing pressure to improve productivity while reducing environmental impact. Rising input costs, climate variability, and sustainability requirements have made efficient resource management more

Value Chain Diagram



important than ever. Better information about grass growth can help farmers reduce waste by being proactive rather than reactive, improve feed efficiency, and make more sustainable decisions.

The "Grassland Modelling for Improved Utilisation" project was designed to address these challenges by providing frequent, automated information about grass growth. The project aimed to demonstrate how EO data could support practical farm decisions and improve the efficiency of grass-based livestock systems.

Farmers participating in the project were particularly interested in tools that could save time and provide reliable data without requiring additional labour. By delivering regular updates on pasture conditions, the system enabled farmers to make decisions based on current information rather than assumptions.

Earth Observation Data Products and Information

The project developed a grass growth prediction system that integrates multiple Earth observation data sources with predictive modelling techniques.

The system continuously monitors grassland conditions and generates predictions that support farm management decisions. Satellite radar (C-Band SAR) imagery is used to estimate ground cover and vegetation conditions across grazing areas. Unlike optical satellite imagery, radar sensors can operate in cloudy weather, ensuring reliable data collection throughout the year. This capability is particularly important in regions where weather conditions frequently limit the effectiveness of optical remote sensing methods.

Atmospheric forecasting data is combined with satellite observations to provide medium-range (multiple weeks) predictions, which are beyond the forecast skill of traditional weather-based models. Weather variables, such as temperature, rainfall, and atmospheric conditions, influence plant growth and are incorporated into predictive models for short-range (roughly three days) predictions. By analysing these factors together, the system can estimate future grass growth rates and identify periods of rapid or limited growth.

The project also developed machine learning algorithms that analyse historical data and real-time observations to improve prediction accuracy by creating field-specific models.

These algorithms continuously refine predictions as new data becomes available, allowing the system to adapt to changing environmental conditions. The resulting insights are delivered to farmers through "traffic light" based dashboards and reports that present information in a clear, accessible format. This allows farmers to quickly understand pasture conditions and make decisions without needing technical expertise in remote sensing or data analysis.

Underlying Observations and Data Sources

The grass growth prediction system relies on a combination of satellite and environmental data from the EU's Copernicus program and farm-level data sources.

Key observations include:

- Earth Observation (C-Band SAR and optical) imagery (Sentinel-1 and Sentinel-2): Used to estimate vegetation cover and changes in grass growth across fields.
- Weather and atmospheric data ERA5/ECMWF: Provides historical and forecasted information on environmental conditions that influence plant growth.
- Historical farm data (farm provided): Includes records of grass growth patterns and field management practices.
- Ground-based measurements (farm provided): Collected during field trials to validate and refine prediction models.

These data sources are processed using predictive machine learning algorithms that identify patterns and relationships between environmental conditions and grass growth.

By combining multiple observations to create an ensemble-based model, the system produces more accurate predictions than traditional single-source, monolithic models. The integration of EO and ground-based data ensures that predictions remain reliable across different farm types and environmental conditions. This approach allows the system to be scaled to new regions while maintaining accuracy.

Impacts and Benefits

The "Grassland Modelling for Improved Utilisation" project has demonstrated clear benefits for farmers, agricultural businesses, and the wider agricultural sector.

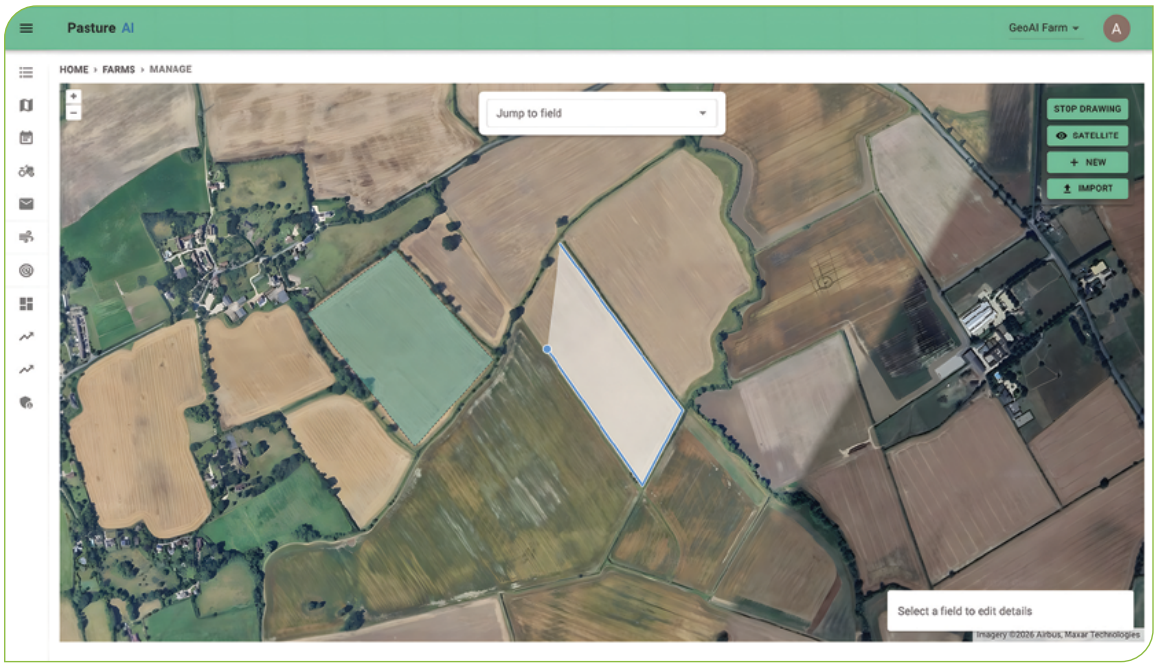


Fig. 1 Agribot Pasture AI Field Creation Interface

One of the most immediate benefits has been time savings. Farmers participating in the project reported that automated grass growth predictions reduced the need for manual field measurements, allowing them to focus on other essential tasks. This improved efficiency has been particularly valuable during busy periods such as calving and harvesting seasons.

"One of our trial farmers, Will from Derby, currently spends 8 hours a week measuring grass, the equivalent of 1 whole working day. Agribot has reduced that to a few minutes."

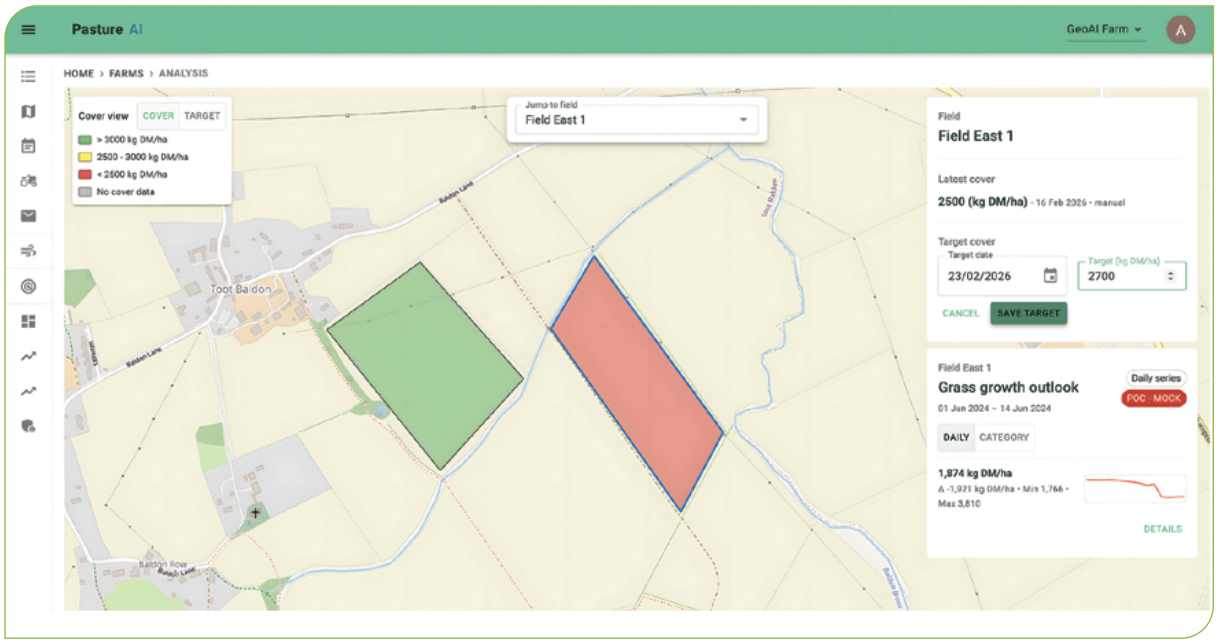


Fig. 2 Pasture AI Field Analysis Feature

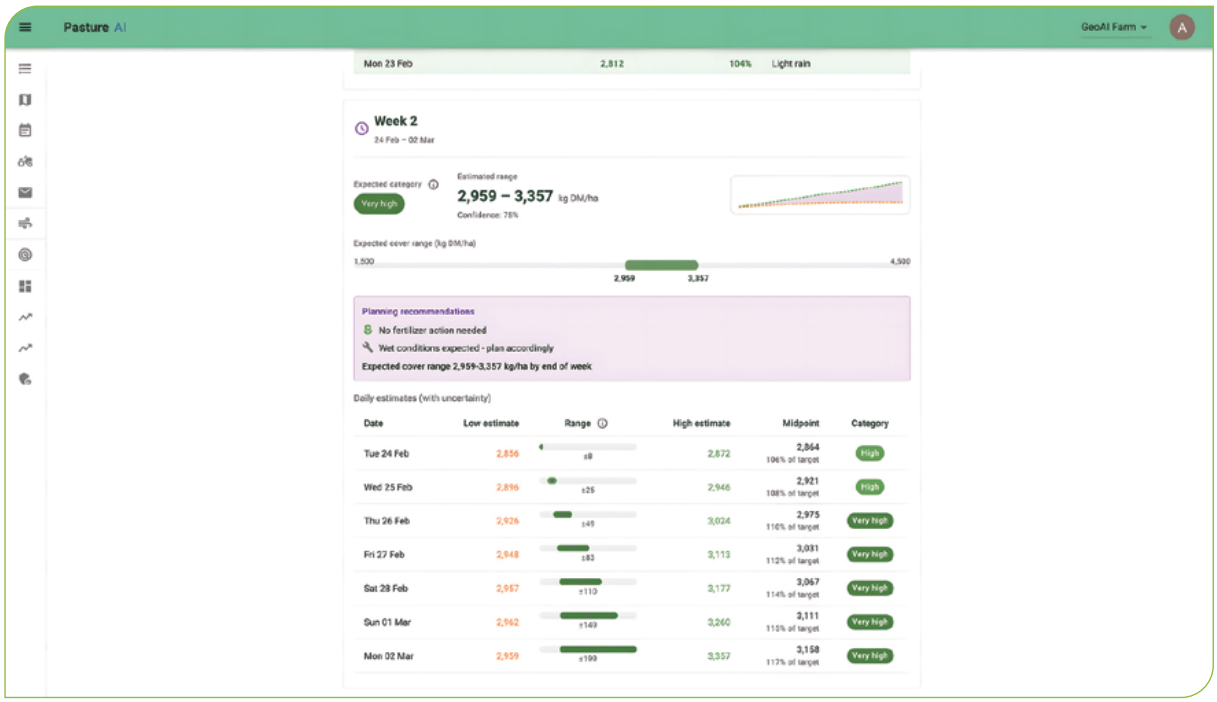


Fig. 3 Field Forecast Dashboard

The system has also strengthened resource management by providing accurate, timely information on grass availability. This enabled farmers to optimise grazing rotations, reduce reliance on purchased feed, and ultimately lower costs while improving livestock performance and overall farm financial sustainability. Environmental sustainability is a further key benefit. With more precise insights into grass growth, farmers can apply fertilisers and irrigation more efficiently, reducing waste and minimising environmental impact. Improved pasture management also supports soil health and biodiversity by preventing overgrazing and encouraging more balanced grazing patterns.

The project has also demonstrated broader benefits beyond individual farms. Accurate grass growth predictions can support supply chain planning, insurance risk assessment, and land management decisions. As the technology is adopted more widely, it has the potential to improve resilience across the agricultural sector.

Feedback from participating farmers has been overwhelmingly positive. Many reported increased confidence in managing their pastures and greater trust in data-driven decision-making. These experiences highlight the importance of practical, user-focused technologies in supporting modern agriculture.



Fig. 4 Blue Dial Farm in Allonby, an Agribot user (Attribution: Innovate UK, 'Grassland Modelling for Improved Utilisation' Project, UK Agri-Tech Centre)



Fig. 5 Agribot team members working with local farmers in Cumbria (Attribution: Innovate UK, 'Grassland Modelling for Improved Utilisation' Project, UK Agri-Tech Centre)

FURTHER INFORMATION AND GUIDANCE

Lead Organisation: Agribot AI Ltd. https://agribot.ai/ / emma@agribot.ai

Partners: UK Agri-Tech Centre: https://ukagritechcentre.com/

Podcast: https://www.youtube.com/watch?v=zNmDj9QVCEc

Project Video: https://www.youtube.com/watch?v=Sp8UsQH3Bs4

02

REGION: AFRICA

GARBAL: An EO-powered Call Centre for Farmers and Herders in the Sahel

Summary

GARBAL is a specialised call center service that bridges the digital divide for farmers and pastoralists across Mali, Niger, and Burkina Faso by transforming complex Earth Observation (EO) data into actionable advice. By integrating satellite imagery on vegetation and water, weather forecasts, and real-time ground data on market prices and cattle concentrations the service provides localised insights via a simple phone call. Operating in 9 local languages, GARBAL allows users without smartphones or internet access to receive precise "scripts" from call center agents regarding pasture availability, water points, and weather forecasts, effectively turning sophisticated space-based data into a practical tool for daily decision-making in the Sahel.

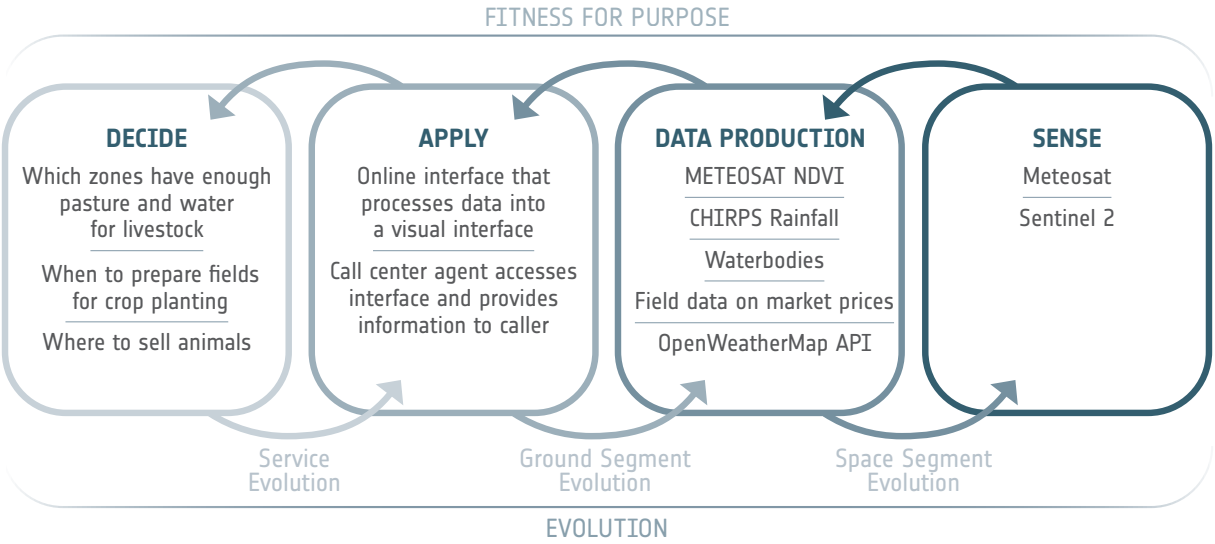
Decision-Making Context and Needs

"If you can predict when the rainy season will start," opined Amadou, "it will help us decide our planting schedule." He was one of a group of 30 farmers and livestock herders who had crowded under a shade tree in Houndé, Burkina Faso, to attend our focus group on using remote sensing data for local agriculture. "And if a satellite can



Attribution: Gaoussou Dao

Value Chain Diagram



show me where last month's rain fell," mused a herder, "I will know where to pasture my sheep." Incongruously, given the myriad of other issues facing the community, all anyone wanted to talk about was satellites.

Similar to many drylands across the world, transhumant movements in the West African Sahel are determined by a diverse array of factors including pasture availability, rainfall, access to water, market conditions and security. Timely and reliable information on these factors is critical for pastoralists for making decisions on mobility. Endogenous information systems exist within pastoral communities to relay much of this information, however they are often reliant on the physical presence of an interlocutor such as a scout who seeks out pasture conditions which brings risks associated with timeliness and insecurity. Regular data on natural conditions like pasture and water have become increasingly available to the spatial community through the growth of open access satellite imagery and open source GIS software. However, few channels exist to transmit this information to pastoral communities.



Attribution: Gaoussou Dao



Attribution: Anne Foucray

Earth Observation Data Products and Information

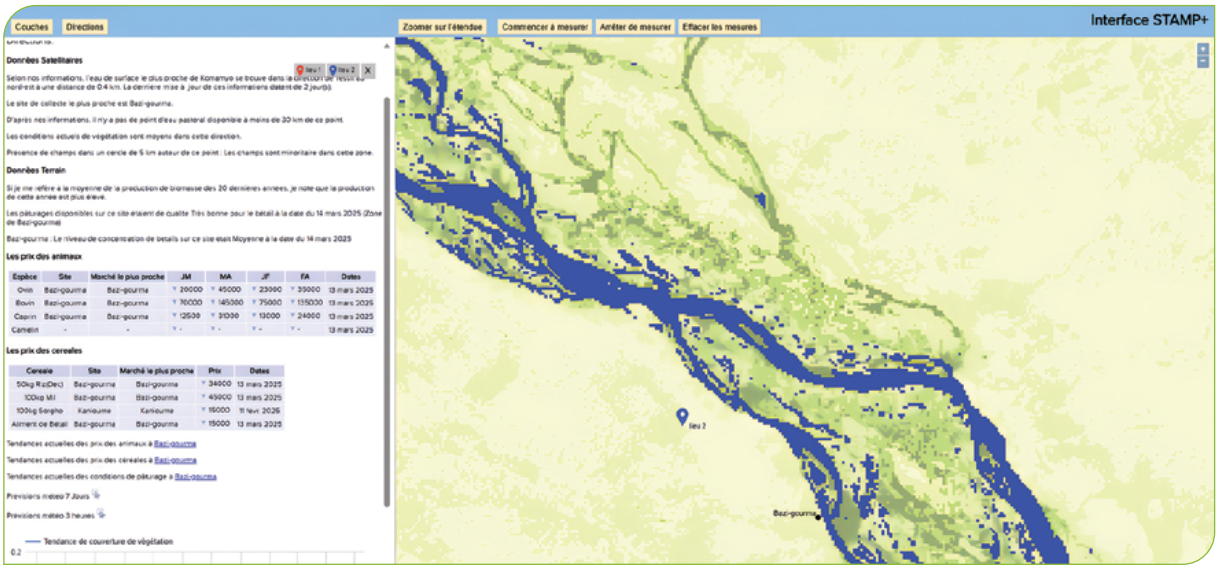
This focus group was one of dozens conducted over the past decade for GARBAL, a call center operating in Mali, Niger and Burkina Faso since 2015 that uses EO data to provide decision insights to farmers and herders in the area. These discussions were how we defined our indicators and prioritised datastreams. Thanks to GARBAL, farmers and herders can access the full benefits of EO imagery with a simple phone call, no computer or smartphone needed. Often fielding more than one million calls per year, the service provides live information on pasture availability, surface water and rainfall to any caller via an interface accessed by a call center agent. The information is provided in 9 languages and in many places GARBAL is the *only* source of localised weather forecasts and agrometeorological data.

GARBAL is run through a consortium coordinated by the NGO SNV whereas the call center is managed by the Telecom provider, ORANGE in Mali and Burkina Faso and Airtel in Niger. Field data on livestock and markets are collected by producer organisations (part of the RBM Network) and static datasets on pastoral infrastructure are provided by government agencies in Mali and Burkina Faso. The data platform is run by Hoefsloot Spatial Solutions, a Dutch geospatial company.

Underlying Observations and Data Sources

GARBAL offers callers a variety of data from Earth observation and field sources, blending satellite imagery with traditional knowledge systems. Field data is collected and treated through pastoral networks, relying on traditional information systems for assessing pasture quality and herd concentration. Information from dozens of sites is collected on market prices, cattle concentration and pasture quality is collected on a weekly basis, processed and displayed in an interactive dashboard for the call center agent.

Earth observation imagery is collected and processed into a number of indices, notably: the Normalised Difference Vegetation Index (NDVI), Dry Matter Productivity (DMP) and Small Water Bodies (SWB) from a number of different satellites including Sentinel 2, and PROBA-V. These images, collected on a dekadal basis, allow for a near-real-time image of pasture



and water availability, which are likewise displayed alongside the field data in the dashboard. The dashboard offers both a map and a textual output or a "script" providing an analysis of the latest data (biomass conditions, distance to the nearest water point) listed in the table to help guide the call center agent during their discussion with the caller. Information from government databases are also included, allowing the caller to know where to find veterinary services and ground water sources. Testing with call center operators has shown that the large volumes of calls received often prevents agents from being able to carefully analyze maps or graphical outputs. As a result, the textual outputs of the service, which provide basic analysis of the data in a "dialog box" tend to be used more often than maps by the call center agents.



Attribution: Anne Foucray

CATEGORY	DATA TYPE	METHOD/SOURCE
Biomass	NDVI, DMP	*Satellite*: METEOSAT, Sentinel-2
Water	SWB	*Satellite*: Sentinel 2
Pastoral Infrastructure	Wells, vaccination parks, veterinary posts, markets	Government databases
Market prices	Livestock, cereals, animal feed	Field data collection
Transhumance	Cattle concentration, cropland cover	Field data collection
Agro-meteorological	Weather forecasts, planting conditions	Weather services, long-term regional projections
Extension services	Agricultural & planting advice; animal health	Digitized technical manuals and technical expert consultations
Weather Forecasts	3-Hourly and Daily forecasts of temperature, wind and rainfall	OpenWeatherMap API

Impacts

Financial Savings: Herders traditionally rely on "scouts" to physically travel and verify pasture conditions, a practice that is both expensive and dangerous due to regional insecurity. GARBAL provides a digital alternative, allowing households to save significant funds and time by planning transhumance routes based on verified satellite data.

Optimized Market Decisions: By feeding live price data for livestock and cereals into the agent interface, the service enables herders to strategically choose which markets to visit. This reduces unnecessary travel with livestock and ensures higher profit margins for producers.

Hyper-Localized Weather Access: Through the integration of the OpenWeatherMap API across a database of every village in all three countries, GARBAL provides the only fully localized weather service available to these communities. This has become the most utilized feature, allowing for precise daily planning that was previously impossible.

Democratization of Seasonal Data: Annual seasonal forecasts produced by national meteorological services are typically trapped in inaccessible PDF reports. GARBAL digitizes these maps and forecasts, making critical climate outlooks available to users without internet access for the first time.

Scale and Accessibility: With over one million calls per year, the service proves that a voice-based, low-tech delivery model is the most effective way to scale the benefits of Earth Observation to hundreds of thousands of rural users who are most vulnerable to climate variability.



Attribution: Anne Foucray

FURTHER INFORMATION AND CONTACTS

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- **Peter Hoefsloot** *Project Lead* / Peter@hoefsloot.com

03

REGION: AFRICA

In Season Yield Forecasting for Decision Making in Malawi

Summary

The 2023–2024 El Niño event triggered a severe drought across Southern Africa, affecting over 27 million people and prompting multiple countries to declare states of emergency, with Malawi experiencing significant crop losses and reduced yields. In response to the urgent need for timely and accurate information to guide decision-making, NASA Harvest, in partnership with the FAO under GEOGLAM, deployed the GEOCIF yield forecasting system to support Malawi's Ministry of Agriculture crop production estimates. Using satellite-based Earth observation data and a machine-learning framework grounded in Climatic-Impact Drivers (CIDs), GEOCIF provided early, subnational yield forecasts and insights to enable proactive, evidence-based decisions to support the government's drought response.

Decision-Making Context and Needs

In Malawi, the 2023-24 El Niño event caused prolonged dry spells and high temperatures that damaged nearly 1 million hectares of crops - resulting in a 23% reduction in crop yields and a state of emergency to be declared in 23 of 28 districts. Such conditions directly impact local farmers across Southern Africa, with consequences for regional food supply, meaning local policy makers need informed, coordinated and effective strategies for handling drought conditions. This decision-making process requires timely and accurate crop health, and environmental conditions information.

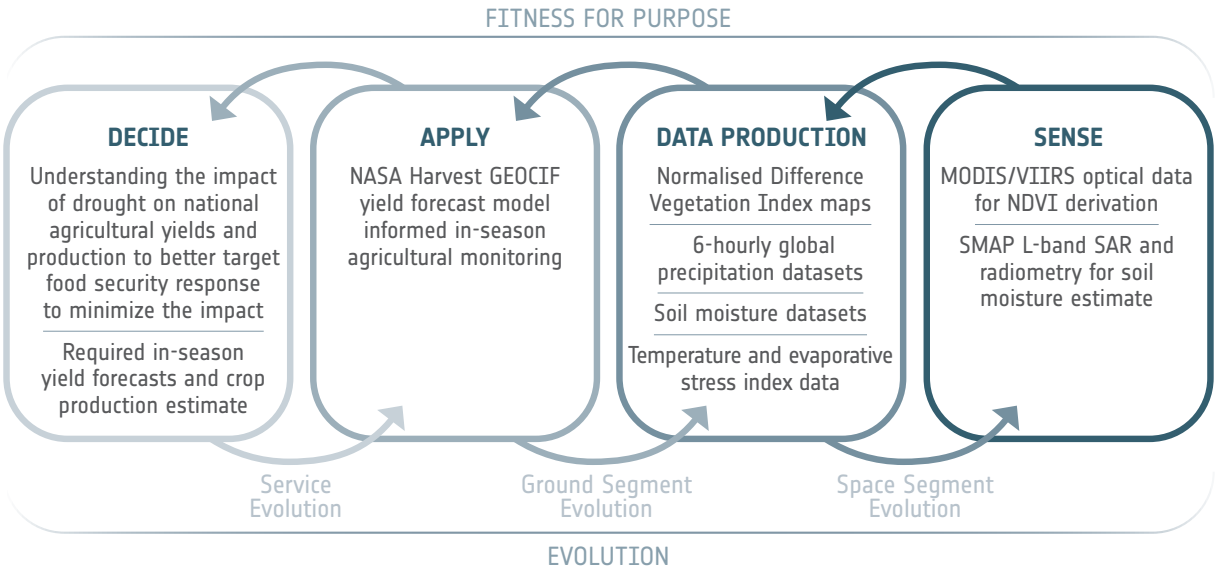


Fig. 1 Training crop cut technicians on sample techniques for the 2023 Crop Cut Campaign in Kasungu District Malawi. Source: Blake Munshell

Earth Observation Application/ Service Description

Under GEOGLAM (Group on Earth Observations Global Agricultural Monitoring Initiative), NASA Harvest partnered with the United Nations Food and Agriculture Organization (FAO) to provide GEOCIF in season yield forecast estimates to the Ministry of Agriculture in Malawi during the 2024 El Niño event to inform the government's drought response. GEOCIF is the Global Earth Observations for Crop Inventory Forecasting model - a machine-learning based approach that uses Earth Observation (EO) datasets and applies the Climatic-Impact Driver (CID) framework to produce a suite of indicators that quantify both average climate conditions (e.g., seasonal temperature, precipitation) and extreme events (heat waves, cold snaps, droughts, and compound hazards). These indicators feed into ensemble models that learn crop-specific, regionally tuned relationships between climate, vegetation health metrics, and historical yield outcomes. The resulting system delivers probabilistic, county/state-level yield forecasts two to three months before harvest, and explainable-AI diagnostics highlighting the dominant CIDs driving forecast uncertainty, and empowering governments

Value Chain Diagram



and partner institutions with timely, actionable insights to support farmers. GEOCIF has been used operationally in multiple yield forecasting exercises for the FAO, Alliance for Green Revolution in Africa (AGRA), and the United Nations Office on Drugs and Crime (UNODC).

The IPCC Sixth Assessment Report defines a CID as a climatic condition or category, like extreme heat, that impacts natural and human systems, such as agricultural yields. The CID framework builds on the development of climate indices by the World Climate Research Program (WCRP) by encouraging the inclusion of non-traditional

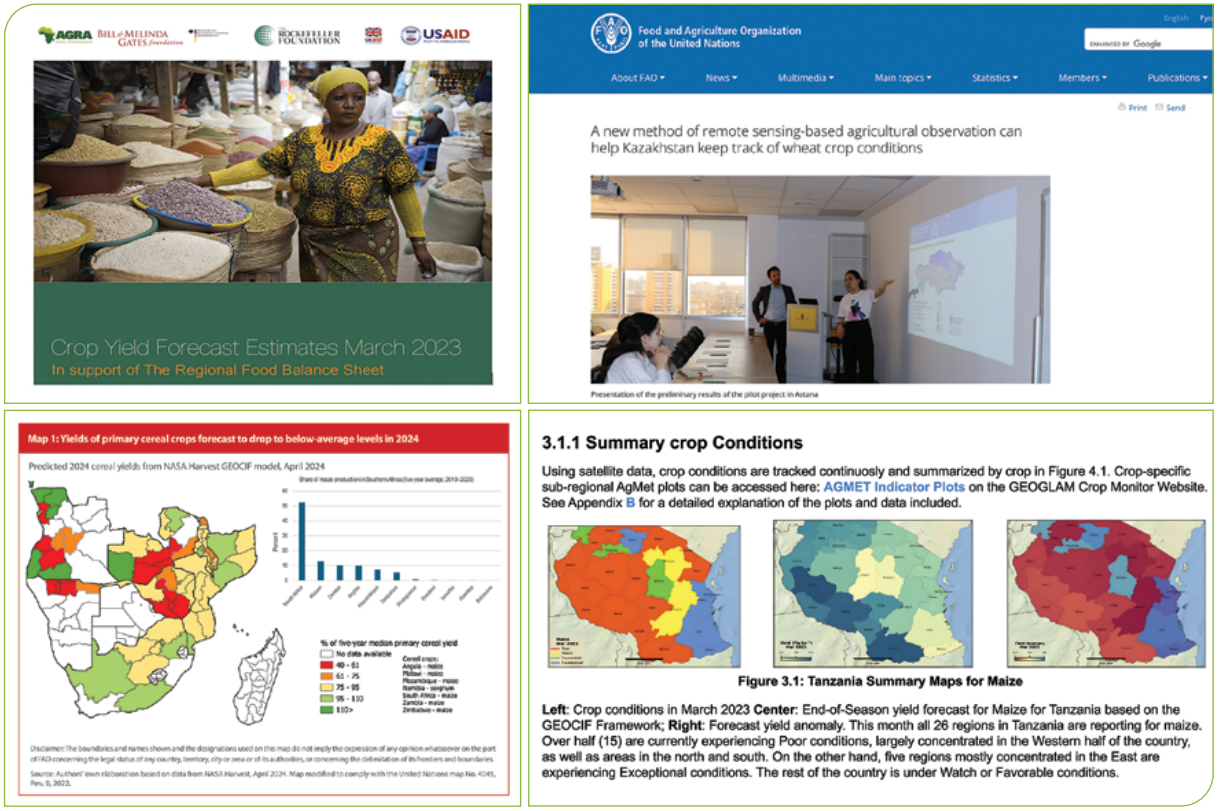


Fig. 2 Public examples of GEOCIF usage. Clockwise from top left: Alliance for Green Revolution in Africa (AGRA) maize and bean yield forecasts for Eastern Africa in 2021 and 2022; Kazakhstan wheat forecast for FAO in 2022 and 2023; Tanzania maize forecast for AGRA in 2021 and 2022, and Southern Africa yield forecast for FAO in 2023

climatic information. It does so by looking beyond drought and precipitation related indices for agriculture and developing a process to identify more precise CID indices and thresholds that can be linked to distinct system responses e.g. canopy temperature above a threshold impacts plant growth through changes in crop photosynthesis.

The NASA Harvest GEOCIF yield forecast model provides early, reliable estimates of in-season crop yields at the district level in Malawi to support strategic planning and risk management. The GEOCIF model uses satellite and environmental data to track growing-season conditions and identify climate risks, such as droughts or heat stress that can affect agricultural production. By combining these data with historical crop production information, GEOCIF produces yield forecasts at an administrative level, along with clear indicators of confidence and risk. This allows decision-makers to better anticipate potential production shortfalls, understand the main drivers of uncertainty, and take proactive steps to support food security and agricultural resilience.

Earth Observation Data Products and Information

Climatic-Impact Drivers are derived from a range of data products based on Earth observations, including: time series of MODIS/VIIRS NDVI; Climate Hazards Center Infrared Precipitation with Stations (CHIRPS) precipitation data; FLDAS and SMAP soil moisture; and temperature and evaporative stress index data from NOAA Climate Prediction Center. A range of these products is shown below in Figure 4 from NASA Harvest Agrometerological Indicator Graphics.

The AGMET tool combines multiple key EO variables for agricultural monitoring into coherent contextualized visualizations that clearly show

CLIMATIC IMPACT-DRIVERS (CIDs)

INDEX	DESCRIPTION	TYPE	CATEGORY
FD	Number of Frost Days (Tmin<0°C)	Cold	Extreme
TN10p	Percentage of days when Tmin<10th percentile	Cold	Extreme
TNn	Minimum daily minimum temperature	Cold	Extreme
CDD	Maximum consecutive dry days (Precip<1mm)	Drought	Extreme
TX90p	Percentage of days when Tmax>90th percentile	Heat	Extreme
TXx	Maximum daily maximum temperature	Heat	Extreme
SDII	Average precipitation during Wet Days (SDII)	Rain	Mean
TG	Mean of daily mean temperature	Temperature	Mean
DTR	Mean Diurnal Temperature Range	Temperature	Mean
CD	Days with TG<25th percentile of daily mean temperature and RR<25th percentile of daily precipitation sum	Compound	Extreme
CW	Days with TG<25th percentile of daily mean temperature and RR>75th percentile of daily precipitation sum	Compound	Extreme
WD	Days with TG>75th percentile of daily mean temperature and RR<25th percentile of daily precipitation sum	Compound	Extreme
WW	Days with TG>75th percentile of daily mean temperature and RR>75th percentile of daily precipitation sum	Compound	Extreme

Fig. 3 Representative CIDs representing two types: Mean, Extreme; and seven categories: Drought, Heat, Temperature, Rain, Compound, Snow and Cold

how current season conditions compare with recent averages and extremes, enabling users to detect anomalies early in the season and adjust monitoring priorities or response plans accordingly. The system delivers regular updates (every 7–12 days) of EO time series for key variables — NDVI, precipitation, soil moisture, evaporative stress, and temperature — and contextualizes them against 5- and 10-year historical ranges to reveal deviations from normal patterns. By integrating multiple environmental and vegetative variables into standardized, crop-specific indicators and updating them frequently, the tool provides timely, digestible insights into in-season crop health that supports proactive decision making rather than retrospective analysis.

These satellite based inputs along with subnational crop production data are used in GEOCIF to learn crop-specific, regionally calibrated relationships between climate conditions, vegetation health, and historical yield outcomes. With these inputs, the model produces probabilistic yield estimates at the subnational scale, along with diagnostics that identify the dominant CIDs contributing to forecast uncertainty and model drivers.

Underlying Observations and Data Sources

The primary data sources for GEOCIF are: the CHIRPS rainfall dataset, which uses a variety of space and ground based sensing platforms; NASA's Terra and Aqua atmosphere, land and ocean environmental satellites; and the SMAP global soil moisture mission.

- MODIS (Multispectral radiometer): for deriving NDVI; 250m spatial resolution for daytime imaging, 1000m at night, with a swath width of 2330km providing global coverage every one to two days. Imagery in 36 bands between Visible (VIS) and Thermal Infrared (TIR), with historical data available back to 1999.
- VIIRS (Multispectral radiometer): for deriving NDVI; Up to 400m spatial resolution, with 22 channels in the VIS - TIR range. Provides near global coverage every day.
- CHIRPS (quasi-global rainfall dataset: for GEOCIF precipitation inputs. Integrated dataset of station measurements and satellite observation for land-only rainfall. Available at 6-hourly to seasonal time scales, with data starting in 1981. 0.05° x 0.05° spatial resolution.

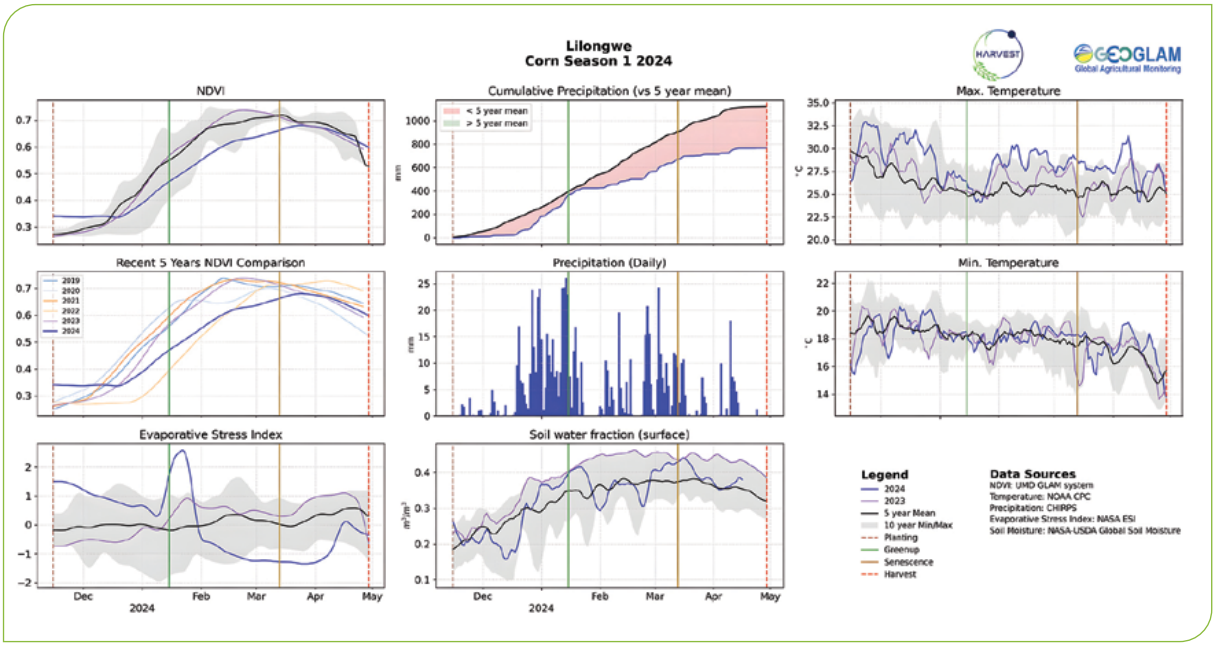


Fig. 4 NASA Harvest Agrometeorological Indicator Graphics

- SMAP SAR (L-band radar): for soil moisture estimates. Less than 3km spatial resolution over 70% of swath, with 3-day temporal resolution. Data beginning in 2015.
- SMAP Radiometer (L-band radiometer): for soil moisture estimates. 40km spatial resolution with 3-day temporal resolution. Data available from 2015.

Impacts and Benefits

During the 2024 cropping season, in partnership with FAO the NASA Harvest GEOCIF yield forecast model was adapted for use at the request of the Malawi Ministry of Agriculture and provided on a monthly basis to inform in-season agricultural monitoring and crop production estimates. In-season yield forecasts are important as they provide additional evidence of potential crop production shortfalls often earlier than traditional crop assessments and at a larger geographic scale. This timely data can be used to reduce uncertainty and support proactive decisions while there is still an opportunity to respond early to potential shortages and reduce impacts to the most vulnerable populations.

GEOCIF provided the Ministry with reliable and more frequent updates on the yield forecasts and early warning signals on national food security that enabled policy makers in the public, private and non-state sectors to make early, informed decisions to address the impending food situation. The results were used to validate the crop estimates from the traditional crop production survey from the Ministry of Agriculture, and the National Committee on Crop Estimates recommended the incorporation of the model into the crop estimates survey as an early warning and crop monitor tool for the Ministry.

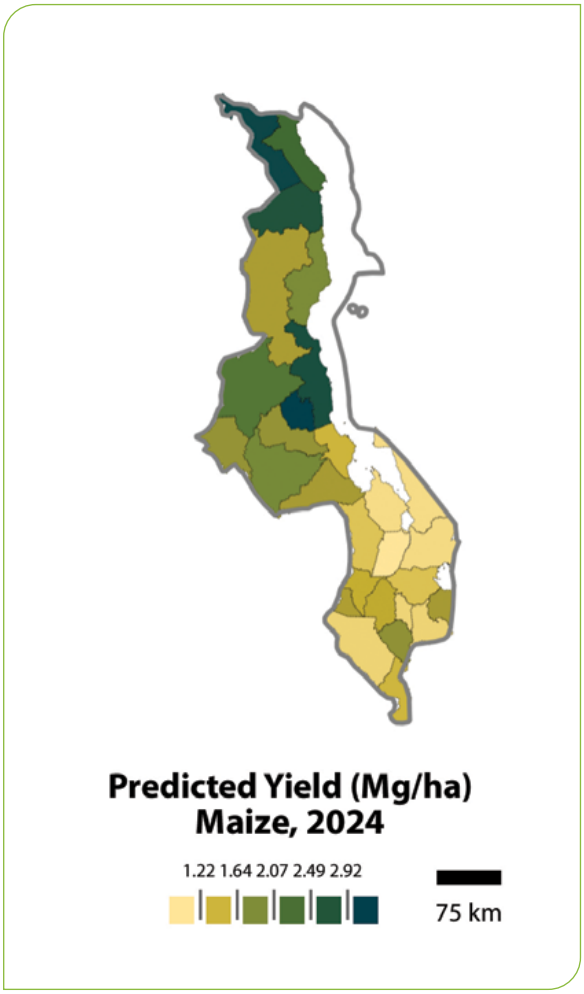


Fig. 5 GEOCIF yield forecast estimates from 2024

FURTHER INFORMATION AND GUIDANCE

Points of contact

- NASA Earth Science Division: aries.keck@nasa.gov
- Christina Justice: justicec@umd.edu
- Ritvik Sahajpal: ritvik@umd.edu
- Jonathan Pound: jonathan.pound@fao.org

Agmet Indicator Tool: https://cropmonitortools.org/tools/agmet/
Description: https://www.cropmonitor.org/agmet-eo-indicators-explained

HarvestStat Subnational Crop Production Data: https://www.harveststat.org/

Subnational Crop Production Dataset Access: https://github.com/HarvestStat/HarvestStat-Africa

Video story: https://www.youtube.com/watch?v=aiDRq1D-8IY

NASA Harvest: https://www.nasaharvest.org/

Crop Monitor: https://www.cropmonitor.org/

GEOGLAM: https://www.geoglam.org

DISASTERS

CASE STUDIES



01 REGION: AMERICAS

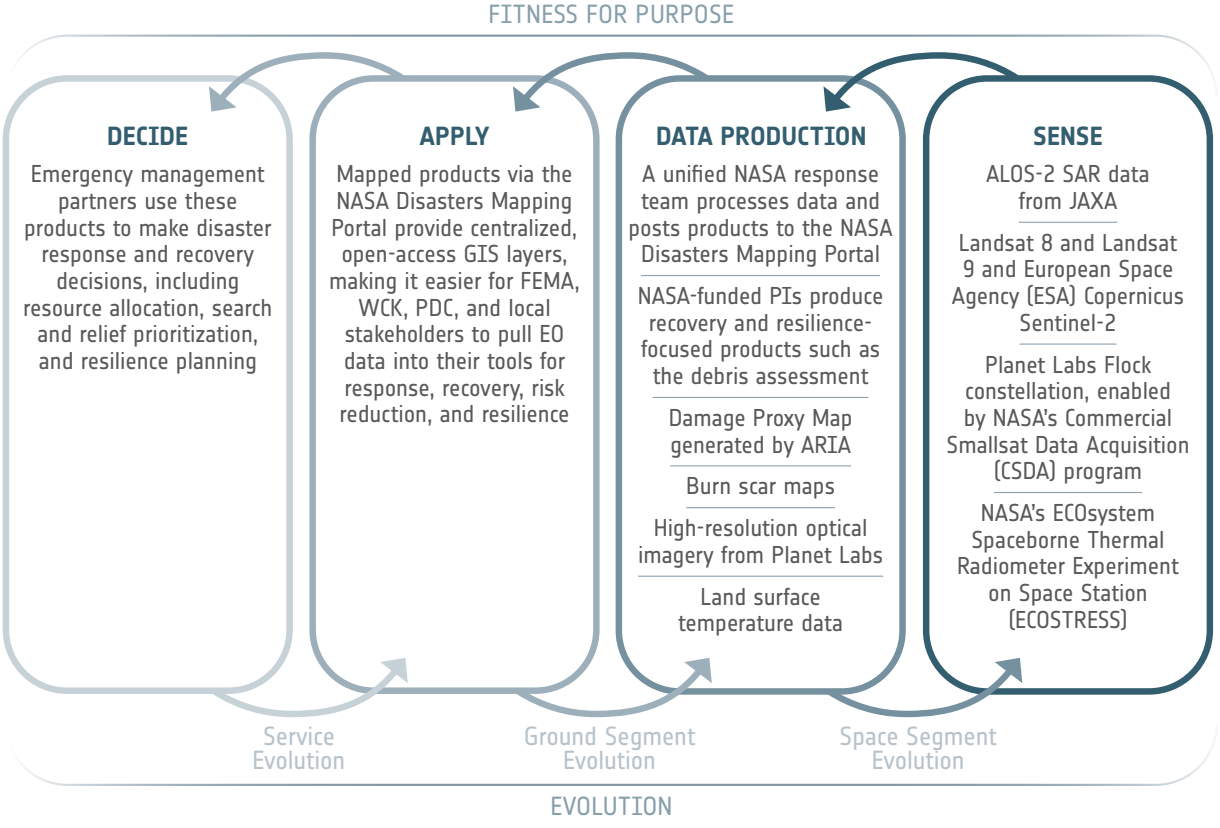
NASA's Disasters Program - From Response to Resilience

Summary

In 2023, devastating wildfires in Maui swept through Lahaina causing 5.5 billion dollars in damages and destroying 2,200 structures. These wildfires demonstrated how rapidly extreme events can overwhelm communities and how essential timely, trusted information is for decision-makers. NASA's Disasters Program worked across centers and with partners to deliver satellite-based damage assessments – most notably the ALOS-2 Synthetic Aperture Radar (SAR)-derived damage proxy maps and Sentinel-2 burn-area products – that equipped responders with actionable intelligence when smoke, debris, and restricted access hindered traditional assessments. These products helped federal, state, and nonprofit partners rapidly identify the most affected neighborhoods, allocate resources, and guide both operational response and early recovery planning. The activation also highlighted NASA's growing emphasis on resilience: using Earth observations not just to understand disaster impacts after they occur, but to strengthen preparedness and reduce risk.

The Program continued to support community resilience to natural hazards when, after another disaster response activation, partners expressed concern about the location and quantity of debris. Hurricane Helene produced major and widespread damage across western North Carolina. Fallen

Value Chain Diagram



trees and other debris fuel wildfires, block transportation corridors and prevent recovery efforts. By identifying statistically significant debris "hot spots," the program is working to provide emergency managers with a decision-ready tool for recovery planning and risk reduction.

Artificial intelligence (AI) and Machine Learning (ML)-informed debris assessments, rapid access to civil and commercial Earth observations, and cutting edge applied disaster science represent more than technical advancements – these directly address challenges across the disaster lifecycle, where rapid, trusted Earth observations and applications support both immediate response and long-term community resilience.

The NASA Disasters Program works to address response, recovery, risk, and resilience from event-specific support to scalable, anticipatory, and repeatable methods that reduce vulnerability across geographies. By combining local partner insights with Earth observation science – and delivering tools through the Disasters PORTAL – the program strengthens communities' ability to anticipate cascading impacts, accelerate recovery, and build long-term resilience.

Decision-Making Context and Needs

Challenges addressed:
Compound hazards and cascading impacts (extreme winds, rapid fire spread, widespread destruction) created urgent, evolving information needs for responders and humanitarian organizations. Earth observation (EO) products helped fill observation gaps, provide consistent geographic coverage, and support cross-agency coordination in a fast-moving crisis.

Who was involved:
NASA's Disasters team, including funded science teams, the Disaster Response Coordination System across multiple NASA centers, including



Fig. 1 Wildfires rage in Lahaina, Maui as the U.S. Coast Guard and partners conduct rescue efforts (Attribution: U.S. Coast Guard)

the Advanced Rapid Imaging and Analysis (ARIA) team at NASA's Jet Propulsion Laboratory (JPL)/ Caltech for Damage Proxy Map (DPM) generation, and partners such as the Federal Emergency Management Agency (FEMA), World Central Kitchen, and the Pacific Disaster Center.

How EO data (and other inputs) are supported.

EO data**:**
SAR and optical satellite observations provided damage and burn mapping, plus pre-event and post-event context, crucial for allocating search and relief teams, planning debris management, and prioritizing community services.

Other inputs**:**
The ARIA team conducted preliminary validation using media reports and other imagery, increasing user confidence in the DPM while communicating appropriate use of the products. DRCS frameworks and the Disasters Mapping Portal's open, standardized delivery further supported multi-stakeholder coordination and repeatable integration into local workflows.

Earth Observation Data Products and Information

Damage Proxy Map (DPM) – ALOS-2 SAR (ARIA/ JPL-Caltech)**:** Highlighted zones of likely structural damage and supported response triage, directing teams toward hardest-hit neighborhoods. (Available on ARIA Share, JPL's public data repository, and the Disasters Mapping Portal).

Sentinel-2 Burn and Pre- and Post-Event Imagery**:** Delivered intuitive before-and-after views that responders and recovery planners used to visualize burn severity and extent.

Mapped products via the NASA Disasters Mapping Portal**:** Centralized, open-access GIS layers, made it easier for FEMA, WCK, PDC, and local stakeholders to pull EO data into their

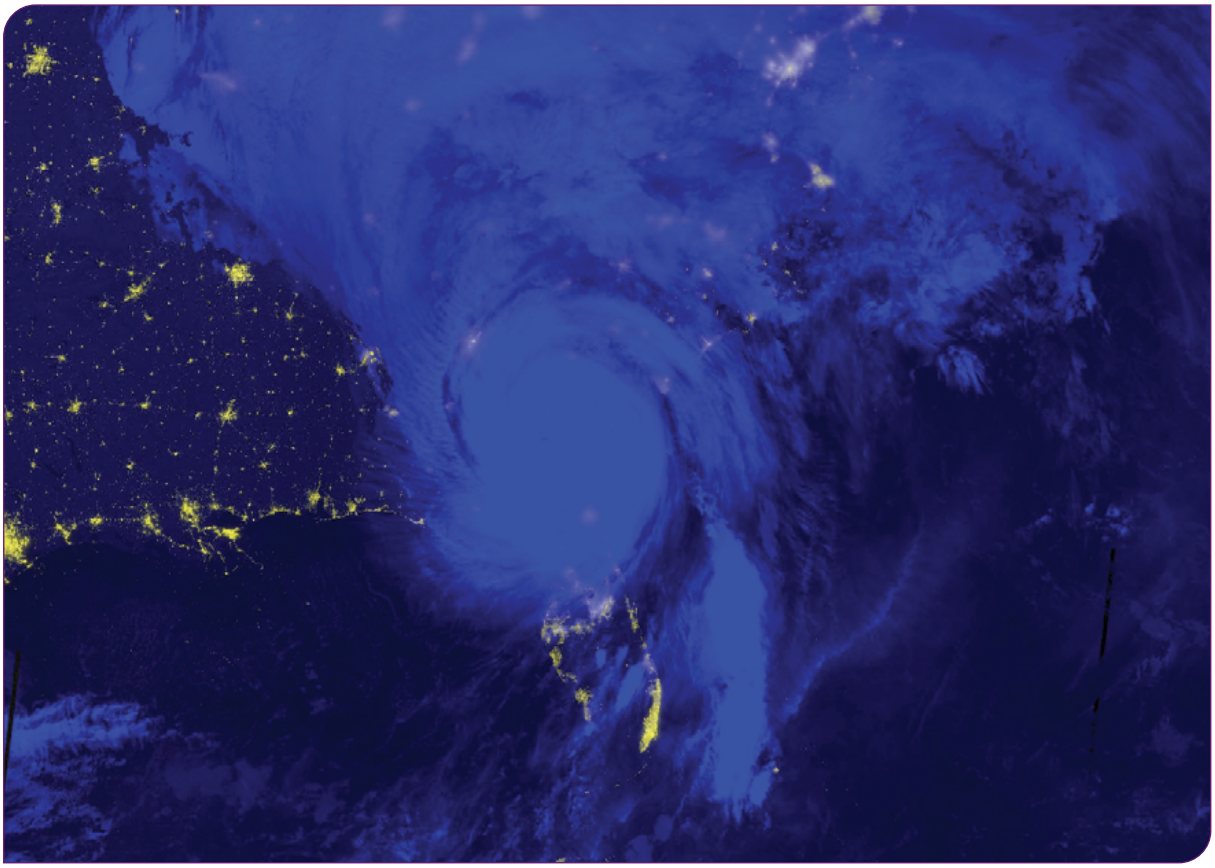


Fig. 2 NASA Black Marble Blue/Yellow Composite imagery showing nighttime lights shortly after Hurricane Helene made landfall in Florida. Near real-time Black Marble data has been made available on the NASA Disasters Mapping Portal to support FEMA's request for data to aid in identifying power outages (Attribution: NASA Worldview)

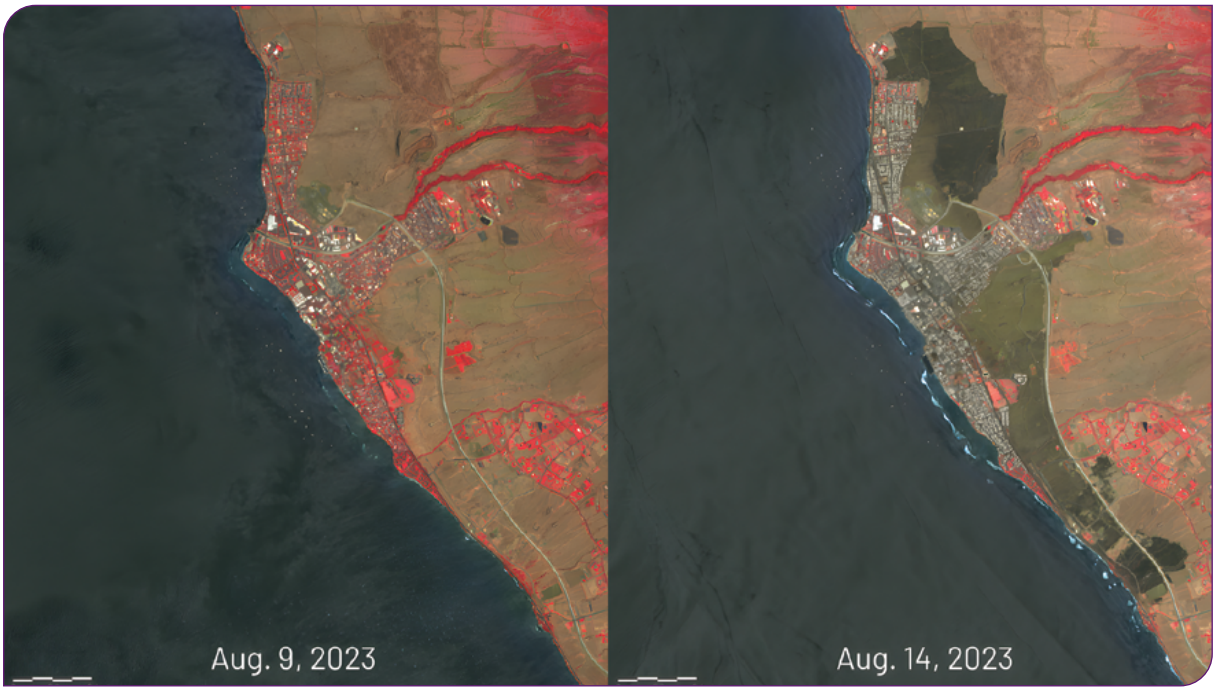


Fig. 3 Color infrared imagery from ESA Copernicus Sentinel-2 satellite overpasses of Lahaina, Maui before and after wildfires swept through the city (Attribution: NASA/MSFC, USGS, Jacob Reed. Copyright contains modified ESA Copernicus Sentinel data (2023) processed by ESA)

operational tools. This approach directly mitigates common information gaps (fragmented data sources, inconsistent formats, slow distribution) that impede rapid situational awareness in complex disasters.

How those products solved challenges:

Speed and accessibility: Rapid SAR-based damage mapping without daylight or clear skies addressed cloud and smoke issues and the need for immediate situational awareness while ground access was limited.

Operational integration: Publishing in standard GIS formats through the Disasters Mapping Portal accelerated uptake by emergency operations centers, enabling layering with local datasets (roads, shelters, utility networks) for actionable decision support.

Transparency and caveats: Clear guidance on DPM limitations over vegetation helped users interpret products responsibly, reducing misapplication and improving on-the-ground efficiency.

Underlying Observations and Data Sources

ALOS-2 Synthetic Aperture Radar (SAR) from the Japan Aerospace Exploration Agency (JAXA): Pre-event and post-event images (July 17, 2022, June 18, 2023, and Aug. 13, 2023) powered the Damage Proxy Map, which flags pixels with increased scatterer change – interpreted as likely damage to buildings and structures; the activation page notes pixel size of approximately 30 square meters and advises caution when interpreting results over vegetated areas.

Copernicus Sentinel-2 color-infrared imagery (Aug. 9, and Aug. 14, 2023) was used for pre-event and post-event burn visualization, clearly mapping burned zones around Lahaina to support impact assessment.

Disasters Mapping Portal and ARIA Share served as distribution points for the damage and burn products, enabling open, standardized GIS access for partners in their existing workflows. The Portal is central to the Disasters Program's model of delivering trusted, timely, and actionable science.

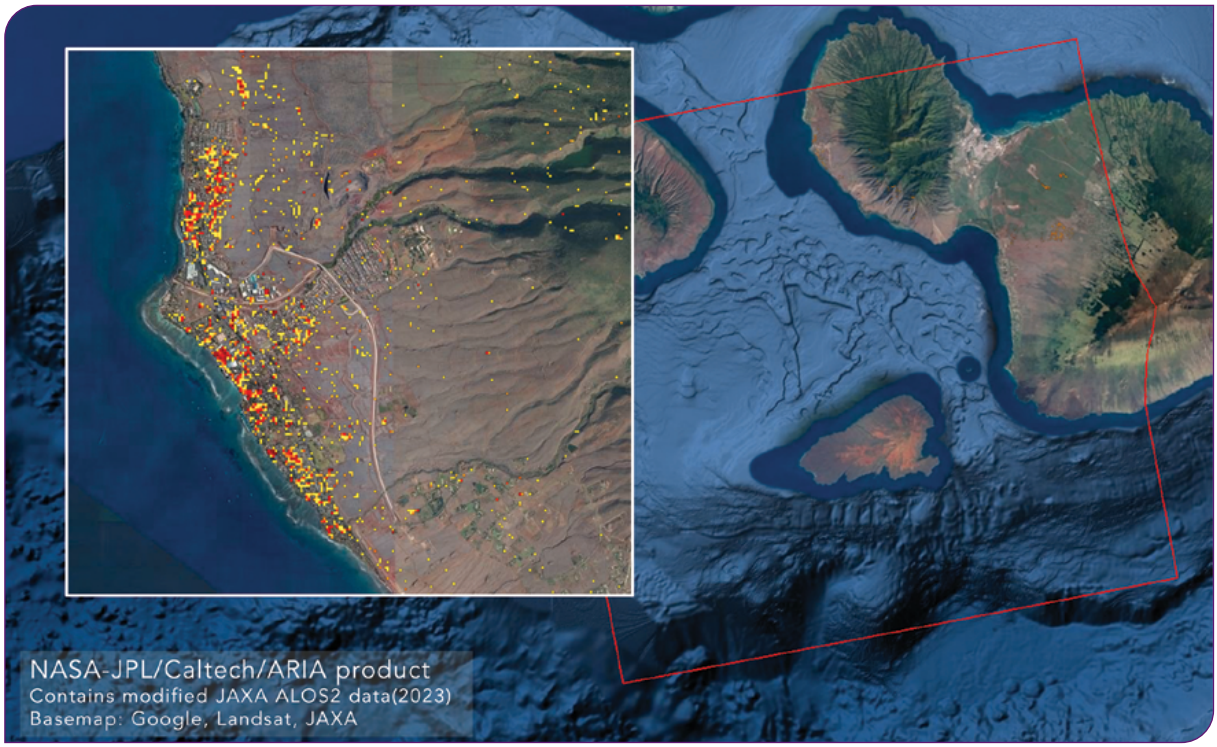


Fig. 4 Damage proxy map depicting buildings likely damaged by the Maui wildfires (Attribution: NASA's Jet Propulsion Laboratory. Original data copyright JAXA (2022,2023))

Impacts and Benefits

Human impact and context:
The Maui fires were described as the deadliest U.S. wildfires in more than a century, with catastrophic loss concentrated in and around Lahaina. Beyond the immediate destruction of homes, businesses, and cultural heritage, the disaster created recovery challenges that require sustained community support and scientific expertise.

What the work accomplished:
NASA's Disasters team rapidly coordinated across centers to deliver decision-ready maps and scientific expertise – notably a DPM derived from ALOS-2 SAR – to identify likely damaged structures and burned areas. These products gave responders and humanitarian groups actionable insight on where to allocate scarce resources, helping to prioritize search, relief, and recovery under extremely challenging conditions.

Primary beneficiaries:
FEMA, World Central Kitchen, Pacific Disaster Center (PDC), and other operational stakeholders were among the direct beneficiaries. NASA supported affected residents of Maui through better-targeted aid and planning enabled by the maps and data shared through the NASA Disasters Mapping Portal.

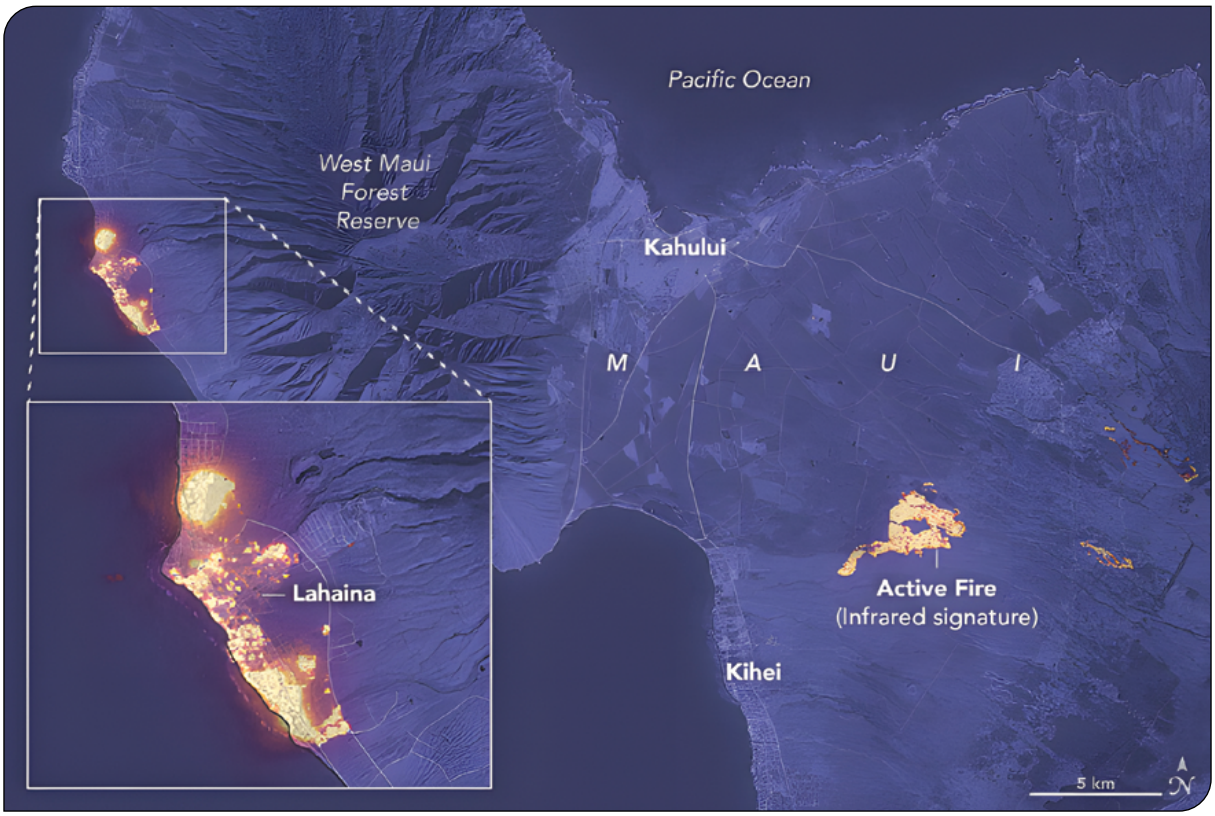


Fig. 5 Shortwave infrared imagery of wildfires burning in Lahaina and northeast of Kihei, Maui on Aug. 8, 2023. Fires are shown in yellow (Attribution: NASA Earth Observatory image by Lauren Dauphin, using Landsat data from the U.S. Geological Survey)

FURTHER INFORMATION AND GUIDANCE

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https://appliedsciences.nasa.gov/what-we-do/disasters/disasters-activations/hawaii-wildfires-aug-2023

https://science.jpl.nasa.gov/projects/aria/

https://appliedsciences.nasa.gov/sites/default/files/2024-08/DRCS%201-PAGER_Updated_Aug-05-2024.pdf

02

REGION: ASIA AND PACIFIC

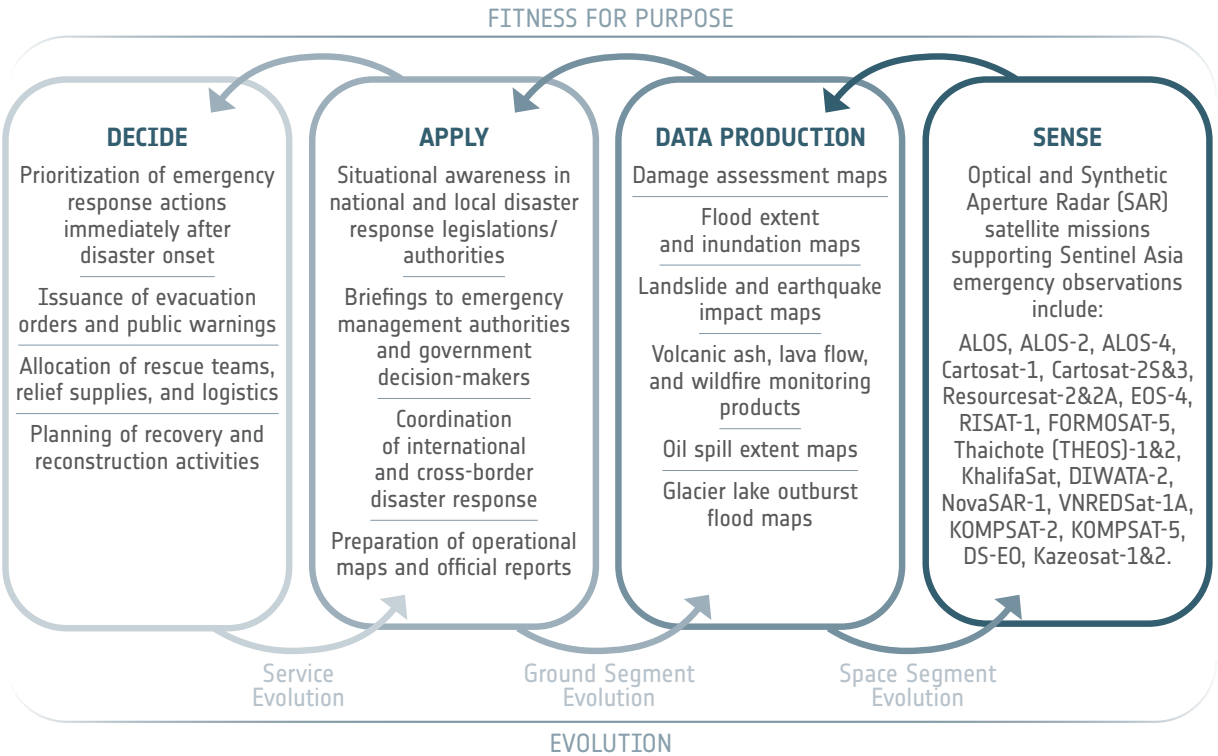
Sentinel Asia: Earth Observation–Enabled Disaster Response and Resilience in the Asia-Pacific

Summary

Sentinel Asia is a voluntary regional cooperation framework established in 2006 under the Asia-Pacific Regional Space Agency Forum (APRSAF) to support disaster management through satellite Earth observation (EO) data. By coordinating the capabilities of space agencies, data analysis institutions, and disaster management authorities, Sentinel Asia enables rapid, on-demand access to EO-derived information for emergency response across the Asia-Pacific region. This mechanism allows countries and regions without their own EO satellites to benefit from timely satellite-based information during disasters.

Since its establishment, Sentinel Asia has supported **more than 500 emergency observation activations** in **over 30 countries and regions**, addressing a wide range of natural hazards including floods, earthquakes, landslides, volcanic eruptions, and wildfires. Through the timely provision of actionable, decision-ready information, Sentinel Asia directly supports disaster response operations by helping authorities assess impacts, prioritize actions, allocate resources, and coordinate national and international assistance. The initiative remains fully operational and continues to strengthen disaster response and resilience across the region through sustained international collaboration and capacity building.

Value Chain Diagram



Decision-Making Context and Needs

Countries in the Asia-Pacific region face a diverse range of natural hazards that can cause large-scale human and economic losses. Disaster management agencies often operate under time pressure, uncertainty, and incomplete information, especially during the early stages of an emergency. Cloud cover, limited ground access, and damaged infrastructure can further complicate situational awareness.

Sentinel Asia was established to address these challenges by ensuring that disaster response organizations have rapid access to reliable EO information, regardless of national technical capacity. By fostering international cooperation and data sharing, Sentinel Asia helps bridge resource gaps and strengthens regional disaster resilience. The initiative supports decision-makers who require clear, trusted information to act quickly and confidently in high-stakes situations.

Earth Observation Data Products and Information

Sentinel Asia operates as an on-demand emergency response service. When a disaster occurs, authorized disaster management agencies submit an observation request through the Sentinel Asia coordination mechanism. Satellite data are then acquired, processed, analyzed, and converted into decision-ready information products.

The resulting EO products are tailored to the needs of operational users. Rather than raw imagery, users receive interpreted maps and visualizations that clearly delineate affected areas and potential impacts. These products are designed to be easily understood and rapidly integrated into emergency response workflows, even by non-specialist users.

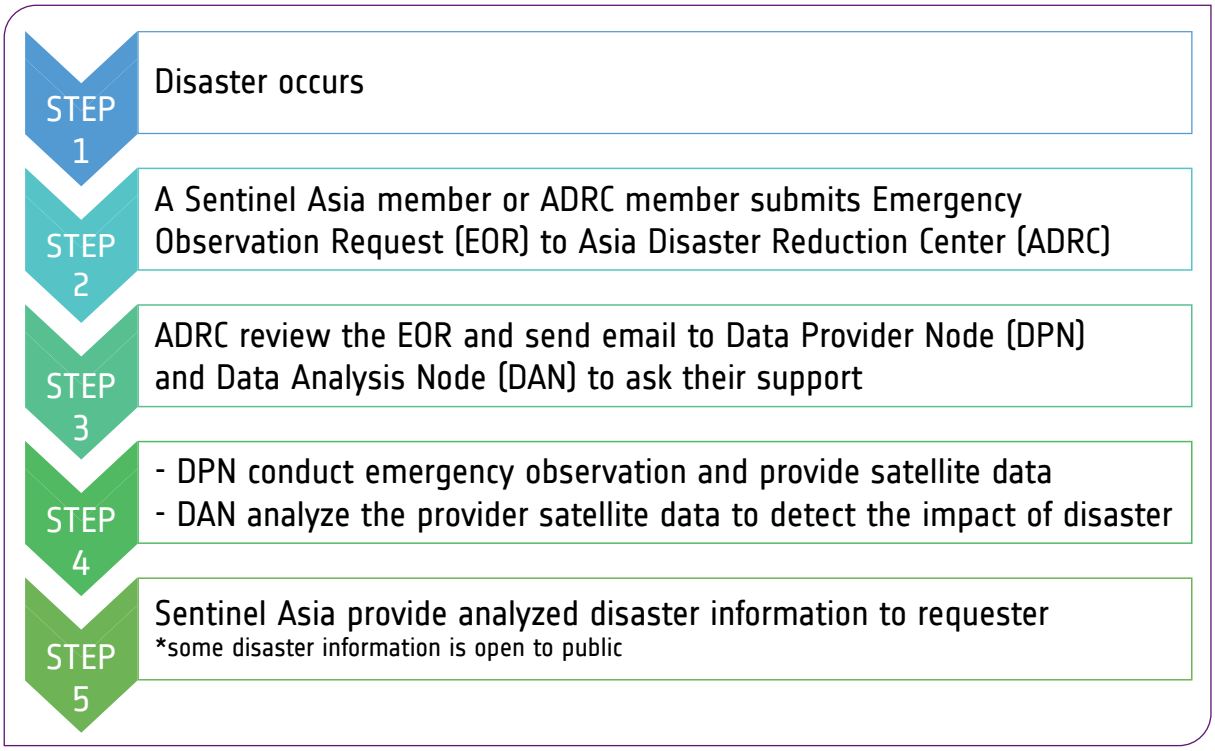


Fig. 1 Sentinel Asia Disaster Observation Process (Attribution: Sentinel Asia)

Underlying Observations and Data Sources

The Sentinel Asia initiative is underpinned by a broad, multi-national collaboration involving space agencies, disaster management authorities, research institutions, and international organizations across the Asia-Pacific region. Sentinel Asia operates under the framework of the Asia-Pacific Regional Space Agency Forum (APRSAF), with the Japan Aerospace Exploration Agency (JAXA) serving as the executive secretariat and the Asian Disaster Reduction Center (ADRC) acting as the primary coordination hub for emergency observation requests. The Joint Project Team (JPT) comprises more than one hundred member organizations, including national space agencies, data analysis institutions, and governmental disaster management agencies from over 30 countries and regions.

Earth observation data used within Sentinel Asia are contributed by participating space agencies designated as Data Provider Nodes (DPNs). These include, among others, JAXA (Japan), the Indian Space Research Organisation (ISRO), the Korea Aerospace Research Institute (KARI), Thailand's Geo-Informatics and Space Technology Development Agency (GISTDA), the Taiwan Space Agency (TASA), the Mohammed Bin Rashid Space Centre (MBRSC, United Arab Emirates), the Philippine Space Agency (PhilSA), the Space Technology Institute-Vietnam Academy of Science and Technology (STI-VAST), Center for Remote Imaging, Sensing and Processing (CRISP, Singapore), and the JSC National Company Kazakhstan Gharysh Sapary (KGS). These agencies provide satellite data on a voluntary basis to support emergency response activities across the region.

Sentinel Asia makes use of a diverse constellation of Earth observation satellites, encompassing both optical and Synthetic Aperture Radar (SAR) sensors. Satellite missions supporting Sentinel Asia emergency observations include ALOS-2 (JAXA), Cartosat-2S&3 and Resourcesat-2&2A (ISRO), FORMOSAT-5 (TASA), Thaichote/THEOS-1&2 (GISTDA), KhalifaSat (MBRSC), and DIWATA-2, NovaSAR-1 (PhilSA), DS-EO(CRISP), and Kazeosat-1&2 (KGS). The availability of SAR data is particularly critical for disaster monitoring in conditions of persistent cloud cover or during nighttime operations, such as during monsoon-related flooding or tropical cyclones.

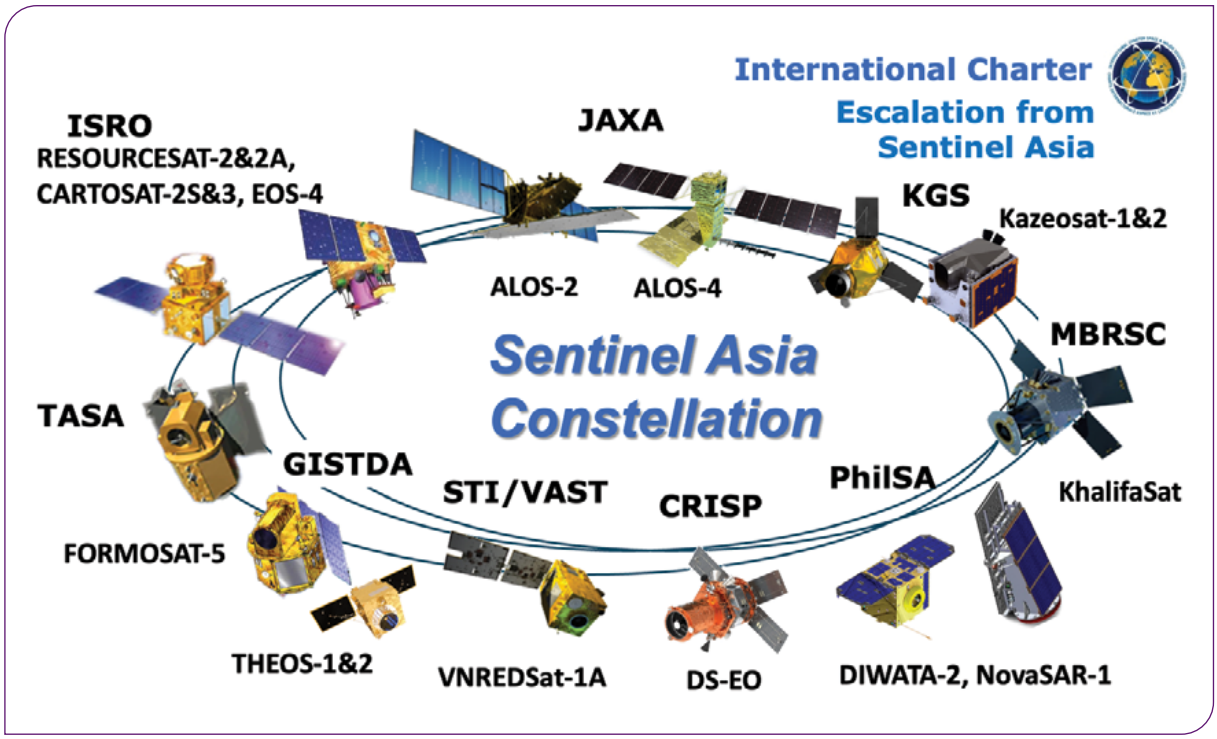


Fig. 2 Sentinel Asia Contributing Satellite Missions (Attribution: Sentinel Asia)

Satellite imagery acquired through these missions is processed and interpreted by Data Analysis Nodes (DANs), which include universities, research institutes, and specialized analysis centers across the region. By combining observations from multiple satellite missions and agencies, Sentinel Asia enhances temporal coverage, spatial resolution, and the robustness of disaster-related information. This multi-source, collaborative observation approach ensures continuity of data supply and builds confidence in the derived information products used by disaster management authorities for time-critical decision-making.

Impacts and Benefits

Since its establishment, Sentinel Asia has delivered substantial and measurable benefits for disaster response and resilience across the Asia-Pacific region. To date, the initiative has supported more than 500 emergency observation activations, addressed a broad spectrum of natural hazards and supported response activities in over 30 countries and regions.

In terms of hazard type, the majority of Sentinel Asia activations have been related to hydrometeorological disasters, particularly flood events, reflecting their high frequency and wide spatial impact across the region. Flood-related activations account for well over half of all emergency observations, including flooding, flash floods, and inundation associated with tropical cyclones and monsoon rainfall. These activations have been critical for mapping flood extent, identifying isolated communities, and prioritizing emergency response actions.

Geological hazards, including earthquakes and landslides, represent a significant secondary portion of activations. Earthquake-related observations have supported rapid damage assessment in both urban and rural settings, while landslide monitoring has been particularly important in mountainous and high-rainfall regions, where secondary hazards often follow major storms or seismic events.

Sentinel Asia has also been activated for volcanic eruptions, supporting ash plume monitoring, lava flow mapping, and exclusion zone management,



Fig. 3 Flooding in Vietnam, October 2016 (Attribution: Licensed under CC)

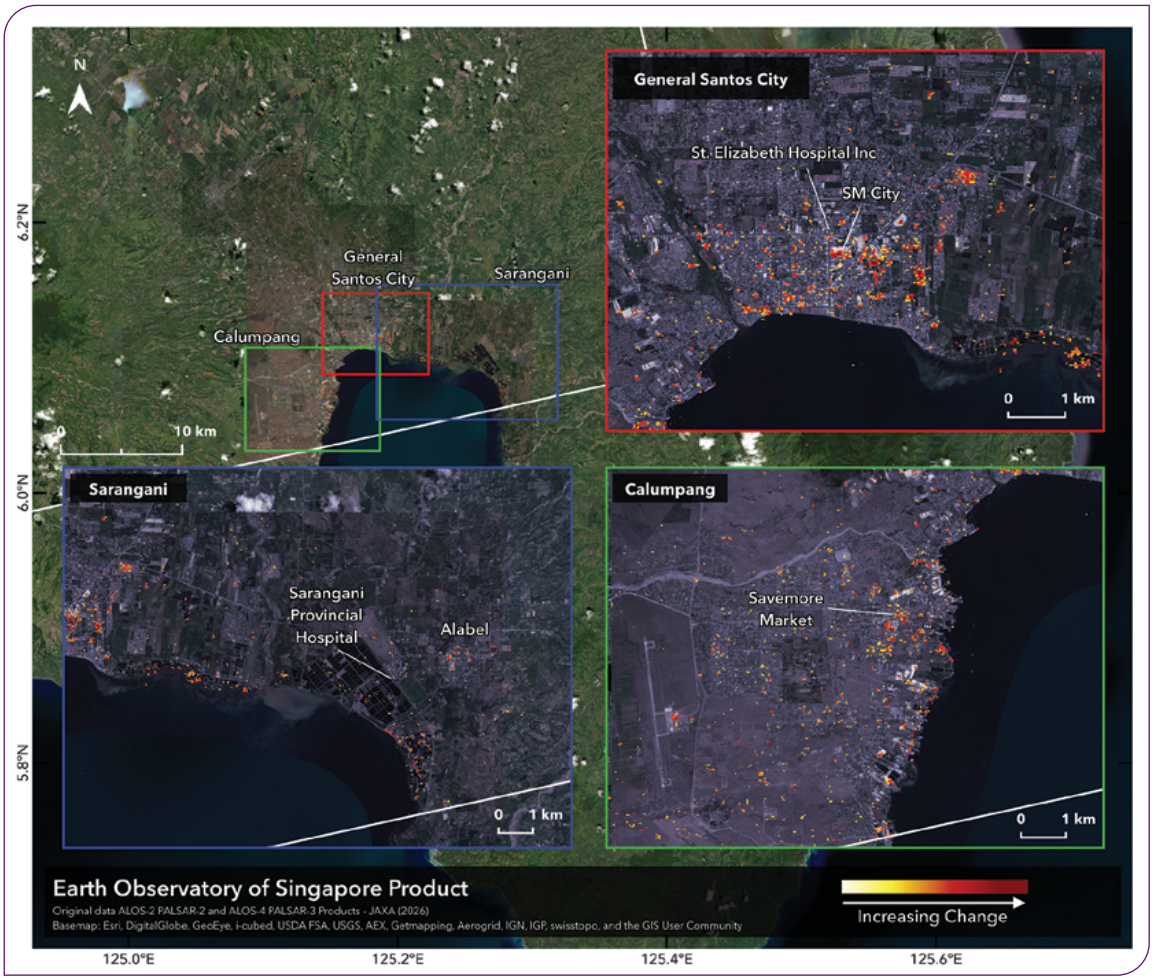


Fig. 4 Sentinel Asia Value Added Damage Proxy Product of Philippines earthquake, June 2026 (Attribution: Earth Observatory of Singapore - Remote Sensing Lab (EOS-RS), Original data ALOS-2 PALSAR-2 and ALOS-4 PALSAR-3 Products - JAXA (2026))

as well as for wildfires, where EO-based products have been used to assess burn extent and support firefighting and recovery planning. In addition, a smaller number of activations have addressed other hazard types, such as storm-related coastal flooding and environmental accidents, demonstrating the flexibility of the Sentinel Asia mechanism.

Beyond the numbers, the accumulated impact of these activations lies in their operational value. The repeated use of Sentinel Asia products has enabled disaster management authorities to act more quickly and confidently, even in situations where ground information is unavailable or unreliable.

For example, in September 2024, Typhoon Yagi affected Lao PDR, Myanmar, the Philippines, Thailand, and Vietnam. In response, disaster management organizations in each country, along with the Centre for Humanitarian Assistance on Disaster Management (AHA Centre), requested emergency observations from Sentinel Asia. By utilizing satellite data and flood extent maps provided by Sentinel Asia, the AHA Centre was able to enhance the planning for emergency response operations in a timely manner.

Over time, the initiative has strengthened institutional trust in EO based decision support, enhanced technical capacity among participating agencies, and reinforced regional cooperation in disaster risk reduction. Through its Joint Project Team framework, Sentinel Asia continues to play a vital role in protecting lives and livelihoods and improving resilience across the Asia Pacific region.

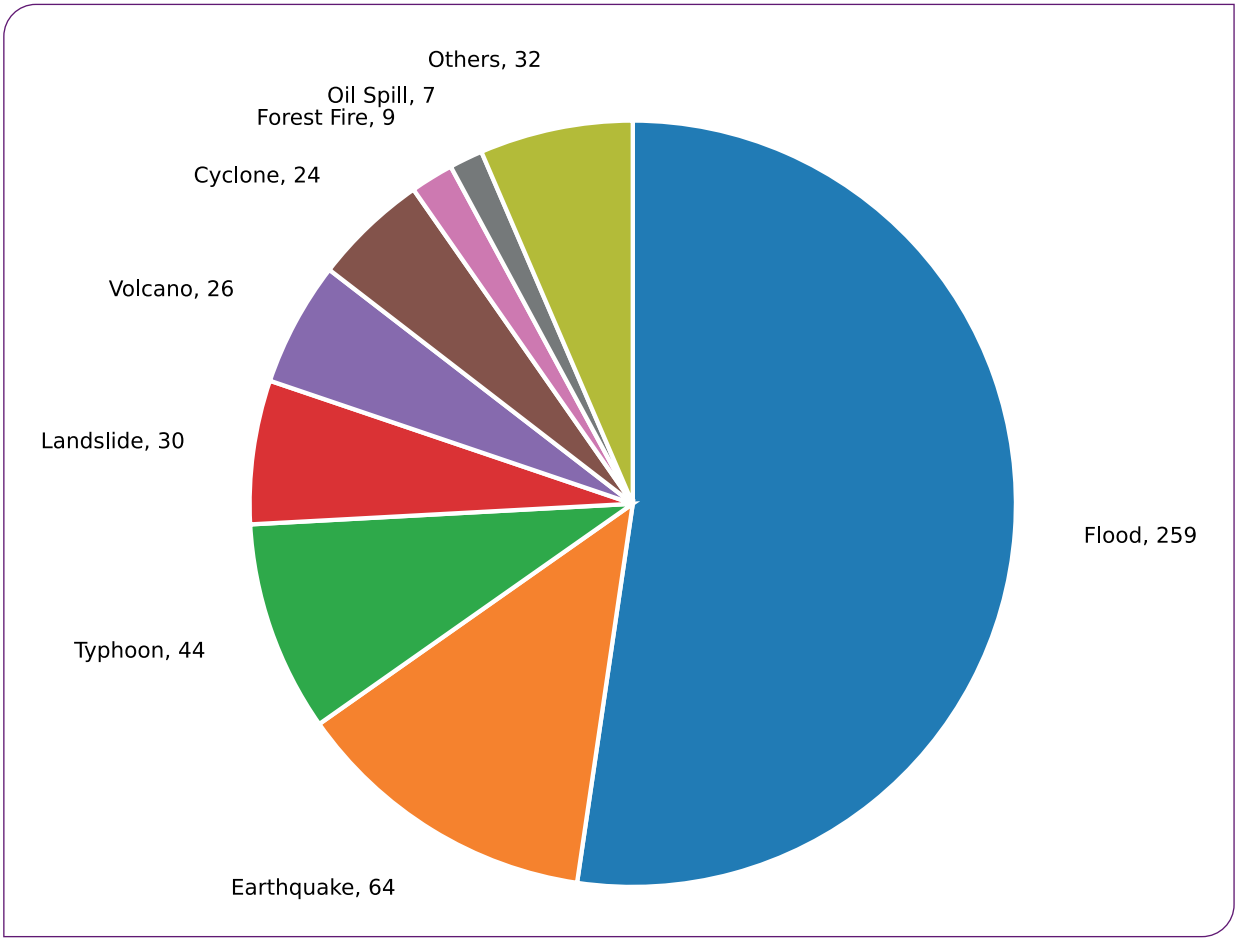


Fig. 5 Breakdown of Sentinel Asia Emergency Observations by Disaster (Attribution: Sentinel Asia Annual Report, 2024)

FURTHER INFORMATION AND GUIDANCE

Sentinel Asia
https://sentinel-asia.org

Asia-Pacific Regional Space Agency Forum (APRSAF)
https://www.aprsaf.org

Japan Aerospace Exploration Agency (JAXA)
https://www.jaxa.jp

03

REGION: AFRICA

Supporting Disaster Risk Financing in Morocco Through EO-Based Flood and Exposure Mapping

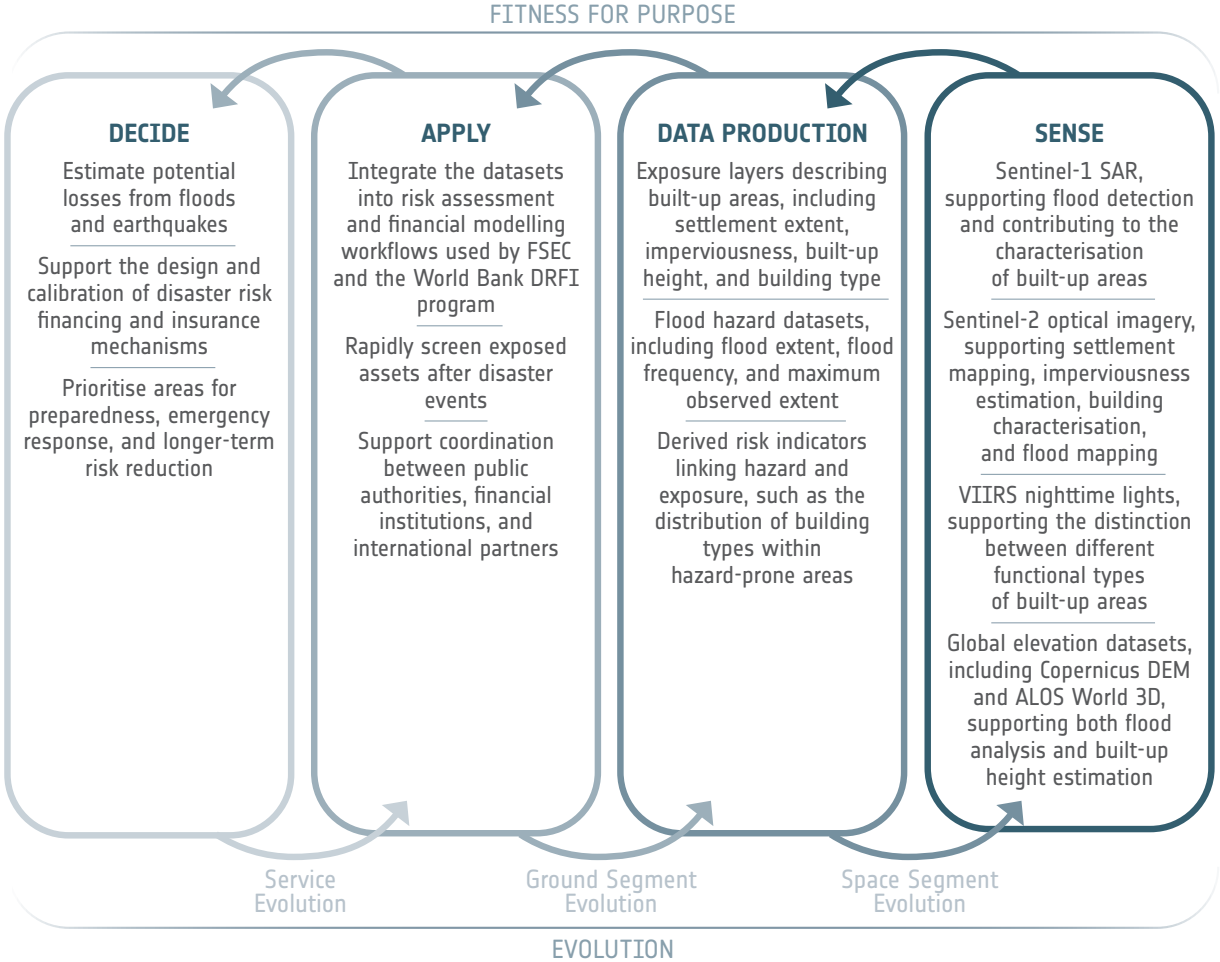
Summary

Morocco is regularly affected by natural hazards, particularly floods and earthquakes, creating significant challenges for disaster response and financial risk management. For institutions such as the Fonds de Solidarité contre les Événements Catastrophiques (FSEC), estimating potential losses in advance is essential. In practice, however, this has long been constrained by the limited availability of consistent and spatially detailed information on both hazards and exposed assets.

Within ESA's GDA Disaster Resilience activity, an EO-based effort was carried out to strengthen risk assessment capabilities in Morocco. The World Bank DRFI Program and FSEC helped define user requirements and operational workflows.

The activity combined two complementary components. The first focused on exposure, generating datasets that describe where built-up assets are located, how dense and tall they are, and what types of buildings are present. This included settlement extent, imperviousness, built-up height, and building type classification.

Value Chain Diagram



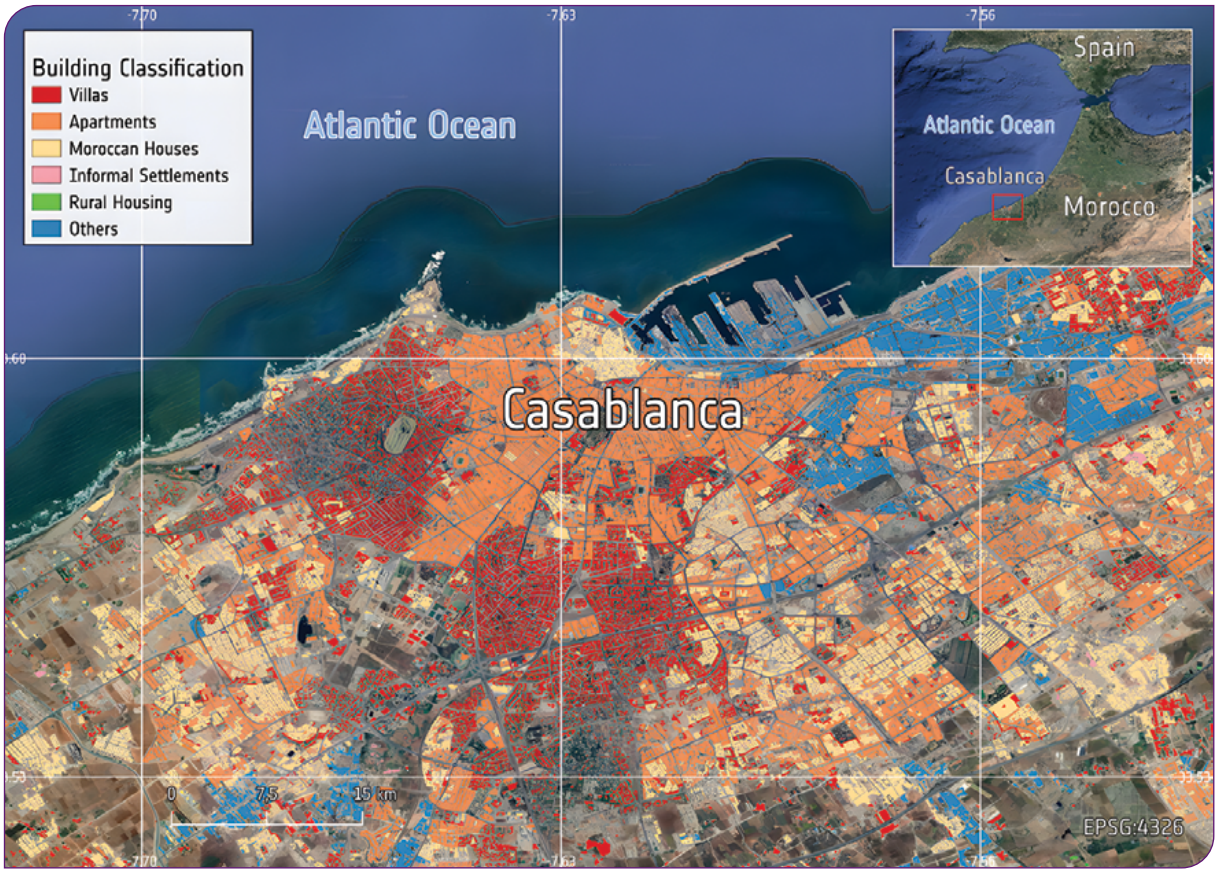


Fig. 1 Building Type Classification for Casablanca, Morocco (Attribution: DLR)

The second focused on hazard, generating flood datasets from satellite observations to identify the spatial extent and recurrence of flooding events.

Together, these datasets improved national-scale hazard and exposure assessment. Their value became particularly evident after the 2023 Marrakesh–Safi earthquake, when the exposure information was used to rapidly assess the distribution and types of affected buildings, supporting early damage appraisal and response prioritisation. The case shows how EO can strengthen disaster risk financing and support preparedness, response, and recovery.

Decision-Making Context and Needs

Morocco has established institutional mechanisms to manage the financial consequences of natural disasters, with FSEC playing a central role in compensation and recovery. For these mechanisms to work effectively, risk needs to be assessed in advance by combining information on where hazards occur with a realistic representation of the assets that may be affected.

In practice, this has often been difficult. Information on buildings and infrastructure is frequently fragmented, uneven in detail, or not regularly updated. In particular, datasets describing not only where built-up assets are located, but also how dense, how tall, and what type of buildings are present, are often missing or incomplete. Hazard information, especially for floods, can also be inconsistent across the country or not readily usable within financial risk models. As a result, estimating potential losses and designing financial protection mechanisms becomes more uncertain.

As part of ESA's GDA Disaster Resilience activity, Morocco served as a practical case through which EO-based approaches could be tested against real disaster risk financing needs. The World Bank DRFI Program and FSEC were closely involved in framing the use case, articulating the priority information gaps, and providing feedback

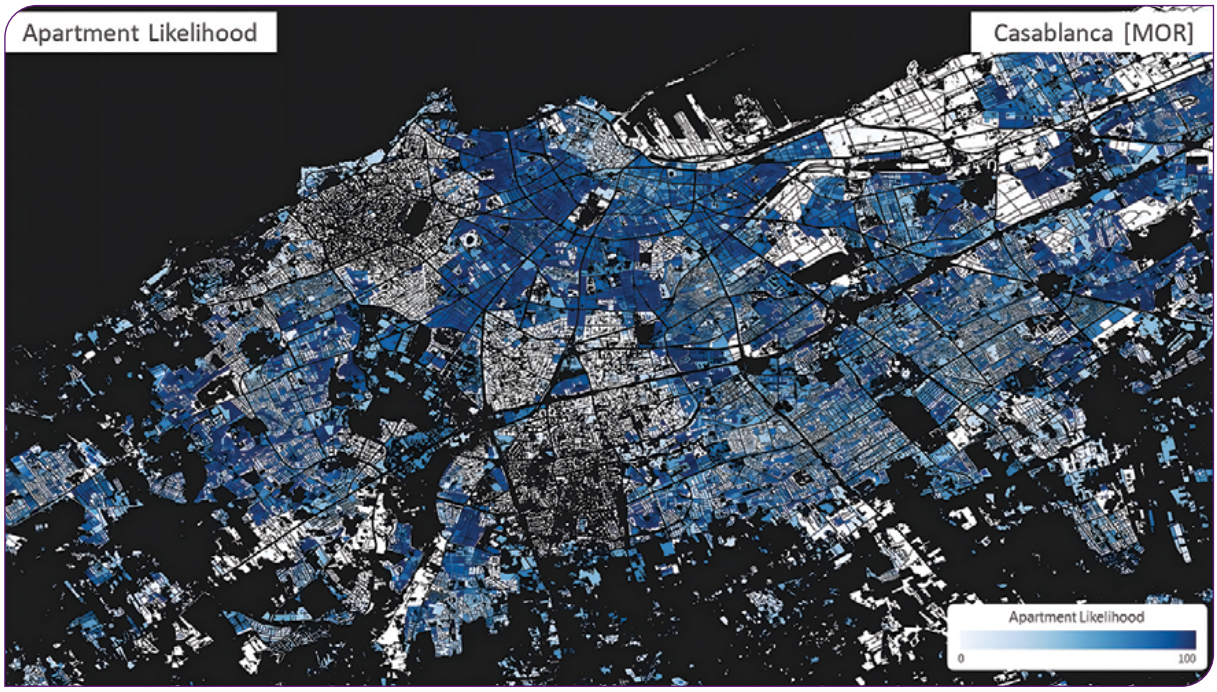


Fig. 2 Apartment likelihood map for Casablanca, Morocco (Attribution: DLR)

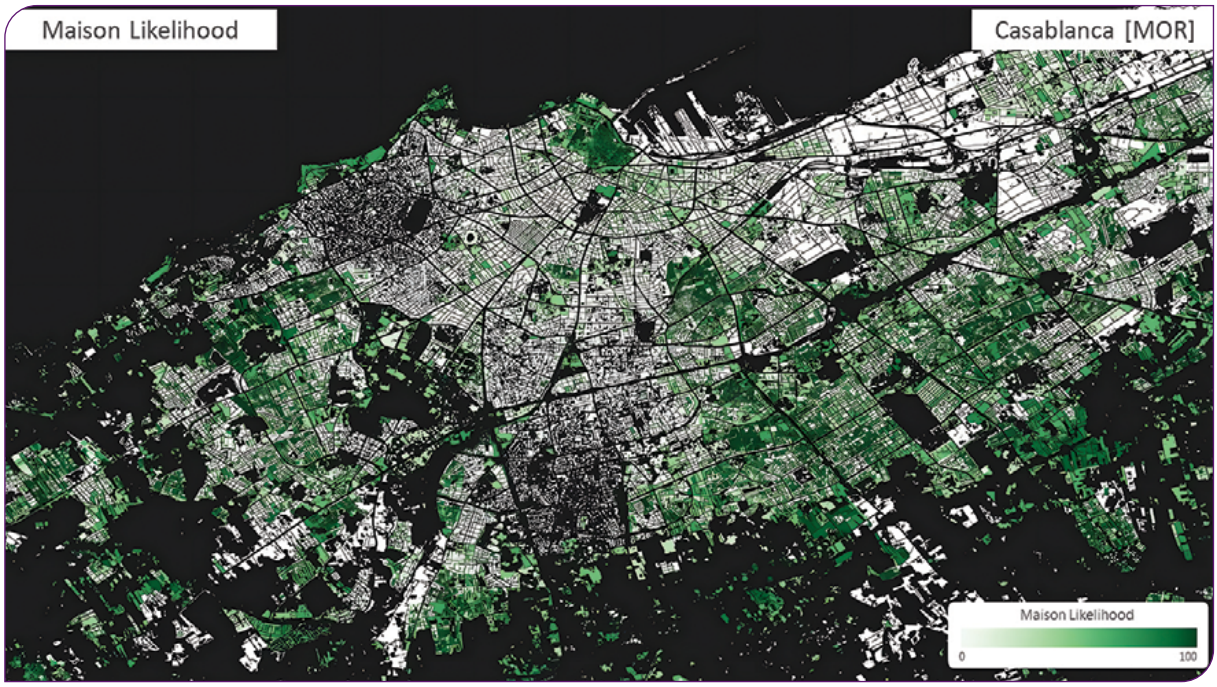


Fig. 3 Moroccan house likelihood map for Casablanca, Morocco (Attribution: DLR)

so that the resulting datasets could be aligned with operational workflows and decision-making requirements.

The work was therefore developed in close interaction with users, allowing the products to be refined iteratively based on feedback. This helped ensure that the final outputs were not only technically robust, but also practical to use within existing institutional workflows.

Earth Observation Data Products and Information

To address the identified gaps in exposure and hazard information, the activity produced a set of complementary EO-derived datasets designed to provide a spatially detailed and nationally consistent representation of risk components across Morocco.

On the exposure side, the work was built on DLR's World Settlement Footprint (WSF) framework, which provides satellite-derived information on the spatial distribution of human settlements. For Morocco, this included settlement extent information together with dedicated layers describing imperviousness and built-up height. The imperviousness layer estimates sealed surfaces within built-up areas, supporting assessment of urban density and flood-related runoff. The built-up height layer captures the vertical dimension of settlements.

In addition to these layers, a dedicated Building Type Classification product was developed specifically for this Morocco activity. It distinguishes between classes such as villas, apartments, Moroccan houses, rural housing, informal settlements, and a broader non-residential category including industrial, commercial, military sites, and greenhouses. This added an important dimension to the exposure analysis, because different building types are associated with different vulnerabilities and economic values, which in turn influence potential loss estimates and recovery needs. Examples from Casablanca (Figures 1, 2, 3) show how the dedicated Building Type Classification moves beyond a simple built-up mask, distinguishing between settlement types.

On the hazard side, flood extent datasets were generated from satellite observations by combining radar and optical information to improve detection under different environmental conditions (Figures 4, 5). These products support flood extent and frequency analysis.

Together, the datasets provided integrated hazard and exposure information suitable for risk analysis and financial modelling.

Underlying Observations and Data Sources

The activity combined several EO and geospatial data sources to characterise exposure and flooding.

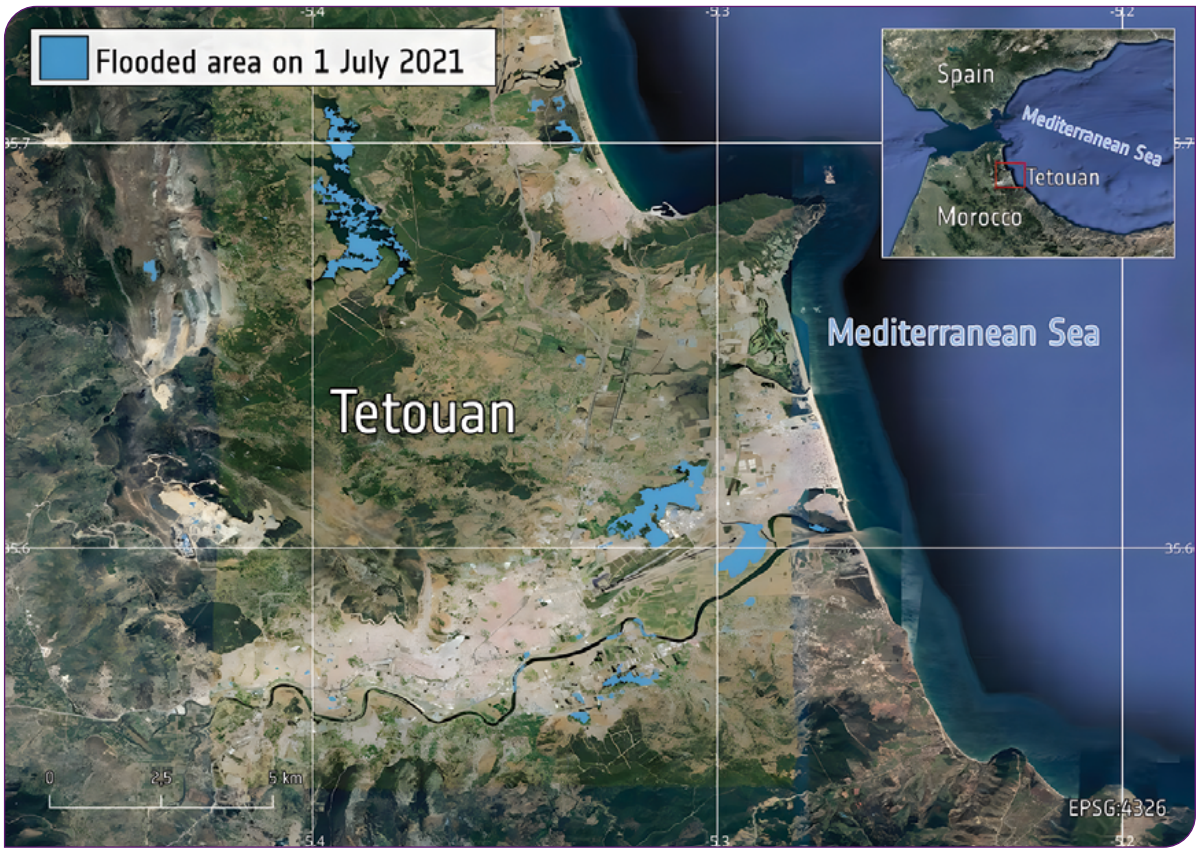


Fig. 4 Leveraging Sentinel-1 and -2 data, the Tetouan, Morocco, flood map innovatively identifies both rural and urban flooded areas (Attribution: LIST)

Sentinel-2 optical imagery played a central role in the exposure component. It supported the delineation of settlement patterns, the estimation of imperviousness, and building type classification. Sentinel-1 SAR data was mainly used for the hazard component, as it enables flood detection even under cloud cover and in rapidly changing conditions. It also contributed to the broader characterisation of built-up areas through settlement-related analyses.

To better represent the vertical dimension of exposure, global elevation datasets were integrated, notably the Copernicus DEM and ALOS World 3D. These datasets were used both to estimate built-up height and to support flood analysis. In addition, terrain information derived from FABDEM was used to support the building type classification.

The activity also incorporated VIIRS nighttime light observations, which provided additional information on the functional character of built-up areas. These data were particularly useful in helping distinguish between residential and non-residential zones.

Complementary geospatial datasets also played an important role. OpenStreetMap and Facebook road data provided contextual information supporting building type classification and neighbourhood delineation.

A combination of EO and auxiliary geospatial data enabled richer representation of exposure and flood-prone context for risk analysis.

Impacts and Benefits

The activity strengthened the ability of Moroccan institutions to assess disaster risk using more consistent and spatially detailed information on both hazard and exposure. A key benefit lies in the richer characterisation of exposed assets. Exposure analyses can now consider settlement density, height, and building type. This makes it possible to represent exposure more realistically within financial risk models and to support more robust estimation of potential losses.

The dedicated Building Type Classification product is particularly valuable in this respect. Different building types imply different vulnerabilities and economic values. Introducing this level of differentiation helps move from generic exposure estimates towards assessments that are more meaningful for financial planning, emergency appraisal, and post-disaster recovery analysis.

The practical value of the datasets became especially evident after the 2023 Marrakesh–Safi earthquake. In that context, the exposure layers were used to rapidly assess the likely distribution and typology of affected buildings, providing an early indication of the types and distribution of impacted assets. This supported initial damage appraisal and helped prioritise response efforts at a time when rapid information was essential.

Beyond individual events, the integration of hazard and exposure information supports a more structured approach to risk analysis. Stakeholders can identify where built-up assets are concentrated in hazard-prone zones and better understand the characteristics of those exposed assets, helping to inform preparedness planning, prioritisation, and longer-term risk reduction strategies.

At the same time, the activity highlighted important limitations. In particular, the rapid and short-lived nature of many flood events in Morocco makes them difficult to capture using satellite observations alone. Some exposure products, especially the Building Type Classification, also depend on the availability and representativeness of reference and ancillary data, which may affect generalisation in some parts of the country. These limitations highlight areas for further refinement.

Overall, the activity shows how EO-based information can strengthen disaster risk financing by providing consistent, scalable, and operational inputs for decision-making. Beneficiaries include disaster risk management and financial planning institutions, as well as affected communities. This is particularly important in contexts where faster and better targeted early assessments can influence how recovery support is prioritised after a disaster.

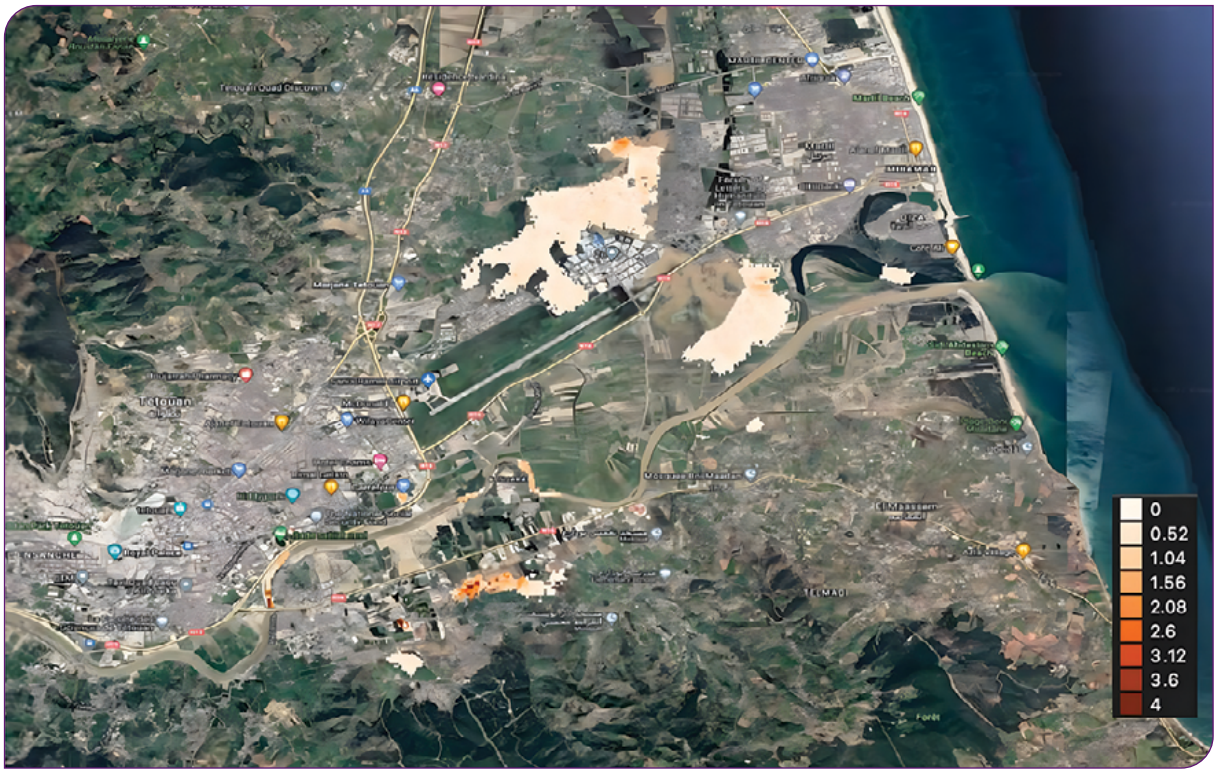


Fig. 5 Water depth computed on the flooded areas. Different colors identify different water depths in meters. Tetouan, Morocco. (Attribution: LIST, CIMA Foundation)

FURTHER INFORMATION AND GUIDANCE

Points of contact

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- Mattia Marconcini, DLR (German Aerospace Center) - MindEarth / email: mattia.marconcini@dlr.de; mattia.marconcini@mindearth.ch

Key organisations and programme context

- European Space Agency (ESA) – Global Development Assistance (GDA), Disaster Resilience thematic area: https://gda.esa.int/thematic-area/disaster-resilience/
- World Bank – Disaster Risk Financing and Insurance (DRFI) Program: https://www.worldbank.org/en/programs/disaster-risk-financing-and-insurance-program
- Fonds de Solidarité contre les Événements Catastrophiques (FSEC), Morocco
- Indra Space – Earth Observation Applications: https://www.indracompany.com/
- DLR – Team: Smart Cities and Global Urban Intelligence: https://www.dlr.de/en/eoc/about-us/german-remote-sensing-data-center/land-surface-dynamics/smart-cities-and-global-urban-intelligence

04

REGION: ASIA

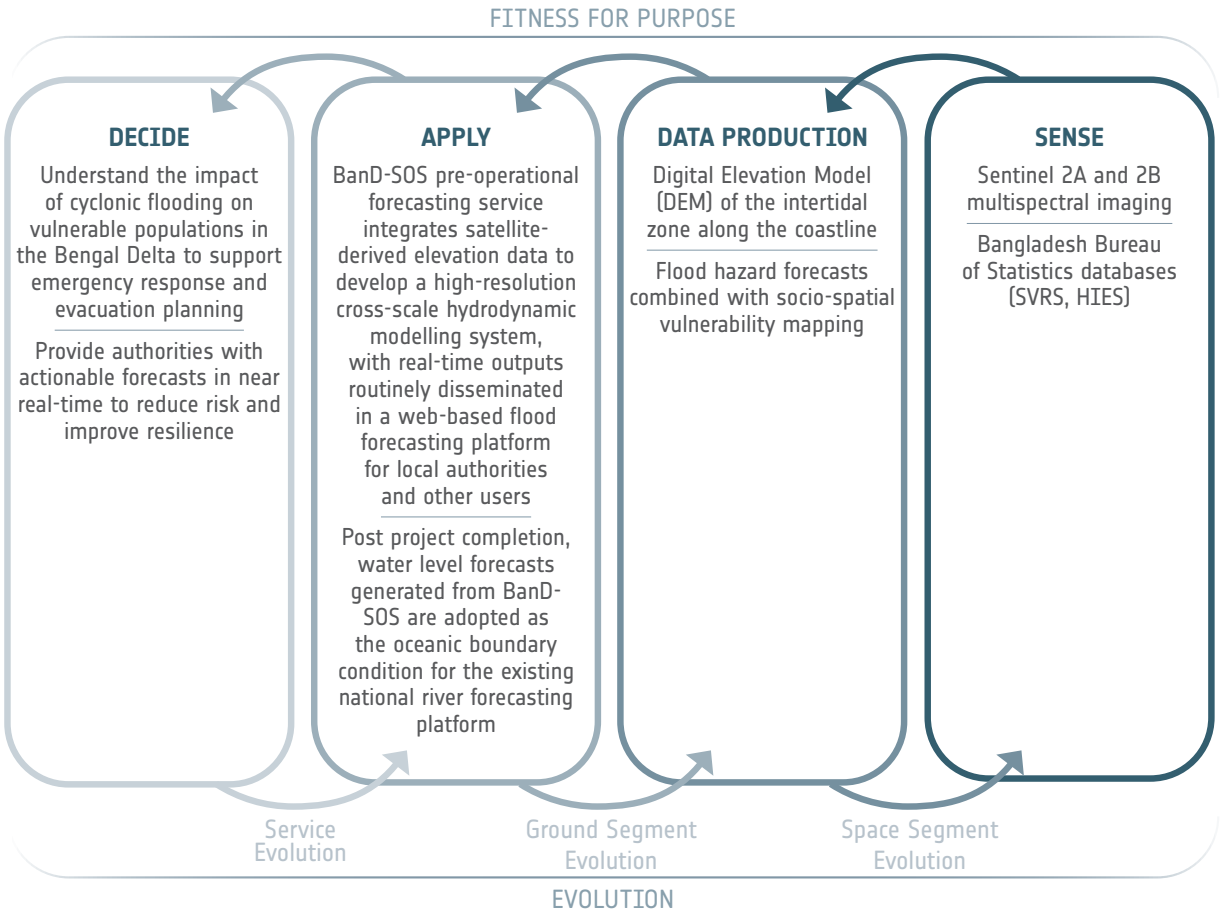
Bangladesh Delta Floodings: An Integrated Framework for Social Adaptation to Cyclone Surges

Summary

Trialled in the Bengal Delta in Bangladesh, BanD-SOS aims to establish a pre-operational service for forecasting cyclonic flooding and the associated societal risk. The main component of this service is the forecast of flooding hazards in real time. In addition, coastal vulnerability indices at the sub-district level are disseminated with flood forecasts to provide a quick view of the vulnerability of the exposed population.

BanD-SOS marks the first-ever deployment of an operational coastal flood forecasting platform capable of predicting cyclonic flooding in the Bengal Delta. The platform is currently operated by the Bangladesh Water Development Board (BWDB), the governmental water management organisation in Bangladesh and a partner public authority of the project. The dissemination platform is accessible via an immediately useful web portal, accessible to all users, in real time (https://bandsos.github.io). The system was deployed and has been running continuously since November 2022. It has been put to the test in real life during several cyclones since its deployment. Among these events, Cyclone Remal in May

Value Chain Diagram



2024 is noteworthy, which severely impacted the coastal region of Bangladesh. The forecast provided by BanD-SOS was used by BWDB in better preparing for the management of this disaster with localised flood forecasts. The BanD-SOS service is managed by local engineers at BWDB and is being integrated into the larger BWDB forecasting capabilities as an essential tool. BanD-SOS is in its 4th year of operation and continues to operate for the ongoing 2026 cyclone season.

In early 2026, the platform migrated to a more reliable computing environment and updated to accommodate changes in upstream data sources, including NOAA global atmospheric forecasts. Future improvements by engineers at BWDB are planned, including incorporation of new bathymetric datasets in the highly dynamic Bengal delta region, as well as enhancement of the online dissemination portal to meet new local needs.

Decision-Making Context and Needs

The Bengal Delta, straddling Bangladesh and India, is hit by a major tropical cyclone every 3 years on average. Their occurrence is relatively moderate compared to other tropical regions, representing only 5% of global cyclones. The impact of these events is, however, major, representing 50% of the cyclone victims recorded globally. This is due to the very low topography of the delta above sea level (less than 5 metres)

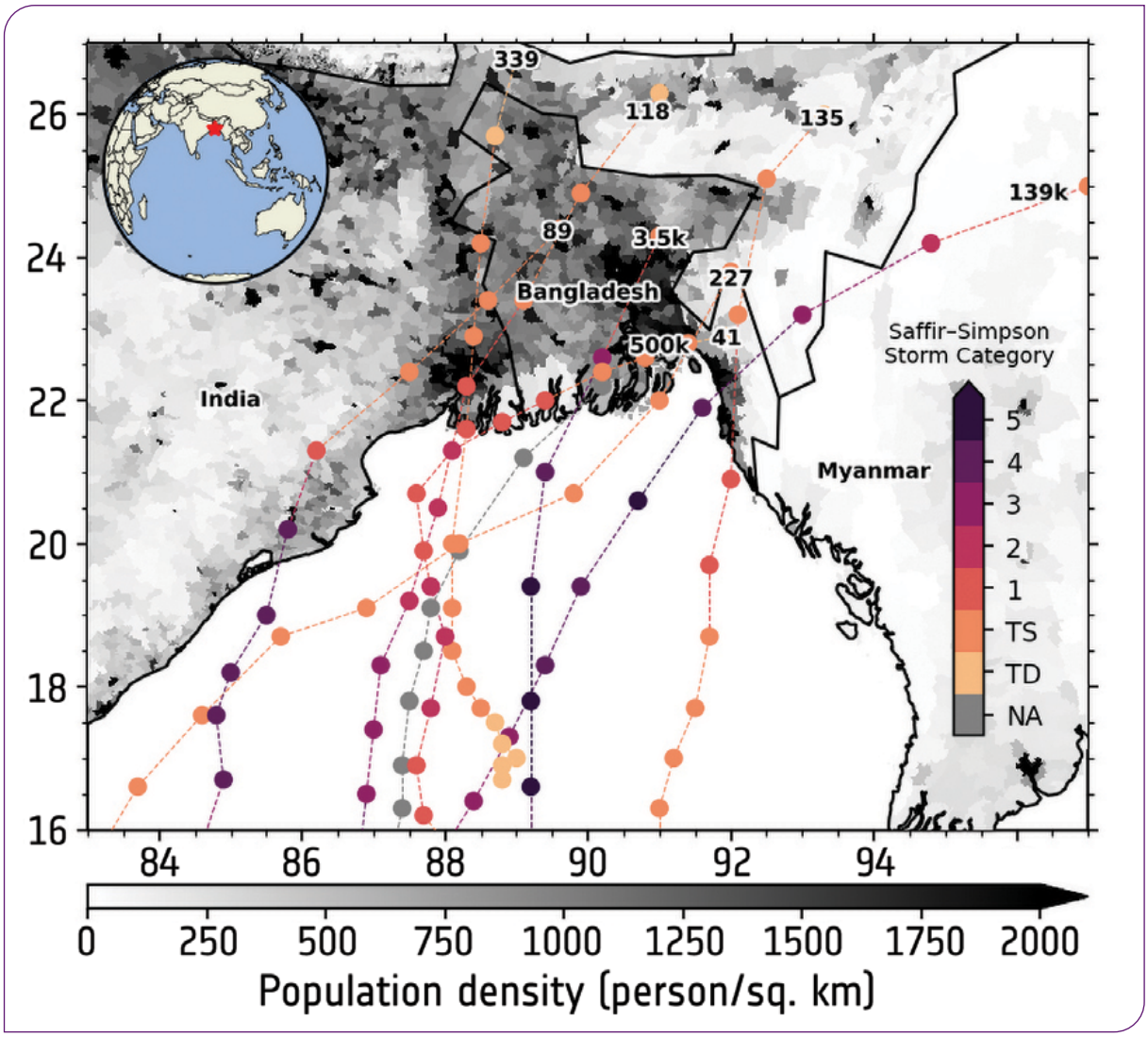


Fig. 1 Trajectories and intensities of major cyclones that have struck the Bengal Delta over the past five decades, with the number of victims recorded for each (Attribution: © Jamal Uddin Khan (LIENSs, La Rochelle))



Fig. 2 Coastal defenses installed along the coastline of Kuakata (South Bangladesh) (Attribution: © Jamal Uddin Khan (LIENSs, La Rochelle))

and the fragility of coastal defense structures, combined with the high density of the vulnerable population (Figure 1)

The exposure of the Bengal Delta to cyclonic flooding is increasing in the current context of sea level rise due to climate change.

The objective of the BanD-SOS project was to develop a pre-operational flood forecasting system whose function is to:

- provide in real time the basic information necessary for the implementation of evacuation and protection operations when a hurricane event occurs;

- assist in the development of public policies for adaptation to the flood hazard necessary to ensure the resilience of the Delta population in the medium to long term.

To this end, the BanD-SOS service consisted of pre-operationalizing a numerical forecasting platform for cyclonic flooding over Bengal, for which we have completed the proof of concept (Khan et al., 2021). The BanD-SOS service ensures the prediction of the flood hazard, combined with spatialised information of the socio-spatial vulnerability of the exposed territories.

The main user of the first operational service available is the Bangladesh Flood Forecasting and Warning Center (FFWC).

Earth Observation Data Products and Information

The BanD-SOS platform uses the SCHISM hydrodynamic model coupled with the WWM wave model, which simulates the temporal evolution of sea level and waves every 5 minutes on a scale of a hundred metres. Considering the interaction of the tide, the cyclonic effect, and river inputs from the mainland, it reproduces sea level variability across the entire coastal ocean-delta-river continuum. It is particularly well suited to capturing the extreme water levels that develop at the peak of cyclonic episodes.

Spatial remote sensing is at the heart of the BanD-SOS system. Thanks to an archive of high-resolution Sentinel-2 satellite images, the project team has been able to calculate a Digital Elevation Model (DEM) of the area along the coastline between high and low tide, known as the "intertidal zone." This is a key element of the BanD-SOS platform, as cyclonic inundation dynamics depend on the topography of the shallow shorefront and the intertidal zone. This is particularly important for the Bengal Delta with vast, gently sloping beaches and typically not observed by topographic nor hydrographic surveys.

Underlying Observations and Data Sources

The BanD-SOS system relies on a combination of satellite and ground-based data to produce accurate forecasts of cyclonic flooding. The main satellite inputs come from Sentinel-2A and -2B multi-spectral imaging, which provide high-resolution imagery necessary to calculate the Digital Elevation Model (DEM) of the intertidal zones along the Bengal Delta coastline.

In addition to satellite data, BanD-SOS uses information from the Bangladesh Bureau of Statistics, including the Sample Vital Registration System (SVRS) and the Household Income and Expenditure Surveys (HIES). These datasets provide socio-economic and population information that is essential for mapping the vulnerability of populations exposed to flooding. Together, these sources enable BanD-SOS to couple hydrodynamic forecasts with spatialised vulnerability information, providing actionable insights for both emergency response and long-term planning.

The system is continuously operated and maintained by BWDB engineers, ensuring sustainability and reliability of the forecasts. The recent migration to a more robust computing environment and incorporation of updated upstream data sources (e.g., NOAA global atmospheric forecasts) further strengthen the operational quality of the service.



Fig. 3 Flood in Bangladesh (Attribution: © Jamal Uddin Khan (LIENSs, La Rochelle))

Impacts and Benefits

The BanD-SOS project established a pre-operational production chain for coastal flooding prediction, accessible on demand via a web interface for non-specialist end users. The platform is fully open-source, hosted on GitHub Pages, and allows users to view forecasts for the next 14 days as well as replay past events. Results are fully public and easily interpretable by non-experts, enabling authorities and other stakeholders to take timely action.

During Cyclone Remal, which formed unusually fast in 3 days and lasted 36 hours, more than 800,000 Bangladeshis evacuated the coast. Approximately 4.6 million people were affected, 40,000 homes were destroyed, and 133,000 were damaged. The BanD-SOS forecasts closely matched observed flooding, capturing three successive peaks of maximum water levels of 2–3 meters above high tide.

According to the Flood Forecasting and Warning Center (FFWC), BanD-SOS supported field officials in preparing for inundation and potential infrastructure failures. Future improvements are planned, including adjusting forecasts with local mean sea level (MSL) observations to increase accuracy. Overall, the project demonstrates the effectiveness of an operational, real-time flood forecasting system in saving lives, informing emergency response, and supporting the resilience of vulnerable populations.

The demonstration of the replication of this pre-operational chain will be realized with the porting of the solution to the Amazon Delta, highlighting the potential for broader application beyond the Bengal Delta.



Fig. 4 Bangladesh, July 16th, 2020. Storm surges caused by more frequent and powerful cyclones push walls of water 80 to 100 km along the delta rivers (Attribution: © Moniruzzaman Sazal / Climate Visuals Countdown)

FURTHER INFORMATION AND GUIDANCE

Points of contact

- Fabien DURAND: fabien.durand@ird.fr
- Jamal KHAN: jamal.khan@ird.fr

BanD-SOS tool: https://bandsos.github.io/

Youtube video **Band SOS, forecasting cyclonic flooding and the associated societal risk***:*

https://www.youtube.com/watch?v=rkZDswUoe9I

ECONOMIC SECURITY & INFRASTRUCTURE

CASE STUDIES



01

REGION: EUROPE

InSAR Norway for Risk Mitigation, Adaptation, and Resilience

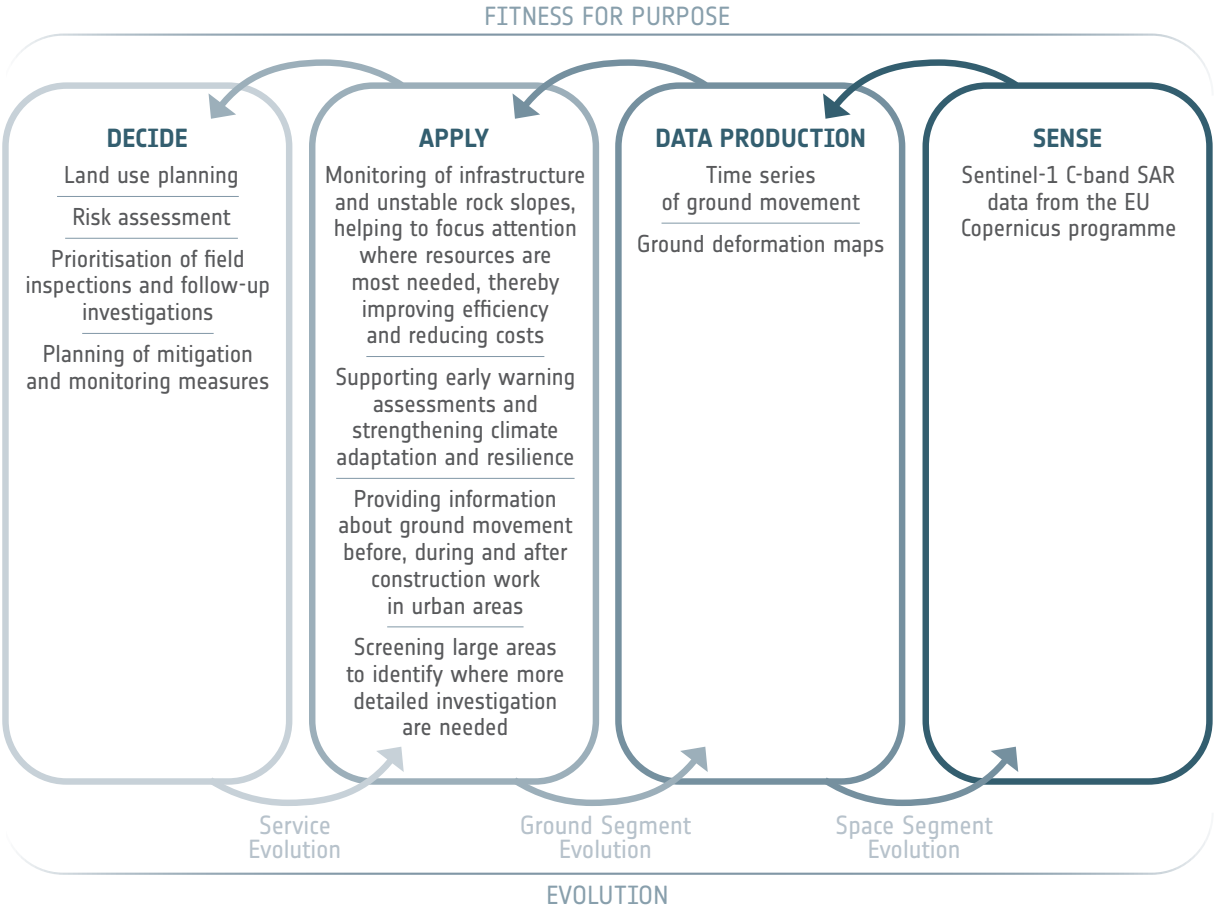
Summary

InSAR Norway is a national ground motion monitoring service that uses satellite-based Interferometric Synthetic Aperture Radar (InSAR) to systematically detect and map land movement across Norway. By combining regular Sentinel-1 radar observations with advanced processing and interpretation, the service provides nationwide information on ground deformation with millimetre-scale precision.

This service has been established to support public authorities, infrastructure owners, researchers, and other users who need reliable information about land movement in a changing climate. Norway faces a wide range of ground instability challenges, including unstable rock slopes, landslides, subsidence in urban areas, and deformation affecting roads, railways, dams, and other critical infrastructure. By providing regular nationwide coverage, InSAR Norway helps users identify where change is happening, where conditions appear stable, and where closer investigation may be needed.

A key outcome of InSAR Norway is improved risk mitigation through early identification of

Value Chain Diagram



unstable ground conditions. The service helps reveal patterns of movement that may otherwise remain unnoticed until damage occurs or hazards escalate. This supports more preventive planning, more targeted field investigations, and more efficient use of resources. It also helps decision-makers prioritise follow-up efforts and respond earlier to emerging ground instability.

Today, InSAR Norway is fully operational and continuously updated, and it has become an important part of Norway's geospatial infrastructure. By turning satellite observations into accessible and actionable information, the service strengthens national capacity for risk reduction, climate adaptation, and long-term resilience.

Decision-Making Context and Needs

Norway faces many challenges linked to ground movement, including unstable rock slopes,

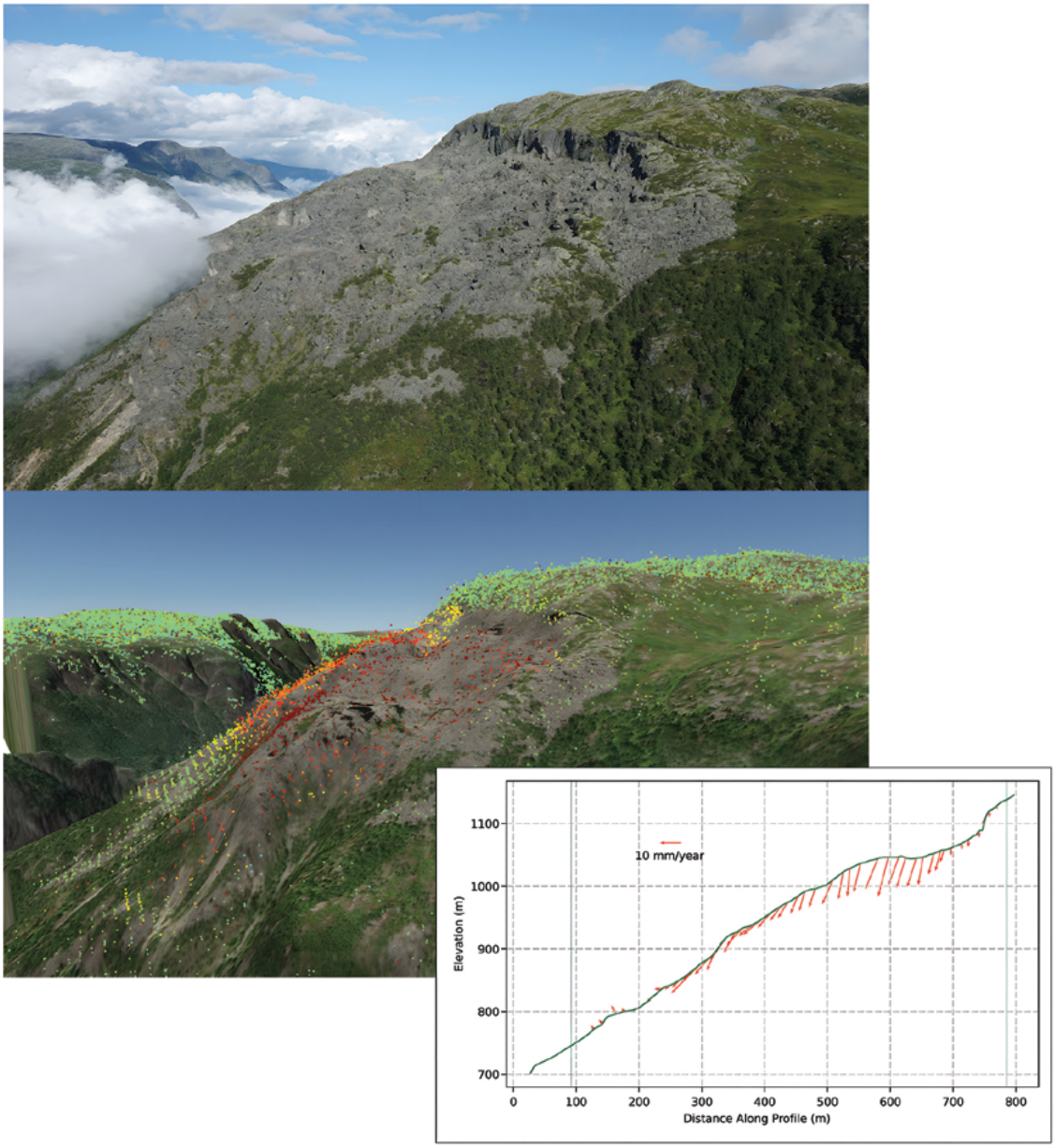


Fig. 1 Example of InSAR-based monitoring at the Gámanjunni unstable slope in Manndalen, Troms. (Attribution: Gökhan Aslan (InSAR Norway, NGU)

landslides, subsidence in urban areas, and deformation affecting roads, railways, dams, buildings, and other critical infrastructure. These challenges are becoming more important in a changing climate, where shifts in precipitation, snowmelt, erosion, and freeze-thaw conditions can affect slope stability and ground conditions. At the same time, there is a need for better overview and earlier insight. Ground investigations and local monitoring remain essential, but they are often limited to specific sites and require significant time and resources. InSAR Norway was established to complement these methods by providing regular, nationwide information on where the ground is moving and where further attention may be needed. The service supports public authorities, infrastructure owners, researchers, and planners by helping them screen large areas, prioritise follow-up, and strengthen the basis for land-use planning, risk

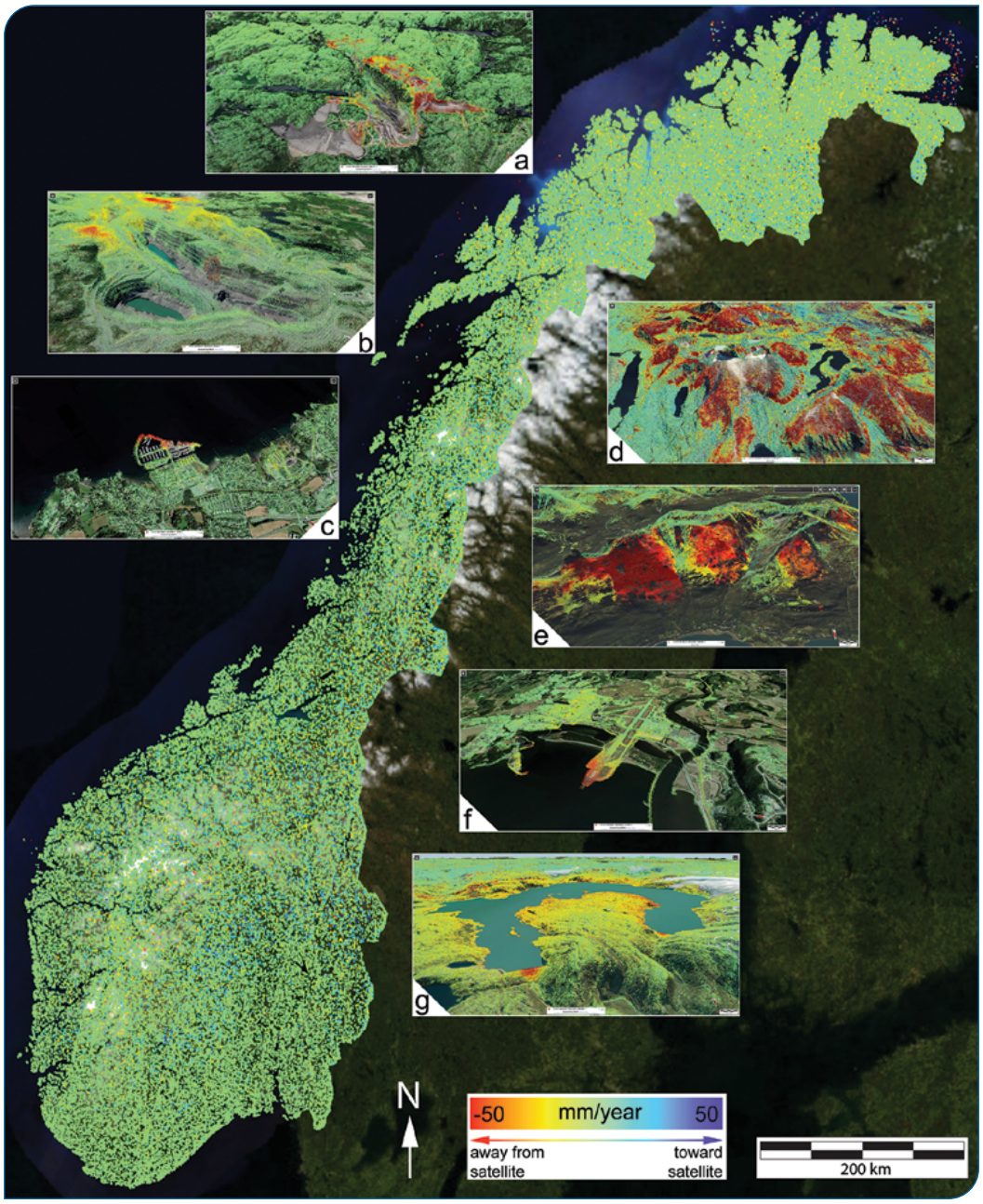


Fig. 2 InSAR Norway: nationwide ground deformation mapping and selected application examples: (a) settlement in mine tailings, (b) instabilities in the open-pit Bjørnevatn mine in Finnmark, (c) subsidence in reclaimed land at Grillstadfjæra in Trondheim, (d) permafrost-related ground deformation, (e) unstable slopes at Piggtind and Sjævasstind in Troms, (f) subsidence in reclaimed land at Trondheim Airport, Værnes, and (g) deformation affecting the Storglomvatn hydropower dam. (Attribution: Gökhan Aslan (InSAR Norway, NGU))

assessment, and infrastructure management. In this way, satellite-based observations become a practical source of decision support, used in combination with geological knowledge, field observations, and other monitoring data.

Earth Observation Data Products and Information

InSAR Norway provides ground deformation information derived from satellite radar observations. The main products include ground deformation maps and time series that show how the ground moves over time. These products make it possible to identify areas with stable conditions, detect areas showing movement, and follow how deformation develops. For users, this means access to consistent, nationwide information that can support screening, follow-up, and interpretation. The products are particularly useful for identifying areas that may require closer investigation, supporting risk assessments, and improving the basis for land-use planning and infrastructure management. Because the information is updated regularly and covers large areas, it offers a practical way to detect patterns and changes that may not be visible through field observations alone. In this way, the service helps turn Earth observation data into practical and actionable information for day-to-day decision support.

Underlying Observations and Data Sources

The core observations and data source is SAR (Synthetic Aperture Radar) data from the Copernicus Sentinel-1 mission. Sentinel-1 provides systematic radar observations with consistent revisit cycles, enabling monitoring over large areas. These observations are used in InSAR processing to detect subtle surface deformation with millimetre-scale sensitivity. This makes it possible to identify and follow ground movement affecting unstable rock slopes, landslides, subsidence, and infrastructure.

Impacts and Benefits

Although InSAR cannot directly replace on-site investigations and local monitoring methods, InSAR Norway has given users a new overview of ground movement across the country. For the first time, authorities have gained a comprehensive overview of where the ground is actually moving, where it is stable, and where changes are emerging over time. This shift from fragmented, local observations to continuous, nationwide insight has fundamentally improved monitoring of potentially dangerous areas.

The service helps protect buildings, roads, railways, dams, and reservoirs, as well as other critical infrastructure, and also supports the monitoring of climate-driven slope instability.

FURTHER INFORMATION AND GUIDANCE

InSAR Norway was launched in 2018 by the Geological Survey of Norway (NGU), the Norwegian Water Resources and Energy Directorate (NVE), and the Norwegian Space Agency. It is a nationwide, freely accessible, and web-based map service that makes InSAR-based ground motion information available across Norway. The research institute NORCE has also played a central role in the development of the technology.

InSAR Norway portal: https://insar.ngu.no

INSAR.No: A National InSAR Deformation Mapping/Monitoring Service In Norway – From Concept to Operations. https://ieeexplore.ieee.org/document/8898614

02

REGION: EUROPE



From the Sky to Soil

Summary

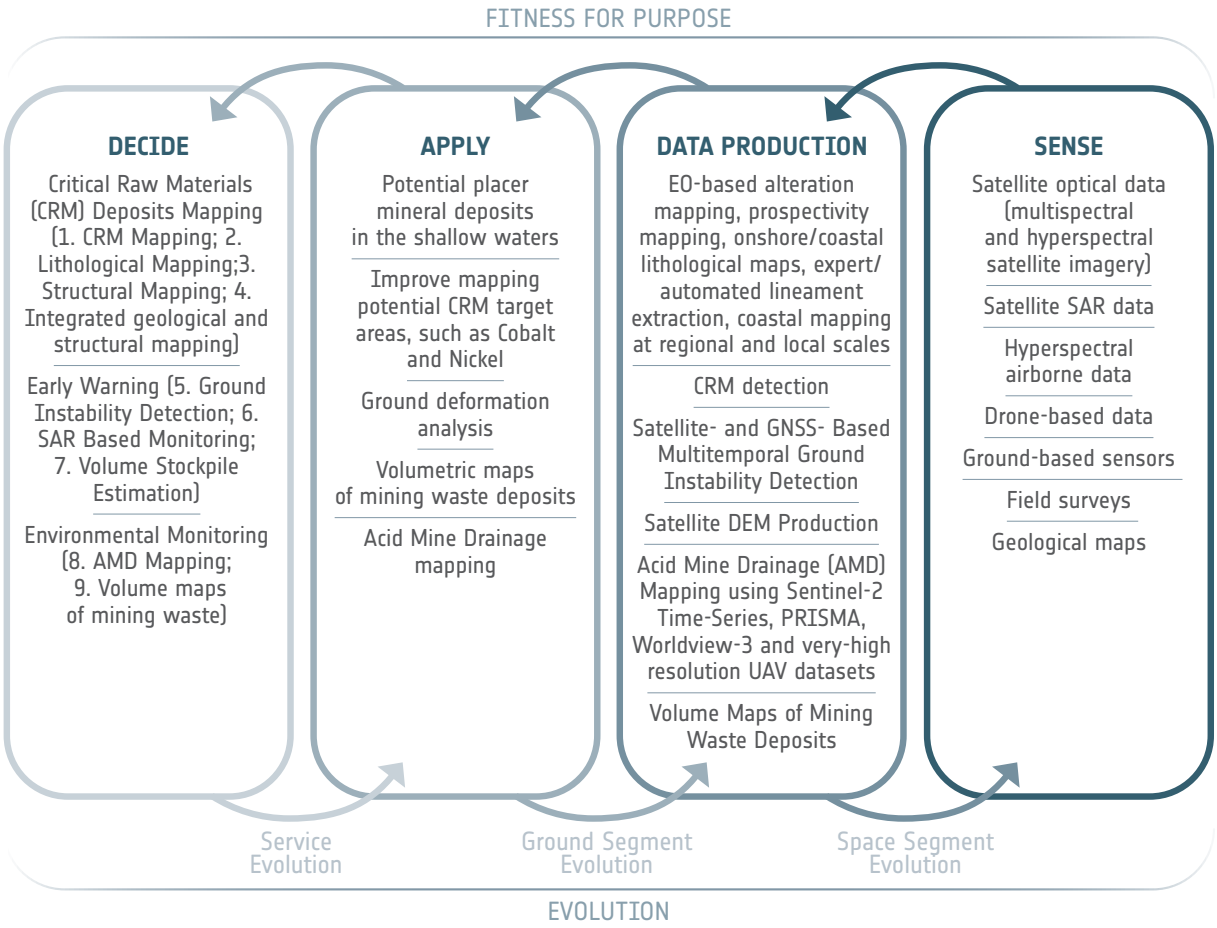
S34I was a 30-month European project, started in January 2023, researching and developing new data-driven methods to analyse Earth Observation (EO) data, supporting systematic mineral exploration and continuous monitoring of extraction, closure, and post-closure activities, with the aim of increasing European knowledge and autonomy in raw materials resources. Copernicus and other satellite sensors (optical and radar) were exploited, while other sensing methods, such as airborne and low-altitude platforms, ground-based techniques, and fieldwork, were applied for calibration, validation, or to complement Copernicus data. The innovative EO-based products/services developed provide new and more accurate mineral mapping/exploration, environmental and mine monitoring, and mine safety across the different phases of the mine life cycle. Ultimately, S34I provided 50 new open datasets, 20 new methods to analyse EO data using Artificial Intelligence (AI) at different phases of the mining life cycle, nine new prototype EO-based services with 22 products tailored for mining stakeholders, one research and innovation agenda on EO for mining, and a set of recommendations for better policy and guidelines for EO uptake by the mining industry.

Decision-Making Context and Needs

The importance of sourcing critical raw materials (CRMs) within the EU has been highlighted by the adoption of the Critical Raw Materials Act in 2024, strengthening the need to enhance the sustainability and safety of extractive activities. This underscores the urgency of ensuring that extractive activities align with EU sustainability and safety directives. The S34I project addresses critical challenges facing the European raw materials sector. At the same time, mining activities are increasingly scrutinised due to their environmental impacts, including land degradation, water contamination, and greenhouse gas emissions. These concerns often lead to low public approval and delays in project development. Another key challenge lies in the fragmented nature of data used in the mining lifecycle. Traditional exploration and monitoring approaches rely on limited, site-specific datasets that are not easily integrated, resulting in inefficiencies and uncertainty in decision-making. Despite these challenges, significant opportunities emerge from advances in EO and digital technologies. The availability of large-scale, continuous and free satellite data, combined with AI and data analytics, enables a shift toward more efficient, transparent, and sustainable mining practices. This could strengthen Europe's strategic autonomy while supporting the transition to a greener, more digitally enabled economy.

During the exploration phase, EO data were used to identify mineral signatures and geological structures. When combined with existing geological data, this enables more accurate and less invasive identification of potential deposits, reducing both costs and environmental disturbance. Two pilot study areas were selected: one in Aramo, Spain, where the main objective was to improve mapping potential CRM target areas, such as Cobalt and Nickel, across both the exploration area and old mining waste deposits. The other pilot was in the Rias Baixas, Spain, where the main objective was to examine probable placer mineral deposits in the shallow waters of the Vigo estuary and to ascertain the potential of EO techniques for scrutinising or

Value Chain Diagram



making decisions during the mineral exploration phase in coastal zones and shallow waters.

In the active mining phase, EO technologies support continuous monitoring of operations and safety conditions. Techniques such as ground deformation analysis provide near real-time insights into potential risks. In this phase, another pilot was used, located in Gummern, Austria. The main objective of this site was to demonstrate continuous monitoring of CRM extraction using ground instability maps, mineral stockpile volume estimation, and improved volumetric maps of mining waste deposits.

In the closure and post-mining phase, EO data plays a crucial role in long-term monitoring. For that, we selected three pilots. In Lausitz (Germany) and Outukumpu (Finland), the potential of free and commercial remote sensing datasets, including Sentinel-2, WorldView-3, and UAV imagery, was evaluated for large-scale, pixel-level mapping of AMD (Acid Mine Drainage). Two representative areas in the post-mining landscape of Lausitz were selected, covering post-mining lakes with varying AMD levels. In Outukumpu, expert manual validation was conducted, and water quality parameters were obtained. Aijala's mine (Finland) closed its operations in 1961 and experienced instability problems in 2017, when a tunnel collapsed in the southern area. The same approach (SAR data and INSAR techniques) used to produce ground instability maps at the Gummern mine (active mine) was applied here to detect subsidence.

Earth Observation Data Products and Information

S34I developed and deployed a portfolio of EO-based data products, primarily leveraging satellite data (mainly from the Copernicus Programme), complemented by airborne, UAV,

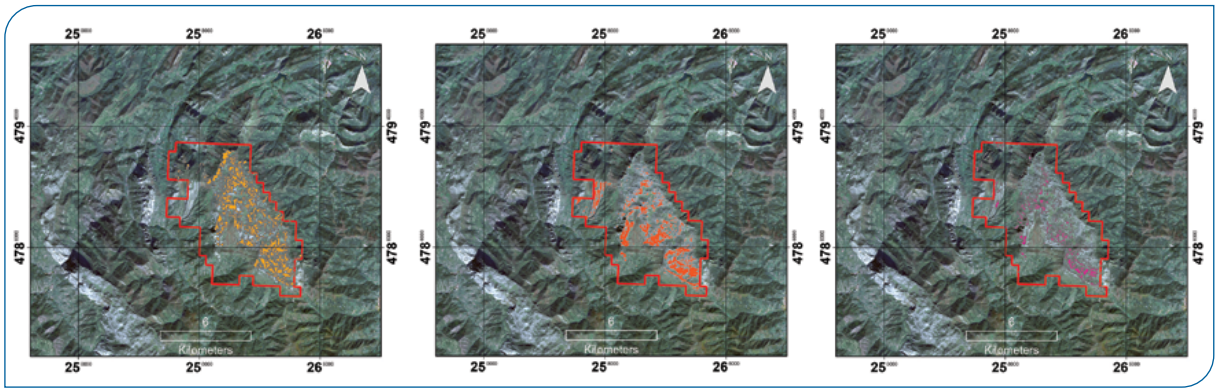


Fig. 1 Examples of prediction maps of hydrothermal alteration areas in Aramo (coloured pixels) generated from (a) PRISMAdataset, (b) Landsat-9 dataset and (c) Sentinel-2 dataset

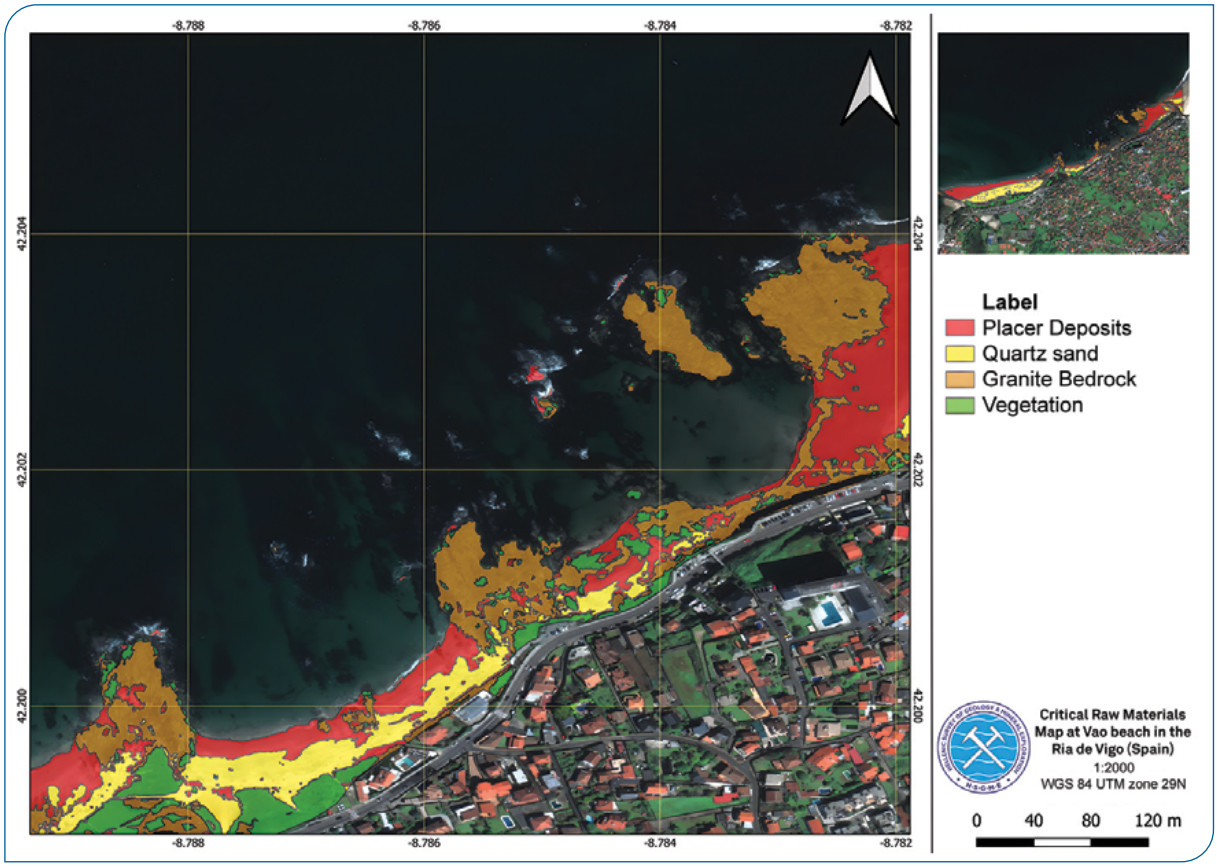


Fig. 2 Map of the surface distribution of CRMs at Vao beach in the Ria de Vigo region of Spain, from the WorldView-3 satellite

and in-situ sources. Mineral prospectivity and geological mapping products are mainly derived from multispectral and hyperspectral satellite imagery, enabling the identification of mineral signatures and geological structures while providing spatial probability maps for resource exploration (Fig. 1 and Fig. 2).

Ground deformation monitoring (InSAR products) is based on radar satellite data such as Sentinel-1, enabling the detection of millimetre-scale surface displacement over time (Fig. 3).

A key innovation of S34I is the fusion of EO data with complementary inputs, including geological datasets, in-situ sensor measurements, historical mining and environmental records, and operational data from mining companies. This integration enables multi-dimensional analysis, improving the reliability and usability of EO-derived information. The deployed EO products transform raw satellite data into actionable information, reducing uncertainty by combining multiple data sources, enabling near real-time insights through automated processing, and

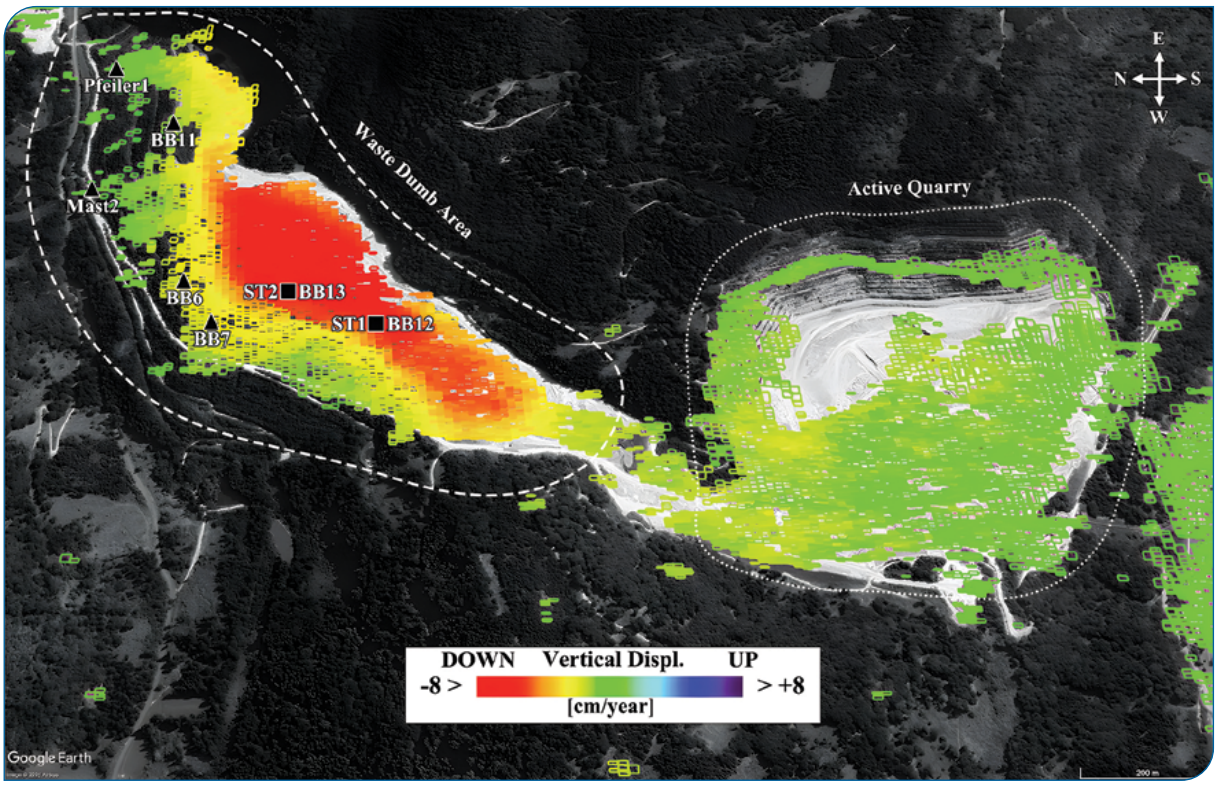


Fig. 3 Enhanced 2-D Up-Down (vertical) ground displacement velocity maps for Gummern

improving accessibility and transparency with user-friendly visualizations and open data access where possible. Through these EO data products, S34I delivers reliable and harmonised datasets (products and services) for stakeholders across the mining lifecycle, provides decision-ready information tailored to operational, environmental, and regulatory needs, enhances situational awareness through continuous monitoring, and promotes greater transparency, supporting trust among industry, regulators, and society.

Underlying Observations and Data Sources

The S34I project relies on a combination of EO data and complementary datasets to support decision-making across the mining lifecycle. These datasets provide multi-scale, multi-temporal, and multi-source observations, enabling a comprehensive understanding of geological conditions, operational activities, and environmental impacts.

Satellite EO data is primarily sourced from the Copernicus Programme, but also from other missions. Optical imagery (multispectral and hyperspectral) supports mineral prospectivity mapping, land cover classification, and environmental monitoring.

SAR data (and InSAR techniques) enable continuous monitoring of ground stability, subsidence, and infrastructure risks, independent of weather or daylight conditions (Fig. 4).

High-resolution aerial imagery (hyperspectral data) and drone-based surveys provide higher spatial resolution data for targeted analysis and calibration of satellite observations. Underwater Hyperspectral Imagery (UHI) data collected using a Remotely Operated Vehicle (ROV) were also used from underwater surveys at the shallow-water pilot site (Fig. 5).

Ground-based sensors and field surveys for sampling data (soil, water, geological samples) ensure accuracy and calibration of EO-derived products and support detailed environmental assessments. Also, existing geological maps and surveys support mineral exploration by integrating EO data with established geological knowledge.

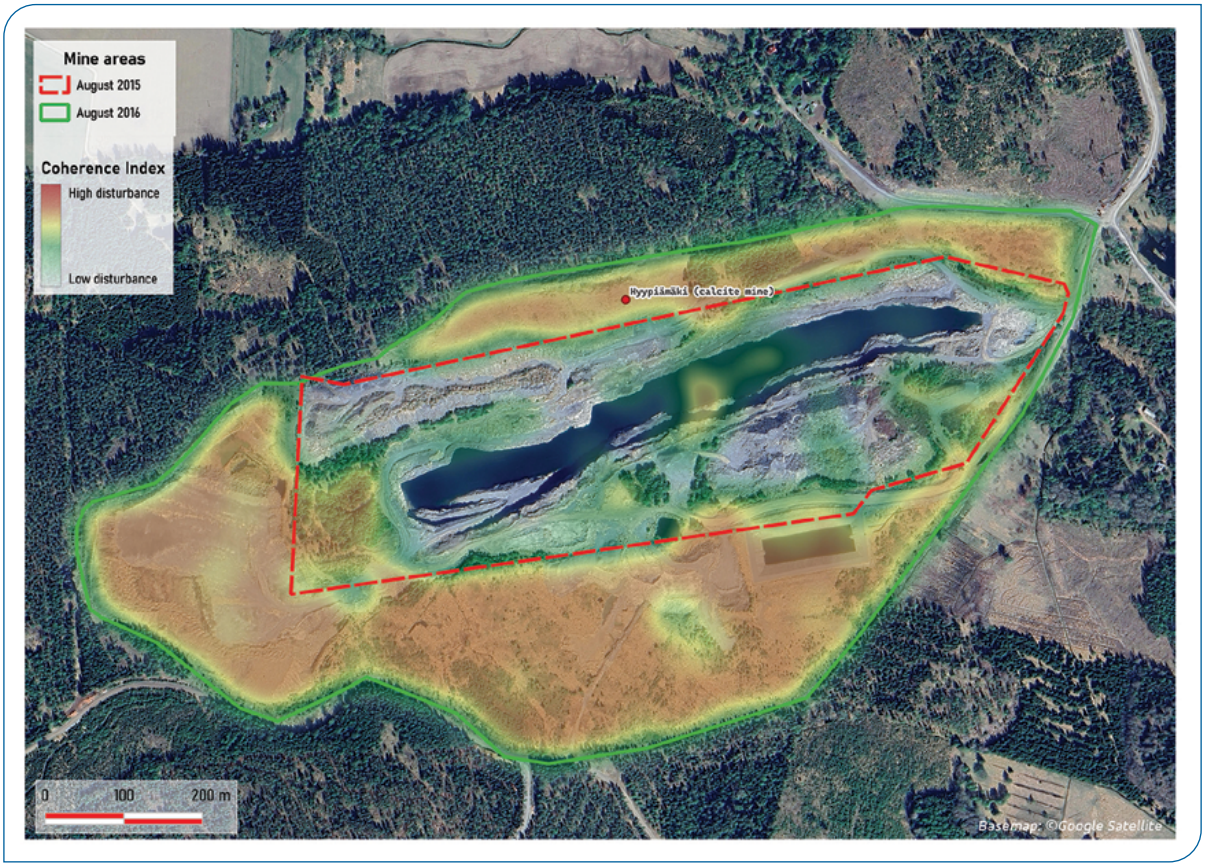


Fig. 4 Temporal Coherence Changes in the Aijala

S34I combines these datasets within integrated digital platforms, where EO data is fused with other inputs using advanced analytics and artificial intelligence. Geoportal (geo.s34i.eu) is a geospatial repository which stores and visually displays the spatial data generated under the scope of S34I, available as maps, and also stores significant datasets (Fig. 6). A geospatial processing infrastructure based on CREODIAS was also developed, to host advanced EO derived methods and AI based models prototyping to support the technical experimentation, and pilot validations/ demonstrations for the pilot use cases.



Fig. 5 ROV with instrumentation customized to collect UHI

Impacts and Benefits

S34I has demonstrated that integrating EO data with in-situ measurements and advanced algorithms can transform how mining activities are planned, monitored, and managed by improving exploration efficiency, enabling continuous environmental monitoring, enhancing safety and risk management, increasing transparency and accountability, and integrating fragmented data into unified, evidence-based decision-making systems.

The impacts of S34I extend across multiple stakeholder groups, delivering both direct and indirect benefits by improving safety and operational awareness for the mining workforce, enhancing environmental protection and transparency for local communities, providing reliable and efficient monitoring tools for public authorities and regulators, enabling more cost-effective and sustainable practices for industry, supporting better risk assessment and environmental, social, and governance alignment for investors, and contributing to supply security,

sustainability, and the green and digital transition for wider society and the European Union.

S34I also contributes to a shift toward a more sustainable and socially responsible mining sector by promoting environmental stewardship through continuous monitoring, supporting evidence-based governance with transparent data, enhancing public trust through accessible information and enabling long-term resilience in raw material supply chains. By aligning technological innovation with societal needs, S34I demonstrates how EO can play a central role in building a more sustainable, resilient, and trusted raw materials sector.

Effective implementation of EO technologies depends on efficient multi-actor collaboration supported by clear objectives, well-defined needs, and detailed execution planning. It is essential to foster collaboration between entities with diverse interests (public, private, and academic) to continuously analyse and optimise current methodologies.

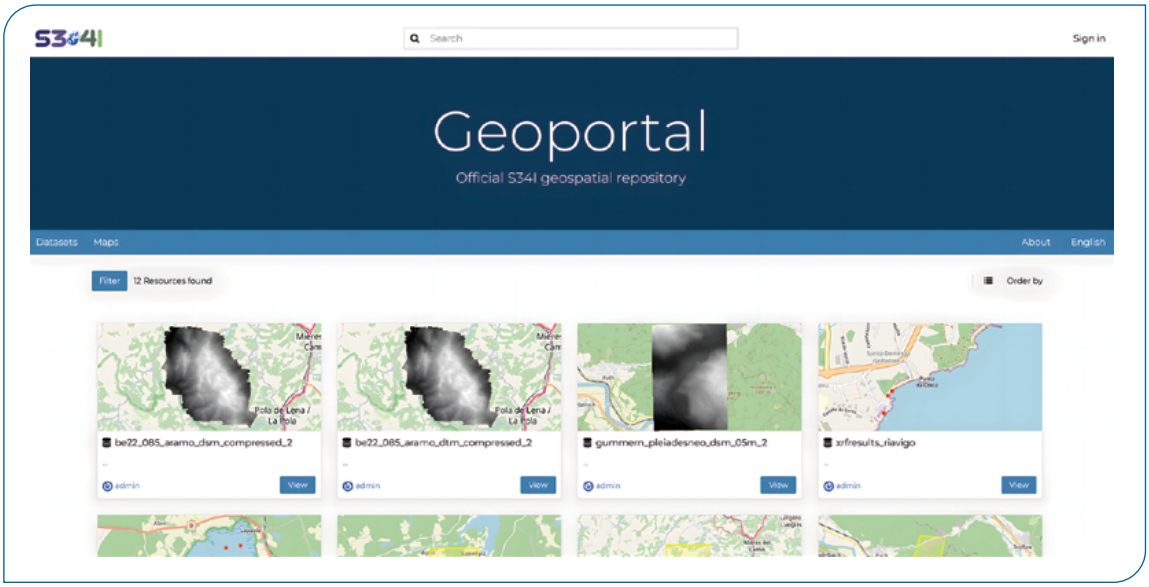


Fig. 6 Geoportal

FURTHER INFORMATION AND GUIDANCE

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S34I web page: https://s34i.eu/

Zenodo S34I community: https://zenodo.org/communities/s34i/

Online MOOC: https://s34iclassroom.fgg.uni-lj.si/

s34i EU Project Presentation: https://www.youtube.com/watch?v=EMXesbwZG7k

S34I Final Conference Highlights | Innovation, Sustainability & Europe's Raw Materials Future: https://www.youtube.com/watch?v=2lIpPmkNHho

03

REGION: EUROPE

EO4ER – Using Earth Observation and Climate Projections for Local Solar Energy Production and Distribution

Adapting solar and power systems to climate change is necessary to reduce greenhouse gases (GHG) emissions. But the reverse is also true. As photovoltaic (PV) installations grow rapidly in homes, municipalities and companies, the local distribution of electricity faces increasingly changing conditions such as bidirectional power flows, congestion risks, voltage deviations, and exposure to extreme weather events.

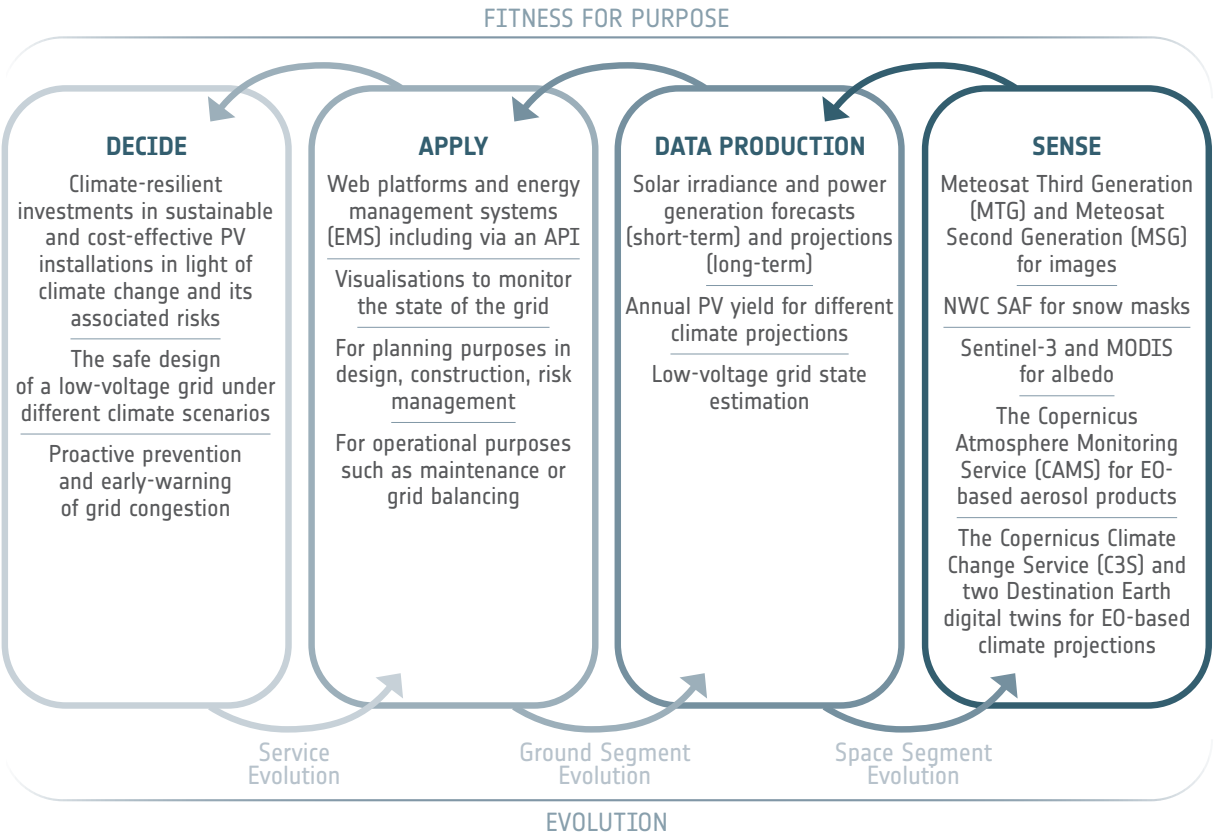
The EO4ER (Earth Observation for Energy Risks) project addresses these challenges by developing a climate service to enhance the resilience of local electricity grids and their stakeholders. The service combines Earth Observation (EO) data, weather forecasts, climate projections, and real-time grid modelling into a unified digital twin. After deployment in a European village (Hittistetten, Germany), these data sources can be jointly leveraged to enable short-term forecasting, and long-term scenario analyses for solar systems and low-voltage grids.

Hence, EO4ER demonstrates how EO can empower co-benefits of climate action: not only can EO-informed climate adaptation ensure a sustainable and efficient reduction of GHGs, but it can trigger clear social benefits at local level as well.



Fig. 1 A power distribution grid at local level: the case of Hittistetten in the city of Senden (Attribution: SWU Netze)

Value Chain Diagram



Decision-Making Context and Needs

Although the objective of the Paris Agreement for 2050 will likely not be achieved according to Copernicus reports, scientists emphasise that each degree is crucial to fight the climate emergency. To this end, EO4ER makes a strong case for how EO can simultaneously address the two pillars of efficient climate action: mitigation and adaptation. EO thus becomes an enabler of co-benefits and no-regret measures for the climate.

On one hand, reducing GHG emissions requires an energy transition which relies on the deployment of photovoltaic (PV) systems. Achieving a carbon-free energy system is more important than ever, as future transport and heating sectors will increasingly use electricity. In Germany, the majority of PV systems are installed at the low-voltage (LV) grid level, predominantly on rooftops, and PV installation rates continue to grow. The conventional "install-and-forget" approach, which relies on over-dimensioned grid components, will no longer be sufficient, as LV grids were originally designed for unidirectional, radial power flows from transformers to households. With the increasing penetration of PV, grid operation must shift from passive to active management.

On the other hand, decreasing emissions thanks to renewable energy is wasteful if the infrastructure is not adapted to climate risks. Most DSOs (distribution system operators) are in charge of securing, strengthening and modernising the power network, notably against climate extremes. As electricity becomes increasingly critical, they must adapt the grid to more decentralised solar power generation, implement a smart grid with flexibility services like dynamic energy management, allowing more electric vehicles (EVs), batteries and heat pumps on the grid, or preparing for hydrogen. Their role in climate adaptation is then obvious, and so is the relevance of EO data to their activities.

Despite European DSOs covering different geographical areas (local, regional and sometimes national), there are approximately



Fig. 2 Example of low-voltage substations used in Hittistetten (Attribution: SWU Netze)

3.2 million independently operated LV grids in Europe. Thus, the municipal level is instrumental for managing grids, and local stakeholders must enact Sustainable Energy and Climate Plans (SECAPs) to do so. This is the case of the Energy Use Plan (*Energienutzungsplan*) adopted by the city of Senden in 2023, which is the main local energy policy applicable to Hittistetten. As the local DSO, SWU Netze's role is to implement parts of the plan, especially with its technical expertise on data, current and future grid capacities, connection options, and renewable energy projects.

Earth Observation Data Products and Information

EO4ER delivers a digital twin emphasising the usability of the tool for the end-user, in this case a local grid operator. The successful co-design process extensively relied on local knowledge and in-situ data with a need assessment then translated into technical and functional requirements.

Three challenges were identified by the DSO and addressed by EO4ER. First, the effects of climate change on the DSO's assets, especially as their lifetime spans over 40-60 years. EO can assess physical risks which not only contributes to increasing the security of the assets, but to the energy security of the population as well. Second, an increasing number of fluctuating systems with high power, e.g. PV and EV chargers, are being connected to the grids. This increases the risk of power overproduction and grid congestion, leading to outages. EO helps to forecast solar energy generation so that DSOs can regulate the energy supply. Third, the constraints of limited resources (time, money, people, skills) which are inherent to most organisations.

These challenges were translated into two main functional aspects: 1) prevention of grid congestion events based on the next hour solar generation; 2) PV and grid infrastructure planning under various climate scenarios.

From these functional requirements, the project responds to the DSO's data needs: solar irradiance; PV power feed-in to compute grid load; extreme weather events; potential analysis for PV. For this, historical and real-time datasets were collected, nowcasting was provided at around 2-hour-ahead, forecasts were sent at two different time horizons (day ahead and 18-month-ahead), and climate projections from different models were compared for 2050.

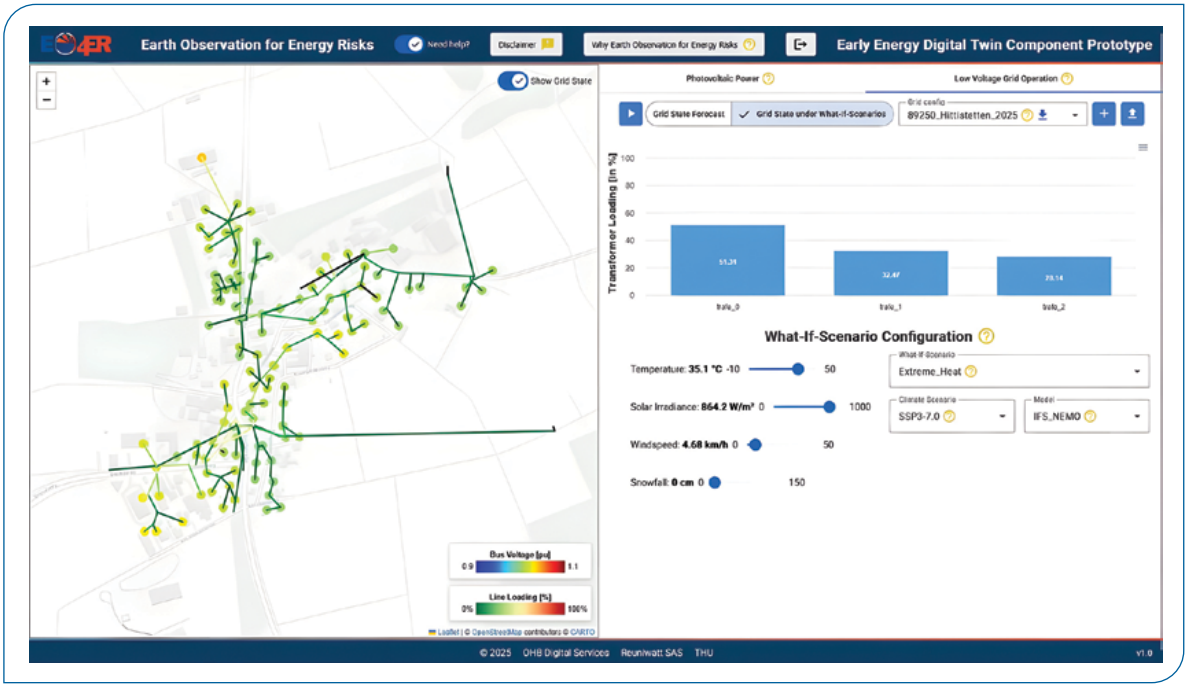


Fig. 3 EO4ER's user interface: assessing the state of the grid under climate scenarios

Underlying Observations and Data Sources

The use of satellite-based Earth observation (EO), or satellite remote sensing, is instrumental in this climate service. Indeed, EO4ER integrates a heterogeneous set of raw EO datasets as well as EO-derived weather forecasts and climate projections. Non-EO data include in-situ data from local stakeholders.

First, in a direct manner, two Meteosat missions are leveraged: *Meteosat Second Generation* (MSG) provides infrared images via the SEVIRI radiometer, while *Meteosat Third Generation* (MTG) collects spectral images from the FCI imager. Derived from the raw data of these two missions, snow mask products are compiled from EUMETSAT's NWC SAF service.

Other raw EO data originates from the MODIS instrument, and from the Sentinel-3 satellite of the Copernicus programme. This European Union (EU) programme also processes EO products which blend satellite- and ground-based data, for example for aerosol from the Copernicus Atmosphere Monitoring Service (CAMS).

EO4ER also uses EO in an indirect manner by using weather forecasts and climate projections

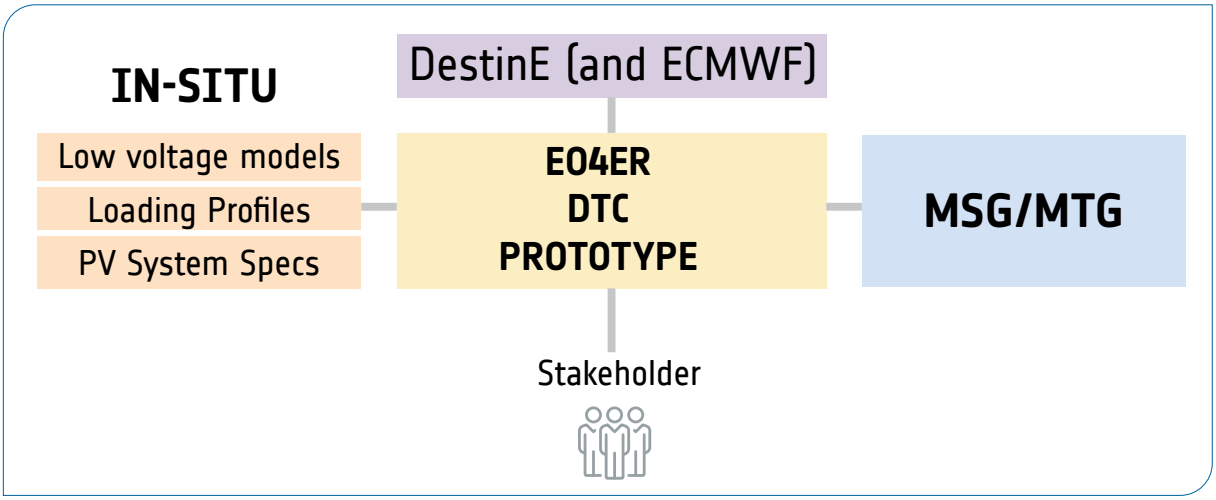


Fig. 4 Overview of external interfaces of the EO4ER design

made accessible by the EU's *Destination Earth* programme, notably the *Climate Change and Adaptation Digital Twin* for temperature and wind speed. Here, the fundamental role of EO must be recalled in the training and validation of weather and climate models.

Impacts and Benefits

EO4ER has successfully demonstrated a grid-state nowcasting system in Hittistetten, a low-voltage grid with three independently operated LV/MV transformers. The project supported SWU Netze, a local DSO which is responsible for planning, construction, operation and maintenance of a 3,000-km-long power grid for 55,400 houses.



Fig. 5 More than users, DSOs have the capacity to promote the use of EO for a sustainable energy transition (Attribution: THU)

At the level of the end user, EO4ER helped to optimise the DSO's resources to conduct its activities. The optimisation of the grid maintenance and renovation are cost-effective measures if the DSO knows which assets are the most exposed to extreme temperature or wind, and how the last two occurring hazards affect power supply. EO4ER can also help DSO teams to save time, money and energy consumption when conducting both planning tasks (risk assessments, grid design) and operational actions (scheduling, balancing, maintenance) as it provides real-time data and analytics in a user-friendly platform.

From a social perspective, ensuring the resilience of local renewable energy production implies numerous benefits as it can sustain high-quality jobs at local level (within and outside the DSO), maintain stable energy prices independent from geopolitical shocks and, hence, reduce energy poverty. Sharing solar energy can also boost a sense of pride and belonging to the village, whilst reducing eco-anxiety. Similarly, locally-produced solar power facilitates electric mobility which, in turn, can benefit the citizens' health and quality of life, notably in terms of air pollution, noise and active mobility (e.g., electric bikes).

Lastly, EO4ER supported the capacity of SWU Netze in providing data and technical expertise in Senden's ongoing work to design its *Integrated Climate Protection Strategy*. This policy will prioritise a set of climate action measures on climate adaptation, but also on climate mitigation with a focus on affordable energy supply, street lighting, e-mobility, district and municipal heating planning.

Given its direct alignment with the *EU Green Deal* and the UN's Sustainable Development Goals 7 (*Affordable and clean energy*), 9 (*Industry, innovation and infrastructure*), 11 (*Sustainable cities and communities*), 13 (*Climate action*), EO4ER concluded on the high scalability and replicability potential of this service, especially in developing countries where renewable installations and local energy grids are common in addition to being a key pillar of economic security.



Fig. 6 EO-based weather and climate services for renewable energy mainly address four SDGs (Attribution: United Nations)

FURTHER INFORMATION AND GUIDANCE

Contacts

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- Prof. Gerd Heilscher, Institute of Energy Technology and Energy Economics, Ulm University of Applied Sciences / Gerd.Heilscher@thu.de

Scientific publications

Hense, W., Auschra, F., Belkilani, K., Turpin, M., Langer, D., Graeber, D., Heilscher, G., 2025. Development and validation of an open-source grid state nowcasting system utilizing high resolution irradiation forecasts, in: 24th International Wind & Solar Integration Workshop. Presented at the 24th International Wind & Solar Integration Workshop, Berlin, Germany.

Communication and dissemination

- https://reuniwatt.com/en/company-news/eo4er-winning-project-at-esas-next-open-science-meeting/
- https://eof.esa.int/component/eo4er-earth-observation-for-energy-risks/
- https://www.thu.de/de/Seiten/News_THU_forscht_fuer_ESA.aspx
- https://www.ohb-ds.de/en/reference/eo4er
- https://destination-earth.eu/event/webinar-harnessing-the-power-of-destination-earth-part-2-digital-twins-driving-the-future-of-energy-risk-management/
- https://www.photon.info/en/news/eo4er-project-satellite-data-from-space-for-solar-forecasts-on-earth/
- DTC stakeholder workshop - SWUN
- EO4ER_ESA_OPEN_SCIENCE_MEETING_2026_small_2_1022.pdf
- https://dea.destine.eu/web/stories/viewer/682b4ae2610ba87222fb40f9

ECOSYSTEMS

CASE STUDIES



01

REGION: OCEANIA AND THE PACIFIC

Building Ecosystem Resilience Starts with Condition: Applying the Habitat Condition Assessment System (HCAS) to Australia

Summary

Healthy ecosystems underpin biodiversity persistence, climate resilience, and human wellbeing. Yet decision-makers often lack consistent, repeatable information on where habitats are intact, where they are degrading, and how those patterns are changing through time. In Australia—a continent-scale country with diverse ecosystems, frequent natural disturbances, and multiple governance jurisdictions—this challenge has historically limited national environmental reporting and coordinated action.

The Habitat Condition Assessment System (HCAS) addresses this gap by providing Australia with a national, satellite-based capability for monitoring ecosystem condition. Developed through a long-term partnership between Australia's National science agency, CSIRO, and the Australian Government Department of Climate Change, Energy, the Environment and Water (DCCEEW), HCAS integrates Earth observation (EO) data, environmental variables, and field-based ecological knowledge to deliver consistent ecosystem condition information across the entire continent.

Value Chain Diagram

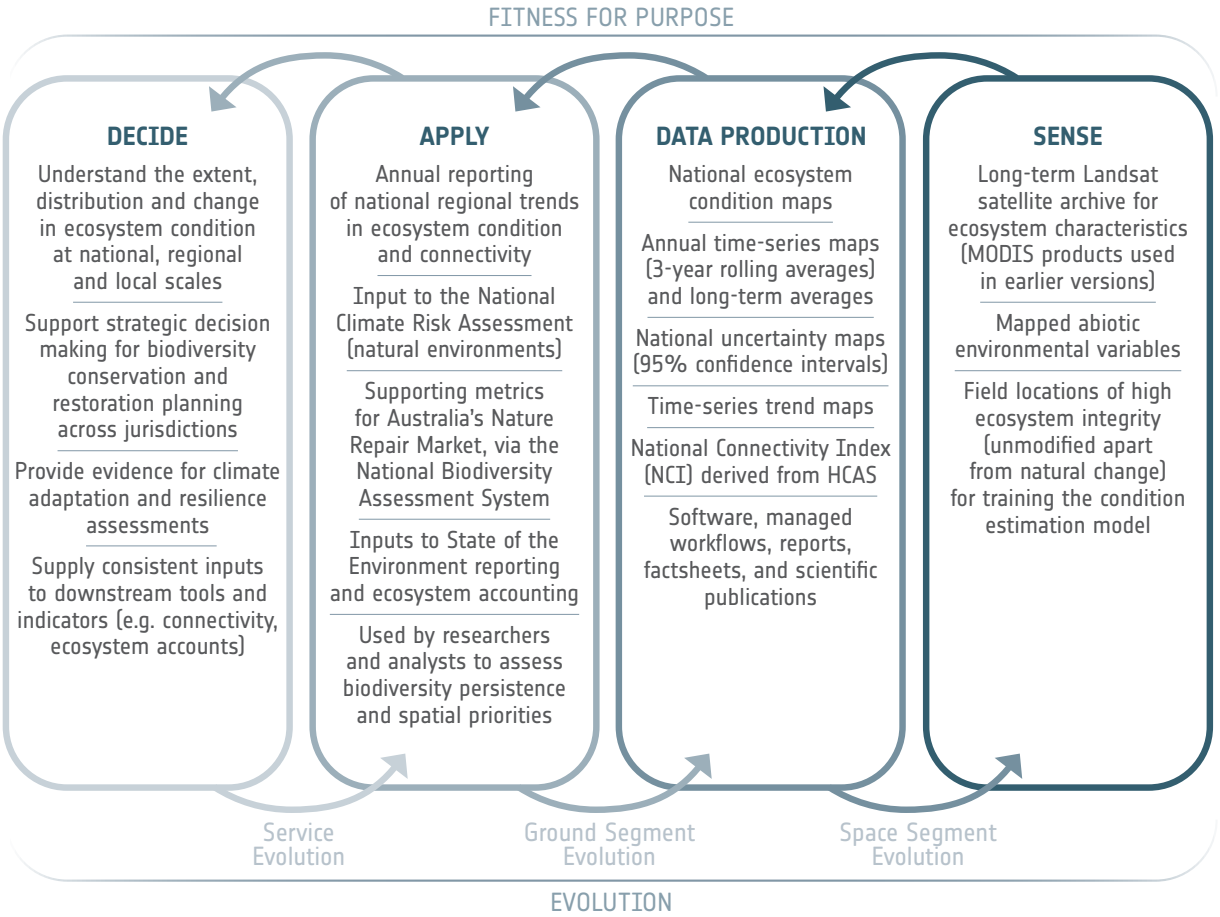




Fig. 1 Collecting field data in the Australian rangelands (Attribution: Terrestrial Ecosystem Research Network (TERN))

The most recent version of HCAS delivers a coherent time series from 1988 to 2025, mapped at 90-metre resolution, yielding a single, common metric across all terrestrial ecosystems. By accounting for rainfall, fire, and other natural variability, HCAS helps distinguish ecosystem dynamics from human-driven impacts.

Today, HCAS underpins national environmental reporting, supports climate risk and resilience assessments, and provides critical inputs to Australia's emerging Nature Repair Market. HCAS has progressed from an experimental research tool to an operational national monitoring system, informing decisions on conservation, restoration, and climate adaptation at scale.

Decision-Making Context and Needs

Australia's ecosystems support globally significant biodiversity, but they are subject to widespread pressures from land use change, altered fire regimes, invasive species, and climate extremes. Governments and land managers need to prioritise resources and evaluate conservation and restoration outcomes.

Some jurisdictions have developed ecosystem condition products, but differing methods and uneven coverage limit national comparability, especially for biodiversity and matters of national environmental significance that cross boundaries.

Before HCAS, there was no cost-effective, repeatable national method that could assess ecosystem condition while also accounting for Australia's strong natural variability. This gap significantly constrained the capacity of land managers and policy makers to respond flexibly to environmental change and strategically deploy policy, regulations and funding.

HCAS was developed to meet this need. From early on, DCCEEW partnered closely in its design, ensuring that the system evolved in response to real policy and reporting requirements. HCAS has since become an annually updated operational system embedded in national decision processes.

Earth Observation Data Products and Information

HCAS expresses ecosystem condition as a score between 0.0 (removed or highly modified habitat) and 1.0 (high-integrity habitat that supports native species and ecological processes). HCAS integrates multiple ecosystem characteristics.

Three types of spatial data are combined:

- Remotely sensed ecosystem characteristics, describing vegetation structure, function and composition
- Physical environmental variables, such as climate and soils, which define what is ecologically "expected" at a location
- Reference sites, representing contemporary locations where ecosystems retain high integrity.

For each pixel, HCAS compares observed ecosystem characteristics with those expected under reference conditions. The closer the match, the higher the condition score.

For example, increased tree cover may indicate recovery in a wet forest but degradation in a semi-arid grassland. Additionally, ecosystems naturally fluctuate in response to rainfall, fire, and climate variability—changes that should not be confused with loss of integrity.

HCAS addresses these challenges using a multivariate statistical framework that:

- Analyses all ecosystem characteristics together
- Allows reference characteristics to vary with environmental gradients
- Estimates condition as distance from locally appropriate reference sites.

The result is a more realistic assessment across heterogeneous landscapes.

HCAS delivers:

- Annual ecosystem condition maps using three-year rolling averages
- A long-term average condition baseline
- Trend maps showing directional change through time

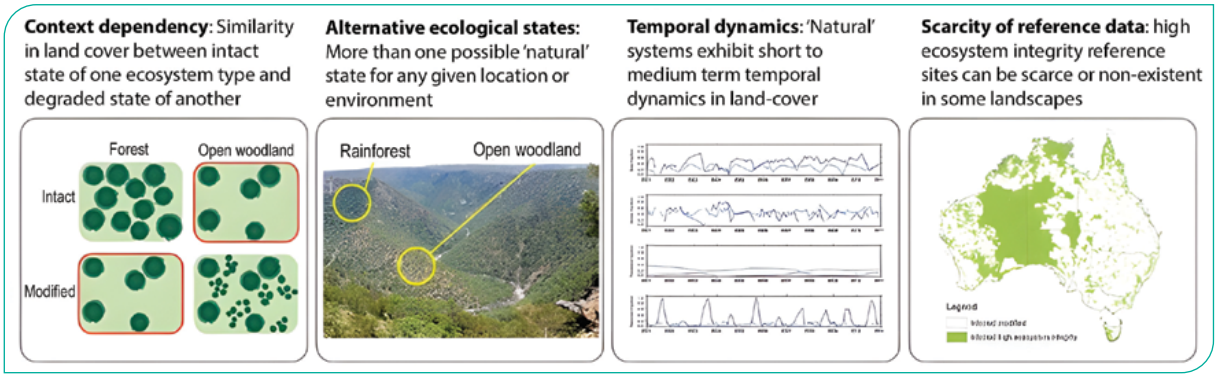


Fig. 2 The four main types of ecological application challenges for satellite remote sensing (Attribution: Harwood et al. (2016); Williams et al. (2024))

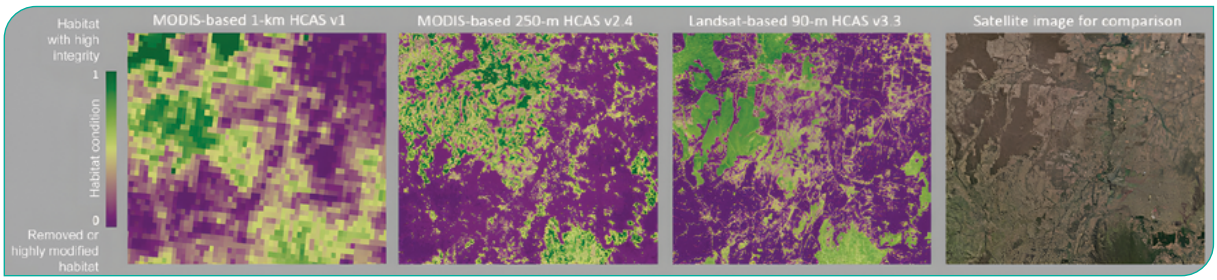


Fig. 3 Evolution of HCAS (Attribution: CSIRO, Landsat imagery courtesy of the U.S. Geological Survey, processed via Google Earth Engine)

- Spatially explicit uncertainty estimates, improving transparency and confidence in use
- The National Connectivity Index, combining condition and landscape configuration
- A Product Guide describing the data collection, its limitations and uses.

HCAS has evolved alongside EO capability, moving from coarser MODIS inputs (250 m) to higher-resolution Landsat-based variables (90 m), improving its ability to capture finer-scale patterns relevant to management. The method can be adapted to higher-resolution or regional applications where suitable data are available

All project datasets and inputs are published to an open repository, eg: https://doi.org/10.25919/zhfq-1x80.

Underlying Observations and Data Sources

HCAS uses analysis-ready Landsat Annual Geomedian and Fractional Cover percentile data from 1988–2025 from the Geoscience Australia archive, processed on CSIRO's Earth Analytics Science Innovation (EASI) platform.

Climate and soil layers provide ecological context for assessing conditions against local expectations; provided as Open Source infrastructure through Australia's Terrestrial Ecosystem Research Network (TERN).



Fig. 4 Ecosystem experts participating in facilitated workshops (Attribution: CSIRO)

Reference sites are identified through multiple lines of evidence, including field-based monitoring, protected area data, land-use and infrastructure layers and vegetation extent. Experts and local knowledge holders are an important source of information, contributing assessments via workshops and the online Habitat Condition Assessment Tool (HCAT) that anchors the model in real-world ecological understanding.

HCAS continues to evolve as new EO capabilities emerge. Planned EO enhancements include:

- Fused Landsat–Sentinel-2 time series to improve temporal fidelity
- Integration of Sentinel-1 SAR indices to better capture vertical vegetation structure
- Tailored products to support specific decision contexts, such as restoration planning and climate adaptation.

These developments will further strengthen the role of EO in guiding ecosystem-scale decisions under climate change.

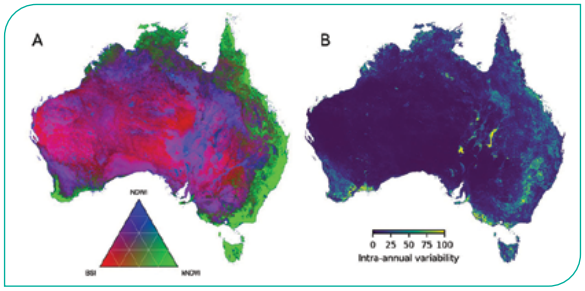


Fig. 5 Four of the fourteen HCAS EO variables: (A) aridity [BSI], productivity [kNDVI] and water [NDWI] gradients – shown as an RGB composite; (B) intra-annual variability in ecosystem characteristics [EDEV] (Attribution: CSIRO [image], Geoscience Australia [data])

Impacts and Benefits

HCAS demonstrates how long-term EO data can be translated into actionable environmental intelligence. Its beneficiaries include national and state governments, land managers, researchers, and emerging environmental markets.

Key impacts include:

- National environmental reporting: HCAS underpins indicators in Australia's annual

reporting and informs the State of the Environment report

- Climate adaptation and risk assessment: HCAS contributes to assessments of ecosystem vulnerability and resilience within the National Climate Risk Assessment framework
- Nature Repair Market: HCAS currently inputs to two core biodiversity metrics used to calculate baselines and change, ensuring restoration actions are assessed in their broader landscape context
- Ecosystem accounting: HCAS supports measures of change in biodiversity persistence and threatened species habitat in Australia's National Ecosystem Accounts
- Connectivity and capacity: By integrating with the National Connectivity Index, HCAS helps quantify how fragmentation and condition jointly affect ecosystem capacity.

Beyond formal reporting, HCAS has revolutionised how decision-makers see and talk about ecosystems, shifting the conversation from isolated sites to connected landscapes observed consistently through time.

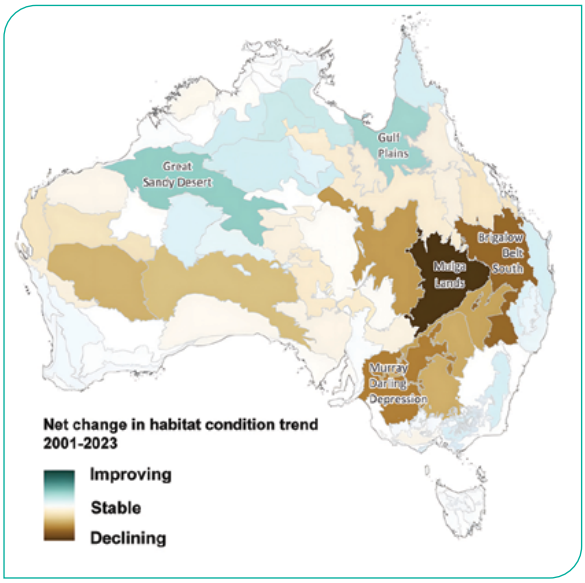
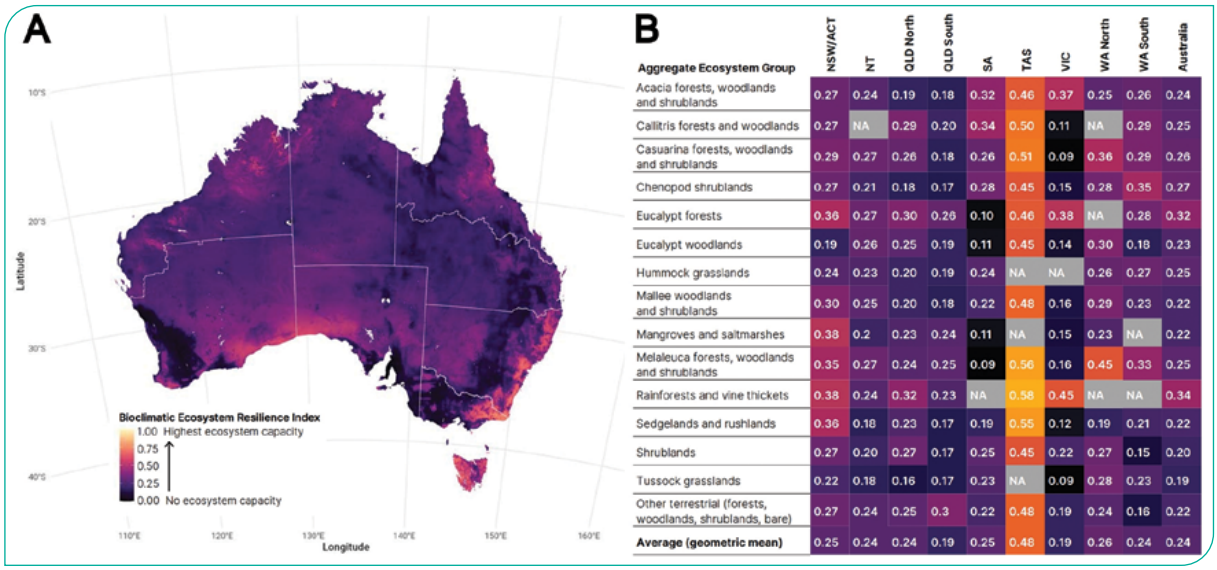


Fig. 6 Net change in habitat condition trends at the bioregional scale. (Attribution: DCCEEW Annual Report 2024–25)



Aggregate Ecosystem Group	NSW/ACT	NT	QLD North	QLD South	SA	TAS	VIC	WA North	WA South	Australia
Acacia forests, woodlands and shrublands	0.27	0.24	0.19	0.18	0.32	0.46	0.37	0.25	0.26	0.24
Callitris forests and woodlands	0.27	NA	0.29	0.20	0.34	0.50	0.11	NA	0.29	0.25
Casuarina forests, woodlands and shrublands	0.29	0.27	0.26	0.18	0.26	0.51	0.09	0.36	0.29	0.26
Chenopod shrublands	0.27	0.21	0.18	0.17	0.28	0.45	0.15	0.28	0.35	0.27
Eucalypt forests	0.36	0.27	0.30	0.26	0.10	0.46	0.38	NA	0.28	0.32
Eucalypt woodlands	0.19	0.26	0.25	0.19	0.11	0.45	0.14	0.30	0.18	0.23
Hummock grasslands	0.24	0.23	0.20	0.19	0.24	NA	NA	0.26	0.27	0.25
Mallee woodlands and shrublands	0.30	0.25	0.20	0.18	0.22	0.48	0.16	0.29	0.23	0.22
Mangroves and saltmarshes	0.38	0.2	0.23	0.24	0.11	NA	0.15	0.23	NA	0.22
Melaleuca forests, woodlands and shrublands	0.35	0.27	0.24	0.25	0.09	0.56	0.16	0.45	0.33	0.25
Rainforests and vine thickets	0.38	0.24	0.32	0.23	NA	0.58	0.45	NA	NA	0.34
Sedgelands and rushlands	0.36	0.18	0.23	0.17	0.19	0.55	0.12	0.19	0.21	0.22
Shrublands	0.27	0.20	0.27	0.17	0.25	0.45	0.22	0.27	0.15	0.20
Tussock grasslands	0.22	0.18	0.16	0.17	0.23	NA	0.09	0.28	0.23	0.19
Other terrestrial (forests, woodlands, shrublands, bare)	0.27	0.24	0.25	0.3	0.22	0.48	0.19	0.24	0.16	0.22
Average (geometric mean)	0.25	0.24	0.24	0.19	0.25	0.48	0.19	0.26	0.24	0.24

Fig. 7 Application of HCAS-informed indicators in Australia's National Climate Risk Assessment: the Biodiversity Ecosystem Resilience Index (BERI) (Attributions: A- Liedloff et al. (2025), B National Climate Risk Assessment)

FURTHER INFORMATION AND GUIDANCE

HCAS project team (CSIRO): hcas@csiro.au

HCAS project overview, factsheets, reports and data:
https://research.csiro.au/biodiversity-knowledge/projects/hcas/

Open-source HCAS implementation (R):
https://github.com/csiro/ClassicHCAS

DCCEEW online mapping tools incorporating HCAS:
https://gis.environment.gov.au/gispubmap/rest/services/land/hcas/MapServer

HCAT: https://biocollect.ala.org.au/hcat (data entry portal)
https://research.csiro.au/biodiversity-knowledge/projects/expert-knowledge-biodiversity/
(project overview, factsheets, reports and data)

Key publications

- Harwood TD, Donohue RJ, Williams KJ, Ferrier S, McVicar TR, Newell G and White M (2016) HCAS: A new way to assess the condition of natural habitats for terrestrial biodiversity across whole regions using remote sensing data. Methods in Ecology and Evolution, 7(9), 1050-1059. DOI: 10.1111/2041-210X.12579.
- Valavi R, Williams KJ, Lehmann EA, Collings S, Levick S, Giljohann KM, Liu N, Johnson S, Munroe SEM, Van Niel TG, Paget M, Malley C, Lyon P, Harwood TD and Ferrier S (2026) A scalable workflow for ecosystem condition assessment from Earth observation data. Preprint submitted to EcoEvoRxiv June 2026. Landing page: https://publications.csiro.au/publications/publication/PIcsiro:EP2026-2108
- Williams KJ, Ferrier S, Lehmann EA, Harwood TD, Donohue RJ, Giljohann KM, Valavi R, Liu N, Ware C, Lyon P, van Niel TG, McVicar TR, Richards AE and Malley C (2024) Overcoming Key Challenges of Satellite-based Monitoring of Ecosystem Condition: A Continental-scale Example From Australia (preprint). EcoEvoRxiv Preprints, 171. https://doi.org/10.32942/X2333Q.
- Williams KJ, Liu N, Valavi R, Levick SR, Lehmann EA, Collings S, Giljohann KM, Johnson S, Botha EJ, Munroe SEM, Van Niel TG, Newnham G, Paget M, Malley C, Carlile P, Gunawardana D, Lyon P, Richards AE, Tetreault-Campbell S and Ferrier S (2025) Habitat Condition Assessment System (HCAS) version 3.3: Guide to the 90-metre data collection. Technical report EP2025-2979. CSIRO, Canberra, Australia. DOI: https://doi.org/10.25919/jz55-5d44

Figure attributions

- DCCEEW Annual Report 2024–25: https://www.dcceew.gov.au/sites/default/files/documents/annual-report-2024-25.pdf
- Geoscience Australia Landsat Analysis Ready Data Collection 3: https://dx.doi.org/10.25914/6099413995ed0; https://doi.org/10.1109/IGARSS.2018.8518312
- Liedloff et al. (2025): https://doi.org/10.25919/zh60-g027
- National Climate Risk Assessment: https://www.acs.gov.au/pages/systems-naturalRegional Ecosystem Accounting Program: https://www.csiro.au/en/research/natural-environment/natural-resources/Natural-capital-accounting/Flinders-Norman-Gilbert

02

REGION: EUROPE

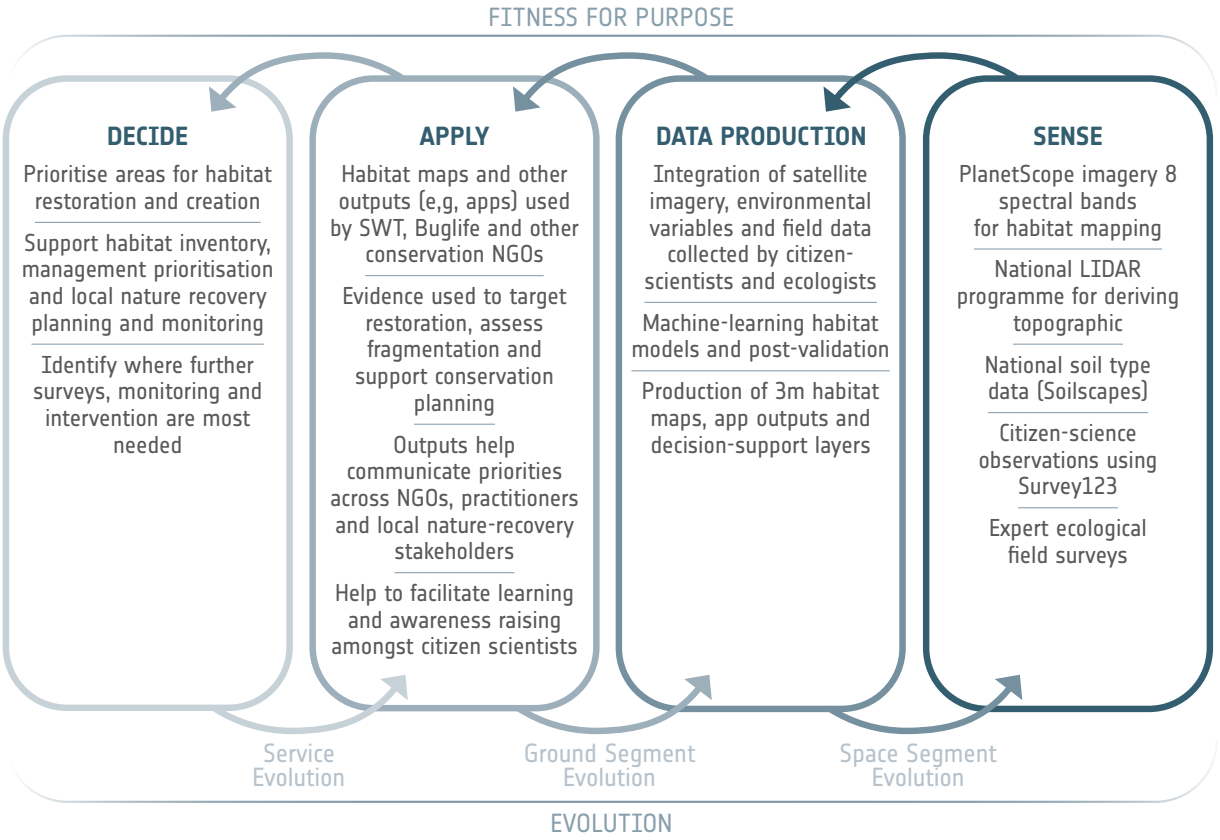
Space4Nature: Empowering Nature Recovery with Citizen Science and Earth Observation

Summary

Space4Nature was established in 2022 to address a biodiversity challenge faced by conservation organisations in the UK county of Surrey (South-East England): they need up-to-date fine-scale habitat mapping to guide restoration, monitoring and nature-recovery planning. However, traditional field surveys alone are expensive, time-consuming, difficult to repeat regularly, and often constrained by access to privately owned land. To address this, the University of Surrey (UoS), Surrey Wildlife Trust (SWT) and Buglife developed a collaborative approach that combined Earth Observation (EO) satellite data, ecological expertise, structured citizen science and machine learning (ML).

Using standardised surveys designed around UK Habitat Classification criteria (Level 4 and 5), over 350 trained volunteers (citizen scientists) collected data from over 1000 quadrats, capturing habitat data for chalk, acid and neutral grasslands, as well as heathland, across 11 test sites, between 2022 and 2025. These field observations were combined with PlanetScope satellite imagery, a range of relevant vegetation indices, as well as topographic parameters and soil type data to produce 3m resolution habitat maps with high internal classification performance, alongside independent validation across many long-term monitored grassland sites.

Value Chain Diagram



The resulting maps reveal the fragmented distribution of the chosen habitats, providing an evidence base for restoration targeting habitat inventory and Local Nature Recovery Strategy-related planning.



Fig. 1 Surrey Wildlife Trust staff and volunteers discussing survey locations and habitat assessment in the field (Attribution: SWT)

The project's main current user bodies are SWT and Buglife, but the methodology is intended to be reproducible for other Wildlife Trusts, environmental NGOs, local authorities and wider actors involved in local nature-recovery planning.

Decision-Making Context and Needs

Conservation organisations in Surrey need more than general habitat statistics; they need spatially detailed, practical evidence showing where priority habitats remain, how fragmented they are, and where restoration or further survey effort would have the greatest value. This need is especially important for habitats such as chalk and acid grassland and lowland heathland, which persist as small, scattered and often isolated patches across the county and are thus vulnerable to degradation. For organisations working on habitat recovery, connectivity, and long-term stewardship, broad national habitat products are often too coarse, too generalised, or too quickly outdated to guide action at site and landscape scales. The project, therefore, addressed a real information gap between the level of detail required by local conservation practice and what conventional mapping approaches could realistically provide.

A second challenge is that expert-led surveys, while essential, are resource intensive and

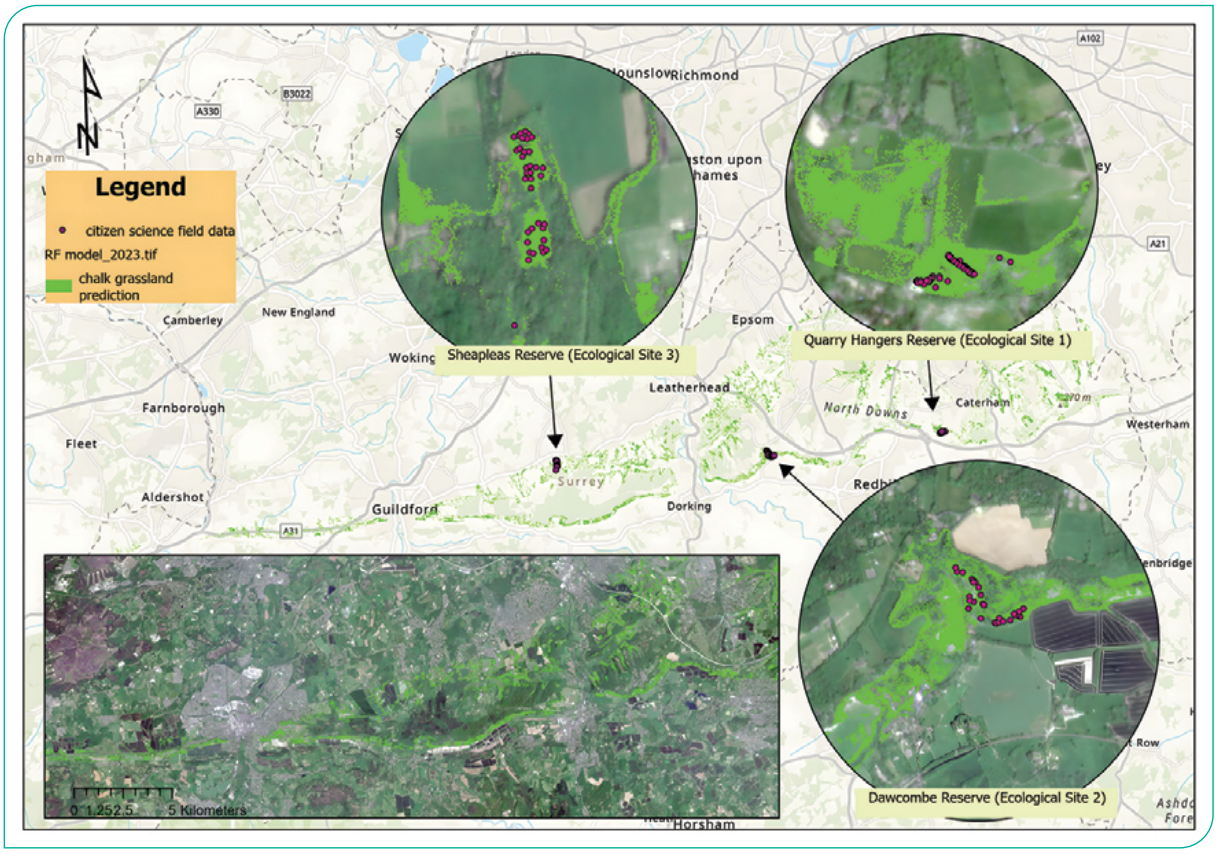


Fig. 2 Space4Nature's chalk grassland prediction map for Surrey, showing fragmented habitat distribution and citizen-science survey locations (Attribution: University of Surrey)

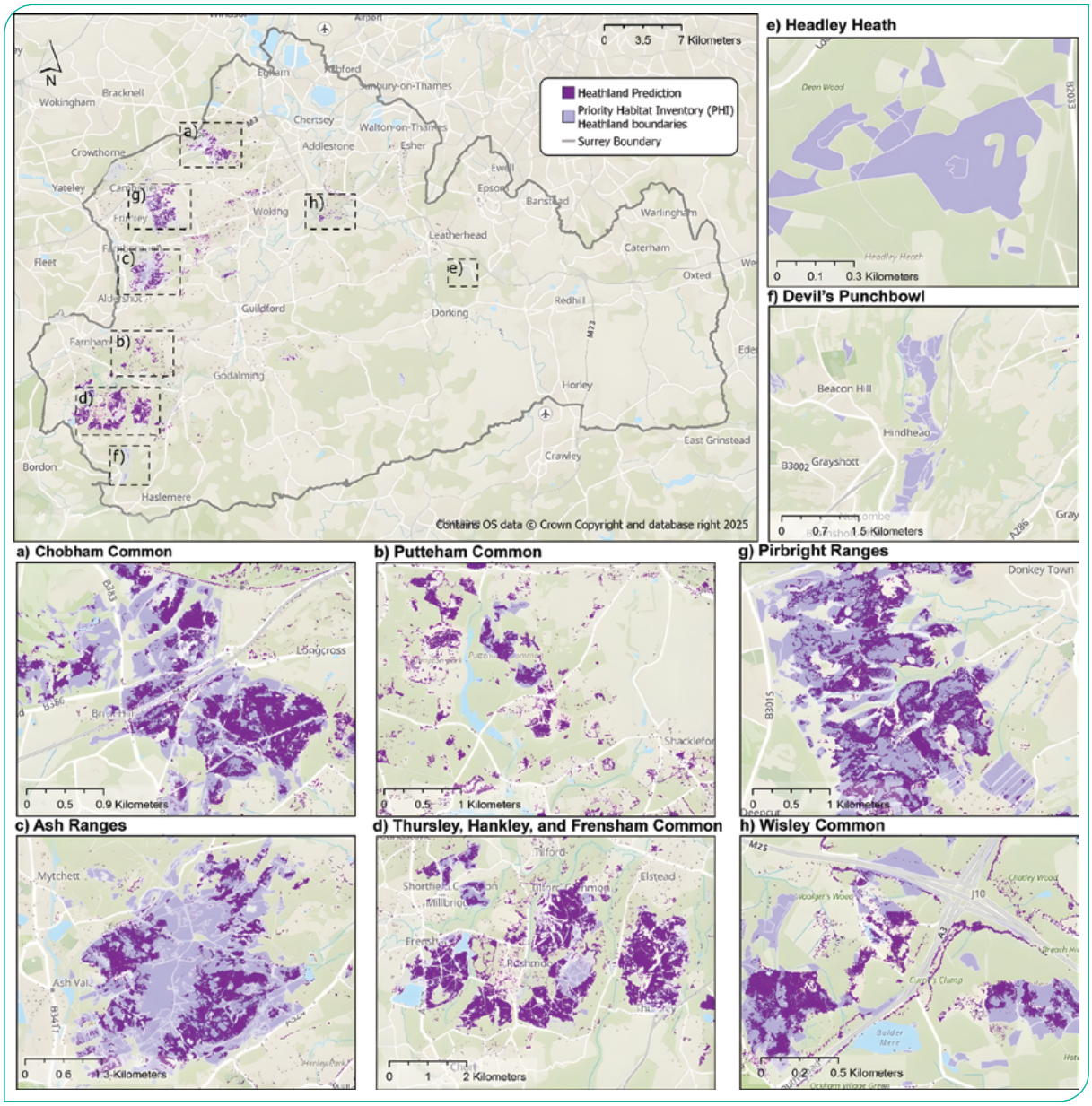


Fig. 3 Lowland heathland prediction habitat map alongside Priority Habitat Inventory areas (Attribution: University of Surrey)

difficult to scale, depending on staff time, repeat visits, funding, and access to land. Space4Nature responded to these constraints by combining ecological expertise with structured citizen science and Earth observation, so that evidence collection could be expanded without losing ecological rigour.

The main current users are Surrey Wildlife Trust (SWT) and Buglife. SWT needed better habitat evidence to support conservation planning, habitat inventory, connectivity assessment and engagement with land managers, while Buglife needed outputs that could help identify opportunities for habitat restoration and creation. More broadly, the approach will be provided to other Wildlife Trusts across the UK, environmental NGOs, local authorities and statutory actors involved in local nature recovery planning, including the evidence needs associated with Local Nature Recovery Strategies.

Earth Observation Data Products and Information

A key product from the work is the app-supported field evidence generated through the Survey123-based citizen science workflow. The app was designed to guide volunteers through standardised

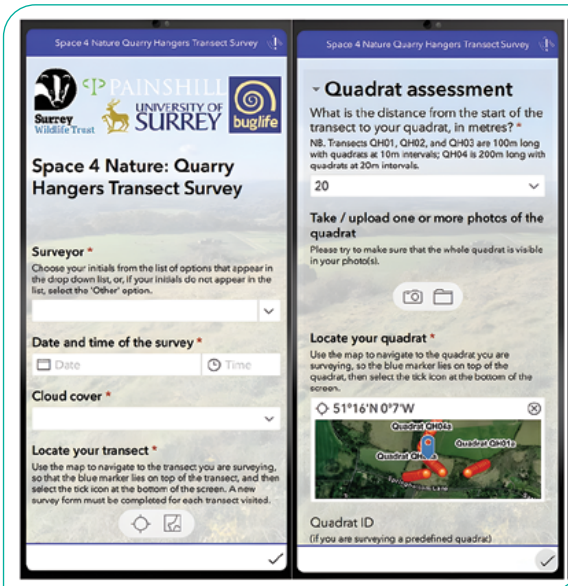


Fig. 4 The Space4Nature Survey123 app guided volunteers through standardised habitat surveys based on UK Habitat Classification criteria (Attribution: SWT)

habitat surveys using UKHab-informed questions on indicator species, vegetation structure, bare ground, scrub, management, and site condition. This meant that the field records were not just lists of species observations in isolation, but structured habitat information that could be linked directly to mapped outputs. For users, this created a more transparent evidence chain between field observations, ecological interpretation and final habitat products.

Rather than asking users to interpret complex EO datasets directly, the Space4Nature methodology translates them into practical habitat evidence that can be used in day-to-day conservation planning and prioritisation. The main products are fine-scale habitat maps at 3m resolution, produced for priority habitats such as chalk and acid grassland and lowland heathland across Surrey.

The project also generated decision-support layers and validated outputs that are easier for users to interpret. These include mapped patterns of habitat extent, fragmentation and potential restoration opportunity, helping SWT and Buglife identify habitat stepping stones, target restoration and habitat creation, and support wider planning discussions.

Underlying Observations and Data Sources

Space4Nature is built on a combination of EO derived data, environmental spatial data, structured citizen-science field surveys, and expert ecological validation. Across the three habitat types, the core EO input was PlanetScope imagery in 8 spectral bands useful to derive critical vegetation indices and 3m spatial resolution, which is fine enough to detect small, fragmented habitat patches that are often missed or blurred in coarser national products. Multi-temporal imagery (May-September) was used so that habitat mapping could reflect seasonal vegetation characteristics rather than relying on a single snapshot in time. This was particularly important for distinguishing habitats that may look similar on one date but differ in structure, composition or seasonal behaviour. For example, the spectral signature of acid grassland is often confused with heathland vegetation.

These satellite data were combined with a set of environmental variables that help explain where habitats are likely to occur. These included topographic variables derived from LiDAR-based terrain models, such as slope, aspect and plan and profile curvature, topographic wetness index, etc, together with soil information from national soil datasets. These layers were important because fragmented habitats such as chalk and acid grassland are not determined by vegetation signal alone: they are also shaped by underlying ecological conditions such as soil type, drainage, exposure and landform. Therefore, when combining EO with these environmental covariates, the project generated habitat evidence that was ecologically more realistic and easier to interpret in management terms.

A defining feature of Space4Nature was its use of structured citizen-science observations collected through 1 m² quadrat surveys using the ArcGIS Survey123 app. The app was designed around UK Habitat Classification (UKHab) criteria and guided volunteers through a standardised set of habitat questions, including indicator species, vegetation structure, bare ground, scrub cover, signs of management and condition. This meant that the

field data were collected in a consistent format that could be linked directly to habitat modelling. Citizen scientists were recruited and trained by SWT, and the survey design was carefully tested to make it accessible while retaining ecological value. The process also provided participants with learning and experience.



Fig. 5 Citizen scientists collecting structured habitat data in the field using fixed quadrats (Attribution: SWT)

Ecological expertise from SWT was central throughout. SWT helped select sites, co-designed the survey protocols, trained volunteers, reviewed submitted records, and validated whether quadrats met the relevant UKHab habitat criteria before data were used in the modelling. In this way, citizen science did not replace expert ecology but worked within a quality-controlled framework supported by digital tools, field methods and expert judgement. The result was a robust evidence chain linking satellite observations, field data and ecological validation into habitat products that conservation users could trust.

Impacts and Benefits

Space4Nature has delivered impact in three connected ways by improving the evidence available for conservation action, by widening public participation in nature recovery and by demonstrating a model that can be transferred and built on beyond the original project. Together, these benefits matter because they help elevate habitat mapping from a one-off technical exercise towards a more practical, inclusive and repeatable form of environmental decision support.

First, the project has improved the evidence base for conservation action in Surrey. The fine-scale habitat maps produced through Space4Nature have filled important gaps left by broader national datasets and by field surveys that are difficult to repeat at the county scale. For users such as SWT and Buglife, this has meant better spatial evidence on habitat extent, fragmentation and likely restoration opportunities. The outputs have supported more rapid grassland habitat inventory, better targeting of restoration and habitat creation, and a clearer understanding of where ecological connectivity could be strengthened. For Buglife, the Space4Nature outputs are particularly relevant to the Surrey Chalk Lines project, which focuses on calcareous grassland restoration through advice to landowners and managers, community engagement, botanical and entomological surveys, and practical habitat management work. The mapped evidence will help Buglife identify where chalk grassland fragments remain, where habitat creation could strengthen ecological links, and where restoration activity could contribute most effectively to pollinator recovery across the Surrey Hills landscape.

Second, Space4Nature has shown that citizen science can generate value well beyond data collection alone. The project created opportunities for volunteers to learn plant identification, habitat survey methods and the wider purpose of conservation mapping, helping more people engage directly with nature recovery in Surrey. SWT built a local citizen science network around this work and created a feedback process so that volunteers could see how their surveys contributed to real outputs and decisions. This strengthened community stewardship and made the project more socially grounded, while also broadening the evidence base available to conservation organisations. It also provided a strong foundation from which SWT could develop other citizen science projects and volunteer engagement activities.

Third, the project provides a scalable and reproducible approach that is relevant beyond a single habitat or organisation. The project provides a methodology as a transparent and accessible framework for strategic conservation planning and is intended to be relevant for other Wildlife Trusts, environmental NGOs, local authorities and local nature recovery actors. One important legacy strand is now extending the approach to small ponds and wetlands through PhD research that uses freely available EO and machine learning, with future plans to incorporate citizen science for finer UKHab wetland classification.



Fig. 6 Buglife activities- Practical habitat creation and restoration activity contributing to chalk grassland recovery (Attribution: Buglife)

FURTHER INFORMATION AND GUIDANCE

Dr Ana Andries (University of Surrey) / ana.andries@surrey.ac.uk

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Daniel Banks (Surrey Wildlife Trust) / Daniel.Banks@surreywt.org.uk

Zoe Channon (Surrey Wildlife Trust) / Zoe.Channon@surreywt.org.uk

Peter Hewetson (Buglife) / Peter.Hewetson@buglife.org.uk

https://www.spaceclimateobservatory.org/space4nature

https://eu.eventscloud.com/website/16803/uk-cop-showcased-organisations/

https://storymaps.arcgis.com/stories/a0d45ce35b6f4630a4c431b7b5b86446

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https://www.youtube.com/watch?v=EyyVbbje6X4

https://www.youtube.com/watch?v=GqIKLkzdfxQ&t=5s

https://figshare.com/articles/online_resource/Space4Nature_Training_data_collection_methods/31979634?file=63610872

Chalk mapping peer-reviewed publication:
https://www.tandfonline.com/doi/full/10.1080/22797254.2026.2691799

Lowland heathland peer-reviewed publication:
https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.70407

HEALTH & WELL-BEING

CASE STUDIES



01

REGION: AMERICAS

Improving Forecasts of Human West Nile Virus (WNV) Disease Risk in the United States

Summary

West Nile virus (WNV), a zoonotic virus transmitted primarily to humans by an infected Culex spp. mosquito (after feeding on infected birds), is the leading mosquito-borne disease in the contiguous United States. As a persistent public health hazard in many U.S. states, there is a need for better knowledge of when and where WNV outbreaks will occur to help target public health responses. In particular, the Northern Great Plains are a hot spot for WNV transmission, and South Dakota has the highest long-term incidence of West Nile neuroinvasive disease in the country.

The project aimed to forecast WNV risk through a sustainable software system integrating entomological surveillance data of mosquito infection, epidemiological surveillance of human WNV cases, and remotely-sensed environmental data for the South Dakota Department of Health surveillance activities. Models are calibrated and predictions are validated with historical data. To generate real time forecasts, an automated Google Earth Engine App is used to process data into the ArboMAP (Arbovirus Mapping and Prediction) system. ArboMAP automates data ingestion, processing, and modelling and generation of reports to support public health decision making.

ArboMAP has been integrated into the South Dakota Department of Health operational WNV surveillance activities. This software tool produces weekly, county-level maps and seasonal forecasts of WNV risk that the South Dakota Department of Health can use to alert the public during high peak WNV transmission periods.

After the successful integration of ArboMAP in the South Dakota Department of Health WNV

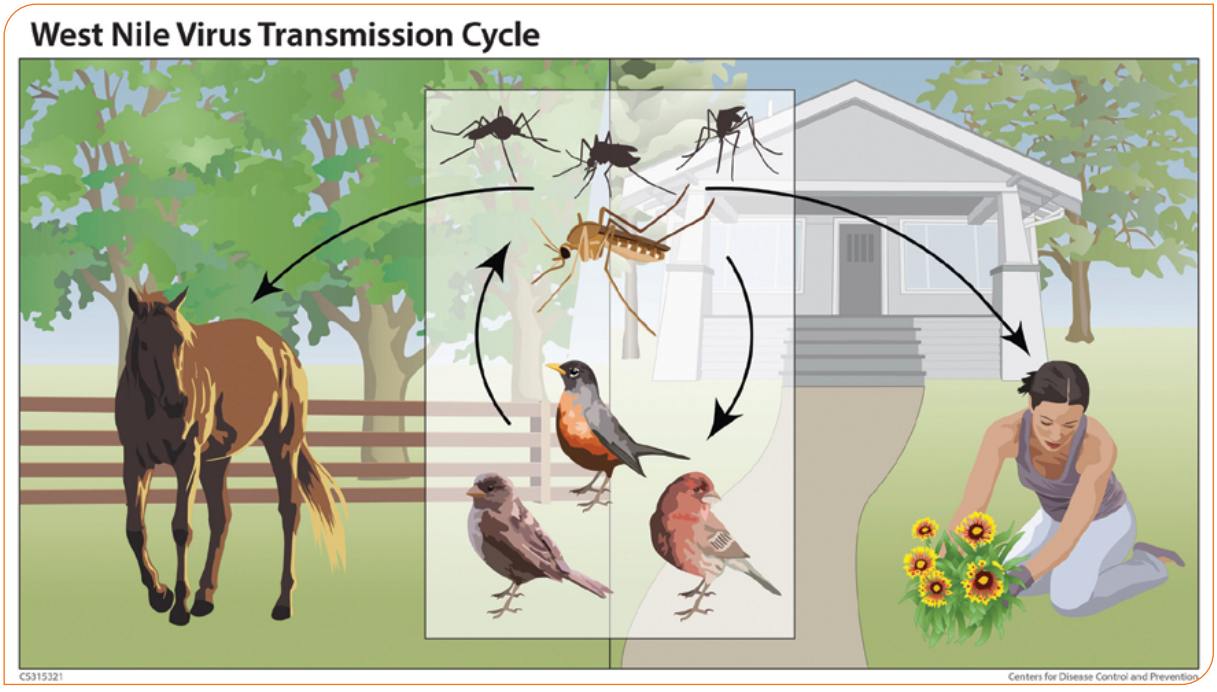
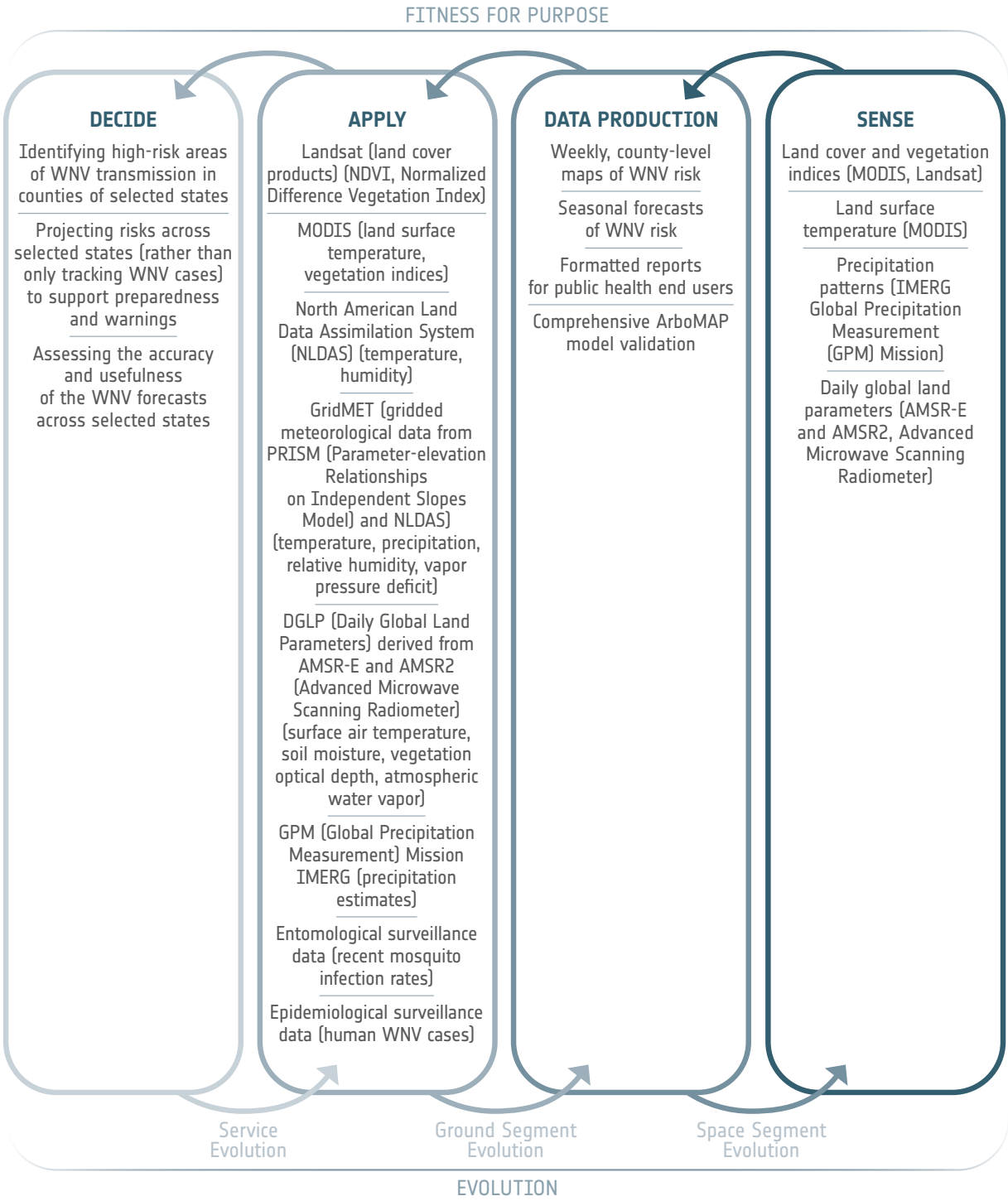


Fig. 1 Transmission cycle of West Nile virus (Attribution: CDC)

Value Chain Diagram



surveillance activities, the project team partnered with departments of health and collaborating universities to determine the feasibility of ArboMAP implementation in four other states of WNV burden. The states of Louisiana, Michigan, Nebraska, and Oklahoma have a substantial burden of severe WNV neuroinvasive disease, but distinctive climate, landscapes, mosquito vector species, and avian host communities compared to South Dakota. The team analyzed relationships between climate variations and WNV transmission in these states, finding that best predictors of human WNV cases were mean daily temperature and humidity. They used these results to update and improve the ArboMAP modelling approach to capture the characteristic environmental triggers of WNV outbreaks.



Fig. 2 Female Culex tarsalis mosquito (Attribution: CDC)

Decision-Making Context and Needs

WNV is a nationally notifiable disease that is reported to state and territorial health departments and subsequently to the U.S. Centers for Disease Control and Prevention through ArboNET (https://www.cdc.gov/vector-borne-diseases/php/arbonet/index.html). Disease transmission is associated with summer and fall months, with peak transmission from July to September. This project fuses weather, satellite, and regional entomological and epidemiological survey data to predict WNV case prevalence, supporting decision makers to prepare, warn, and mitigate disease transmission risk and protect community health. Dr. Michael Wimberly, University of Oklahoma, said: "We came up with some new ideas for how to develop an improved system for forecasting West Nile virus, leveraging information in satellite imagery."

The departments of health represent the key decision-makers who have incorporated these modelled outputs into the state's operational surveillance activities. The first project partner, the South Dakota Department of Health, articulated the utility and value of the ArboMAP forecasting tool. Dr. Lon Kightlinger, South Dakota Department of Health, said: "The information that we're getting from the project are maps of risk factors associated with things that we, at the health department, really can't track or figure out. Things that have to do with climate, lay of the land and precipitation. I think this will be absolutely an essential tool in controlling West Nile here in South Dakota." Furthermore, Dr. Josh Clayton, South Dakota State Epidemiologist reiterated the importance of understanding annual epidemiology trends: "It helps complete the picture in terms of what we see for the year."

The team co-designed and co-developed the ArboMAP system with all public health partners. Regular design and evaluation workshops facilitated partner feedback, including prioritizing visualizations (vs written text), incorporating consistent colour and format, using stand-alone figures for communication, and highlighting key results on the first pages.

Earth Observation Data Products and Information

This project incorporated environmental parameters associated with the distinctive climate, landscapes, mosquito vector species, and avian host communities. Estimating the vector suitability indices for Culex spp. mosquitoes is crucial to understand the influence of mosquito development, survival, and potential of WNV transmission.

Dr. Michael Wimberly, formerly of South Dakota State University and currently at the University of Oklahoma, said: "What we're able to do is strengthen the disease collection data by using the Earth observation data. You can't track mosquitoes all across this huge, sparsely-populated state [South Dakota]. That's where the Earth observations come in. We can look everywhere across the state."

MODIS (NASA's Terra) and Landsat offer land cover data. The North American Land Data Assimilation System (NLDAS) integrates observation-based and model reanalysis data to derive land surface and hydrological models. GridMET represents gridded meteorological data from the Parameter-elevation Relationships on Independent Slopes Model (PRISM). The Advanced Microwave Scanning Radiometers (AMSR-E and AMSR2) and the Integrated Multi-satellitE Retrievals for GPM (Global Precipitation Measurement) provide data on global precipitation estimates.

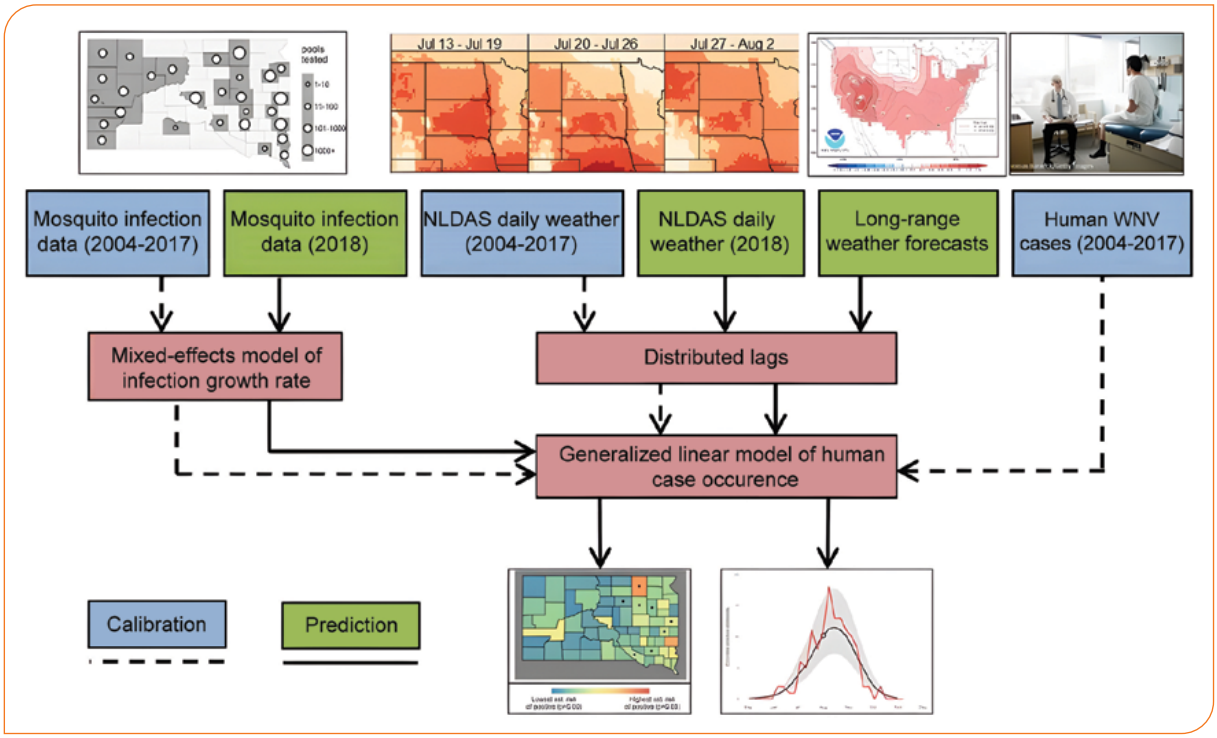


Fig. 3 Schematic of West Nile virus forecasting using ArboMAP illustrating data flows for calibration and prediction (Attribution: Michael Wimberly, ArboMAP)

Underlying Observations and Data Sources

These primary Earth observation data products for ArboMAP are entomological and epidemiological surveillance data; NASA's Terra and Aqua atmosphere and land environmental satellites; NASA's and NOAA's NLDAS land-surface model datasets; NASA's and USGS's Landsat; and the IMERG global precipitation estimates.

- MODIS (Multispectral radiometer): for deriving land surface temperature and vegetation indices
- Landsat (optical/infrared): for deriving NDVI and land cover products
- NLDAS (North American Land Data Assimilation System): for deriving temperature and humidity
- GridMET (gridded meteorological data from PRISM and NLDAS) (land-surface model): for deriving temperature, precipitation, relative humidity, and vapor pressure deficit
- AMSR-E and AMSR2 (advanced microwave scanning radiometer) – using DGLP (Daily Global Land Parameters): for deriving surface air temperature, soil moisture, vegetation optical depth, and atmospheric water vapor
- Integrated Multi-satellitE Retrievals: for GPM (Global Precipitation Measurement) (precipitation radar and microwave scanning radiometer) – for deriving precipitation estimates
- Entomological surveillance data: for estimating recent mosquito infection rates
- Epidemiological surveillance data: for estimating human WNV cases.

Impacts and Benefits

This project created an impactful decision-support tool for the South Dakota, Louisiana, Michigan, Nebraska, and Oklahoma Departments of Health, and residents have benefited from more precise and timely public alerts of WNV risk. Dr. Michael Wimberly, University of Oklahoma, commented: "Part of the [project] goal was always to create something transferrable and sustainable." Mosquito control programs now have real-time information that can guide their

operational WNV surveillance activities, including vector control (e.g., insecticide spraying). Training workshops can be offered to epidemiologists and other staff members to build capacity for their knowledgeable use of ArboMAP for ongoing WNV surveillance activities. With this real-time information, public alerts and other educational outreach activities have been developed and implemented across counties during high peak WNV transmission periods.

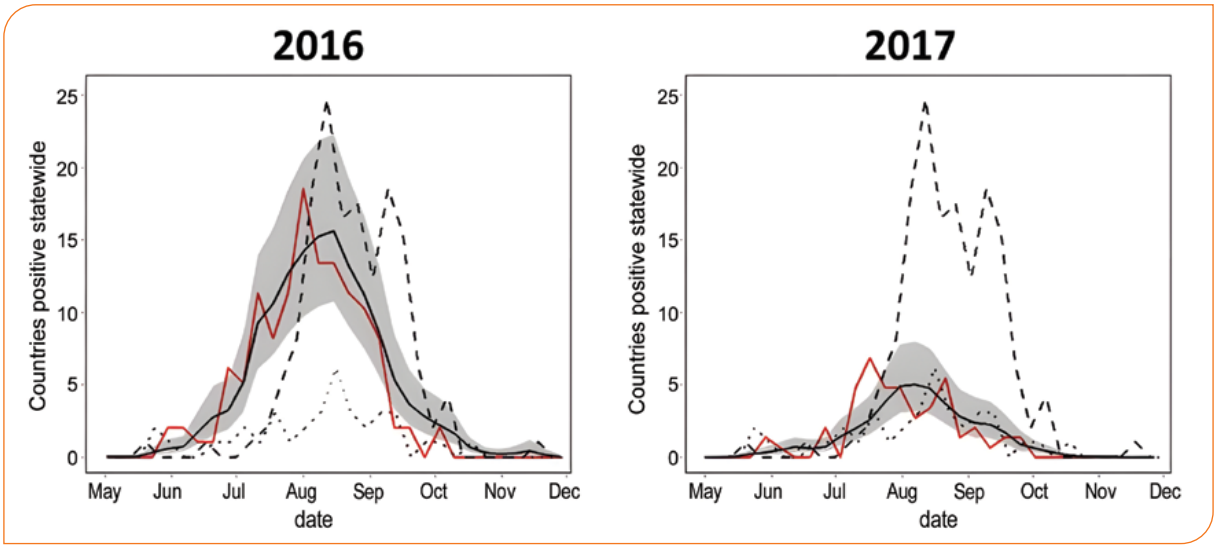


Fig. 4 Prospective WNV forecasts, including the prediction with 95% intervals (black line and gray shading), observed cases in 2016 or 2017 (red line), observed cases (dashed line in 2012, dotted line in 2015) (Attribution: Michael Wimberly, ArboMAP)

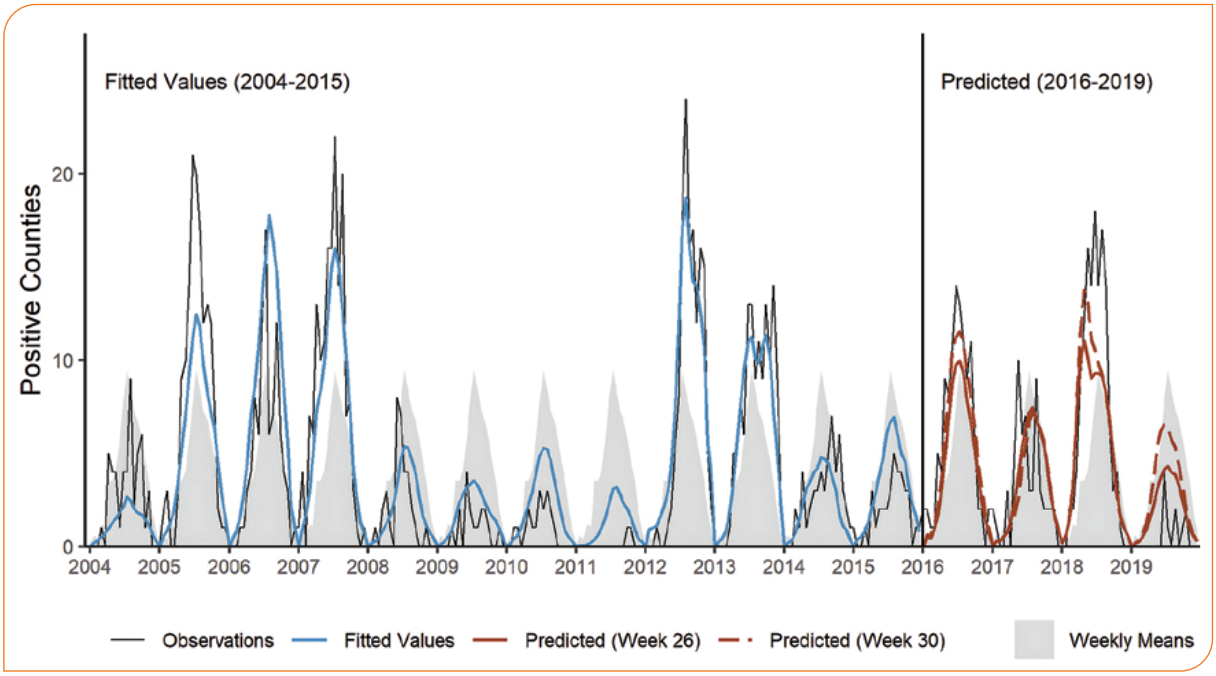


Fig. 5 User-centered diagram showing the workflow for WNV forecasting (Attribution: Michael Wimberly)

FURTHER INFORMATION AND GUIDANCE

Open data repository: https://github.com/ecograph/ArboMAP

Core EO datasets: NASA's Terra and Aqua atmosphere and land environmental satellites; NASA's and NOAA's NLDAS land-surface model datasets; NASA's and USGS's Landsat; and the IMERG global precipitation estimates.

Point of contact

NASA Earth Science Division: aries.keck@nasa.gov

References (project documentation)

- **YouTube Video:**

  Mosquito Meets MODIS: South Dakota Fights West Nile Virus:
  https://www.youtube.com/watch?v=ag-Zo0izSNg

- **Websites:**

  - ArboMAP (Arbovirus Mapping and Prediction to Forecast Mosquito-Borne Disease Outbreaks):
    https://ecograph.net/arbomap/
  - EcoGRAPH (Ecological and Geospatial Research and Applications in Planetary Health):
    https://ecograph.net/
  - USGS:
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Scientific Publications

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02

REGION: ASIA

C5 – Combat Against Climate Change on Cotton Communities

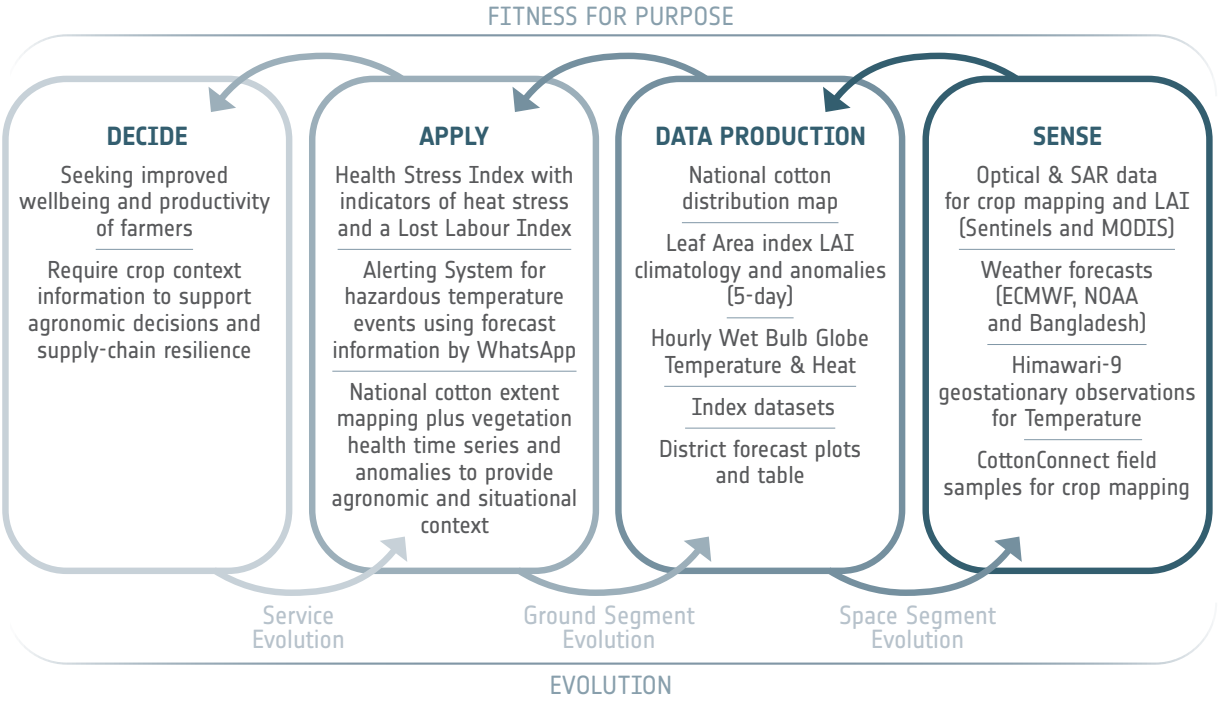
Summary

C5 is an agroclimatic advisory solution designed to help cotton communities adapt to climate change by combining satellite Earth observation (EO) with climate reanalysis and forecast data. The feasibility study in western Bangladesh (Kushtia, Meherpur and Chuadanga) produced a prototype service that translates complex weather and EO-derived indicators into simple, actionable guidance for farmers and the support organisations that serve them. The core innovation is an explicit focus on farmer health and labour productivity under extreme heat, alongside crop context information to support agronomic decisions and supply-chain resilience.

Key outcomes from the feasibility study include:

- an operationally generated Health Bulletin workflow (translated to Bangla) that provides district-level forecast heat risk information and practical health guidance;
- a national-scale cotton distribution map for 2023;
- a 40+ year hourly archive of heat stress indices (including Wet Bulb Globe Temperature, work-rest category and a Lost Labour Index) to quantify trends and support adaptation planning;
- an alerting concept for heatwaves and cold waves using open forecast sources to enable proactive risk communication.

Value Chain Diagram



The demonstrator project was undertaken in 2023-24 by Assimila Ltd (UK) and CottonConnect - a social enterprise that works across the cotton supply chain to improve sustainability, traceability and livelihoods by delivering farm programmes and supply-chain services that make cotton production more resilient.

Decision-Making Context and Needs

Cotton production is a labour-intensive, climate-sensitive livelihood activity. In Bangladesh, cotton communities are increasingly exposed to higher temperatures and humidity, more frequent heatwaves, and disruptive extremes such as droughts and flash floods. Stakeholder consultations highlighted that extreme heat and humidity are already constraining safe time in the field, reducing daily productive hours and increasing the incidence of dehydration, cramps and heat-related illness.

> "Usually we work outside from 6 am to 1 pm. But when the temperatures are high, we can only work from 6 am to 10 am. That loss of 3 working hours means that jobs can take 2–3 times as long if the hot temperatures persist."
>
> (Male cotton farmer, Bangladesh)

Adaptation decisions the project was designed to support include:

- work planning: when to work, when to rest, and what health precautions to take (hydration, shade, heat illness signs);
- timing of key agronomic activities (planting, spraying, picking and harvesting) under heat and precipitation constraints;
- targeting of extension support and health outreach by CottonConnect field teams, NGOs and local health services;
- government and sector planning: understanding where cotton is grown, how conditions are changing, and what support measures are required.

The stakeholder consultation process highlighted the trend of lost labour hours due to adverse environmental conditions as an issue of local concern. The project analysed trends for the study region in Wet Bulb Globe Temperature (WBGT), a heat metric that considers air temperature, relative humidity, wind speed and direct solar radiation - factors that determine how much heat a person experiences and their ability to cool down through sweating. It is a metric that has been found to be a stronger predictor of negative heat-related health outcomes than air temperature or the heat index (a combination of air temperature and relative humidity). It is also used in national legislation and workplace health and safety. The analysis showed a clear upward trend over the past 3 decades in the amount of time workers would be recommended not to work to stay within safe physiological boundaries.

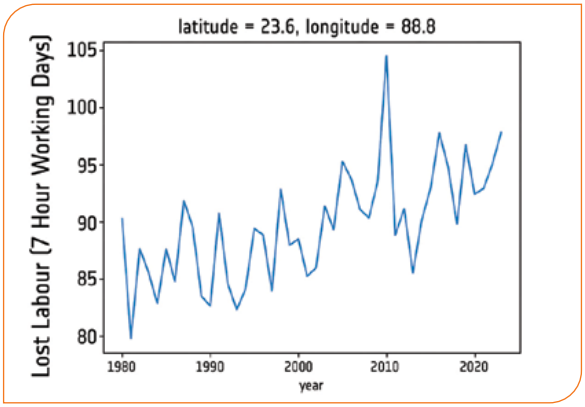


Fig. 1 Total number of working days in which it would have been recommended not to work to remain safe in the heat conditions in Chuadanga district in Bangladesh

Project end users and stakeholders span the cotton supply chain: farmers and pickers (women and men), ginners and spinners, seed companies, NGOs working with farmer groups, and government agencies including the Cotton Development Board and the Ministry of Agriculture. CottonConnect plays a central intermediary role, translating analytics into locally appropriate advice and disseminating it through established farmer engagement channels.

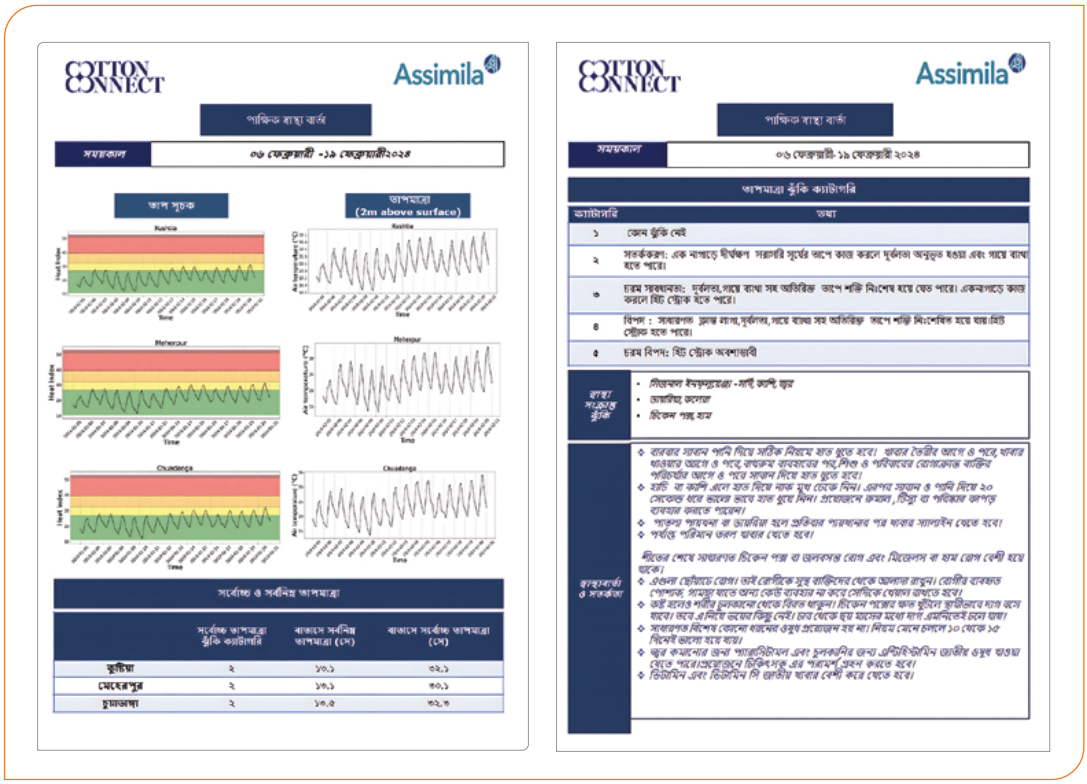


Fig. 2 Health Bulletin / advisory product example for Health Bulletin 06-19 february, 2024 in Bangla

Earth Observation Application/ Service Description

C5 (Combat Against Climate Change on Cotton Communities) integrates EO and climate datasets into three user-facing components:

- Health Stress Index: historic and near-term indicators of heat stress relevant to outdoor work, including work-rest guidance and a Lost Labour Index;
- Alerting System: definition and detection of hazardous temperature events (heatwaves and cold waves) using forecast information;
- Crop Context: national cotton extent mapping plus vegetation health time series and anomalies to provide agronomic and situational context.

Service delivery during the feasibility study focused on fortnightly Health Bulletins, first drafted in English and then simplified and translated to Bangla. Bulletins and key messages were disseminated via WhatsApp where possible, with audio summaries and physical printouts used to reach farmers with limited smartphone access or literacy constraints.

A processing pipeline was established to generate forecast plots and summary tables daily and publish them to a cloud repository for CottonConnect staff.

Earth Observation Data Products and Information

C5 produces and uses EO-derived products that directly address the decision needs described above. Key products include:

- Cotton distribution map (2023): National 10 metre land cover classification (using Copernicus Sentinel-1 and -2 data) identifying cotton, mixed cotton and other classes; used for targeting support and understanding production geography.
- Vegetation health time series and anomalies: Leaf Area Index climatology and standardised anomalies (using MODIS sensor data) and associated indicators used as proxies for crop condition and stress.
- Heat stress indices (historic archive): Hourly Wet Bulb Globe Temperature (WBGT) and

PRODUCT	COVERAGE / RESOLUTION	UPDATE FREQUENCY	DELIVERY TO USERS
Cotton distribution map	Bangladesh; 10m	Annual (prototype demonstrated for 2023)	Maps for analytics and planning; supports targeting and traceability
LAI climatology and anomalies	Bangladesh; 500m	5-day (time series) / 4-5 day products	Charts and maps; crop context in workshops and advisory workflows
WBGT / Heat Index / Lost Labour	Bangladesh; 0.1 degree (historic archive)	Hourly plus daily/annual summaries	Open repository; supports trend analysis and planning; informs bulletins
District forecast plots and tables	Pilot districts	Daily processing (fortnightly dissemination)	Bulletins, WhatsApp/audio summaries, and printed handouts

Table 1 Summary of products, update frequency and delivery mechanism

Heat Index from reanalysis; translated to work-rest categories and a Lost Labour Index to quantify productivity constraints.

- District forecast heat risk summaries: Daily updated 15-day forecast time series (air temperature and heat index) aggregated over pilot districts; used to generate bulletin plots and risk tables.
- High-resolution temperature feasibility product: Prototype 2 metre height air temperature downscaling using geostationary satellite and Copernicus Land Surface Temperature data combined with reanalysis data in a machine learning model.

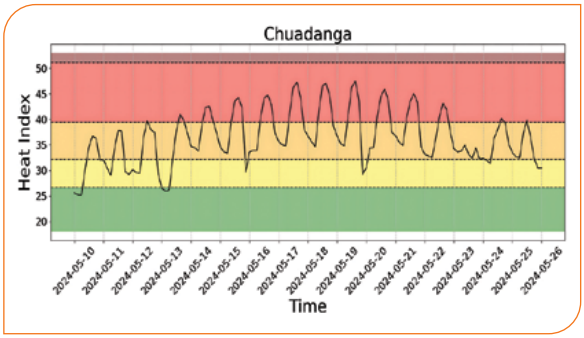


Fig. 3 Heat Index product developed for farmers in Chuadanga

All project datasets and operational bulletin inputs were published to an open repository (short link: bit.ly/c5data) to support transparency and reuse by partners.

Underlying Observations and Data Sources

C5 integrates multiple EO and climate data sources. The main observations and datasets used include:

- Sentinel-2 optical surface reflectance (10–20 metres) for vegetation and crop mapping features;
- Sentinel-1 SAR backscatter (VV/VH; 10 metres) to capture crop phenology and improve cotton extent mapping in cloudy periods;
- MODIS vegetation biophysical parameters, in particular Leaf Area Index (LAI) at 500 metres every 5 days to construct a multi-year baseline and anomalies;
- ERA5 and ERA5-Land reanalysis (ECMWF/C3S) providing temperature, humidity, wind and related variables used to compute WBGT, Heat Index and derived work-rest guidance from 1980 onward;
- NOAA Global Forecast System open forecasts (2 metre height temperature and humidity) used to generate daily district-level forecast plots and heat-risk tables (up to 15 days lead);
- Bangladesh Meteorological Department (BMD) forecast information (used to define and check national heatwave thresholds where available);

- Himawari-9 AHI geostationary observations (albedo, brightness temperatures and geometry) and Copernicus Land Monitoring Service hourly Land Surface Temperature (LST) for high-resolution temperature downscaling feasibility;
- in-situ reference and training data: CottonConnect field samples for crop mapping; meteorological station data (used in model training/validation for downscaling feasibility);
- ESA CCI Land Cover used in reference dataset development for cotton mapping validation.

Impacts and Benefits

C5 was designed to produce measurable value to end users by converting EO and weather data into decisions that protect health and maintain productivity. Benefits observed and evidenced during the feasibility study include:

- improved situational awareness and anticipatory guidance: farmers and intermediaries received forecast-based information and tailored precautions that were not previously available in a consolidated form;
- health protection and productivity planning: the Health Stress Index operationalises work-rest guidance and a Lost Labour Index, enabling conversations about safe labour planning under rising heat exposure;
- better targeting of support: the national cotton map and crop context analytics help CottonConnect and government stakeholders understand where cotton is grown and where interventions should be prioritised;
- supply-chain resilience and ESG reporting potential: data products provide an evidence base for brands and supply-chain actors seeking to understand climate risk, labour impacts and adaptation measures in sourcing regions.

Evidence and performance results reported during the project include:

- cotton distribution mapping achieved an overall classification accuracy of 0.9658 against reference data;
- the EO-based temperature model performed strongly in validation, closely matching ground-station measurements (RMSE 1.18, MAE 0.9; correlation 0.99);
- the feasibility study pilot covered 300 farmers across three districts (Kushtia, Meherpur

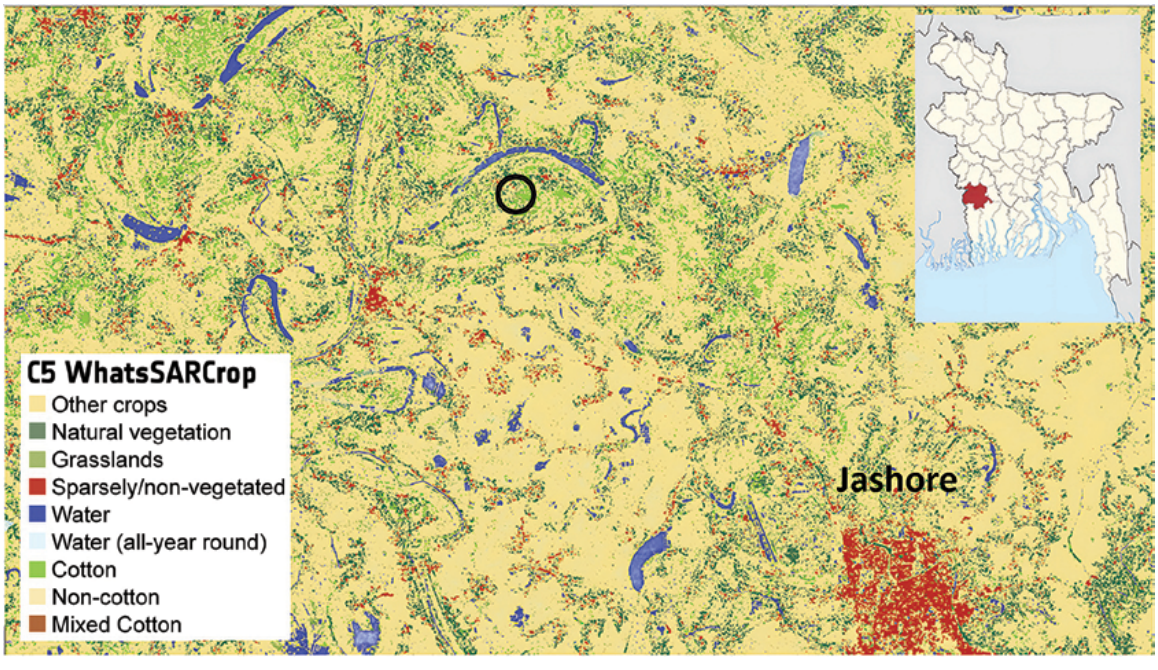


Fig. 4 Cotton extent map

and Chuadanga), with positive feedback reported from direct engagement and a final stakeholder workshop in Dhaka;

- an operational pipeline was demonstrated: forecast data downloaded daily, processed into plots and a risk table, and published to the repository for CottonConnect staff to support bulletin preparation.

Key delivery lessons included the need for hybrid dissemination (digital plus in-person) due to uneven smartphone/WhatsApp usage and literacy barriers, and a recurring user requirement for mid-term and seasonal forecasts (temperature and precipitation) to support planning across the full cotton production cycle.



Fig. 5 Farmer engagement & feedback session in Chuadanga

FURTHER INFORMATION AND GUIDANCE

Open data repository (C5 outputs): bit.ly/c5data

Core EO / climate datasets

- Sentinel-1 and Sentinel-2 (Copernicus): https://browser.dataspace.copernicus.eu/
- MODIS LAI: https://www.earthdata.nasa.gov/centers/lp-daac/data-access-tools
- ERA5/ERA5-Land (C3S): https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels?tab=download
- NOAA GFS forecasts: https://www.ncei.noaa.gov/products/weather-climate-models/global-forecast
- Himawari-9 AHI: https://www.jma.go.jp/jma/jma-eng/satellite/dissemination.html
- Copernicus LST: https://land.copernicus.eu/en/products/temperature-and-reflectance/hourly-land-surface-temperature-global-v2-0-5km

Suggested points of contact

- CottonConnect – programme delivery, farmer engagement and bulletin dissemination (Bangladesh pilot). sunaina.chaturvedi@cottonconnect.org
- Assimila – EO and climate data processing, index development and operational pipeline design. gerardo.lopezsaldana@assimila.eu

References (project documentation)

C5 Final Report (May 2024), ESA C5 project 2023-115 (Assimila and CottonConnect).

C5 Marketing Overview (draft, 2024) – positioning and farmer quote used in Section 1

03

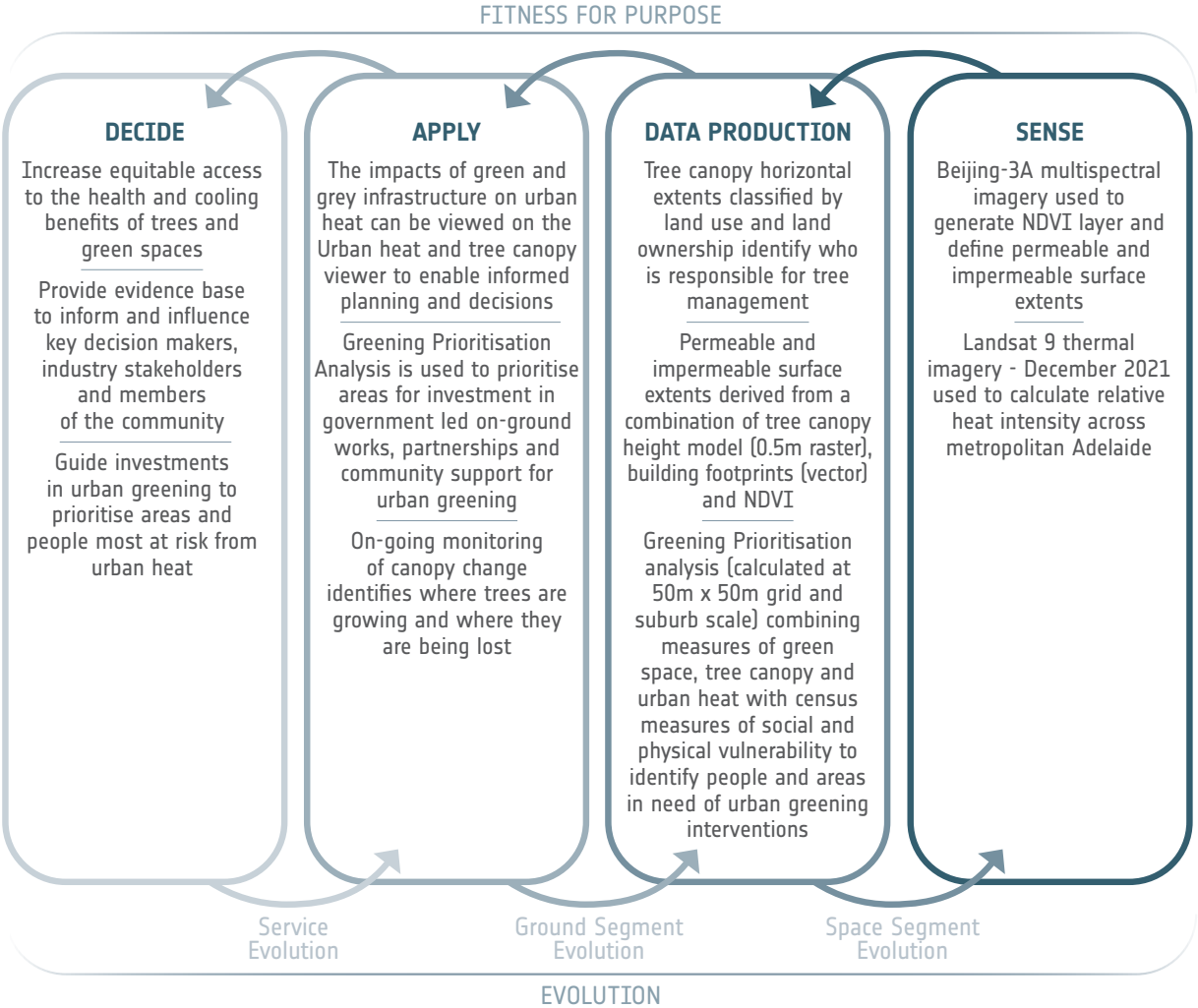
REGION: OCEANIA AND THE PACIFIC

Adelaide Urban Heat and Tree Canopy Mapping Project

Summary

In a changing climate, cities are experiencing the extremes of urban heat through longer and more intense heat waves. The impacts of heatwaves are exacerbated by the "Urban Heat Island effect" (UHI) where high proportions of built or grey infrastructure in cities increase the temperatures experienced, especially at night. The artificial (impermeable) surfaces absorb heat during the day and re-emit it to the local environment long after sunset. Globally, UHI is known to disproportionately impact people from culturally and linguistically diverse backgrounds, people of lower socio-economic status, younger children (<5 years old), older people (>65 years old), and people with chronic health or mental health conditions. These are the people who are less likely to have the adaptive capacity or the physical resilience to cope with urban heat. They may be living alone, or in high density or low quality housing. Trees and other healthy

Value Chain Diagram



green infrastructure are known as 'nature's air-conditioners' and help to cool their surrounds through shading and evapotranspiration and can provide up to 10°C cooling.

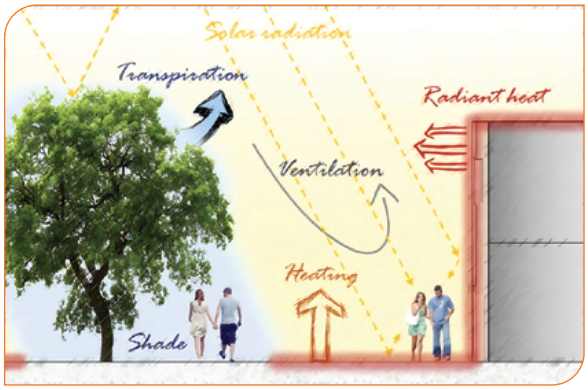


Fig. 1 Schematic illustration of the urban heat island effect and the cooling role of urban vegetation (Attribution: CRC for Water Sensitive Cities)

Between 2016 and 2019, groups of metropolitan Adelaide councils collaborated on a number of projects to map urban heat and tree canopy. Green Adelaide led a project in 2022 working with metropolitan councils to apply the methodology of the proceeding projects and, for the first time, map urban heat and tree canopy data across the entire metropolitan Adelaide region in a single contiguous dataset. The project combined satellite and aerial platform data sources. LiDAR and thermal imagery were captured from aerial platforms and multispectral imagery was captured using the Beijing-3A satellite. LiDAR data was processed to measure the 3-dimensional extents of tree canopy and built structures. Multispectral imagery was used to generate a Normalised Differential Vegetation Index (NDVI) layer. LiDAR and NDVI data were combined to generate a spatial layer defining the extents of permeable and impermeable surfaces. Using this data, Green Adelaide and project partners have a powerful evidence base to identify areas and members of the community that are most impacted by UHI.

In order to prioritise areas most in need of urban greening interventions, Landsat heat intensity data was combined with environmental variables



Fig. 2 Tree canopy height data

from LiDAR and NDVI and national census measures of social and physical vulnerability to produce a Greening Prioritisation Analysis. This analysis is used by Green Adelaide and partners to prioritise areas for on-ground urban greening works or community interventions through grants or education.

Decision-Making Context and Needs

In a changing climate, the impacts of increasingly severe and more frequent heat waves are magnified in cities due to the Urban Heat Island (UHI) effect where cooler trees and green spaces have been replaced by artificial (impermeable) surfaces which act as heat sinks. Australian cities are particularly vulnerable as warming has occurred above the global average. Heatwaves are now ranked as the most significant natural hazard in Australia and are linked to an increase in mortality. Heat waves globally disproportionally impact communities of lower socioeconomic status as they are less able to escape or mitigate the impacts due to a range of factors including poor or high-density housing, cost of air-conditioning, working in manual or outdoor jobs or language barriers inhibiting access to support and health services.

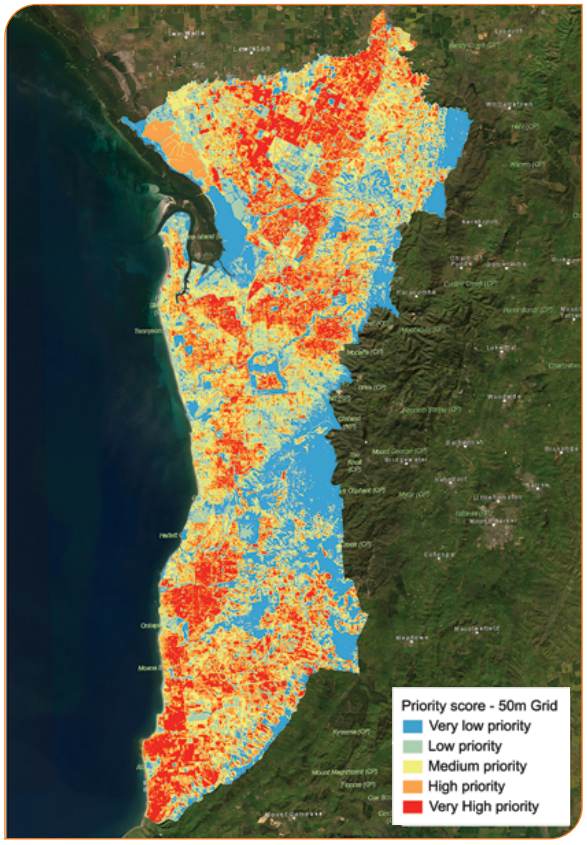


Fig. 3 Greening Prioritisation Analysis data

Green infrastructure including trees and other healthy vegetation are known to provide cooling and other health benefits such as pollution reduction to their local areas. As the need for higher density housing increases, green infrastructure is often in conflict with development and many large trees across metropolitan Adelaide are being lost. Equitable access to trees and green spaces in areas of high density housing or low socioeconomic neighbourhoods has the potential to provide a range of physical and mental health benefits through fostering greater connections with nature, encouraging physical activity, reducing pollution as well as cooling and shading.

Green Adelaide, in partnership with South Australian state government and local metropolitan councils have established the urban heat and tree canopy mapping project using a combination of satellite and aerial based remote sensing. The data describes the extents and interactions between tree canopy, built infrastructure and UHI. These environmental data were combined with census measures of socioeconomic status and chronic health to provide a robust evidence base to guide investment and on-ground urban greening actions which aim to mitigate urban heat for the most vulnerable people in our community.

Earth Observation Data Products and Information

Data from a range of remote sensing platforms have been used to build a comprehensive evidence base to understand the drivers of urban heat across metropolitan Adelaide, identify the areas and communities who are most at risk and who are already feeling the impacts, drive investment in urban greening to target those most in need and then monitor changes over time.



Fig. 4 Adelaide's permeable and impermeable surface

Data describing tree canopy, green spaces and the built environment were captured using a combination of aerial LiDAR and satellite-based multispectral imagery from the Beijing-3A satellite. A Normalised Difference Vegetation Index (NDVI) was derived from the multispectral imagery and was combined with LiDAR data to identify the extents of permeable and impermeable surfaces. High resolution (2m) aerial thermal imagery provided valuable insights to the heat impacts of different surface types, trees and green spaces. These layers have been shared publicly in an interactive map to engage with the community and support individual landholder choices.

Future actions and investments will be guided by the Greening Prioritisation Analysis (GPA). This analysis brings together environmental data describing tree canopy, green spaces and built infrastructure extents with census measures of social vulnerability and chronic health and Landsat urban heat intensity imagery. The analysis was calculated at suburb scale and at 50m x 50m grid to provide landscape scale guidance of policies and government strategies as well as target on-ground work at the street and neighbourhood scale. This analysis identifies the areas most in need to increase equitable access to the benefits of urban green infrastructure.

Underlying Observations and Data Sources

The project uses a variety of satellite and aerial based sensor platforms to provide a detailed picture of metropolitan Adelaide's urban forest, built infrastructure and how they interact to drive urban heat.

- Classified LiDAR (12ppm) - for derived tree canopy height model, tree canopy horizontal and built infrastructure extents (0.5m resolution)

- Aerial thermal imagery - 2m spatial resolution for day-time and night-time capture. Used for identification of urban heat islands (125m x 125m areas > 2°C above mean local temperature), identification of thermal properties of different surface types and colours (ie. different coloured roofing, roads, irrigated vs non irrigated lawns etc)

- Beijing-3A multispectral (NIR) imagery - 2m native resolution, panchromatic 0.5m resolution GSD used to generate Normalised Differential Vegetation Index (NDVI) to identify areas of actively growing vegetation. This was combined with LiDAR data to identify extents of permeable (natural) and impermeable (artificial) surfaces.

- Landsat satellite thermal imagery sampled at 30m resolution. Represented as an urban heat intensity value which measures the amount of heat in the landscape associated with urban development, when compared against a natural analogue.

- A Greening Prioritisation Analysis (GPA) was undertaken to identify areas of high priority for urban greening to support heat mitigation. The GPA combines environmental variables of tree canopy, green space and built infrastructure extents, urban heat intensity and census variables of socioeconomic status, and chronic health.

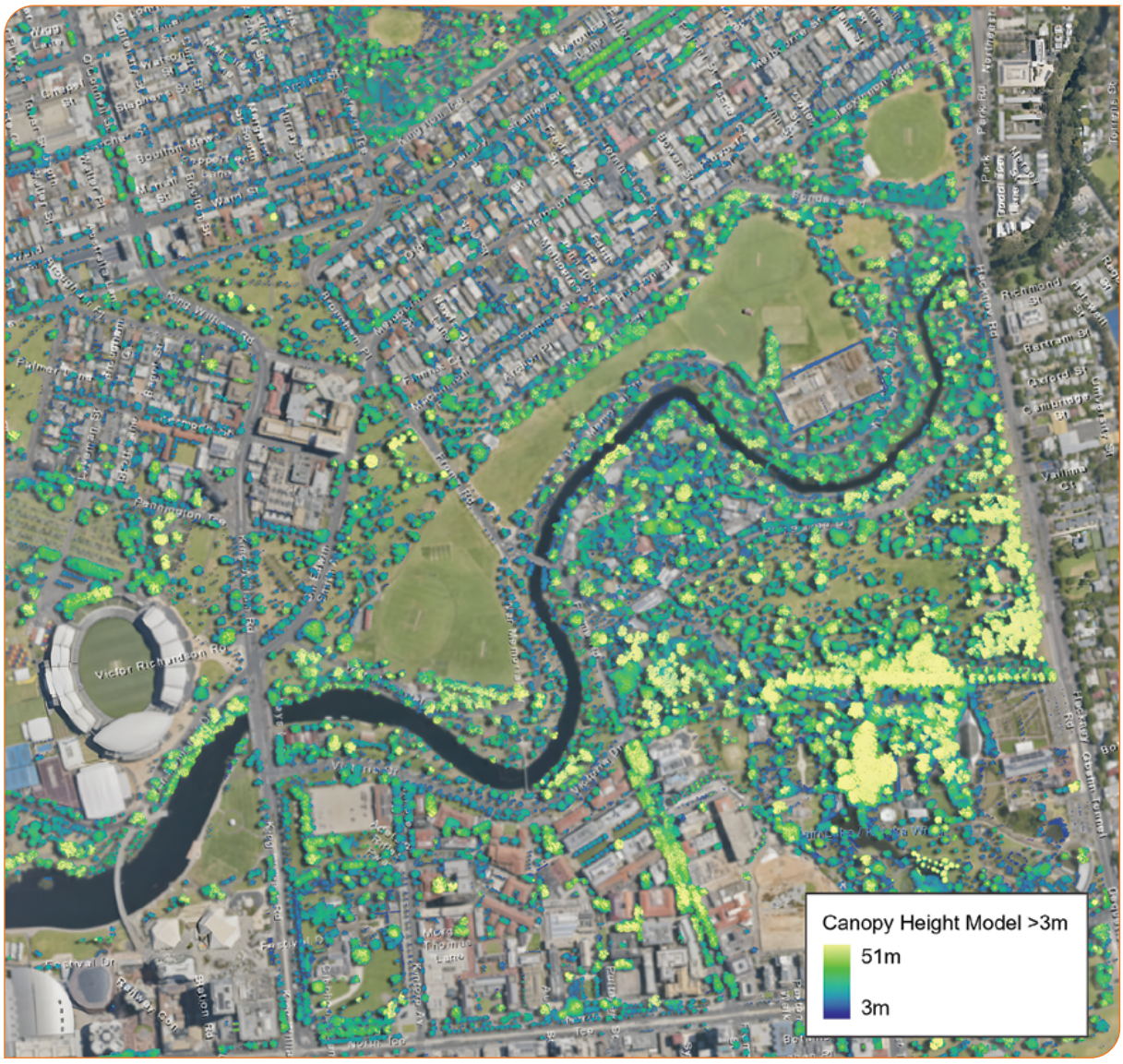


Fig. 5 Tree canopy height model of Adelaide

Impacts and Benefits

State government:

- Using the data to guide investments in on-ground works and social interventions such as environmental stewardship educational programs and prioritising areas for community and school based environmental grants
- Guiding decisions where to plant trees to offset the impacts of major road infrastructure projects
- Guiding planning policy on tree canopy and green space targets in housing developments
- Monitoring achievements of previous tree canopy planting, urban greening and urban heat mitigation strategies.

Councils:

- Prioritise street tree planting to target areas most impacted by urban heat as part of wider urban heat mitigation solutions
- Installation of cool surfaces such as light coloured roofing and permeable paving
- Water sensitive urban design feature installation
- Heat wave refuge initiatives.

Community:

- Data used to inform personal decisions regarding maintaining or increasing green space in home gardens and avoiding artificial turf, dark coloured roofing or paving
- Inform grant applications for community groups revegetation or rewilding projects.

FURTHER INFORMATION AND GUIDANCE

Green Adelaide

- Contact: Sarah White, Regional data officer / sarah.white4@sa.gov.au
- Urban Heat and tree canopy mapping project page

Department for Environment and Water

- Urban Heat and Tree Mapping viewer
- Urban Heat Viewer FAQ

04 REGION: ASIA

Enhancing Resilience to Poor Air Quality in India's Economic and Political Hub

Summary

Industrialisation in the Delhi National Capital Region (Delhi-NCR) has led to a massive increase in air pollution and urban heat island effects. These two threats compound each year and are deeply detrimental to the economy, public health, and environment in this important region of India. Open wastelands—characterised as barren or exposed soil—could be exacerbating air pollution in the Delhi-NCR.

A group of researchers at the Indian Institute of Tropical Meteorology have developed the Air Quality Warning and Integrated Decision Support System for Emissions (AIRWISE), to predict city-scale air pollution events and provide warnings and mitigation scenarios to residents and planners. The tool is now being enhanced with public Earth Observation data, to better understand and model the widespread impacts of open wastelands. This project has two objectives to support regional urban planners and policy-makers:

1. To identify and map open wastelands in the Delhi-NCR and estimate their contribution to particulate matter pollution using Earth Observation and machine learning;

2. Use scenario-based simulations to assess the potential benefits of covering open wastelands in vegetation, via surface temperature reduction and improved air quality.

These efforts to improve the existing AIRWISE toolkit using Earth Observation are supported by the European Space Agency and Future Earth's Joint Program.

Decision-Making Context and Needs

The Delhi-NCR is home to 46 million residents, and serves as the economic and political centre of India. The region has experienced rapid expansion and urbanisation, and subsequently, an increase in urban heatwaves and air pollution. While they are at their worst in winter, pollution levels in the Delhi-NCR cause excess deaths annually due to exposure to elevated harmful particulate matter, on average equivalent to smoking 9 cigarettes per day. Heatwaves further contribute to air pollution by increasing surface ozone. And these are not just medical emergencies; schools and businesses have to close, and productivity can drop by 19–40%, massively impeding economic progress every year.



Fig. 1 Air pollution has serious impacts on health and the economy in Delhi's National Capital Region (Attribution: Saikat Gosh)

The effects of both extreme heat and poor air quality are felt disproportionately by poorer and weaker residents as well, as they tend to spend more time outdoors with less access to air conditioning and air purifiers. The increased use of these appliances, while offering temporary relief, can further exacerbate negative impacts by putting pressure on the electrical grid and further

Value Chain Diagram

FITNESS FOR PURPOSE

DECIDE

Supports operational use by urban planners, public health agencies, regulators, and policy makers in Delhi-NCR to issue warnings and protect the population ahead of poor air quality events

To design targeted mitigation strategies for heat stress and air pollution, especially from wasteland-derived dust sources

Enables evidence-based decisions on converting wastelands into green spaces

Strengthens early warning and response actions for extreme pollution and heat events using AIRWISE outputs

Provides a repeatable framework for adoption to other urban areas, as well as incorporating new policy decisions back into the boundary conditions

APPLY

AIRWISE Air Quality Early Warning System provides improved air quality predictions and advance warnings of extreme air pollution events (as maps, web dashboards, tailored indicators, and reports)

The existing AIRWISE System provides information on the contribution of different emission source sectors and NCR districts to pollution in Delhi

This project will provide an enhanced Decision Support System (DSS) that builds on AIRWISE capabilities (sectoral and district-level pollution attribution) to support barren/wasteland management through targeted greening interventions for mitigating heat stress and improving air quality

simulates nature-based adaptation or stress-event scenarios for greening identified open wastelands, producing a variety of decision-relevant air quality indicators (as map-based outcomes and as guidelines for policymakers)

DATA PRODUCTION

AIRWISE provides air quality forecasts up to 72 hours in advance, and its DSS enables sector-wise and district-level pollution attribution for improved air quality management and policy decisions

AIRWISE incorporates satellite-based aerosol optical depth, land surface temperature, and land cover, with in-situ air quality and meteorological data

Processed into:

- EO-informed boundary conditions and inputs for air quality models
- High-resolution wasteland maps for all 19 NCR districts using Sentinel-2 and machine learning classifiers (Random Forest, k-means)
- Dust emission estimates from identified wastelands

SENSE

Aerosol optical depth observations (NASA MODIS and VIIRS, ISRO Oceansat-3 EOS-06)

Burnt area products (Copernicus Sentinel-2)

Soil moisture (Copernicus Sentinel-1 Synthetic Aperture Radar)

Land use/land cover change (Copernicus Sentinel-2)

Land surface temperature (Copernicus Sentinel-3 Sea and Land Surface Temperature Radiometer)

Atmospheric reanalysis data (ECMWF ERA-5)

Service Evolution

Ground Segment Evolution

Space Segment Evolution

EVOLUTION

increasing air pollution from power plants. If left unaddressed, these cascading effects will only worsen with climate change.

Open wasteland sites across the Delhi-NCR (defined as barren or exposed soil) act as a significant dust source in this region, contributing to particulate matter pollution and local heat stress. However, it is still unclear where these sites are, how they are changing over time, and how much their dust may be exacerbating air pollution and urban heat island effects.



Fig. 2 Visible air pollution over suburban trees and open wasteland in New Delhi, November 2016 (Attribution: Saurabh Kumar, CC BY-SA 4.0)

Earth Observation Data Products and Information

The AIRWISE system (Figure 3) incorporates two types of workflows: the Air Quality Early Warning System and the Decision Support System.

- The Air Quality Early Warning System generates air quality forecast maps at different scales: 10 days in advance at 10 km x 10 km, 3 days in advance at 2 km x 2 km, and 3 days in advance at 400 m x 400 m.
- The Decision Support System is being further enhanced to develop an integrated decision support system at NCR district-scale, simulating future air quality to both perform chemical fingerprinting of different pollution sources, and test emission reduction scenarios (via greening of open wastelands).

The results of both workflows are disseminated on a web platform as geospatial data products and India Meteorological Department bulletins. To map NCR wastelands, machine learning algorithms like Random Forest and weka KMeans model classifiers have been applied, followed by an accuracy assessment. Google Earth Engine is being used to enable rapid and repeatable data acquisition and an operational early warning and decision support framework.

Underlying Observations and Data Sources

A number of inputs are fed into the toolkit:

- Aerosol optical depth observations from MODIS (NASA Terra and Aqua satellites), VIIRS (NASA Suomi National Polar-orbiting Partnership), and EOS-06 (ISRO Oceansat-3 satellite).
- Burnt area products and land use/land cover change (specifically open wasteland) from Copernicus Sentinel-2 multispectral imagery.
- Soil moisture using Sentinel-1 Synthetic Aperture Radar.
- Land surface temperature from the Copernicus Sentinel-3 Sea and Land Surface Temperature Radiometer.

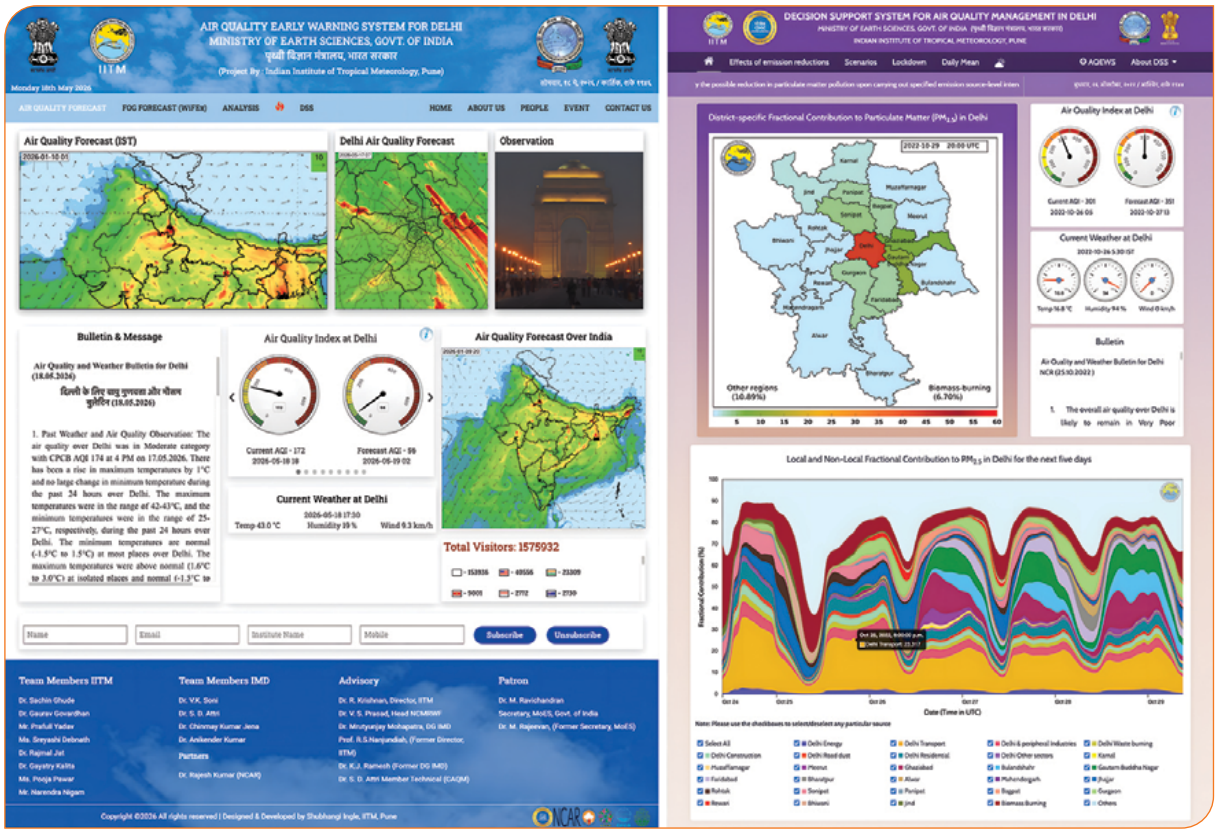


Fig. 3 AIRWISE public dissemination system (ews.tropmet.res.in)

- Meteorological forcings from the ECMWF ERA-5 atmospheric reanalysis data.
- Stationary geographical data and surface measurements from 320 air quality monitoring systems.

To improve the accuracy of the study, the team first updated the land use information for the Delhi-NCR region using recent Sentinel-1 and Sentinel-2 satellite data from 2021, instead of the older 1992 dataset. The finer detail of the newer satellite imagery gives a better picture of current land conditions. Open barren land, an important source of dust emissions, was then identified (Figure 4) using supervised machine learning algorithms in Delhi, and unsupervised

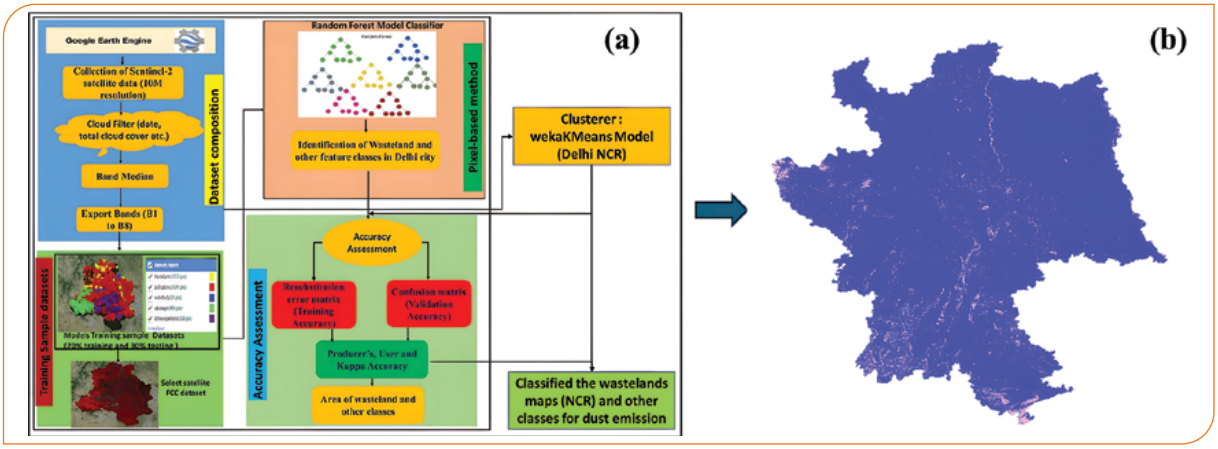


Fig. 4 (a) Algorithm for wasteland identification and (b) resulting identified wastelands in the Delhi-NCR (pink)

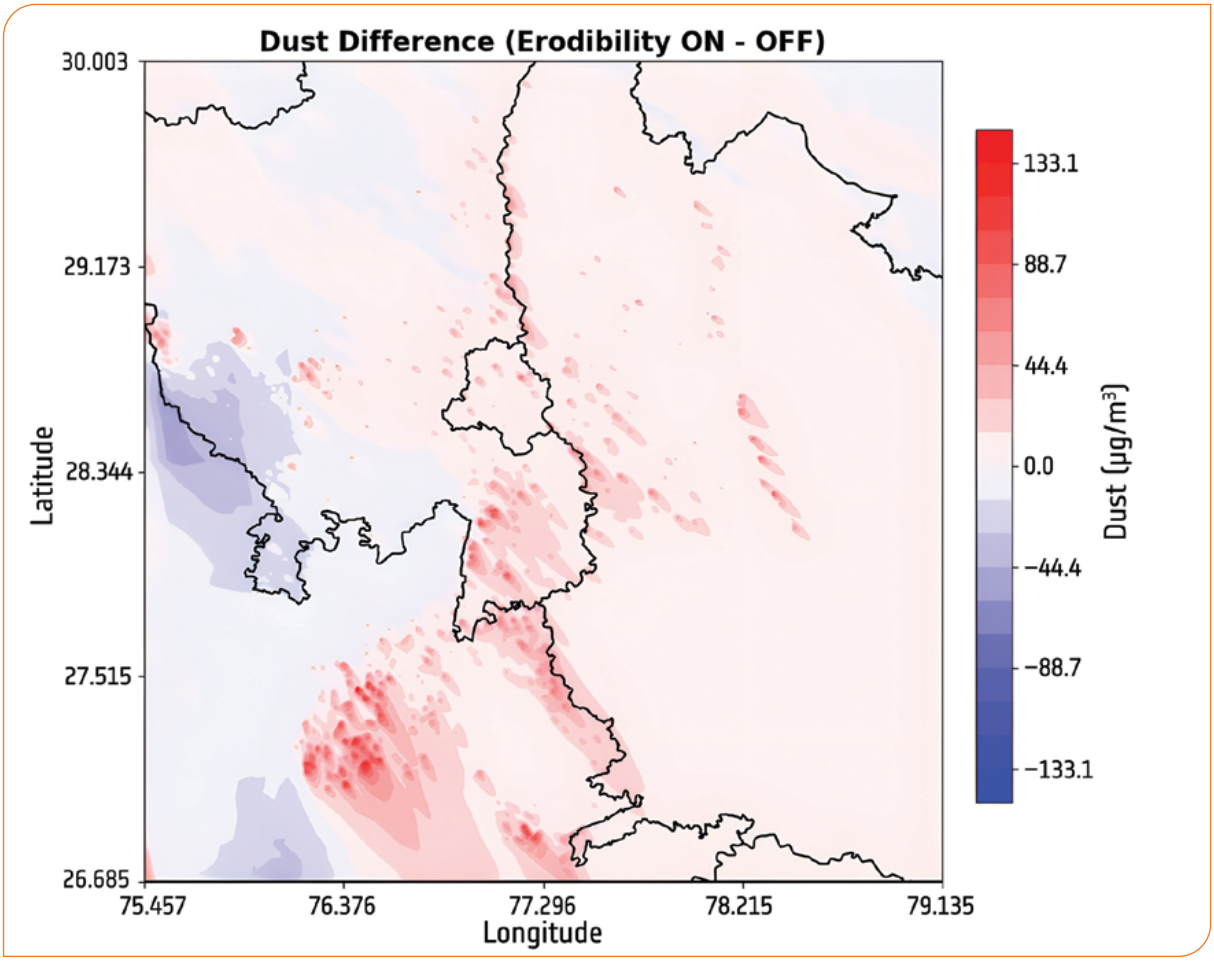


Fig. 5 Spatial distribution of the dust concentration (µg/m³), originating from identified barren land in Delhi-NCR on 28th March 2025

in other districts, to understand the distribution and impact of these dust sources.

Figure 5 shows the level of dust concentration in Delhi-NCR from the open barren/wasteland areas identified. The pattern clearly highlights that dust emissions from open barren land regions can significantly increase dust concentrations in the atmosphere both locally and regionally through its regional transport.

Impacts and Benefits

Key stakeholders benefitting from the AIRWISE findings include the Commission for Air Quality Management (CAQM), the Central Pollution Control Board (CPCB), the Delhi Pollution Control Committee (DPCC), and the National Disaster Management Authority (NDMA). These bodies are able to use the forecasts and bulletins across the early warning system to respond and protect residents accordingly. The decision support system then allows local and regional authorities to test and implement adaptation solutions, such as increasing vegetation cover or installing natural or artificial air-filtering infrastructure. By enabling timely and targeted interventions—such as emission control measures and public-health restrictions—this system has demonstrated a clear operational benefit in reducing extreme pollution events. Notably, it helped cut peak pollution levels in Delhi by about 18–22% during a severe episode, highlighting its effectiveness in mitigating the intensity of high pollution periods. This ability to proactively "cut the peaks" significantly reduces public exposure during the most hazardous conditions and strengthens overall air quality management.
The Commission for Air Quality Management (CAQM) in the National Capital Region and the adjoining areas, which is responsible for managing air quality in the city of Delhi, has recognized the AIRWISE system as a key partner in new investigative initiatives to reduce particulate matter pollution and improve air quality in extreme circumstances.

The ESA and Future Earth funded stage of the project aims to inform urban planners, policy-makers, and the general public, to what extent open wastelands are contributing to poor air quality, and provide a series of adaptation scenarios for greening these wastelands. Through the Earth Observation-driven analysis, the project will enable planners and decision makers to design more informed, targeted interventions to effectively reduce air pollution in the Delhi-NCR.

The satellite-driven system can accurately simulate and forecast air quality over large areas by accounting for regional weather-related forcings. But the coupling of Earth Observations with ground-based sampling stations and a variety of data resolutions means these forecasts can be delivered at street-scale, where it really matters.

FURTHER INFORMATION AND GUIDANCE

Open data repository (C5 outputs): bit.ly/c5data

Core EO / climate datasets

- Sentinel-1 and Sentinel-2 (Copernicus): https://browser.dataspace.copernicus.eu/

Point of contact

- Dr. Sachin D. Ghude, Indian Institute of Tropical Meteorology / sachinghude@tropmet.res.in

Web Resources

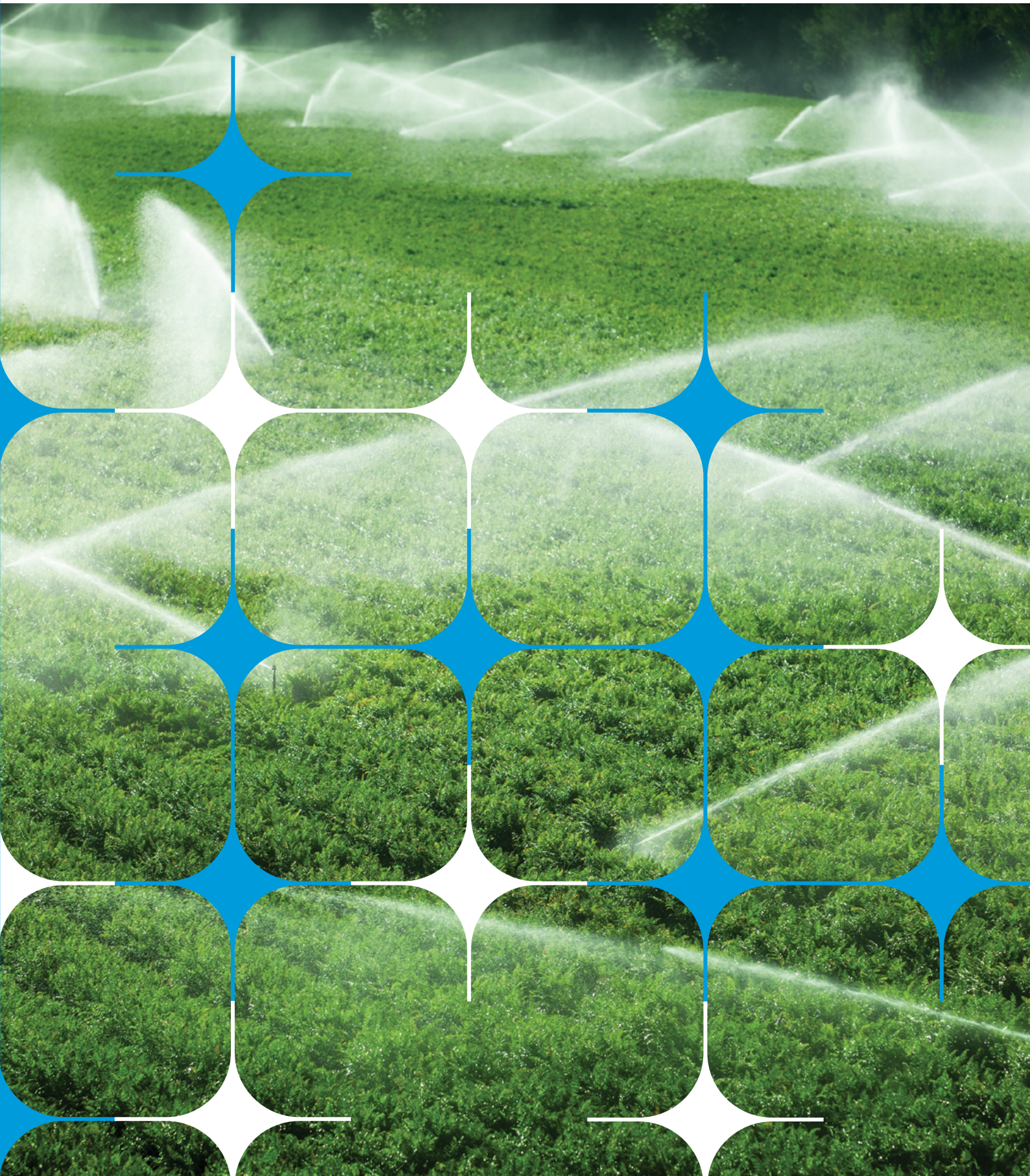
- Air Quality Early Warning System homepage with bulletin and near-future forecasts: https://ews.tropmet.res.in/
- Decision Support System with recent and forecasted contributions to particulate concentrations: https://ews.tropmet.res.in/dss/index.php

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- Kaginalkar, A., Ghude, S.D., Mohanty, U.C., Mujumdar, P., Bhakare, S., Darbari, H., Dwivedi, A.K., Gavali, P., Gavhale, S., Islam, S. and Kadam, G., (2022). Integrated urban environmental system of systems for weather ready cities in India. Bulletin of the American Meteorological Society, 103(1), E54-E76. https://doi.org/10.1175/BAMS-D-20-0279.1
- Ghude, S.D., Kumar, R., Govardhan, G., Jena, C., Nanjundiah, R.S. and Rajeevan, M., (2022). New Delhi: air-quality warning system cuts peak pollution. Nature, 602(7896), pp.211-211. https://doi.org/10.1038/d41586-022-00332-y

WATER

CASE STUDIES



01 REGION: EUROPE

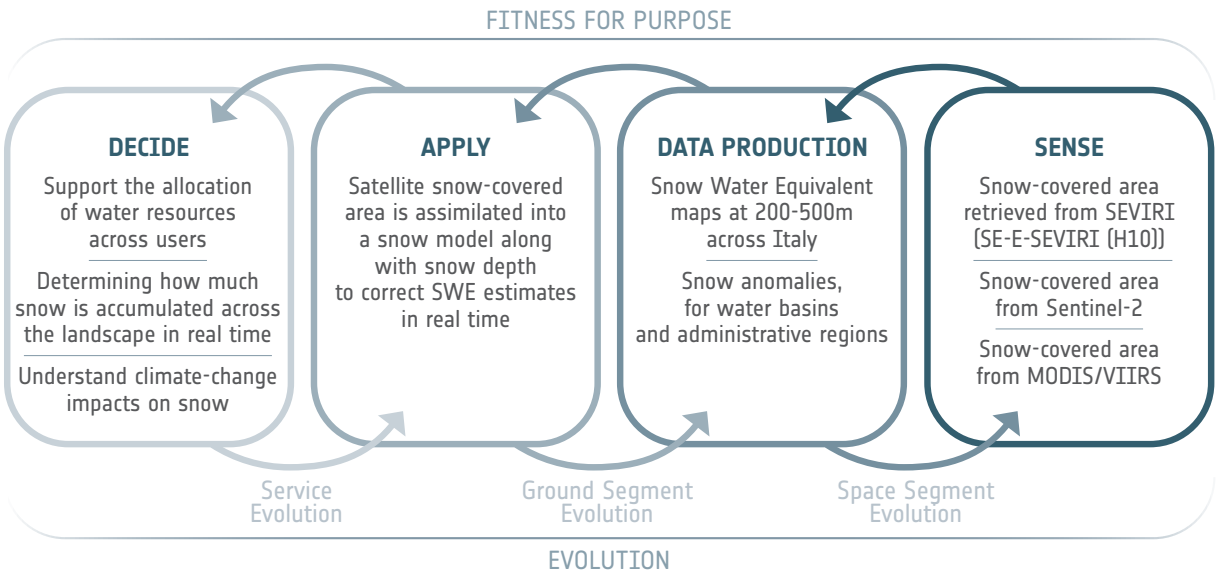
EUMETSAT's H SAF Snow Water Equivalent Maps Supporting Water Management in Italy

Summary

Northern Italy, dominated by the Po River basin and the Alpine headwaters, is one of Europe's most climate sensitive hydrological systems. Recent analyses, including climate models and long term meteorological observations, reveal several coherent trends in water availability, drought severity, snow dynamics, and streamflow behaviour. Since the early 2000s, the Po River basin has entered a period of recurring drought, amplified by global warming (Faranda et al., 2023). Warmer temperatures are also driving a decrease in snow depth and snow covered area, reducing meltwater contributions to spring and summer streamflow. Six decades of meteorological data from the Po River basin show increasing drought severity, with temperature emerging as a key intensifier. The Po is then transitioning from a reliable perennial river into a system prone to seasonal and interannual water shortages.

Italy as a whole is a topographically and climatically complex region including some of the highest mountain peaks in Europe (the Alps and the Apennines). The central question is: how much snow is accumulated across the landscape at any given time? Determining the most accurate approach for quantifying snow amount and its spatial distribution remains an open question, as several options exist—including in situ measurements, remote sensing data, and models—each with distinct advantages and limitations. For other geographical areas, a successful approach has been the definition of models that assimilate in situ and remote sensing data to obtain reanalysis products that provide reliable estimates of the snow water resources.

Value Chain Diagram



Decision-Making Context and Needs

Water management in Italy operates at multiple levels, with responsibilities shared between the national government and local authorities. Regions, watershed districts, and municipalities all play a role, especially during emergencies. For example, local mayors can issue urgent water-use restrictions in response to extreme events such as droughts or water shortages. These local measures reflect how the hydroclimatic conditions directly affect communities.

Snow is a key part of this system, as it acts as a natural water reserve that feeds rivers and supports water availability during spring and summer. Thus, monitoring how much water is stored in the form of snow in the mountains is essential for effective water management.

To support this need, the CIMA (International Centre for Environmental Monitoring) Research Foundation developed S3M Italy, an operational system used in civil protection activities. It combines data from weather stations, satellites (Sentinel-2/MIS, TERRA/MODIS (up to September 2024); Suomi NPP/VIIRS (since September 2024), and METEOSAT/SEVIRI), and ground-based snow sensors to provide up-to-date information on snow conditions. This allows local to national authorities to monitor snow amount in near real-time and make informed decisions, especially during critical periods.

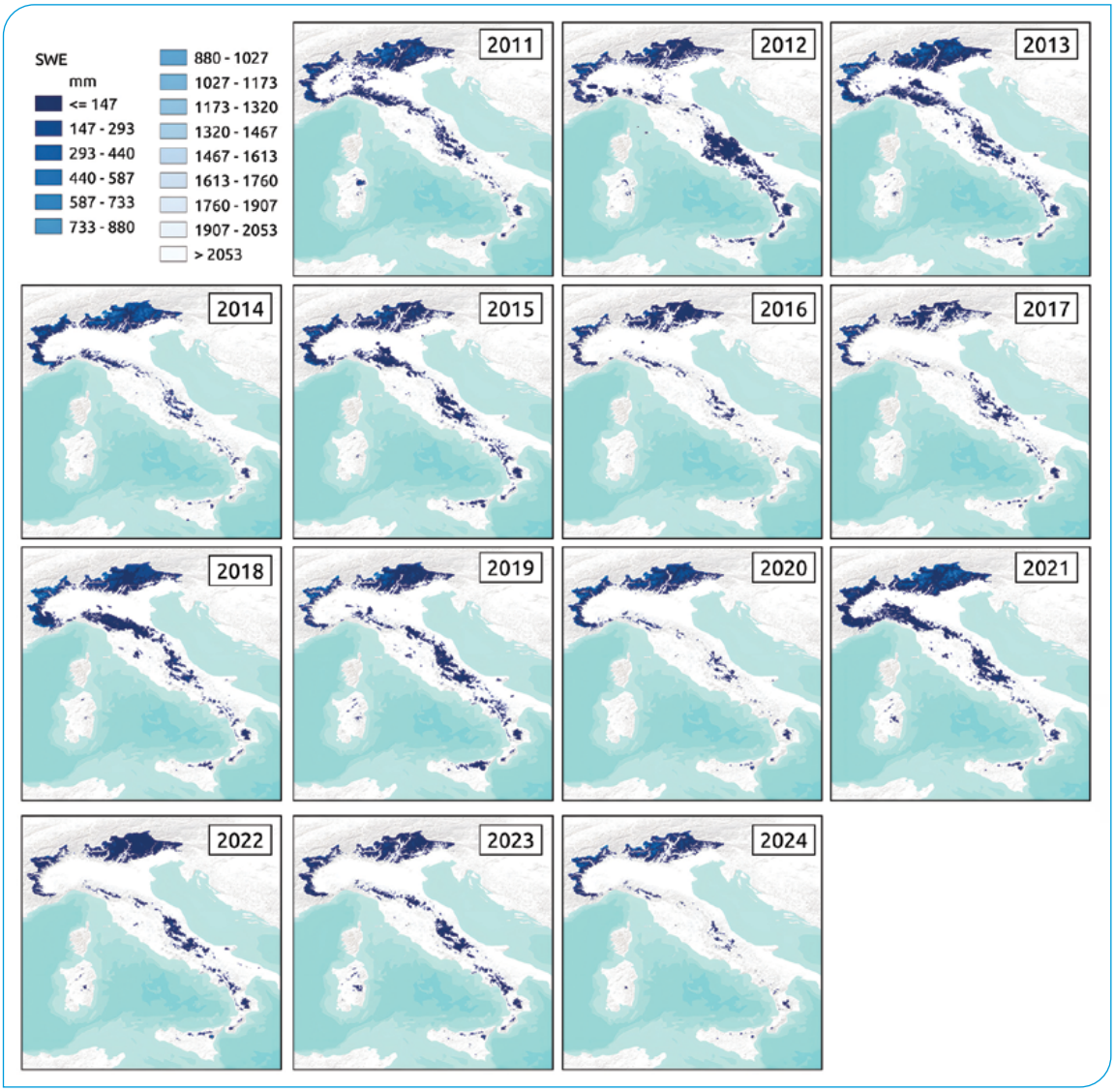


Fig. 1 Mean seasonal Snow Water Equivalent in Italy according to S3M Italy (Attribution: modified from Avanzi et al., 2023: https://essd.copernicus.org/articles/15/639/2023/)

Earth Observation Data Products and Information

Building on the integration of satellite and ground-based observations, we developed a set of operational products designed to support decision-making. A key component is a consistent, high-resolution snow dataset for Italy (IT-SNOW), which provides daily estimates of snow water equivalent (SWE) across the country from 2010 to present. This long-term consistency allows not only real-time monitoring, but also the construction of a robust climatology of snow conditions.

To ensure accessibility and impact beyond the scientific community, these products are disseminated through dedicated dashboards and visual tools, designed for both technical users and the general public (https://www.cimafoundation.org/en/italy-snow-updates/). In parallel, we actively engaged with national and international media outlets to communicate the evolving snow conditions and their impacts. This combination of near real-time information, historical context, and targeted communication helped to turn Earth observation data into actionable data for decision-makers and to inform society.

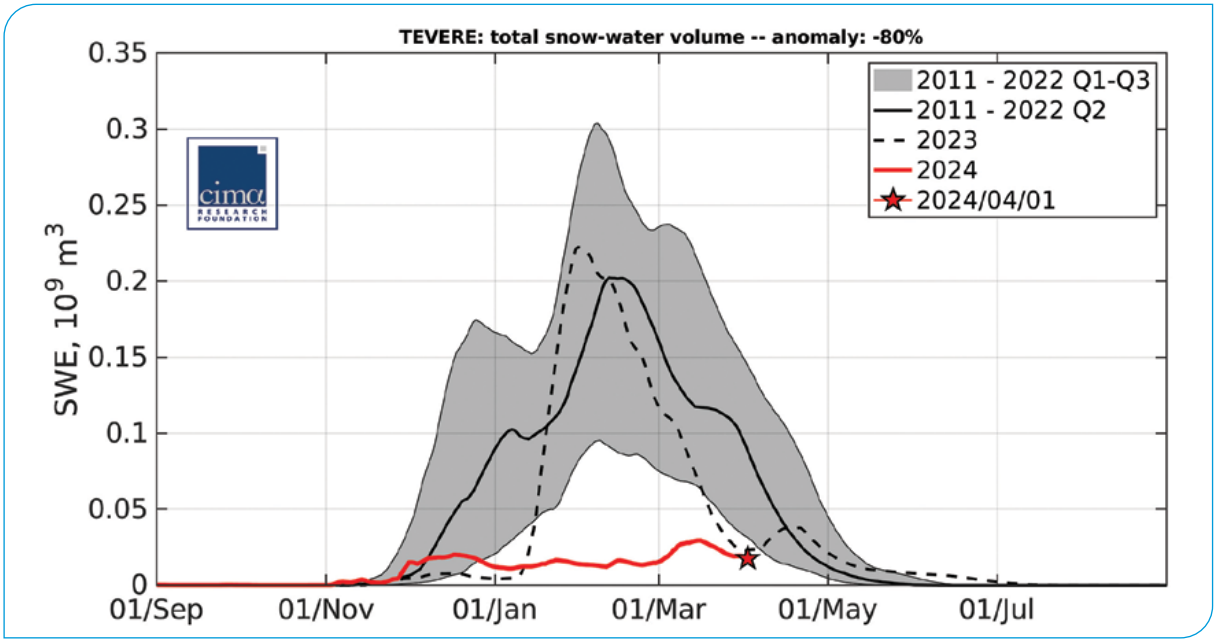


Fig. 2 Seasonal evolution of total SWE for the Tiber basin in real-time, during the season 2023-24 (red) as opposed to the long-term median (black line) and the 2022-23 season (dashed black line)

Using this reference baseline, we generated anomaly maps and further indicators that show how current snow conditions compare to historical averages. These products make it possible to quickly assess whether a given season is characterized by snow deficit or snow excess, and to quantify the magnitude of events such as the 2023–2024 snow deluge in terms of stored water. This type of information is particularly relevant for water management, as it translates snow conditions into a metric directly linked to water availability.



Fig. 3 Example of real-time map showing deficit of SWE for the main Italian rivers, April 2024 (Attribution: CIMA Research Foundation)

Underlying Observations and Data Sources

To better understand how much water is stored in snow across Italy, we relied on a combination of satellite data, ground measurements, and modeling. Key Earth Observation (EO) inputs included snow-cover maps from Sentinel-2/MSI and MODIS/VIIRS satellites, as well as products from METEOSAT/SEVIRI (provided by EUMETSAT's H SAF). Sentinel-2 and MODIS provide high spatial resolution but at rather low frequency and METEOSAT provides measurements at high frequency but rather low spatial resolution. Combining those provides frequent wide area observations of snow conditions.

These satellite data were combined with information from thousands of weather stations and hundreds of snow sensors on the ground. By integrating all these sources in the S3M Italy system, we produced a dataset called IT-SNOW, which delivers daily maps of key variables such as snow depth and snow water equivalent at high spatial resolution (about 500 meters), from 2010 to now.

This approach helps overcome the limitations of using any single data source alone. Satellite observations provide broad spatial coverage, while ground measurements improve accuracy, and modelling ensures consistency over time. The resulting information allows users to track how snow accumulates and melts across the country, offering a reliable and up-to-date picture of snow water resources to support water management decisions.

Impacts and Benefits

The 2023–2024 winter in Italy provides a clear example of how Earth observation–based snow information can support real-world decision-making. After months of severe snow deficit (down to −53% compared to historical

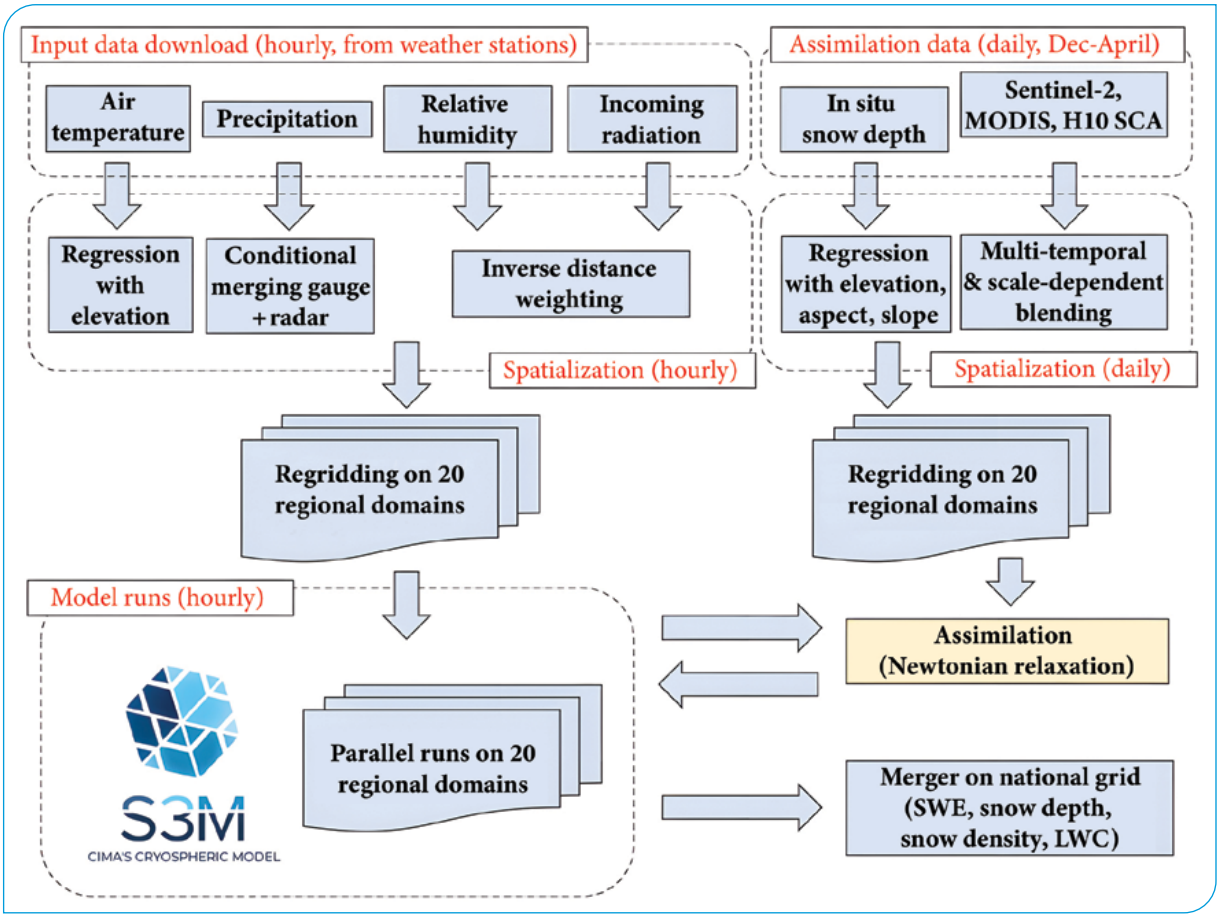


Fig. 4 Schematic of S3M Italy (Attribution: Avanzi et al., 2023: https://essd.copernicus.org/articles/15/639/2023/)

conditions by mid-February), northern Italy experienced an abrupt transition in early March 2024, when two weeks of intense snowfall led to a surplus of +13% in snow water resources by early April. This rapid shift, effectively ending a multi-year snow drought in the Alpine region, had immediate implications for water availability, hydropower production, and drought mitigation.

Through S3M Italy, this evolution was tracked in near real-time, allowing authorities and stakeholders to quantify not only the magnitude of the recovery, but also its spatial distribution. Crucially, the system revealed that most of the surplus was concentrated above 2000 m, while lower elevations remained in deficit. This information is essential for water management, as it indicates potential mismatches between total snow availability and its timing and usability for downstream needs.

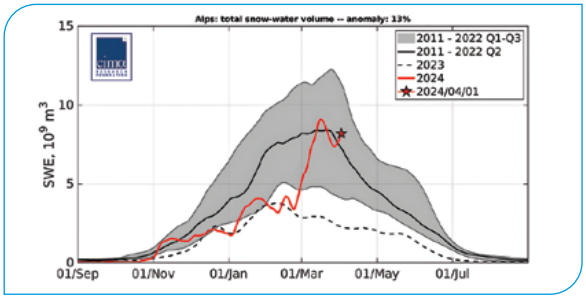


Fig. 5 Total SWE for the Italian Alps, season 2023-24 (red) as opposed to the long-term median (black line) and the 2022-23 season (dashed black line)

The ability to place current conditions in a historical context, through anomaly maps and climatological comparisons, provided an intuitive way to communicate the severity of both the initial deficit and the subsequent recovery. These insights supported local to national authorities, watershed management, and civil protection agencies in assessing water resources and planning accordingly during a highly variable season.

Beyond institutional users, the work also had a strong societal impact. Snow conditions and their impacts were widely communicated through dedicated dashboards and extensive media coverage at both national and international levels. This helped to raise public awareness of the links between climate variability, mountain snow, and water security.

Overall, the 2024 snow deluge illustrates the challenges posed by increasing climate variability: while extreme snowfall events can temporarily alleviate drought conditions, their uneven distribution and dependence on temperature highlight the ongoing vulnerability of Italy's water system. The integration of Earth observation data into operational tools such as S3M Italy is therefore key to supporting informed, timely, and transparent decision-making.

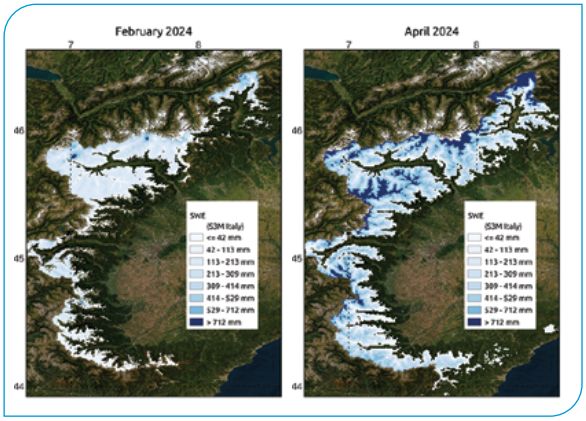


Fig. 6 Distribution of SWE across north-western Italy, February vs. April 2024 (Attribution: CIMA Research Foundation)

The S3M Italy output is also operational on the MyDewetra platform, which is used by the Italian Civil Protection System at both regional and national levels. In particular, Snow Water Equivalent (SWE) information is employed by regional authorities to support hydrological assessments and hydraulic alert procedures. On 1 April 2024, a snowmelt-driven event affecting SWE dynamics impacted the Po River basin, resulting in the issuance of national yellow and orange hydraulic alerts for 2 and 3 April 2024.

An example of the operational use of S3M in Italy is provided by the Eastern Alps River Basin District, which has integrated S3M outputs into its routine water management activities. According to Nico Dalla Libera, "the integration of S3M into our operational workflow has enabled a step change in how snow water resources are

monitored. Previously, assessments relied mainly on point-based in-situ observations, which could not fully capture the spatial heterogeneity of snow across basins and elevation ranges. With S3M, we now have access to spatially distributed, near-real-time estimates of snow water equivalent (SWE), which we incorporate into our monthly bulletins and drought severity assessments. This has strengthened the evidence base for water management decisions and improved our capacity to monitor water availability, particularly during critical periods of water scarcity."

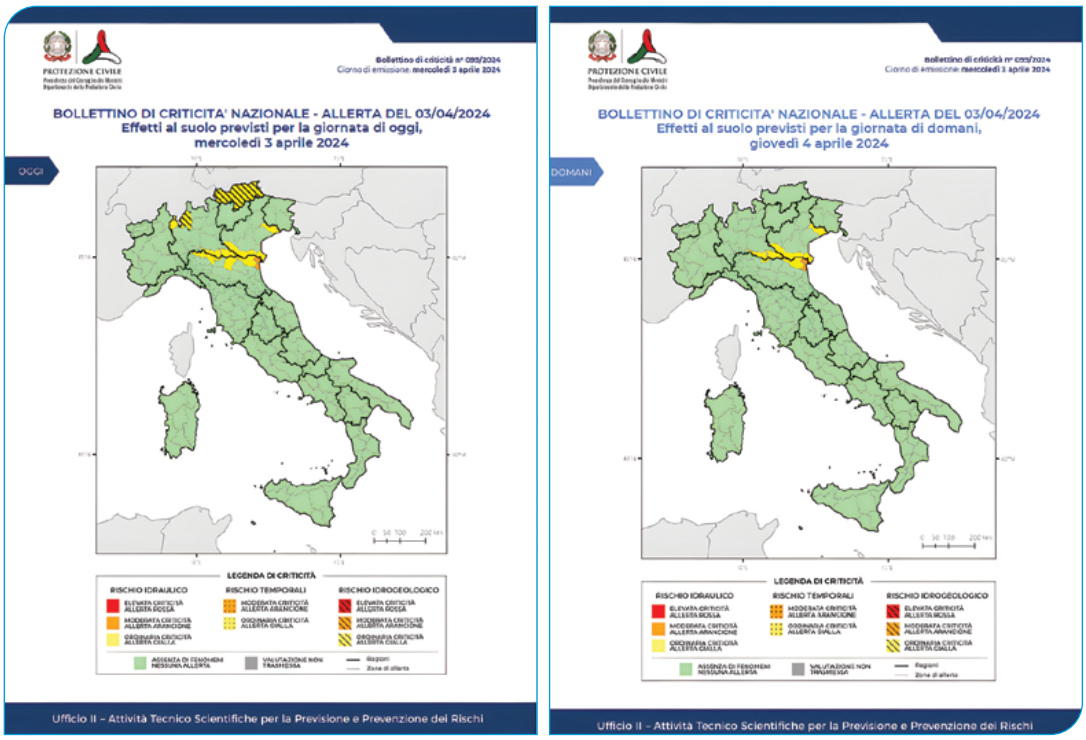


Fig. 7 The Criticality Bulletin is issued every day by the Italian Civil Protection Department (Attribution: Civil Protection Department (DPC))

FURTHER INFORMATION AND GUIDANCE

S3M Italy is managed by CIMA Research Foundation, point of contact Francesco Avanzi (francesco.avanzi@cimafoundation.org) and Simone Gabellani (simone.gabellani@cimafoundation.org).

EUMETSAT H SAF products are freely available for operational use through EUMETCast and FTP services, as well as via the dedicated website: https://www.eumetsat.int/h-saf.
For H SAF activities, the contacts are Silvia Puca (silvia.puca@protezionecivile.it) and Roberto Nicoletta (nicoletta.roberto@protezionecivile.it).

Faranda et al., 2023.: https://iopscience.iop.org/article/10.1088/1748-9326/acbc37

Real time updates for Italy are available on CIMA's snow dashboard (https://www.cimafoundation.org/aggiornamenti-neve-italia/).

More details on this system are available at https://essd.copernicus.org/articles/15/639/2023/essd-15-639-2023.html, while historical data are uploaded annually at https://doi.org/10.5281/zenodo.6861722

The Criticality Bulletin is available at
https://mappe.protezionecivile.gov.it/en/risks-maps/criticality-bulletin/

02

REGION: AMERICAS

Protecting Lives and Livelihoods Across Alaska with NASA Surface Water Data

Summary

The United States Geological Survey (USGS) traditionally relies on *in situ* monitoring stations to measure river flow and assess flood risks nationwide. However, in remote and rugged environments like Alaska, maintaining these stations is dangerous, expensive (costing up to $40,000 annually per station), and labor intensive, leaving many rivers unmonitored. To address this gap, several agencies, including USGS, submitted a request through the 2018 Satellite Needs Working Group (SNWG) survey, seeking a remote sensing solution to track surface water safely and efficiently, in concert with existing in situ networks.

In response to this need, NASA's Observational Products for End-Users from Remote Sensing Analysis (OPERA) project at the Jet Propulsion Laboratory (JPL) collaborated closely with USGS to develop the Dynamic Surface Water Extent (DSWx-HLS) data product. By leveraging near-daily Harmonized Landsat and Sentinel-2 (HLS) satellite observations, another solution from SNWG, this new tool allows the USGS to remotely calculate river widths and estimate streamflow. This solution significantly reduces operational costs and personnel hazards while providing critical data in areas that were previously too difficult to monitor.

Today, USGS actively relies on DSWx-HLS data for operational streamflow monitoring in Alaska. While satellite data can not entirely replace traditional *in situ* monitoring, it successfully augments these efforts and fills critical gaps in data-sparse regions. By the end of 2025, USGS

Value Chain Diagram

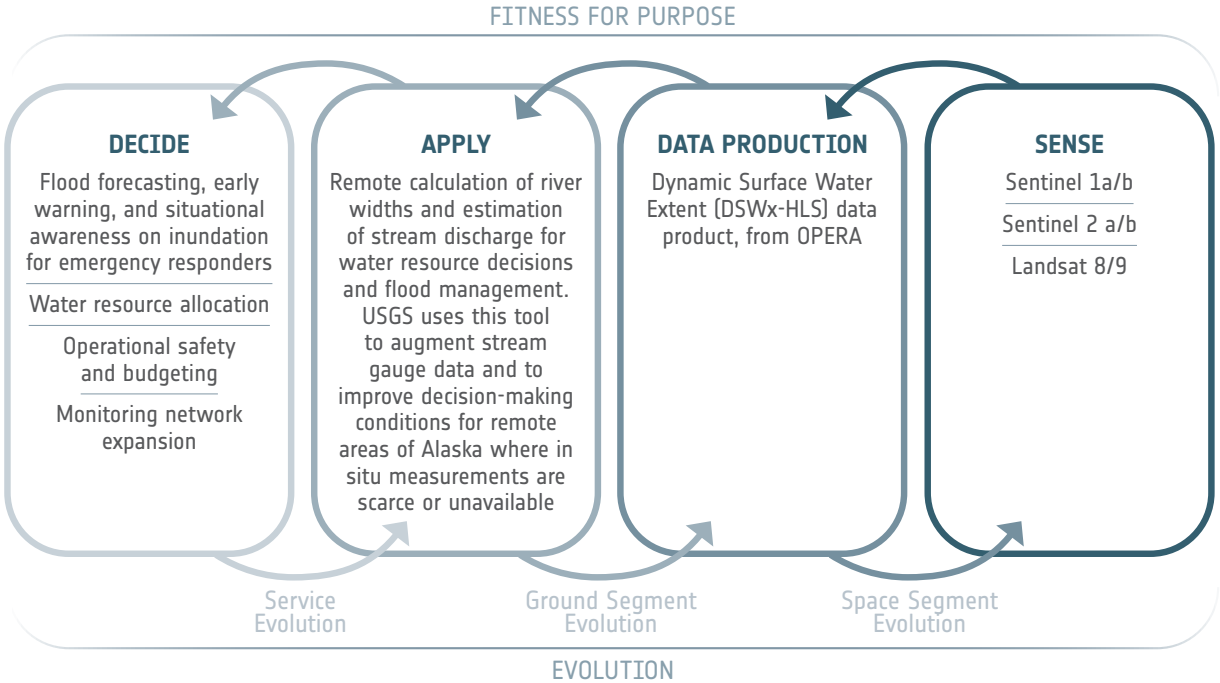




Fig. 1 USGS personnel must ferry traditional flow measuring equipment in remote locations such as across the Ikalukrok Creek in Alaska (Attribution: USGS)

aimed to remotely monitor more than 30 sites using this NASA data. As the technology and methodologies continue to mature, they plan to eventually expand this remote monitoring network to over 70 sites.

Decision-Making Context and Needs

The USGS supports communities in water management and flood risk reduction through observation of streamflow conditions. The scarcity of ground stations and stream gauges in many remote parts of Alaska has historically created obstacles to decision-making. This product directly supports emergency personnel and planners, in preparing for and responding to flood risks across Alaska, especially in those areas where in situ measurements are scarce. Flood early warning can protect life and property, while understanding streamflow conditions more generally supports water management decisions. This work also protects USGS personnel from having to install or service streamflow gauges in dangerous areas.

Earth Observation Data Products and Information

The Dynamic Surface Water Extent (DSWx-HLS) data product is the key product for meeting this need and was co-developed by NASA and USGS to fill critical gaps in sparse ground data regions. The combination of active sensor SAR and optical data from HLS allows more frequent detection and mapping of surface water extent.

Underlying Observations and Data Sources

This product leverages near daily Harmonized Landsat and Sentinel-2 (HLS) observations to calculate surface water extent and estimate

stream discharge. HLS seamlessly combines the longest continuous record of Earth observing data from Landsat with European Space Agency's Sentinel satellite data and provides global Earth observations every 1.6 days. The use of SAR data from Sentinel 1, and eventually from NISAR, provides more frequent measurements of surface water extent, particularly in dark or cloudy conditions that commonly limit the number of available observations in high-latitude areas.

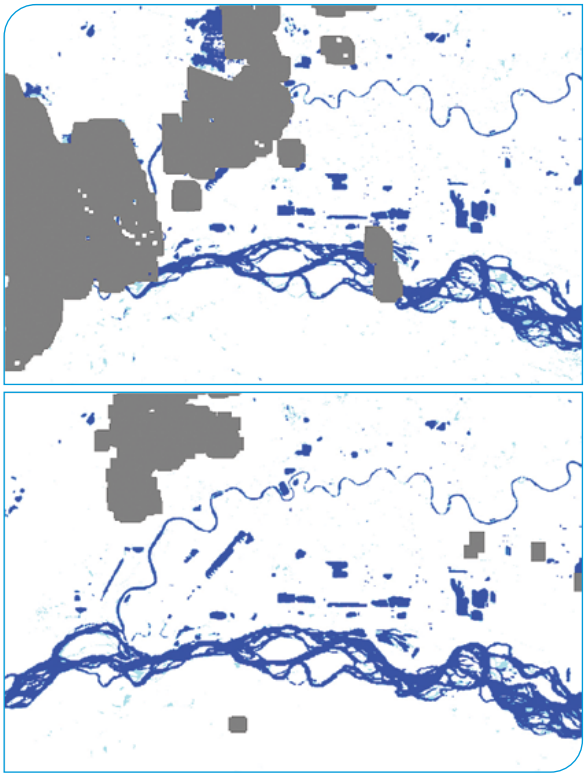


Fig. 2 Surface water extent over Fairbanks, Alaska. Image 2a is June 16th, 2024, and Image 2b is June 17th, 2024 (Attribution: JPL/OPERA)

Impacts and Benefits

USGS relies on this product to estimate streamflow in this region, significantly reducing operational costs and personnel hazards while providing critical data in areas that were previously too difficult to monitor. This provides a greater downstream benefit for effective water resource management and flood risk reduction in previously data-scarce areas, supporting more resilient communities in the long run.

FURTHER INFORMATION AND GUIDANCE

The Satellite Needs Working Group (SNWG) is an interagency working group through the White House National Science and Technology Council that administers a biennial survey to understand the Earth observation needs of civilian federal agencies. SNWG gives survey results to NASA's SNWG Implementation TEam (NSITE) to support a thorough and systematic assessment of responses. During this assessment, subject matter experts from across thematic domains within NOAA, USGS, and NASA review each survey, conduct interviews with respondents to ensure a complete understanding of the need, and identify corresponding innovative Earth data solutions. After the assessment, SNWG solutions are presented for approval by NASA Earth Science Division (ESD) leadership and the Office of Management and Budget (OMB), then implemented by NASA or other teams. Examples of SNWG solutions include the Harmonized Landsat and Sentinel-2 (HLS) product, the NISAR soil moisture product (coming summer 2026), and the Observational Products for End-Users from Remote Sensing Analysis (OPERA) products.

Point of Contact

NASA Earth Science Division: aries.keck@nasa.gov
https://www.earthdata.nasa.gov/data/projects/nsite

Learn More

OPERA DSWx Surface Water Data (https://www.earthdata.nasa.gov/learn/data-in-action/protecting-lives-livelihoods-across-alaska-nasa-surface-water-data)

03

REGION: ASIA

Surface Water Mapping for the Management of Ancient Tank Cascade Systems in Sri Lanka

Summary

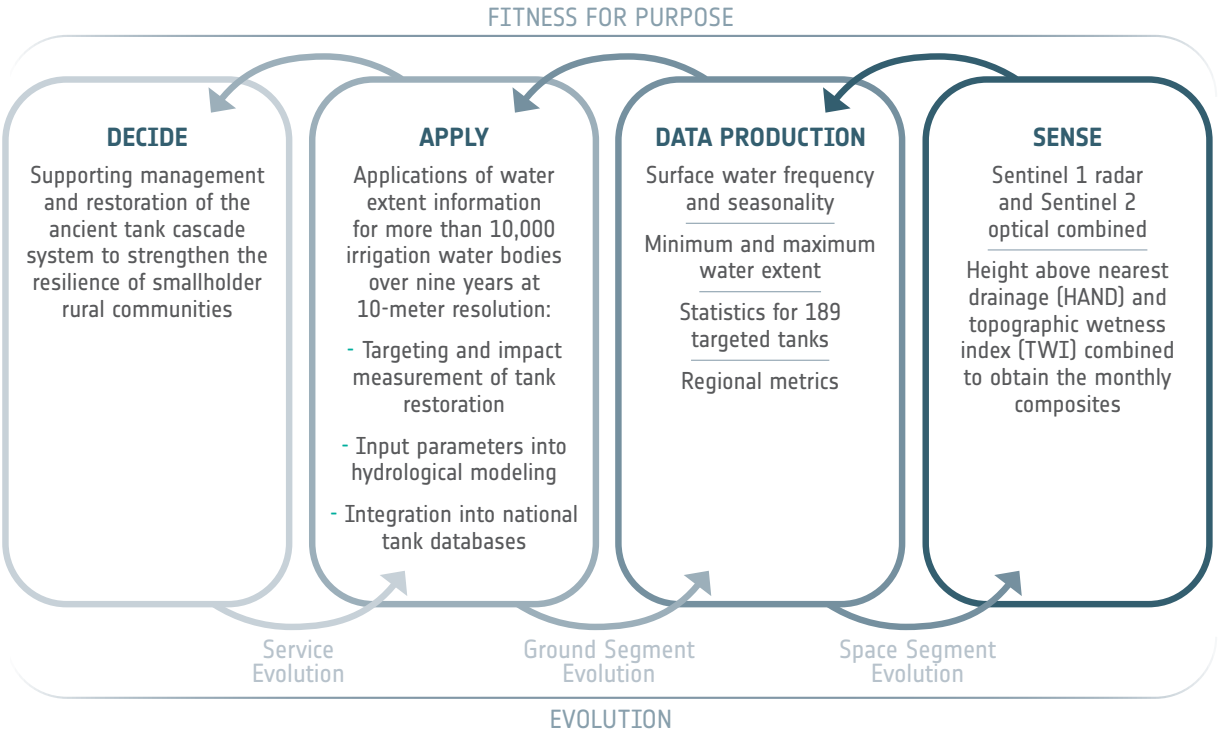
Sri Lanka's ancient tank cascade system, dating back over 2,000 years, comprises more than 30,000 earthen reservoirs known as 'tanks' or '*wewa*' locally which capture rainwater and runoff to irrigate rice paddy fields across the northwest region of the island. This network is recognized as a priority in Sri Lanka's National Adaptation Plan and has long sustained smallholder rural communities through droughts and floods alike. Over time, silt accumulation, ageing infrastructure and fragmented maintenance have degraded many tanks, reducing storage capacity and threatening water security.

In 2025, the International Fund for Agricultural Development (IFAD), the IFAD-funded Smallholder Agribusiness and Resilience Project (SARP) and the European Space Agency's Global Development Assistance (GDA) water resources programme, collaborated on a project that provided long-term water dynamics maps to support evidence-based tank rehabilitation and management. As part of the GDA, GeoVille, an Austrian company, produced the data.

Key outputs from the project include:

- A set of 104 monthly surface-water dynamics maps at a resolution of 10 m, covering a nine-year period from 2017 to 2025 across the six districts of interest. These maps cover over 10,000 water bodies and enable the calculation of the frequency of annual seasonality, as well as the maximum and minimum extent, for each of these tanks. This provides detailed historical insights

Value Chain Diagram



into tank usage. This data can be used to guide restoration efforts and can serve as a key parameter in hydrological modelling. It can also be used for research purposes and integrated into national databases of Sri Lankan water authorities.

- Statistics for 189 tanks targeted by the SARP project to support their restoration efforts.

In the course of 2026, IFAD, SARP and ESA are promoting these datasets to encourage their usage for national water security and sustainable agricultural development.

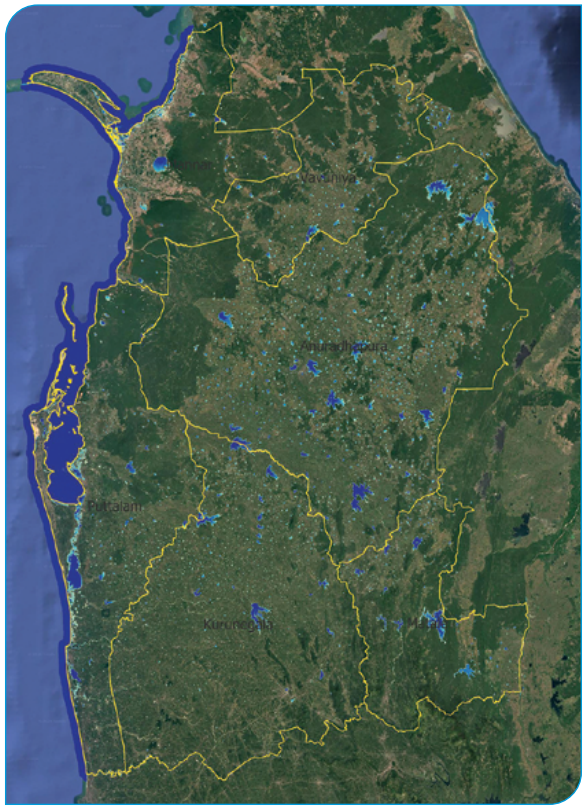


Fig. 1 SARP Project Area



Fig. 2 Galkande Wewa, located in Sri Lanka's Anuradhapura District, was rehabilitated in 2024. The restored tank now provides reliable water for 20 farming families and is able to retain water even through the end of the dry season (Attribution: SARP)

Decision-Making Context and Needs

Sri Lanka's tank cascade system is a uniquely engineered landscape that covers the northern part of the island. Farming communities use the linked reservoirs to capture and distribute runoff for rice paddy cultivation during monsoon seasons. Tanks require maintenance and many have gradually lost storage capacity due to silt accumulation and ageing hydraulic structures. Management and restoration responsibilities such as maintenance of embankments, repairs of spillovers and gates and canal networks are shared between the Department of Agrarian Development (DAD), the Irrigation Department and Provincial Irrigation Departments, as well as local farmer organisations.

Because water moves from one tank to another, conditions at one site can influence other parts of the cascade. Interventions planned without considering these connections may lead to unintended effects upstream or downstream. Government authorities and farmer societies need information on tank usage to identify where the most relevant storage losses occur in order to prioritize support effectively.



Fig. 3 Climate Resilience Awareness Training Conducted by SARP (Attribution: SARP website)

Earth Observation Data Products and Information

The surface water dynamics products were generated using a combination of European satellite missions and complementary geospatial datasets. The input data used to detect areas

covered by water includes monthly composites and time-series derived from Sentinel-1 synthetic aperture radar and Sentinel-2 optical imagery. The Height Above Nearest Drainage (HAND) and the Topographic Wetness Index (TWI) hydrological indices were used to filter out signals from areas unlikely to contain water. This resulted in 104 monthly water-extent maps at 10-metre resolution covering the period from January 2017 to August 2025. The following aggregate products were computed based on the monthly water maps:

- Water frequency: Indicates how often each pixel is classified as water from 2017 to 2025, identifying areas with persistent or infrequent water presence.



Fig. 4 Surface water extent / frequency over a nine year period of the Galkande Wewa, District of Anuradhapura, Sri Lanka (Attribution: GeoVille)

- Water seasonality: Shows the number of months per year in which water is detected and provides insight into seasonal patterns in water availability.

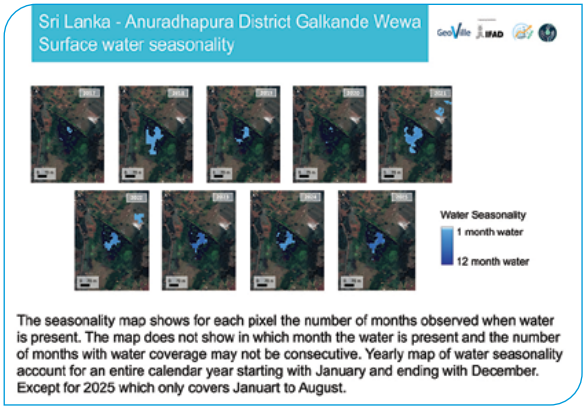


Fig. 5 Seasonal fluctuations over nine years of the Galkande Wewa tank in the District of Anuradhapura, Sri Lanka (Attribution: GeoVille)

- Minimum and maximum surface water extent: Describes the annual minimum (dark blue) and maximum (light blue) areas covered by water. Maximum water extent is defined by water presence during at least one month within one year. Minimum water extent describes the area in which water presence is detected in all months within one year.

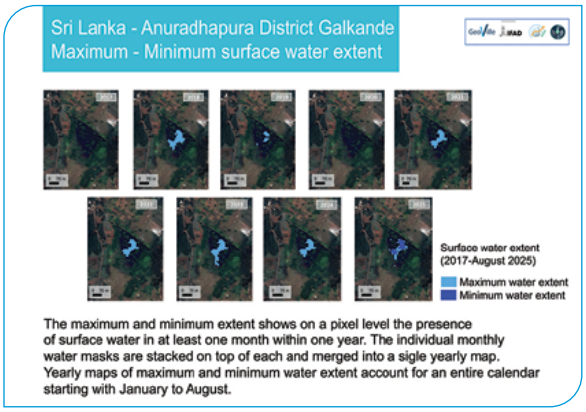


Fig. 6 Minimum and maximum surface water extent over nine years of the Galkande Wewa, District of Anuradhapura, Sri Lanka (Attribution: GeoVille)

Targeted Tank Metrics

This initiative provided SARP with monthly surface area measurements for the 189 tanks selected for restoration by the project. These records show how each tank expanded during the rainy season and contracted during dry periods, capturing nine years of responses to monsoons, droughts and seasonal variability.

These long-term insights show how each tank has been used, indicating where full capacity has been attained and where it has not. This time series serves as a basis for analyzing the influence of rehabilitation efforts on tank behavior and resilience across the cascade.

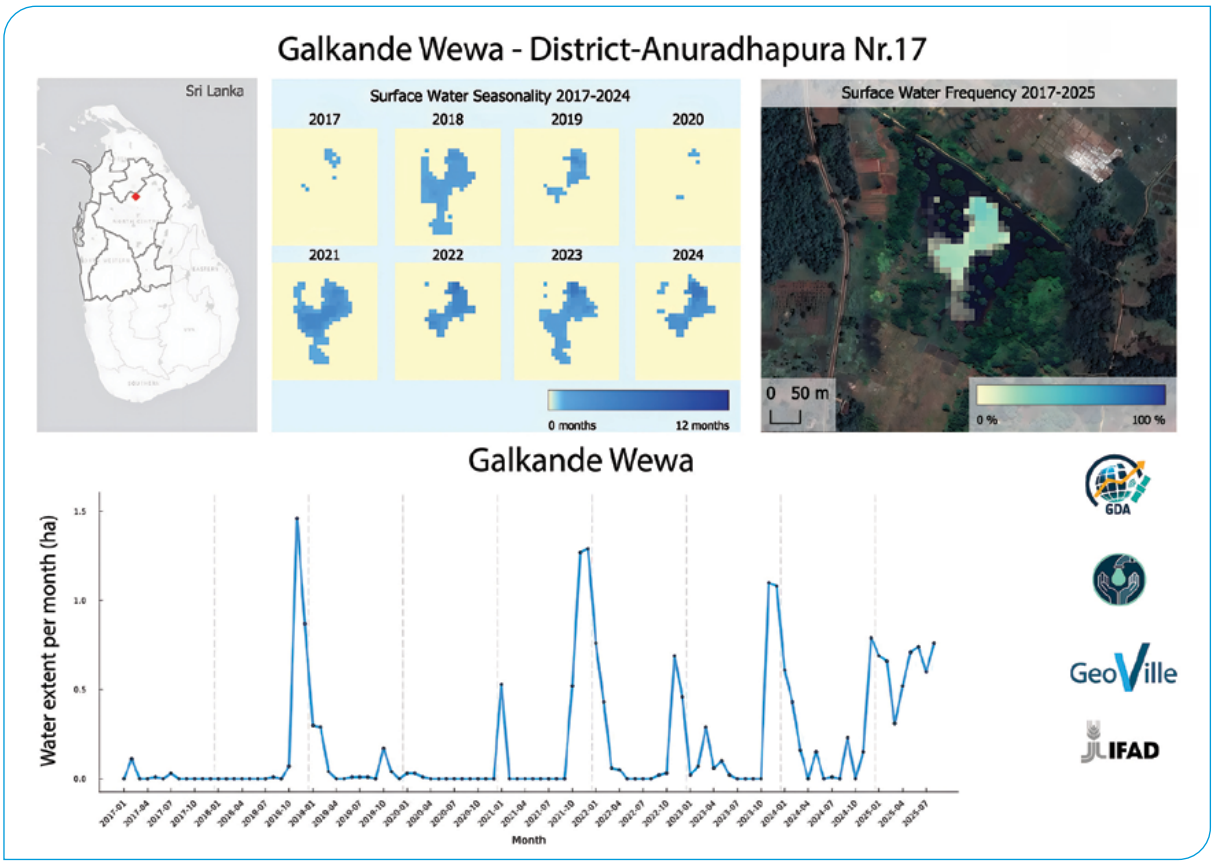


Fig. 7 Water extent profile over the nine years period of the Galkande Wewa in Anuradhapura District, Sri Lanka (Attribution: GeoVille)

Underlying Observations and Data Sources

Surface water dynamics were produced using a combination of satellite Earth observation data and complementary geospatial datasets. The main observations and input include:

- Sentinel-2 optical surface reflectance (10–20 m), used to distinguish water from vegetation and soil under clear-sky conditions.
- Sentinel-1 radar backscatter (10 m), enables mapping of water extent independent of cloud cover, providing reliable observations during the monsoon and wet seasons.
- Height Above Nearest Drainage (HAND), a topographic index used to support interpretation of hydrological behavior across tank systems.
- Topographic Wetness Index (TWI), derived from terrain data to help identify areas with higher potential soil moisture and surface saturation.

Impacts and Benefits

The surface water dynamics dataset provides SARP and national institutions in Sri Lanka with historic and long-term insights to guide the management and restoration of tanks within cascade systems. The project demonstrated several benefits and potential applications:

- Improved insights of tank conditions over time: monthly observations help institutions see how tanks respond to wet and dry periods, providing evidence of reduced storage capacity, seasonal variability, or changes in water availability.
- Linking water behaviour with agricultural activity: when compared with cropland and paddy-extent products, the data help illustrate how water availability aligns with cultivation patterns, supporting agricultural monitoring efforts.
- Basic indicators of climate response: evaluating changes in water presence

alongside rainfall offers initial insights into how tanks react to variable precipitation and extreme events.

- Reference for rehabilitation efforts: historical measurements establish a baseline against which changes following desilting or structural improvements can be assessed.

Beneficiaries and operational use:

- Government agencies such as the Department of Agrarian Development (DAD), Irrigation Department and Provincial Irrigation Departments can use the information to update tank inventories, guide restoration priorities and assess the effects of restoration.
- Water resource planners can use water extent data as an important variable in hydrological or land-use assessments.
- Local farmer organisations can gain a clearer understanding of past tank behavior and seasonal water patterns relevant to their agricultural planning.
- Development programmes, such as SARP, can use the dataset to target interventions and monitor improvements over time.



Fig. 8 A community member operates an irrigation gate as part of the SARP Project (Attribution: SARP website and social media)

FURTHER INFORMATION AND GUIDANCE

Points of Contact

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- IFAD - Sherina Tabassum / s.tabassum@ifad.org

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- Impact-Sphere: https://impact-sphere-gda.esa.int/stories/443

04

REGION: ASIA

Groundwater Analysis to Prevent a Water Crisis in Yemen

Summary

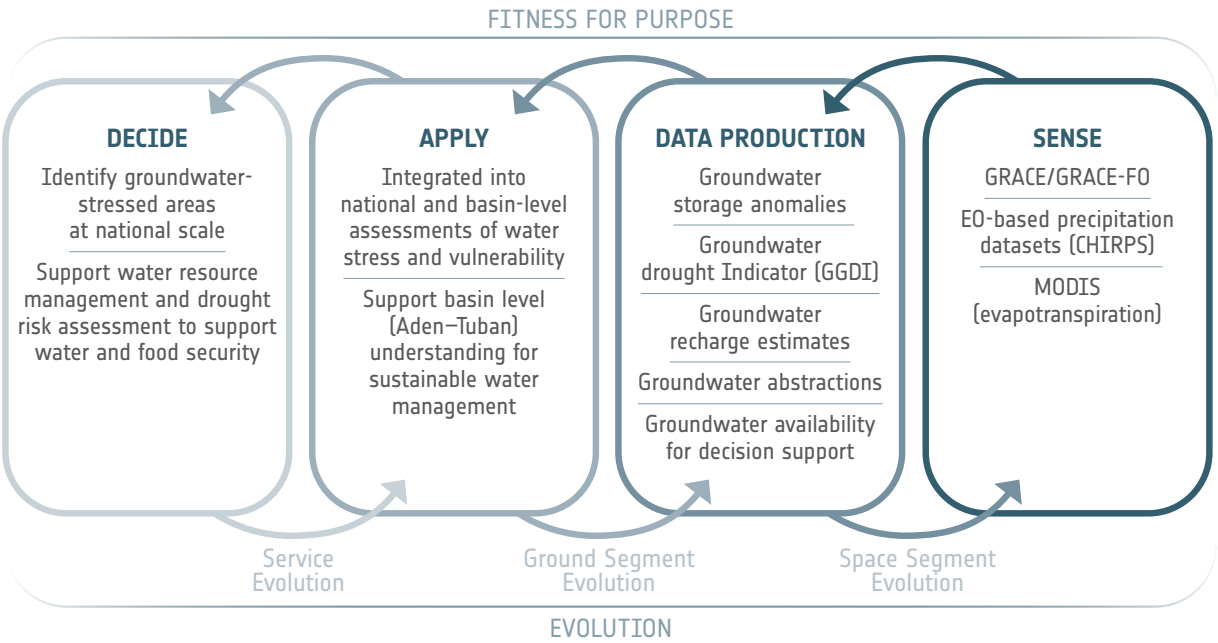
Yemen is facing a severe water crisis, where groundwater—the country's main source of water for drinking, agriculture, and sanitation—is under increasing pressure due to over-extraction, climate variability, and the impacts of prolonged conflict. At the same time, damaged infrastructure and limited monitoring capacity have made it difficult to track water resources and respond effectively to emerging risks.

To address this gap, GMV, in collaboration with the World Bank under ESA's Global Development Assistance program, developed an Earth Observation-based approach to monitor groundwater conditions across the country. Using satellite data, the project provides a consistent picture of groundwater storage, recharge, abstraction, and availability over the past two decades.

The results show a clear long-term decline in groundwater resources, driven by an imbalance between limited natural recharge and sustained water use, particularly in agricultural areas such as the Aden–Tuban Basin. While occasional intense rainfall events provide temporary relief, they do not reverse the overall trend of depletion.

By translating complex data into accessible indicators of groundwater availability, the project supports early identification of water stress and improves the ability of decision-makers to anticipate and respond to water scarcity. This contributes directly to managing risks that affect water access, food production, and public health in one of the world's most fragile contexts.

Value Chain Diagram



Decision-Making Context and Needs

Yemen is currently experiencing one of the world's most severe and complex water crises, driven by a combination of chronic water scarcity, excessive groundwater depletion, and the impacts of the armed conflict. Groundwater represents the backbone of the country's water supply, sustaining drinking water provision, sanitation systems, and agricultural livelihoods. However, it is being systematically over-extracted, leading to widespread depletion and long-term degradation of water resources.

Since the escalation of the conflict in 2014, the situation has been further exacerbated by extensive damage to water and sewage infrastructure, as well as pollution linked to conflict-related activities. These impacts have significantly reduced the functionality and safety of water supply systems across large parts of the country. As a result, many water sources have become unsafe for human consumption, increasing reliance on alternative and often lower-quality sources.

The deterioration of water infrastructure and quality has had direct and severe public health consequences, including recurrent outbreaks of waterborne diseases. Among the most serious was the cholera epidemic between 2016 and 2022, which affected more than two million people and highlighted the strong interconnection between water insecurity, infrastructure fragility, and public health emergencies.

In this fragile context, water scarcity is not only a resource management issue but a humanitarian and health risk driver. Declining groundwater availability directly affects access to safe drinking water, increases exposure to contaminated sources, rises water costs, and reduces agricultural productivity, all of which contributes to worsening food insecurity and vulnerability.

In this context, decision-makers face critical constraints due to the lack of reliable and up-to-date information caused by the disruption of the monitoring networks which has hindered the ability to track groundwater conditions, assess risks, and plan effective interventions.

Earth Observation Data Products and Information

This project delivered an integrated set of groundwater services that transform satellite data into practical information to support sustainable groundwater resources management in Yemen. The framework integrates three complementary components covering

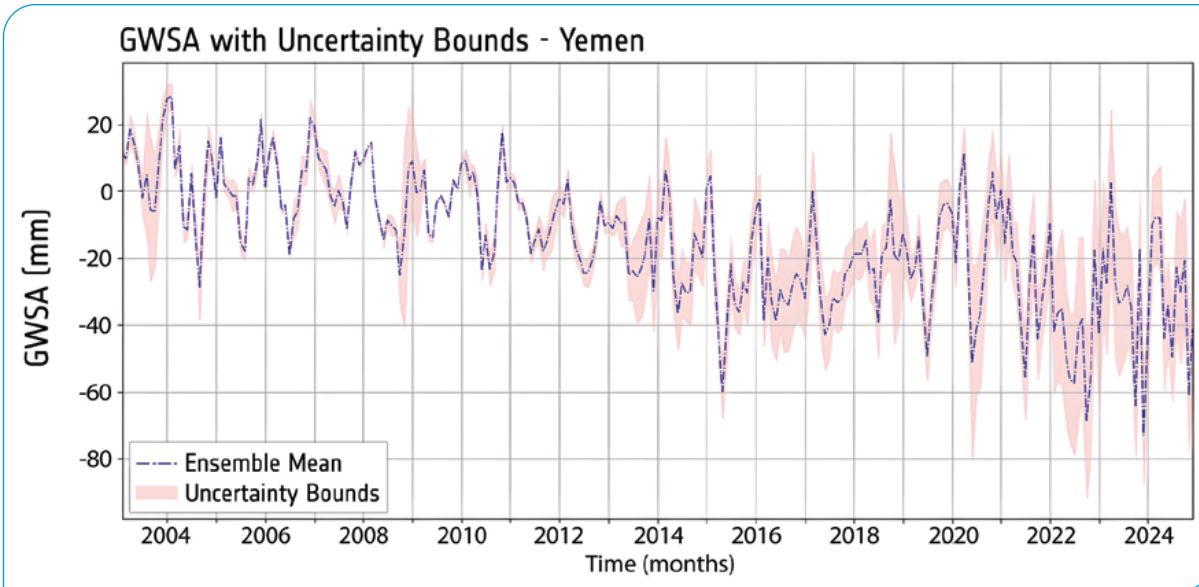


Fig. 1 Groundwater Storage time series in Yemen (Attribution: GMV, ESA's GDA water resources)

groundwater monitoring, quantification, and management. Combined, they provide an extensive view of how groundwater resources have evolved in the past two decades. Together, these components describe long-term changes in groundwater storage, the occurrence of drought episodes, the spatial distribution of recharge processes, and the intensity of groundwater use at basin level.

The results show a clear long-term decline in groundwater resources at national level, reflecting increasing stress on a resource that millions of people depend on for drinking water, agriculture, and sanitation. A distinct west–east gradient emerges, with relatively higher groundwater variability and availability in western regions, particularly along the Tihama coastal plain. These areas experience strong fluctuations driven by both rainfall variability and intensive human use.

At basin scale, the Aden–Tuban system shows a slightly different behaviour. While it also shows an overall declining trend, recent years present short periods of recovery associated with extreme rainfall events and cyclonic activity. However, these improvements are temporary and insufficient to offset the longer-term pressure on the system.

This spatial pattern is closely mirrored in groundwater recharge, confirming that precipitation is the dominant driver of groundwater replenishment in Yemen. Only a limited number of areas, mainly in the western highlands, receive meaningful recharge, while most of the country experiences very low natural replenishment making groundwater systems highly vulnerable to drought and prolonged dry conditions.

On the other side of the balance, the analysis of groundwater abstractions conducted for the Aden-Tuban basin shows that these are consistently high. The strongest pressure is detected during dry periods when rainfall is lowest. This mismatch between when water is available and when it is most heavily used is a key driver of long-term depletion.

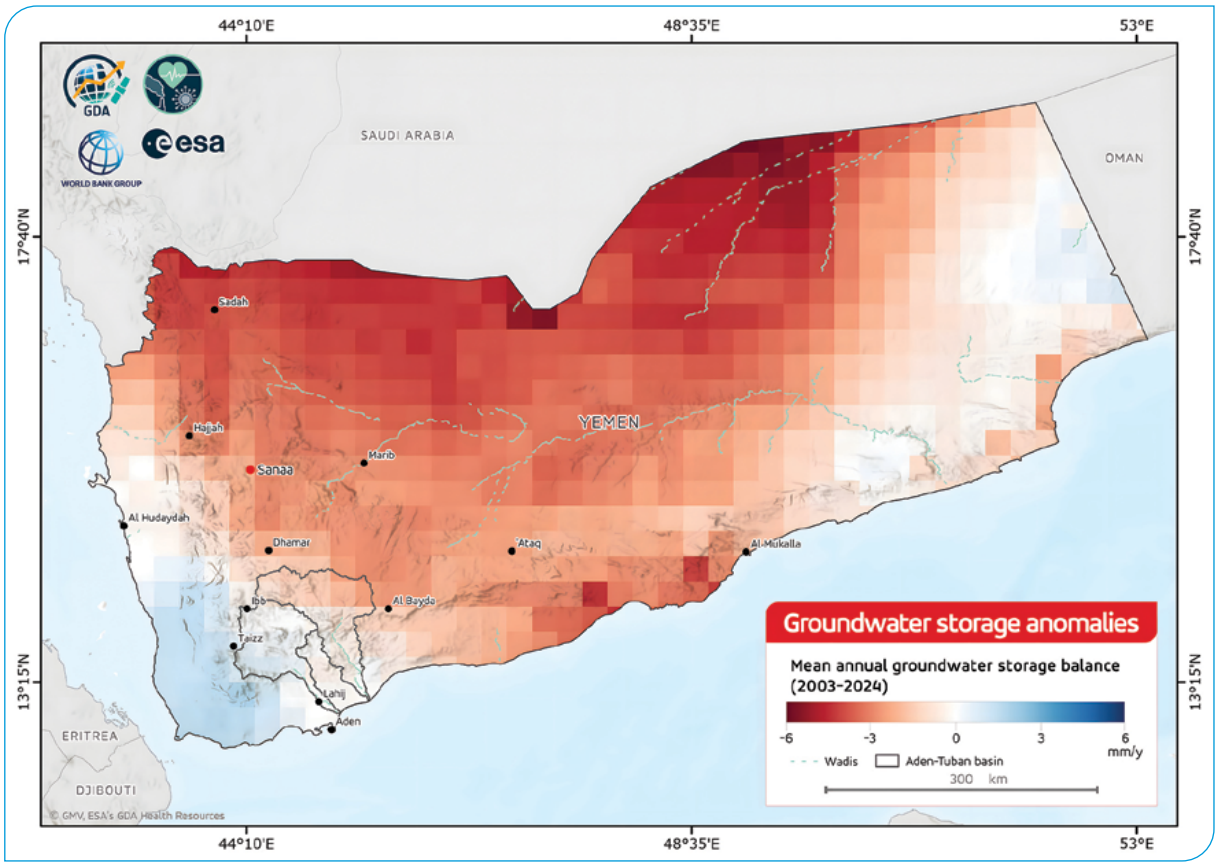


Fig. 2 Mean annual groundwater storage balance (2003-2024) (Attribution: GMV, ESA's GDA water resources)

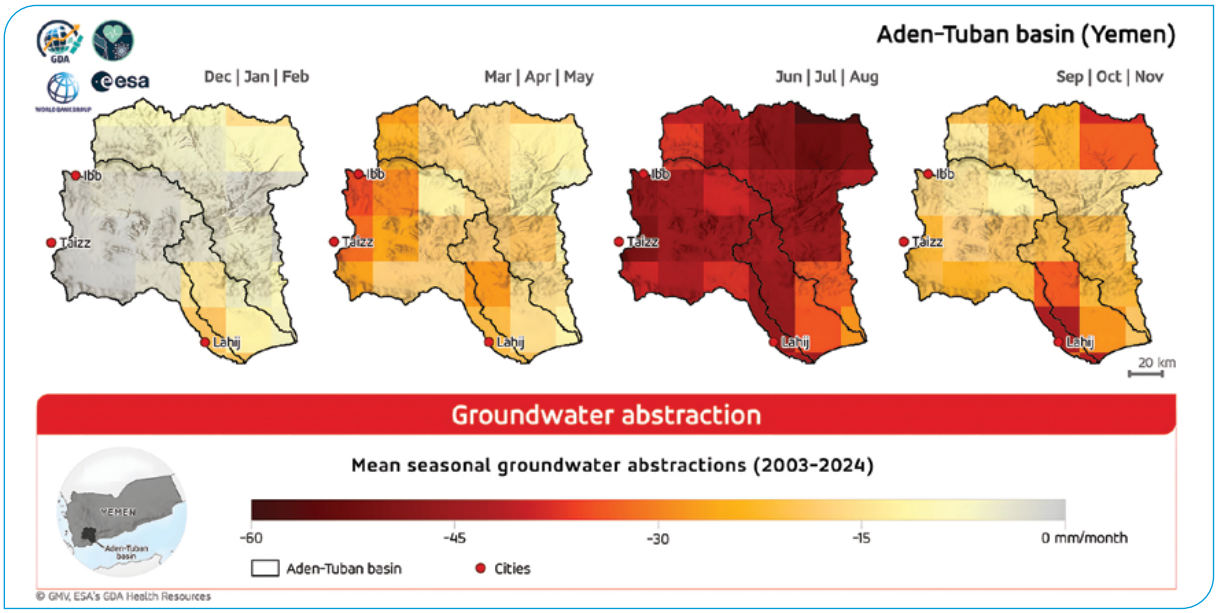


Fig. 3 Mean seasonal groundwater abstractions for Aden-Tuban basin (2003-2024) (Attribution: GMV, ESA's GDA water resources)

To make these results more accessible for decision-makers, groundwater conditions were also translated into a simple indicator of groundwater availability, showing how much groundwater remains compared to the historical maximum and minimum levels. This reveals a clear shift over time: conditions that were once moderate have increasingly moved into low and, in some years, very low levels at national level. These conditions directly affect the reliability of water supply for households, farming, and essential services.

Overall, the results highlight a system under sustained stress, where natural replenishment is no longer keeping pace with human demand. While extreme rainfall events can temporarily ease pressure, they do not reverse the long-term trend of depletion. From a practical perspective, these EO-based insights provide critical support for identifying areas under the greatest water stress and for understanding how groundwater scarcity is evolving in ways that directly affect food security and public health in one of the world's most fragile environments.

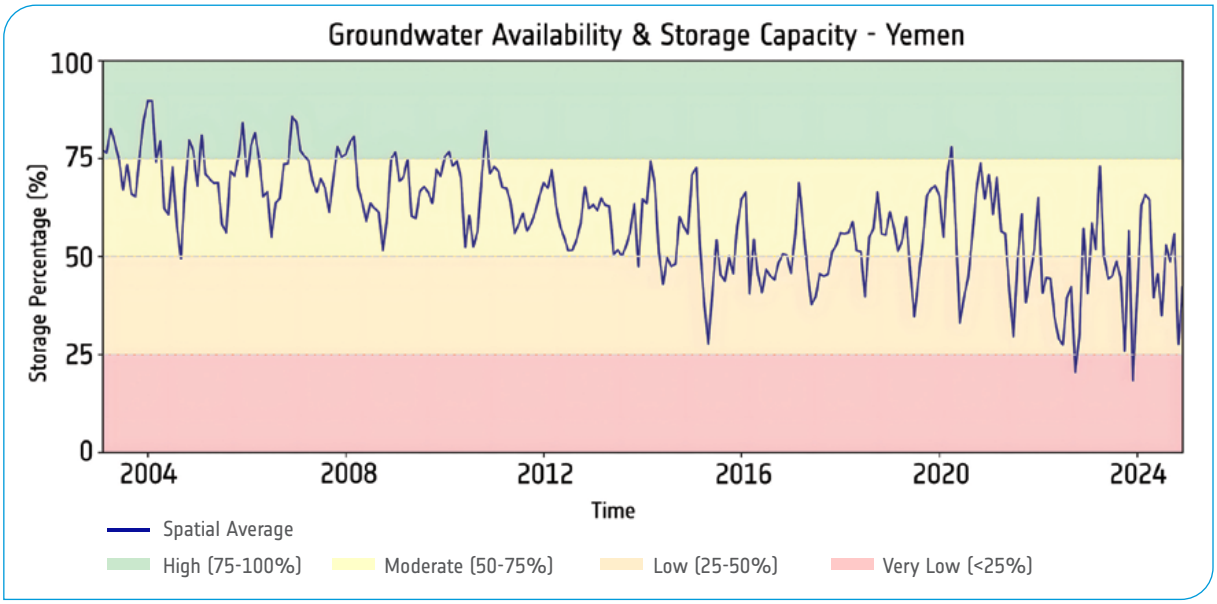


Fig. 4 Spatially averaged time series of Groundwater Availability in Yemen (Attribution: GMV, ESA's GDA water resources)

Underlying Observations and Data Sources

The analysis is based on a combination of satellite observations and global hydrological datasets designed to ensure consistent monitoring in a data-scarce environment.

At the core of the assessment are data from the GRACE and GRACE Follow-On satellite missions, which measure changes in the Earth's gravity field to detect variations in total water storage. To improve reliability, data from two different processing centers were combined, reducing uncertainties and strengthening the robustness of the results.

Since GRACE data capture overall changes in total water stored across the water cycle, the groundwater component needs to be separated by removing the contribution from soil moisture, surface water and vegetation. This information is obtained from the GLDAS global land surface models, which simulate hydrological processes based on satellite observations and meteorological inputs. As in the case of the GRACE processing, three different GLDAS models were used to generate an ensemble, enhancing the estimation's robustness and reducing uncertainty.

Precipitation data are derived from the CHIRPS dataset, which combines satellite imagery with ground observations to provide rainfall estimates. In this study, rainfall patterns are also compared with groundwater changes to better understand how the two are linked over time and across space.

Evapotranspiration estimates were obtained from MODIS to quantify extractions. The combination of all datasets and analysis makes it possible to estimate how water moves through the environment and to quantify the balance between water inputs and outputs.

Impacts and Benefits

The findings demonstrate the value of Earth Observation in fragile and conflict-affected contexts, where water crises are often compounded by the breakdown of monitoring systems and limited access for field-based surveys. The Yemen case shows that EO can provide scientifically robust and policy-relevant insights at both national and basin scales, even when conventional data sources are unavailable. This approach offers a replicable framework that can support evidence-based water management in other constrained environments facing similar data and capacity limitations.

Overall, the results highlight that Earth Observation is not a substitute for in-situ monitoring, but a practical and scalable solution to bridge critical information gaps where ground systems are weak or disrupted. In contexts such as Yemen, combining EO-based monitoring with gradual efforts to rebuild local observation capacity represents a pragmatic pathway toward more resilient and informed water resource management.

FURTHER INFORMATION AND GUIDANCE

This case study was carried out under ESA's Global Development Assistance Program in collaboration with the World Bank, with engagement from the Yemeni Geological Survey and implemented by GMV.

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CEOS, the Committee on Earth Observation Satellites, coordinates civil spaceborne observations of the Earth. Participating agencies strive to address critical scientific questions and to harmonise satellite mission planning to address gaps and overlaps.

www.ceos.org

The European Space Agency (ESA) is dedicated to the peaceful exploration and use of space for the benefit of everyone. Established in 1975, ESA now has 23 Member States and has promoted European scientific and industrial interests in space for over 50 years.

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