Future Spatial Information Needs in Land, Agriculture and Food

And their value for Space Applications

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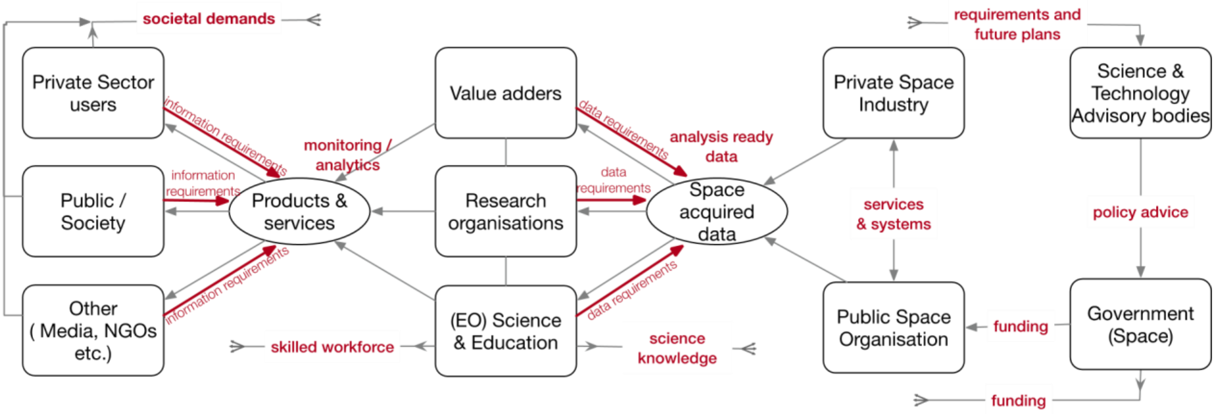
Samenvatting

Trends in de vraag naar Ruimtelijke Informatievoorziening in Landgebruik, Landbouw en Voedsel en de daaruit volgende vraagsturing op satelliet toepassingen.

Satelliettoepassingen hebben een enorme impact op de informatievoorziening van onze landelijke omgeving. Met name de snelle bouw van nieuwe satellietconstellaties en de hedendaagse mogelijkheden van data science zorgen voor een toename van toepassingen. Maar ook gebruikers krijgen door de digitalisering en dataficatie nieuwe wensen. In deze studie zijn de trends in de informatievoorziening en toekomstige behoeften daarin voor het domein van Landgebruik, Landbouw en Voedsel in kaart gebracht. Deze studie draagt daarmee bij aan de beleidsvorming en innovatiestrategie voor de ruimtevaartsector en met name aan vraagsturing waarmee de “maak”partijen in de ruimtevaart op maatschappelijke behoeften kunnen inspelen. Hiertoe is een stakeholdermodel gebruikt om de procesgang van vraagsturing naar ontwikkeling te duiden (Figuur A).



Figuur A: Vraagsturingsmodel op basis van waardestromen tussen verschillende segmenten van belanghebbenden. (Gebaseerd op Sutherland, 2003, ‘Stakeholder Value Network Analysis for Space-Based Earth Observations’). De ‘kraaiepootjes’ geven relaties met vele andere segmenten (omwille van eenvoud niet allemaal afgebeeld).

Het domein Landgebruik, Landbouw en Voedsel is te verdelen in een aantal specifieke thema’s. Het onderscheidende per thema is de aard van de toepassing en/of de aard van de regie-voerende stakeholder:

1. Food security (SDG2): Het monitoren van voedselproductie om globale en regionale voedselzekerheid te garanderen. Satellietdata worden gebruikt om over grotere gebieden de arealen en de opbrengsten te schatten. Interregionale en inter-jaarlijkse vergelijking zorgt voor *early warning* van zorgwekkende tekorten. Data worden gebruikt voor marktinterventies en het aanpakken van voedselcrises, met name door overheden en gelieerde instituten;
2. Soil and irrigation management (SDG2 and 6): Duurzame(re) benutting van bodem en water krijgt steeds meer aandacht o.a. in trends als regeneratieve landbouw maar ook in relatie tot andere thema’s. Satellietdata dragen o.a. bij aan het meten van bodemeigenschappen en bodemvochtdynamiek. Toepassingen hierin zijn voor vele partijen van belang, van boer tot onderzoeker tot overheid;
3. Agricultural monitoring (SDG2, 13, 15): De zgn. wall-to-wall monitoring van landbouwactiviteiten en -output voor het administreren en controleren van o.a. subsidieaanspraak, compliance en prestaties. Dit thema heeft ook een variant voor bijv. contractteelt en financiële diensten (micro-credits, verzekeringen etc.). In steeds meer domeinen worden satellietdata als juridische grondslag gebruikt. De typische gebruiker is dan ook een overheid of financiële instelling;

4. Precision Agriculture (SDG2, 6, 8, 11, 13, 15): Dit is een vorm van agrarisch bedrijfsmanagement waar besluiten onderbouwd worden met data en (wetenschappelijke) kennis. Door betere informatie (actueler, gedetailleerder, direct-toepasbaar) en geautomatiseerde verwerking is precisielandbouw een sleuteltechnologie in de landbouwtransitie. Precisielandbouw toepassingen zijn vooral gericht op de boer;
5. Land use and planning (SDG11): Karteren van landgebruik is een belangrijke hoeksteen in het ruimtelijk beleid. Satellietdata wordt ook steeds meer ingezet voor het monitoren van veranderingen met steeds meer detail. Landgebruikskartering is een overheidsgestuurde activiteit, met veel inbreng van kennisinstellingen;
6. Biodiversity and ecology (SDG15): Voor beleidsopties en verantwoording is het meten en monitoren van indicatoren steeds belangrijker. Satellietdata worden steeds meer gebruikt om dat vlakdekkend en uniform over de hele wereld uit te kunnen voeren. Een belangrijk kenmerk hier zijn ook de schaaltransities om gebiedsdekkende uitspraken te kunnen doen. Satelliettoepassingen in dit thema zijn primair voor onderzoek en vandaaruit naar beleid;
7. Climate mitigation and adaptation (SDG13): Het monitoren van klimaatverandering en het controleren van de effecten en impact van klimaatmitigatie en –adaptatiemaatregelen behoeft steeds meer data, ook tijdreeksen om de klimaatschaal goed te bedienen. Dit heeft daarbij sterke interacties met andere domeinen, en ook hier zijn schaaltransities zeer relevant. Satelliettoepassingen in dit thema zijn primair voor onderzoek en vandaaruit naar beleid.

In deze studie zijn de informatiebehoeften per thema geïnventariseerd door literatuuronderzoek en geverifieerd en uitgebreid door interviews met een selectie van belanghebbenden. Hierbij is naast een beter begrip van huidige toepassingen en aanstaande ontwikkelingen vooral ook getracht om de behoeften voor over 10 jaar te destilleren. In eerste instantie geven gebruikers een aantal algemene wensen en behoeften in de verschillende thema's. Alle technische innovaties die bijdragen aan hogere resolutie, frequentie, spectrale resolutie of het toegankelijker maken van data zijn altijd welkom. Er zijn op die aspecten ook grote stappen gemaakt – waarbij de laatste jaren de sterk toegenomen mogelijkheden van data science een extra dimensie geven.

Het doel van deze studie is om ook vanuit gebruiksperspectief verschillende prioriteiten te benoemen in de trade-offs om nieuwe systemen te ontwerpen. Om de stap van thema's naar technologie makkelijker te zetten, zijn de verschillende informatiebehoeften geanalyseerd op uitdagingen en specifieke trends die vaak thema-doorsnijdend opgepakt kunnen worden. Deze "instrument challenges" geven aan waar beyond-state-of-the-art gewenst is en voor welk thema (Tabel A).

Tabel A: Overzicht van thema's en doorsnijdende challenges.

Instrument Challenges	**Themes:** / **Specific items:**	Food security	Soil & irrigation management	Agricultural monitoring (Off farm)	Precision agriculture Farmer	Land use and land use planning	Biodiversity and ecology	Climate mitigation and adaptation
Land Cover & Land dynamics	Vegetation ❼ species	X	X	X	X		X	X
	Land use ❼ land use change	X		X		X		X
	Agricultural activity detection	X		X				X
	Vegetation health monitoring	X	X	X	X		X	X

Soil & Soil dynamics	Classification ❼ land evaluation ❼ soil quality	X	X	X	X	X	X	X
	Soil /-moisture monitoring	X	X	X	X		X	X
	Soil carbon stock			X	X		X	X
	Terrain height		X		X	X	X	X
Emissions	Emissions		X	X	X		X	X
	Depositions						X	X
Habitat	Interactions			X	X	X	X	
	Object and structure mapping			X		X	X	
Fauna	Fauna activity / identification						X	
	Livestock whereabouts			X	X			
Infrastructure	Data (zero) Latency	X	X		X			X
	Access and Storage	X	X	X	X	X	X	X
	Time series / service continuity	X	X			X	X	X
	Processing automation	X	X	X	X	X	X	X
	Seamless integration / fusion	X	X	X	X		X	X

In onderstaande tabel is per challenge een aantal streefwaardes voor indicatoren voor satellietdataproducten en -diensten weergegeven op basis van de informatiebehoefte in de verschillende thema's.

Tabel B: Overzicht van gebruikers informatiebehoeften en bijbehorende specificaties voor satellietconstellaties.

User information needs	Frequency	Resolution	Spectral	Relevant use cases
Land Cover & Land dynamics	Daily	< 1 meter	Hyperspectral Radar Thermal	Different species, Agricultural activity, Land use changes.
Soil & Soil dynamics	Daily / diurnal	< 5 meters	Radar Thermal	Soil quality indicators, Soil moisture monitoring.
Emissions	Daily / diurnal	<50 meter	Thermal Hyperspectral	GHG, NH3, leakage, surface runoff, nutrients and PPP.
Habitat	Weekly	<5 meter	Hyperspectral Radar Thermal	Interactions, pressures, influences etc.
Fauna	Daily / diurnal	< 10 cm	RGB Thermal	Location of animals

Conclusies

Voor het domein Landgebruik, Landbouw en Voedsel vereisen de toekomstige informatiebehoeften vooral een verbetering van het huidige instrumentarium waar het gaat om resolutie, opname frequentie, spectrale resolutie en een hogere betrouwbaarheid van de informatieproducten. Concreet is daar voor de komende 10 jaar een aantal streefwaarden voor gegeven (zie tabel B).

Een belangrijk knelpunt op dit moment is bewolking: betere integratie tussen sensortypen, om met name de mogelijkheden van radar beter te benutten, is van groot belang om een goede datavoorziening te garanderen. Ook betere integratie tussen ruimtevaart en luchtvaart kan hieraan bijdragen.

Voor veel toepassingen zouden sensoren in het thermische domein (zowel breedbandig als hyperspectraal) van groot belang zijn. Er zijn op dit moment te weinig TIR-systemen waar zowel de spectrale, temporele en ruimtelijke resolutie van voldoende waarde is.

Meer experimenteer- en demonstratieruimte, e.g., via nanosats, HALEs of drones om geavanceerde mogelijkheden aan gebruikers te demonstreren en om business cases goed te kunnen evalueren.

Executive summary

Trends in the demand for spatial information in Land, Agriculture, and Food and the resulting demand management on satellite applications.

Satellite applications are having a tremendous impact on the information provision of our rural environment. In particular, the rapid build-up of new satellite constellations and the contemporary possibilities of data sciences are causing an increase in applications. However, digitalization and datafication are also giving users new requirements. In this study, the trends in the provision of information, and future needs therein, for the Land, Agriculture and Food (Land-Agri-Food) domain have been identified. This study thereby contributes to the policy making and innovation strategy for the space sector, and in particular to demand-driven decision making with which the "making" parties in the space sector can respond to societal needs. To this end, a stakeholder model has been used to interpret the process flow from demand management to development (Figure A).

The Land, Agriculture and Food domain can be divided into a number of specific themes. What distinguishes each theme is the nature of the application and/or the nature of the directing stakeholder:

1. Food security (SDG2): Monitoring food production to ensure global and regional food security. Satellite data is used to estimate acreage and yields over larger areas. Interregional and interannual comparison provides early warning of significant shortages. Data is used for market interventions and addressing food crises, particularly by governments and affiliated institutions;
2. Soil and irrigation management (SDG2 and 6): Sustainable(er) use of soil and water is receiving increasing attention, for example in trends such as regenerative agriculture but also in relation to other themes. Satellite data contributes, among other things, to measuring soil properties and soil moisture dynamics. Applications are of interest to many parties, from farmer to researcher to government;
3. Agricultural monitoring (SDG2, 13, 15): The so-called wall-to-wall monitoring of agricultural activities and -outputs for the administration and control of subsidies, compliance and performance. This theme also has a variant for e.g., contract farming and financial services (micro-credits, insurance etc.). In more and more domains satellite data is used as a legal basis. The typical user is therefore a government or financial institution;
4. Precision Agriculture (SDG2, 6, 8, 11, 13, 15): This is a form of agricultural business management where decisions are supported by data and (scientific) knowledge. Due to better information (more up-to-date, more detailed, directly applicable) and automated processing, precision agriculture is a key technology in the agricultural transition. Precision agriculture applications are mainly focused on the farmer;
5. Land use and planning (SDG11): Mapping of land use is an important cornerstone in spatial policy. Satellite data is also increasingly being used to monitor change with increasing detail. Land use mapping is mostly a government-driven activity, with much input from knowledge institutions;
6. Biodiversity and ecology (SDG15): Measuring and monitoring are increasingly important for policy options and accountability. Satellite data is increasingly being used to be able to do that flatly and uniformly across the globe. An important feature here is also to scale transitions to be able to make area-wide statements. Satellite applications in this theme are primarily for research and from there to be used in policy;
7. Climate mitigation and adaptation (SDG13): Monitoring climate change and proving the effects and impact of climate mitigation and adaptation measures requires more and more data, including time series to properly serve the climate scale. In doing so, this has strong interactions with other

domains, and scale transitions are also very relevant here. Satellite applications in this theme are primarily for research and from there to policy.

In this study, the information needs per theme were inventorised through literature review and verified and extensified through interviews with a selection of stakeholders. In addition to gaining a better understanding of current applications and upcoming developments, the main aim was to distil the needs for 10 years from now. In the first instance, users provide a number of general wishes and needs in the various themes. All technical innovations that contribute to higher resolution, frequency, spectral resolution or making data more accessible are always welcome. Great strides have also been made in these aspects - with the greatly increased possibilities of data science in recent years adding to this.

The aim of this study is to also identify, from a usage perspective, different priorities in the trade-offs to design new systems. To make the step from themes to technology easier, the various information needs have been analysed for challenges and specific trends that can often be addressed cross-theme. These "instrument' challenges" indicate where beyond-state-of-the-art is desired and for which theme (Tabel A).

Tabel B shows target values for indicators for satellite data products and services for each challenge based on the information needs in the different themes.

Conclusion

For the Land, Agriculture and Food domain, the future information needs mainly require an improvement of the current toolset in terms of resolution, recording frequency, spectral resolution and a higher reliability of the information products. Specifically, a number of target values for this have been given for the next 10 years (Tabel B).

A major bottleneck at the moment is cloud cover; better integration between sensor types, in particular to make better use of the possibilities of radar, is of great importance to guarantee a good data supply. Better integration between space and aeronautics can also contribute to this.

For many applications, sensors in the thermal domain (both broadband and hyperspectral) would be of great interest. There are currently too few TIR systems where both spectral, temporal and spatial resolution are of sufficient value.

More experimentation and demonstration space, e.g., via nanosats, HALEs or drones to demonstrate advanced capabilities to users and to properly evaluate business cases.

1 Introduction

1.1 Background

The Netherlands Space Office (NSO) is developing a strategy for the future space program for the Dutch government, aiming for the development of new monitoring instruments. Dutch space technology is mainly characterised by their flagship remote sensing instruments such as Tropomi and SPEXone. To make profound choices for developing new instruments, the qualities of the space sector must be exploited while at the same time fulfilling the most important user needs of the User Communities. These user needs must be mapped, and priorities must be distilled from user needs to include in the trade-offs used to design new satellite systems. In 2017 already user need studies were performed for the themes water quality, air quality and (coastal) water management. In this study the theme land-agri-food is explored.

Land-agri-food was chosen as a separate user need study as it is important for the Dutch economy, 104,7 billion Euro export value 2021 (CBS, WUR) and the Dutch agri-food sector is leading and cutting edge in many branches of agribusiness. Expanding this focus on agriculture towards space technology, is an interesting next step. Also, concerning climate change mitigation and adaptation, agri-food is an important factor for Dutch emissions. On one hand, animal husbandry causes extensive methane and CO_2 emissions and arable farming causes significant NO_x emissions as well. On the other hand, soils can be a large sink of CO_2 and certain agricultural measures can have a relatively quick effect on emissions. Agriculture "owns" and exploits 60-70% of the land surface, emphasizing once more the importance of agriculture and agri-food in the climate problem. Lastly, earth observation has already been proven to be of great use in the realm of agri-food. However, many aspects of the field are still in their infancy and require more, and different data. The probable impact of more sophisticated earth observation systems on a more sustainable and efficient agri-food is evident.

Satellite applications already are a great contributor of information for rural environment uses. Following the increase of available public and private satellite data, scientists are also increasingly developing applications. However, also other users such as policy makers, are starting to use these data because of the further digitisation and datafication of decision-making.

1.2 Purpose and goal

The general goal is to identify and prioritize user needs in the work field of *land-agri-food* that could be solved – or aided by – satellite data. These user needs have to be applicable at national and international level. At the same time the added value of the user needs is compared and validated. Besides aiming at getting a better understanding of current user needs and developments, this report also seeks to distil the needs that will become relevant in the near future (approximately 10 years).

More specifically, the goals of this study are:

- Make an inventory of the contemporary and near future data, information and service needs of User Communities in the agri-food sector in the domains: agri, land use and water;
- Explain and motivate the added value of the needed information or remote sensing service;
- Find synergies and possibilities to use data corresponding to different user needs in order to get the most value out of the data;

In this study the following main user groups are involved: Governments, Research, Industry (incl. SMEs) and societal organisations (incl. NGOs and representatives).

2 Methodology of this study

2.1 Summary

As recommended by NSO, previous NSO-studies and other related literature were studied. This was done in order to be in one line with the expectations of NSO and have a good understanding of what has already been done. With this background information in mind, the main topic of land-agri-food was subdivided into seven themes and relevant stakeholders were identified for these themes. These stakeholders had to be directly involved in the subject matter and not too distant from the actual use of the data – i.e., the data users and not the data providers. Once a variety of stakeholders were mapped, these were contacted by mail or phone and invited to an interview. Having finished the interviews, all results were analysed and presented in a workshop. Participants of the workshop included interviewees but also people new to the study. This workshop was done to validate and prioritise the results of the interviews, and to gather new results by discussing amongst users. Lastly, all results gathered throughout the study were synthesised and elaborated upon in this report.

2.2 Desk research and literature

Firstly, the recommended input by NSO has been studied, consisting of the following documents:

- Downstream roadmaps (2015): (1) Land monitoring, (2) Food security and (3) Precision Agriculture;
- Topsector Agro, a.o. TKI Precision Farming;
- Topsector Horticulture;
- Mission Driven Innovation Policy, theme: Agriculture, Water and Food;
- Documentation Copernicus Land Monitoring Service;
- Latest Reports EARSC;
- Latest literature in land-agri-food, and partly advised by contacted experts (see references).

Secondly, scientific and vocational articles on the domain for this study (Land, Agriculture and Food) have been collected. To further specify the literature search and to bring a more focussed approach to classifying, summarising and analysing results, the broad domain is categorised in seven main themes. This subdivision is based on different stakeholders, different policy aspects and is linked to the 17 international Sustainable Development Goals as proclaimed by UN in 2015:

1. <u>Food security</u> (SDG2): Assuring an adequate supply of diverse nutrition for all. Accurate and up-todate geo-information on food supply and demand are essential to support policies on food security, including market interventions and famine mitigation.
2. <u>Soil and irrigation management</u> (SDG2 and 6): The sustainable management of soils and water for agricultural use. Geo-information is essential to monitor soil degradation and treatment, as well as measuring soil moisture and irrigation necessity.
3. <u>Agricultural monitoring</u> (SDG2): Monitoring the wall-to-wall activity in agricultural fields and linking this to paying agencies and policy agencies. Geo-information can be used to cheaply monitor and validate fields, as opposed to conventional methods which rely on trust or experts visiting fields.
4. <u>Precision Agriculture</u>: A farming management concept based on observing, measuring, and responding to inter- and intra-field variability and needs in crops and to variability and needs of individual animals with the use of digital techniques. Geo-information is indispensable as precision agriculture relies on applying the right measure at the right time and place.
5. <u>Land use and planning</u> (SDG11): Identifying and monitoring changes in land cover and land use within parcels and across land. Land use and planning in the context of agri-food demands accurate

and up-to-date information to monitor, report, verify (MRV) and strategise on the best use of land resources.

6. Biodiversity and ecology (SDG15): Monitoring biodiversity and ecological indicators to maintain these in a sustainable way and assure the overall health of the planet and its inhabitants. As these issues occur at scales from the very small to the very large, remote sensing is an excellent tool to monitor biodiversity and ecology.
7. Climate mitigation and adaptation (SDG13): The assessment of environmental and socio-economic effects of climate change, and the mitigation of, and adaptation to, these effects. The global extent of remote sensing data is essential to cover this subject, as well as the type of data: atmospheric, soil-bound, and hydrological data.

Although these themes are clearly defined and specific, there is undoubtably overlap in their information needs and applications. The themes are outlined in order of appearance.

For each theme, desk research has been performed which is summarised in Factsheets, which are annexed to this report.

2.3 Stakeholder mapping and selection

For each theme within the land-agri-food domain a stakeholder analysis has been carried out, identifying the most important stakeholders that are currently in play in the information needs definition and in data applications development. To harmonise that analysis, a more generic overview of stakeholders has been conceived. As the study focusses on information needs and demand-driven innovation processes, a Demand Process Flow from the user (left) to the supplier (right) has been drawn, which goes counter directional to the materialised data flow.

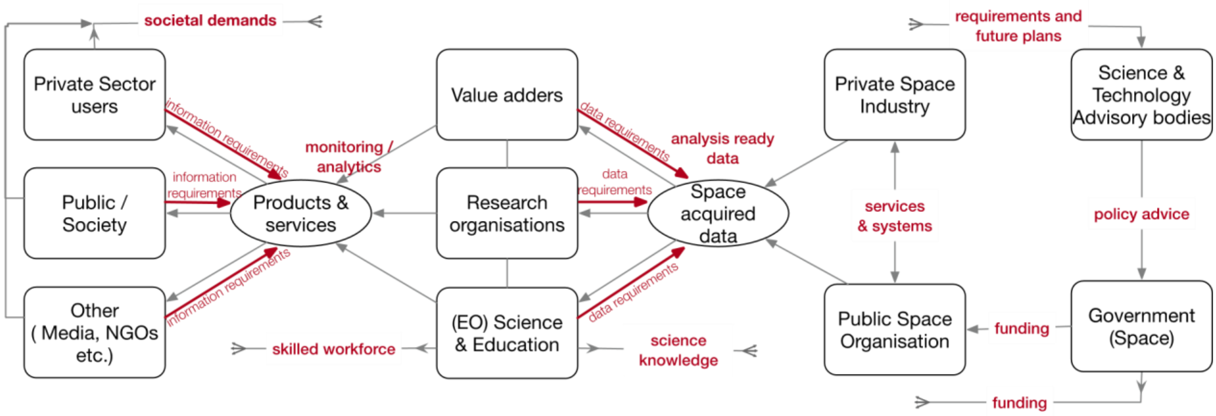


Figure 1: Process flow diagram of satellite data, showing different stakeholder types (square boxes). The 'crow feet' line ends indicate connection to multiple other stakeholders.

By making a process flow diagram (Figure 1) the flow of information requirements was mapped out and stakeholders could be placed at different parts of the pipeline. In total, stakeholders could be placed along seven different parts of the process flow (Figure 1):

1. Private sector users: Private companies that need (processed) information to be directly applied in their daily processes (e.g. farmers, contractors, insurance companies).
2. Public Society: Policy makers (both national and international), governmental administrations and agencies to run their daily processes;
3. Other: NGOs and other organisations that use data and/or information for their cause.This also includes media and representatives of citizens that need information from all other sectors in order to make informed decisions.

4. Value adders: Organisations (mostly companies) that use satellite data to process it to create products – adding value for users further downstream in the pipeline.

5. Research organisations: Research organisations, R&D departments and other contracted research that use satellite data to address specific problems.
6. Science & education: Universities and other academic institutions that do more fundamental science and also educate the new generations of professionals and scientists.
7. Remaining Upstream: Public and private space industry, governmental bodies and other related institutions that develop the space infrastructure and the instruments to acquire data with satellite platforms. The 'upstream' segment is increasingly focussed on delivering "analysis ready data" – hence harmonising and standardising on reliable base data products.

This study focusses on the stakeholders in the two left columns of Figure 1, and respectively number 1 to 6 of the list above. For each of the 7 themes, actors of these stakeholder types were identified.

2.4 Expert user interviews

For each of the seven main themes, a stakeholder analysis was carried out and representatives from the main actors were selected and contacted for interviews. The experts were interviewed in a semistructured way, using a questionnaire (see Text Block 1). This approach allowed to cover both technical experts as well as user representatives. Due to COVID-19 measures, the interviews all took place by telephone or online meetings. In total 27 experts were interviewed, and 4+ per theme. Also, we tried to let the experts talk as much as possible about their needs and not about the current technical possibilities.

The direction the interviews took was dependent on the interviewee's expertise. In some cases, more direct, technical, questions could be asked (e.g., data specs, type of sensors, etc.) or the interviewees themselves would start talking in technical terms. However, in other cases the interviews were less technical, but focussed more on the applicability of the information needs.

Text block 1: Questionnaire used for semi-structured interviews.

Base research questions per theme:

- What are the main issues per theme?
- What are the main stakeholders per theme and why?
- What are the potential new stakeholders?
- What will be the main issues in 5-10 years?

- What is the data and/or information need to monitor/evaluate/solve the challenges?
- What are the sensors, satellite services that could supply this data/information?
- What are the specs of needed sensors, and information?
- Are there possible hiccups, limitations concerning these sensors and/or data?

2.5 Workshop

At the end of the expert and stakeholder consultation phase a workshop was planned. In this workshop the general outcome of the study was validated, and a prioritisation was made in the needs assessment. The workshop was held on March 16, enjoying the participation of 10 stakeholders. The invitees of the workshop were selected from the list of stakeholders and experts (Annex IX).

The workshop was organised as a hybrid meeting with participants both on site and online. In order to assure the active inclusion of the online participants, they were projected on a large screen and actively given time to speak. Also, the virtual environment was constantly monitored for questions.

The general set-up of the workshop was informal and interactive. The workshop had three goals, namely to:

- Validate the results of the study by interactive dialogue with the stakeholders;
- Prioritise the different information needs across themes;
- Look forward into how to enhance demand driven innovation in satellite technology.

The workshop was divided into three parts. In the first part, participants were introduced more precisely to the purpose and results of the study. Then the interim results of the study, as collected through the interviews, were discussed and validated. This was done by first presenting, explaining and collectively discussing Table 1 (presented in the Results chapter). Also, a number of propositions from the study were presented and discussed. Then, the challenges from Table 1 were ranked by the workshop participants on four different dimensions: interpretability, (zero) latency, temporal resolution and spatial resolution. For all dimensions, three classes could be selected: high, medium or low. Participants could place items anywhere along the y-axis of every topic (see Figure 2). A report of the workshop is presented in Annex VIII.

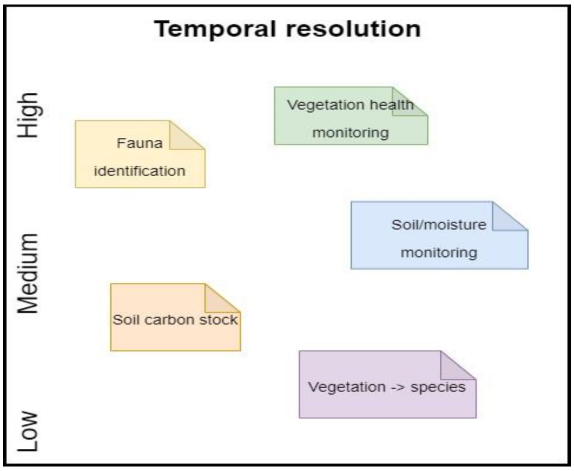


Figure 2: Example of the 4 technical topics that were ranked by the workshop participants

The third part was to encourage the participants to look forward and make suggestions for follow-ups. In a lively debate, participants identified a number of steps for following up on this study.

3 Results

This study has two types of results. The first consists of the land-agri-food challenges as collected through interviews with users, which is summarized in Table 1. The second is a summary of findings collected during the expert user workshop (Annex VIII).

3.1 Desk research

As mentioned in Section 2.2, the subject of this study, the domain land-agri-food, has been subdivided into seven main user themes. Each theme has been described separately in a so-called Factsheet, and the information needs per theme have been assessed with desk research. This involved a review of scientific literature, websites (of stakeholder organisations), and other results including other relevant studies in this domain related to the use of satellite data.

Based on the desk research, actors were identified, and representatives were invited to participate in the interviews.

For each theme, the Factsheets provide a general description of that theme; the current and future challenges in information needs; the involved actors and relevant stakeholders and the requirements in information needs with, but not exclusively, a keen eye for opportunities in satellite Remote Sensing.

The factsheets are considered an intermediary result of this study and are annexed to this report.

During the desk research, it is observed that the use of satellite information and satellite data is often mixed and used interchangeable. In our figure 1 (above), the data is more likely to be 'produced' by the space sector and referred to as 'space acquired data', while information is more likely to be the result of processing and value adding services. And, different actors in the data value chain have different perceptions of data and 'raw' data. In this study, the use of data is intended to be used for the more generic satellite originated imagery, while information is intended to be reserved for the processed product with customer value. However, it sometimes reflects the opinion of the stakeholders and therefore it has not been consistently used.

3.2 EO Challenges in Land, Agriculture and Food

Analysing the results from desk research and interviews, a number of cross-cutting challenges in Earth Observation became apparent that resolve the information needs in multiple themes. In an analysis step, these min user information needs have been identified, clustered and elaborated. It is obvious that within the land-agri-food domain, the themes have overlap in information needs. By identifying these crosscutting challenges, also overlaps with other domains can be further elaborated. This was however not done in the context of this study as it was focused on the land-agri-food domain.

The main results of the identification of these cross-cutting user information needs are illustrated in Table 1. This table shows the relationships between user information needs in the different user themes. Per user information need, also specific information parameters have been identified to further specify the relevant aspect(s).

Besides a number of context challenges, a set of technical or infrastructural challenges have been identified too, as users clearly expressed the importance of these in order to consider satellite data as a competitive alternative for fulfilling their information needs.

Table 1: Overview of the user information needs, specific user parameters related with the seven main user themes.

User information Needs:	Specific needs: (Themes:)	Food security	Soil & irrigation management	Agricultural monitoring (Off farm)	Precision agriculture Farmer)	Land use and land use planning	Biodiversity and ecology	Climate mitigation and adaptation
Land Cover & Land dynamics	Vegetation -> species	X	X	X	X		X	X
	Land use -> land use change	X		X		X		X
	Agricultural activity detection	X		X				X
	Vegetation health monitoring	X	X	X	X		X	X
Soil & Soil dynamics	Classification -> land evaluation -> soil quality	X	X	X	X	X	X	X
	Soil /-moisture monitoring	X	X	X	X		X	X
	Soil carbon stock			X	X		X	X
	Terrain height		X		X	X	X	X
Greenhouse Gasses	Emissions		X	X	X		X	X
	Depositions						X	X
Habitat	Interactions			X	X	X	X	
	Object and structure mapping			X		X	X	
Fauna	Activity / monitoring						X	
	Identification			X	X			
Infrastructure	Data (zero) Latency	X	X		X			X
	Access and Storage	X	X	X	X	X	X	X
	Time series / service continuity	X	X			X	X	X
	Processing automation	X	X	X	X	X	X	X
	Seamless integration / fusion	X	X	X	X		X	X

3.2.1 Land cover and land dynamics

Plant species mapping

The spatial and temporal mapping of plant and animal species is a highly desired information need by farmers, ecologists, and policymakers. It must be noted that some of these applications are also interesting for urban challenges. Also, Remote Sensing gives users the possibility to monitor plant species in remote areas that are hard and costly to reach. Repeated measurement or monitoring can be done with Remote Sensing which makes it an excellent tool for change detection. Within this challenge there are applications that are directly relevant to agriculture and forestry:

- Identifying (crop) species: Farmers, ecologists and policymakers are interested in identifying plant species. This is generally significantly easier when the crop is larger. However, for some aspects of agricultural monitoring, it's necessary to retrieve species information earlier in the season – when the crop is still small.
- Identifying grass species in pastures: This issue is important for sustainable and ecologically friendly grassland management. Identifying separate types of grasses per field would serve as an indicator for biodiversity. Also, monitoring where and how frequent grassland is mown is an indicator for intensification and relevant for biodiversity goals.
- Identifying tree species: Understanding the composition of forests by identifying individual tree species and height is important to create better inventories of biomass, carbon sequestration and biodiversity.
- Plant structure: Recognising plant structure (e.g., low plant, shrub, tree) can give indications of the development of an area and aid in the identification of species. Also, the exact height of tree canopy is a matter of interest to give better estimations of forest biomass and composition.

Other applications of species' mapping are indirectly relevant to agriculture and forestry. Instead, these relate to policies and factors that might influence agriculture and forestry:

- Identifying alien species: Keeping track of alien species is important as these can alter or damage native ecosystems and infrastructure. Some alien species are relatively large (e.g., giant hogweed), which makes it possible to detect these with high enough resolutions at times of flowering. Other times, their footprint can be large (e.g., Japanese knotweed) or their effect on the environment can be clearly identifiable.
- Transition of heathland to grassland: for Dutch nature conservation, monitoring and maintaining native heathlands is an important topic. These ecosystems, however, are often plagued by creeping grasses that replace the heath. This is already done with satellite imagery if the resolution is high enough. Including higher resolution imagery would lead to methods that could be applied faster and would thus result in lower costs.
- Identifying smaller species: The Netherlands makes inventory of species by placing a coordinate on a square meter basis in nature conservation areas – mapping even insects. However, if more specimens of the same species are found on an area of 50x50m, only one location is marked at the centre of gravity of the population. This is quite detailed, even for EU standards, as most countries map on a per hectare basis instead of a 50x50m basis. Currently, this is done by people on the field and is supplemented by aerial images with 20-10 cm pixels, which is useful for larger species.

Land use and land use change

Identifying land use and changes thereof is highly relevant for national, EU and global policies. These spatial and temporal data are important for policymakers to make better informed decision on land planning and management and to better monitor the state of the environment. However, current methods to monitor land use and land cover rely on costly in situ visits to fields, while trust-based methods where land users document their own land use, are cheaper but require validation. It's important to keep in mind that for these challenges, monitoring over time is also relevant. Lastly, monitoring abroad is also relevant for certain organisations that want to comply with farm-to-fork or cradle-to-farm policies.

- Classifying land cover: Essential is that classification occurs accurately and on a scale that is relevant for stakeholders. Current land cover classification is expected to clearly be able to differentiate between what is physically present on parcels – the more accurately the demarcation of parcels occurs, the better. An issue with land cover classification is dealing with heterogeneity within an area – e.g., urban green, strip-cropping. Ideally, this heterogeneity should be identified.

  Furthermore, for Remote Sensing applications within land cover classification, it is future needs aim at being able to identify classes more accurately and to have more specific classes. The chosen classes depend on the stakeholder using the data. Worldwide deforestation monitoring is also an important issue. Lastly, there is an increased focus on smaller features and more specific and diverse practices, like small parcels and strip-cropping.
- Classifying land use: land use classification has similar requirements to accuracy of the classification itself and spatial resolution, compared to land cover classification. However, land cover is a physically observable attribute of land. Land use concerns the (economic) purpose of land. E.g., grass (land cover) can be used for agriculture, but also as a golf course (land use). Special attention was given by interviewees to the intensification of grasslands. Intensification can be an indicator of grassland use and is also important for carbon emission and sequestration measurements.

Agricultural activity detection

Agricultural activity detection is about monitoring the features of interest that are of relevance to policies – both public regulations and industry standards (e.g., food safety, insurances). This challenge stands out in its application on remote and wall-to-wall identification of agricultural activity. One important user group for these data are the Paying Agencies of the Member States of the European Union, who by law are using Remote Sensing to verify farmers claims for financial support. But also on other continents, similar activity takes place. Important challenges for the next 5-10 years:

- An increased focus on smaller features and more specific and diverse practices, like small parcels and strip-cropping.
- Verification of auditable decisions: Satellite data is linked to payments, permits and penalties. When satellite data alone is not conclusive for auditable decisions, integration with in-situ data is required. Also, infrastructure is needed to archive audit-trails over certain periods.
- Event monitoring: Agricultural Monitoring has thematically evolved into monitoring agri-ecological indicators but also monitoring events. This also applies to emission estimations but also for nutrient management and biodiversity, knowing which agricultural measures were applied per parcel is crucial. Particularly of interest for stakeholders are mowing date, fertiliser application, ploughing, irrigation, sowing and harvest date.
- Creation of AI infrastructure: Changing from classical EO to more big-data approaches, where AI is replacing human and semi-automated systems. Hence the need for training data and infrastructure.

Vegetation health monitoring

The goal is to monitor plant health at individual level, so at least sub meter resolution is needed. With various indices plant health can be monitored and plant stress can be detected. There are 3 main stress factors, water deficiency, nutrient shortage and diseases or pests.

- Growth, biomass: this can be monitored already. Soon more data fusion is expected between forecasts, in situ sensors and remote sensing equipment.

- Crop nutrient quality: identifying specific nutrients in crops can be useful for both food safety (e.g., not exceeding maximum levels of nitrate in spinach) and for produce quality assessments. This concerns monitoring crops on a molecular level and relating this information to earth observation. Hyperspectral imaging is thought to be able to help in this challenge.
- Mechanical damage (e.g., flooding, hailstorm) or diseases and pests: Although generally not even visible in high-resolution imagery, there is a need by farmers and their cooperatives, insurances, and policymakers for remotely sensed assessments of damage. Plague identification and spread are sometimes identifiable through proxies. For example, by looking at the effects of a plague. Monitoring damage is also useful to validate damage claims for insurance and for farmers' corporations.

- Weeds: General trend is towards near sensing identification of weeds with automated mechanical weeding and reduction of herbicides (but also former item applies).
- Variable Rate Application (VRA): When fine soil maps and nutrition maps are available, task maps can be made for VRA. VRA can be of great help for precise sowing, manure and nutrient application, pesticide use, irrigation, etc.

3.2.2 Soil and soil dynamics

Soil quality monitoring

Quality of soil refers to the capacity to function adequately for land use, in particular for agriculture and food security. As such is has relations with all 7 main themes of this study. The greatest challenge for RS is assessment of key indicators of soil quality. The key indicator for soil quality is soil organic matter, which is laid out in the next paragraph. On a European and global scale there is much interest in assessing different kinds of soil degradation:

- Soil erosion: This is worldwide a big problem. There are relations with soil use and soil cover on one side and effects of climate change on the other. Worldwide erosion is to a large extent caused by overgrazing of rangelands and clearing forests, but there are many other smaller problems. Impacts of heavy showers and droughts can be diminished by better soil use and maintaining cover crops for example. Hilly terrain is more susceptible to erosion. Changes can be increasingly measured with remote sensing tools. Also keeping track of land management practices is important in this respect.
- Soil compaction: As agriculture has evolved into intensification and upscaling with bigger and heavier equipment this has become a big issue, especially in Europe and North America. This can cause a problem for plant root growth and cause yield loss. Soil compaction is a difficult trait to assess with satellite EO due to its depth of occurrence and the relatively shallow penetration of different sensor types.
- Sealing: Can be a problem in the top layer of the soil due to a combination of heavy showers and fine soil texture. A sealed surface can cause a next shower to run off along the surface and soil moisture will deteriorate. So far it has proven difficult to assess sealing with RS algorithms.
- Salinisation: By sea water penetration or indirectly by irrigation of crops, soils and inland water bodies can salinize. This is causing problems because crops do not grow on salty soils and yields may drop. There are RS applications to assess salinated waterbodies and even concentrations. So far RS assessed soil salination proves difficult but is desired.
- Chemical pollution: Soil can be contaminated by pollutants because of industrial and agricultural processes (e.g., heavy metals, pesticides etc.) or by other chemical sources (e.g., toxic aerosol or medicine residues). The area of effect of these pollutants depends on the type of chemical and the process it is involved in. The molecular scale of pollutants makes it difficult to measure with remote

sensing. This does become easier with high enough concentrations over larger areas, and by looking at the effects that the pollutant has on the environment.

- Depletion of nutrients: Is mostly caused by leaching and general degradation through cropping.

Soil moisture monitoring

Soil moisture measurement is of key importance for many themes and applications. Despite major advances in RS soil moisture assessment in the last decade there is still a high demand for more detailed and more accurate soil moisture measurement with help of satellites. The main mentioned challenges are:

- Regional and local water management: As water use is increasing and climate change effects or causing higher fluctuations of water levels this calls for more accurate rainfall assessment but also more accurate estimates of waterbodies and water retention in soils.

- Parcel soil moisture: For parcel management or precision farming, the soil moisture balance is still even more challenging to map. Evapotranspiration (ET) makes out about 60-70% of the water balance in agricultural canopies and is hard to measure still and often not accurate enough.
- Measuring and predicting drought: In both agriculture and forestry, droughts can have severe consequences to soils, crops, cattle and the livelihood of its owners.

Soil organic matter and carbon monitoring

Soil organic matter assessment has a high attention in projects and studies, from local to international. That has two main reasons: soil organic matter is a very good indicator of soil health and second but not least, it bonds carbon for the long term. Therefore, it can be used for sequestration of CO_2 in the soil. There is already twice as much CO_2 stored in soils worldwide as there is CO_2 in the air. For IPCC Reporting obligations, it would be preferred for data to represent the first 30 cm of soil.

- Assessment of soil organic matter: Carbon farming is the farming management method where credits can be created by sequestering carbon in the soil. This is done by the usual crop growth but also by supplying additional organic manure and crop residue on the soil. Problems now are: accurate ways of monitoring change of soil organic matter and also the durability of the storage. The carbon farming market is growing rapidly, in attention and financing. Carbon farming can also be an incentive for precision farming. For this, especially carbon credit systems are important and under full development.;
- Carbon sequestration outside of agricultural land: Peatlands and forests are of great importance for the sequestration of carbon emissions. Monitoring the carbon fluxes of these areas is thus interesting from a EU climate policy perspective.

Terrain height

- Exact surface level measurements and soil subsidence: Worldwide, accurate altitude measurement in landscapes is still a problem. Accurate surface level measurements are interesting for land planning, precise erosion control and modelling. Furthermore, to account for soil subsidence very accurate soil surface measurements are necessary.

3.2.3 Greenhouse Gasses

Climate change is one of the biggest challenges facing the world and the emissions of greenhouse gasses (GHGs) from land, land conversion and land use are considered a major cause. On the other hand, forests, nature and agriculture can also sequestrate CO_2 in the soil. It is also considered as the key challenge where use of Earth observations (EO) will have a decisive high impact, as it has the capability to capture environmental and socio-economic data over a range of spatial, spectral, and temporal resolutions. General agreement on climate change effect now shows adding pressures on global agricultural and food systems because higher temperatures, rainfall variation and the frequency and intensity of extreme weather events negatively affect both crop and livestock production systems in most regions. This again is expected to cause the shift of production areas to less favourable areas. Other negative effects may be water scarcity, pollution and soil degradation. Also, higher impact of pests and diseases is expected. On the other hand, also some countries or regions may benefit from the changing conditions.

Emissions

In agri-food, GHGs are produced by combustion of fossil fuels, mineralisation of soils, deforestation, oxidisation of dry peatland, methane production from animal husbandry etc. Emission reduction is a general worldwide goal, also for agri-food. For this purpose, it is important that GHG sources on a regional or even local scale (trace gases) can be monitored. For CO_2, NO_x and NH_4 already EO monitoring is in place, or some satellite missions are planned. Still there is more needed on a detailed scale; emissions should be monitored at parcel scale. Because of the large dependence of emissions with crop growth, also accurate spatial assessment of soil texture, soil constituents and moisture are important. Users had a clear interest in detecting the exact origin and quantities of emissions. This should occur at a farm level, or preferably even more precisely – for example, at the level of individual sheds, or even cows. More exact origin and amount detection of nitrogen in soil, canopies, animal facilities and forests would be of great help for biodiversity, climate and agri-monitoring organisations. For carbon farming as mentioned earlier more accurate organic matter measurement with high spatial resolution is urged for.

Depositions

GHG nitrous oxide – coming mainly from industry and traffic – and NH_4 – originating mainly from animal husbandry – are causing excess nitrogen in the environment which is a hazard for plants and animals. Consequentially, nitrogen concentrations are measured in the EU. In the Netherlands this is done via a network of twenty-two NO_2 stations and six NH_4 stations. NH_4 models are used to estimate NH_4 concentrations in other areas. As there are several policies that mandate farmers and other organisations to adequately manage their nitrogen output policy and farmers strive for more accurate data on source level, in which RS could play a decisive role. Other challenges are also: leaching of nitrogen in soil and measuring other plant nutrients in soils.

3.2.4 Habitat

Interaction between people and their surroundings

Ecology also includes the interaction between human and non-anthropogenic actors. As such, the following challenges are relevant for users:

- Interaction between vegetation, animals and people: within and outside of urban areas, the interactions between these three entities is important to understand. In cities, for example, the effect of urban vegetation on human health and wellness has been clearly linked and could be aided by earth observation. Furthermore, the effect (both positive and negative) that people have on surrounding biodiversity due to light, sound and chemical pollution is to be investigated further.
- Effect on urban area biodiversity of surrounding areas: It is not yet clearly understood what the effect is of surrounding areas on the biodiversity within a city. As many urban areas are surrounded by agricultural, forests, water, etc., these ‘green’ areas influence the livelihoods of those inhabiting the cities as well as the biodiversity in the city. Among others, this is interesting for pest control and city temperature, hydrology and air quality.

Object and structure mapping

Object and structure mapping refers to the identification of individual objects (assets) and general structures in the landscape. The most important according to the interviewed users are the following:

- Landscape structures: These include forest clearings, ditches, uncultivated field margins and wooden banks. These structures are important for biodiversity. Ditches and hedgerows are also important elements in EU legislation (e.g., CAP subsidies for hedgerows) and thus, relevant for farmers. These structures are already monitored to a degree with satellite and aerial imagery, and tests have been done with altimetry data to map forest clearings. The information can also be used as controlling evidence for subsidies.
- Identifying potential habitats for species: Understanding the suitability of areas for certain species is important to manage and control *which* animals coexist *where*. The suitability depends on several factors such as temperature, availability of water, vegetation species and quantity. In urban contexts, this is also related to green roofs, city hydrology and heat islands.
- Material identification: Being able to identify materials with remote sensing could be of great help for inventory, mapping and monitoring. Through hyperspectral signatures, different types of materials can be differentiated from one and other – for example, metal, plastic, and asphalt surfaces. But also identifying dead wood, which is of particular interest for forestry.

3.2.5 Fauna

Identifying and monitoring fauna is not only relevant for farm animals, but also for biodiversity. The main challenges within this subject are:

- Fauna identification and activity monitoring: Within (farm) animal monitoring it's important to count animals, track their behaviour and ideally also monitor their emissions. From a biodiversity perspective, identifying birds and their nests is a sought-after solution. This is currently done with aerial imagery, in-situ observations and location trackers. Regarding the last method, these would preferably be smaller and more accurate.

3.2.6 Infrastructure

Besides the user needs described above which are highly theme specific, there are also challenges which relate more to the underlying infrastructure that holds the data and serves the users. The main challenges within this subject are:

Data (zero) latency

Once data is captured, the time it takes for users to be able to work with the data is called data latency. Ideally, latency should be zero, so users can work with data in real-time if they so choose to. However, in practice, latency is always greater than zero. Even in cases where data is streamed, there is always latency. For applications which can function without quick decision-making, data latency isn't as important. However, for certain applications, having smaller latency is essential – e.g., precision agriculture. Still, in most cases, latencies smaller than one day are sufficient.

Access and storage

As satellite data generally involves large quantities of data, a reliable and easy-to-access system is essential for the data to bear its fruits. Access should even be easy to understand for the layperson, and APIs should be adequate and well documented. Attention was given by users to the importance of storage being sustainable in the long term. With ever-growing data and the energy need that comes with it, data centres should be environmentally conscious.

Time series and series continuity

Many users complained about a lack of more evenly spread images in time which would make time series more valuable. For several applications, having country-wide cloudless images and/or mosaics, is essential. These cloudless mosaics should be composed of images that are close to each other in time, and more than one mosaic should be made per year.

In case new satellites are developed, it's also critical that the data of new satellites is comparable with that of older satellites. This would allow longer time-series to be possible without incongruities in the data.

Processing automation

For many applications raw data provided by a service provider still has to be processed by a value adder or the user. Sometimes even atmospheric correction or mosaicking has to be done by the user. In general, there are still advances to be made in process automation for RS applications. Users want analysis-ready data in order to be able to directly work with the data without needing knowledge on pre-processing. This applies even to a higher degree to Precision Farming. For precision farming to become general practice, adequate and sometimes also fast data assessment, data processing and variable rate application (VRA) machinery and equipment is needed. General trend is that data acquisition is performed with a combination of nearby and satellite sensing and data is integrated on the spot for information for variable rate application in real time. Also important in this theme is that there are still large advancements to make in temporal and spatial resolutions of satellite imagery.

Seamless integration/fusion

Also related to series continuity is the seamless integration of older data or systems into newer datasets and systems. To ensure the sustainability of current working applications, new data should be harmonised to fit older data (or vice versa). Additionally, data fusion should be made easy by maintaining clear and well-documented data standards. These standards should be maintained, when possible, not only for similar data, but also for data from different sources.

3.3 Expert interviews: instrument specifications overview

In general, there were also some preferences for instrument specifications distilled from the stakeholder interviews.

3.3.1 Spatial resolution

The required spatial resolution depends on the surface lay-out, the assessment, and the goal of the data. For example, the identification of individual species should be done with resolutions ranging from 1-10cm. On the other hand, to identify land cover at parcel level a resolution of 5-10m would suffice. Still, a resolution of 5m is preferred to the current 'standard' of 10m for most applications. For precision agriculture in particular, a resolution of 1m is indispensable. But as demands always grow, this is no new standard, but will probably become even higher in future.

Soil moisture assessment should be assessed at 90% accuracy at 1m resolution for agricultural purposes. For hydrology-related biodiversity assessments, 5-10m is also acceptable.

3.3.2 Temporal resolution

Regarding the temporal resolution of satellite imagery, the general sentiment is that more frequent is better. Ideally, users would want a country-wide cloudless image every day – in some cases even multiple times a day. However, the actual need of this data depends on the application. For agricultural and land use monitoring, one country-wide cloudless image in the winter is essential, but more frequent images are needed in the growing season. For other applications, such as precision farming, one image per week would be preferable. This of course is an issue in cloudy countries, such as the Netherlands, where one must rely on image mosaics. Mosaics are acceptable as long as they are not composed of images with too many days (approximately >5) in between. For one application one yearly picture was sufficient, namely for the mandatory fauna habitat count of birds and animals in nature conservation areas.

3.3.3 Spectral resolution

Spectral resolution was generally difficult for users to specify. However, it is clear what the users need and how new spectral possibilities can help them achieve their goals. Currently available wavelengths are already of great help; however, higher resolutions are needed for certain applications. Additionally, sensors capturing new wavelengths can aid in the analysis of materials, plant species identification, and in discerning different elements in a heterogeneous field. Several experts stated that the hyperspectral data will increase in the near future but also the applications using AI and hyperspectral data analysis. Some also claimed there is already a lot of hyperspectral data of which data processing is still difficult or unexecuted yet. A few interviewees explained that more data is needed in the shortwave infrared region and some thermal infrared bands.

3.3.4 Vertical penetration (depth)

For certain applications, the penetrative depth of sensor signals (in soils, water and vegetation) is crucial. Being able to reliably measure soil characteristics up to 30cm from topsoil (according to IPCC reporting obligations) would be ground-breaking. Currently, important soil characteristics are moisture, organic carbon (soil organic matter), and bulk density. The measurement depth should ideally be independent of other factors such as moisture content. In another vein, measuring vegetation in a depth-dimension is essential for biomass estimation and structure identification. Existing radar data already gives some idea, but the resolution hereof is generally relatively low.

3.3.5 Data pre-processing and harmonisation

Data (pre)processing is still an issue for many users. Although many organisations are interested in using data, atmospheric corrections and cloud masking are deemed too costly and time-consuming by some. More user-ready information would be preferable and also more information about the raw product.

3.4 Workshop results

Figure 3: Workshop set-up held on March 16th, 2022, in Amersfoort.

After a brief introduction by the project team, Table 1 was evaluated with those present. No omissions were found although there were a few remarks:

- A social-ethical perspective is missing. This was paired with the question: are there also parties that experience disadvantages of developments?
- As a sector, are we focusing on what's right to measure, or are we measuring what is easy to do?

After this evaluation, five one-liners describing our interim results were projected on a screen, and feedback was asked.

1. *In many applications in agri-food, satellite data is an add-on, a nice-to-have, that improves processes or applications and not a "need-to-have".* The participants partly agree that satellite data is not yet a "basic necessity" of users in many themes. Exceptions to this are, for example, land use and agricultural monitoring, where without satellite data the work would be disproportionately more difficult. On the other hand, for some subjects such as soil monitoring and soil dynamics, already existing satellite data isn't widely used yet – even though satellites would have a clear added value.
2. *Demand- and user driven innovation has been limited, or non-existent, so far.* The audience agreed on this too but found the phrasing too extreme. According to participants, there are some initiatives that consult users. According to this perspective, it's generally only useful for users to give their opinions if a technology is already available. The initiative therefore lies with the aerospace sector. However, compared to the meteorological sector, which has a clear say in which sensors are sent into space, the agri-food sector isn't as involved in the aerospace sector. As such, the agri-food sector must work with what is available without having a steering role in these developments. Possible reasons for the lack of user-driven innovation could be because of the widely varying requirements from different users within the agri-food sector, and because there is no strong international community. Agri-food users should organise themselves to create a focused request towards the aerospace sector.
3. *There is a hype in hyperspectral and the thermal spectrum.* Participants agreed, and claimed that there are many developments they have a lot of confidence in. Participants said that there was much to win from having more hyperspectral satellite possibilities. However, as satellites with high spatial and temporal resolution aren't available yet, testing such data is currently limited. Drones could pave the way to develop, validate and demonstrate tools that could later be expanded into hyperspectral satellite business cases.
4. *There isn't enough room for experimentation.* Participants agree with this. Often the first acquaintance with satellite data is only after the launch of an instrument. The Dutch satellite data portal (satellietdataportaal.nl), once conceived as a pre-cursor for the Sentinels of the Copernicus program, was an example of how users can become acquainted with the possibilities of a new instrument or program. Exploring the practical possibilities of new technologies is not possible yet due to a lack of organisation.
5. *Currently the main focus lies on data quality; data services are severely lacking.* Participants agreed. Users don't just look at the data and its quality, but at the whole picture about how data is offered as a service. It is therefore not just about the instrument, but how the instrument contributes to the information need and how this information is disclosed. This also includes aspects such as data delivery, processing and application in processes. Many users don't know what's available. The participants note that it is important to distinguish two innovation tracks:
    a. Real innovation: new sensors/measurements that were not possible before – "high tech innovation".
    b. Increasing accessibility to information: Making it easier for users to use/apply geoinformation themselves – including users that aren't in the geo-data sector. Now

relatively few people can actually work with geo-data. So, the question then becomes: how do we, as a geo-sector, ensure that more people can practically work with geo-data?

The third part of the workshop consisted of building and discussing a roadmap and forming general conclusions. It became clear that developments must continue; new satellite instruments could and should be used for innovative applications, tasks and monitoring in particular. Also, there should be more room to play and experiment with technologies, products and applications – possibly hosted by providers. Experiments should be done with new sensors and platforms, such as combining HALE (High Altitude Long Endurance) drones with sensors as a steppingstone towards putting such sensors on satellites. This would not only give more awareness of the added value of sensors, but also give insights in the practical application of HALE drones in an agri-food context. Lastly, a union or association of agrifood satellite users should be established. Here developments could be evaluated, and user demands could be defined regularly. An investment fund should be set up to stimulate the demand-driven decision making, as well as a fund from users themselves.

4 Conclusions

This study provides an overview of the information needs, and trends therein, for the domain of land, agriculture and food. It shows great progress in traditional themes of applications, like land use and soil and vegetation monitoring, and it shows new explorations in new – so far underdeveloped – challenges as fauna, biodiversity and GHG emissions.

The study shows that the application of Artificial Intelligence, Data Sciences and Machine Learning techniques is entering this domain at great pace and that it has an impact on the value of data and how that value is expressed: a stronger emphasis on more harmonised and continuous time series is required to make use of the modern AI technologies. Data fusion has already become a second nature as many applications and developers no longer rely on satellite-only solutions.

This research resulted in two main lines of results. The first line concerns how satellite data can be a realistic alternative to satisfy current and future information needs. The second looks at the infrastructure that is needed to make these data accessible and easily workable for users, as well as the structures needed to assure that users that *aren't* very acquainted with geo-data can see the added value of this data and are able to make use of it.

4.1 Information needs

In general, all users prefer higher spatial and temporal resolutions, as well as more possibilities in the hyperspectral realm. However, it's important to differentiate between *nice-to-haves* and *must-haves.* The prioritisation defined by users in all studied themes, coupled with realistic expectations of technology and the development thereof, resulted in the following findings. These are deemed developments which would have the largest impact on the land-agri-food sector – and all related sectors – if realised. Therefore, in order of relevance, improvements in satellite data should address:

1. Improved spatial resolution;
2. Improved temporal resolution;
3. Extended spectral data, better resolution (bands, bandwidths) / hyperspectral data.

Figure 4 shows how the different items in the distinct challenges rank and prioritise on these three points.

Many potential applications of satellite data are not yet fully exploited as the applications could not perform as well as hoped for. Therefore, any improvements in the above three characteristics will make more use of satellite data and technology possible.

Due to expectations, arising from drones and airborne systems, similar needs arrive for satellite data. Users have little sympathy for physical constraints as the speed of satellites, the required amount of light on a CCD, or shutter times.

In the results section of this report, more detailed specific information needs per theme have been reported. The study digested the large field of land, agriculture and food by first dividing the domain into 7 themes – based on their stakeholder focus – and then cross sectioning those with 6 challenges with distinct properties and information needs. This brought 6 explicit challenges, as shown in Table 1 (first column), for the improvements of instruments and missions that have multiple application purposes. This also shows the interlinkages between the different themes where different applications can be designed for different stakeholders based on the same data.

The study also showed that the user community in land, agriculture and food is very heterogeneous: from developers to policy makers. It showed that the value chain is still a very supply driven process, where the beneficiaries of information products have little to no influence on that chain, and none at all in the development of new instruments.

Figure 4 provides a visual oversight of all information needs collected in this study. All information needs are eager for the best available resolution, but in this figure, the needs have been placed next to each other for readability and located in the triangle to reflect their most dominant need. The points of the triangle represent the best available resolution, the coloured areas provide a rough quantification of these resolutions. For example, 'land use change' is not in need of daily data or 1-meter pixels, while 'object boundaries' should have less then 1 meter pixels; and 'biodiversity' requires more spectral resolution (more bands, in broader spectral range, but sometimes specific small bands).

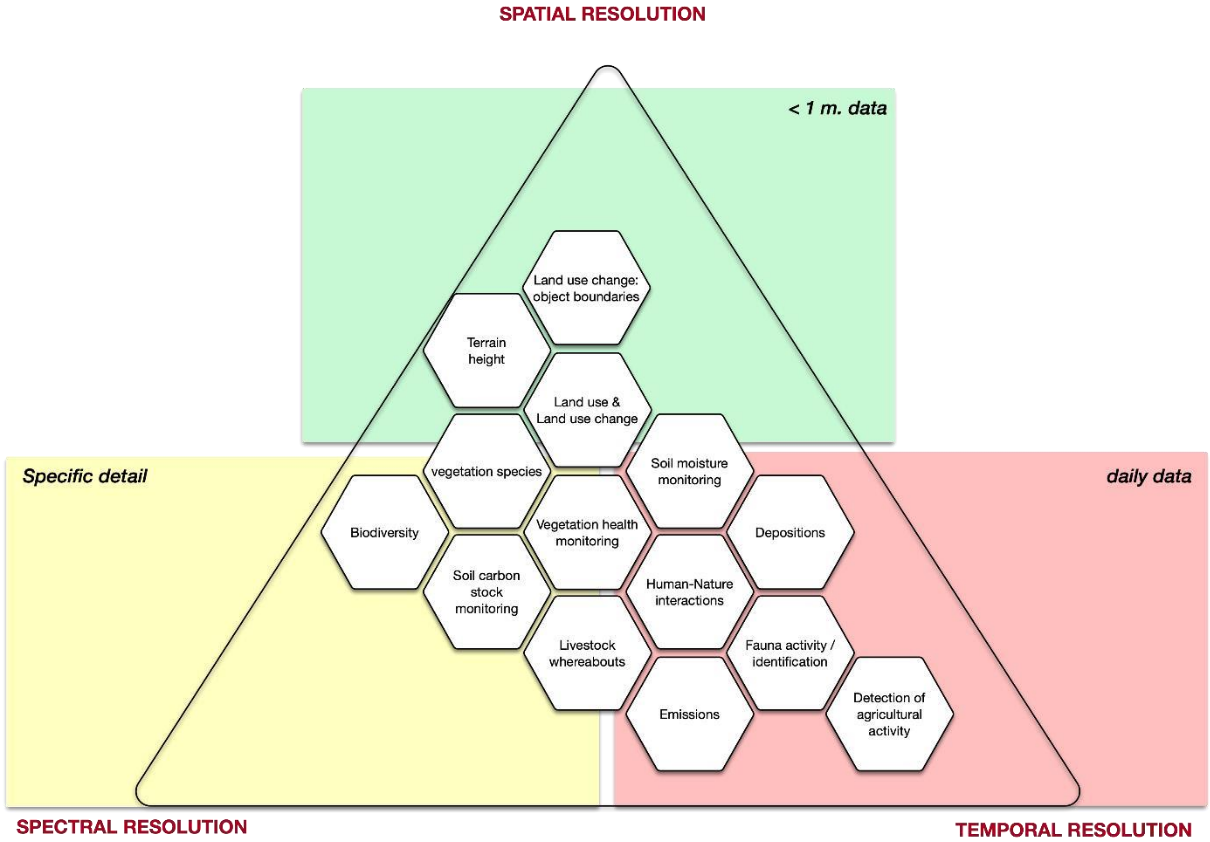


Figure 4: Summary of information needs in Land, Agriculture and Food, mapped on the prioritisation in temporal, spatial and spectral resolution. The specific needs from Table 1 are ranked based on the requirement for spatial, temporal, and spectral resolution. The location towards one or another corner is a relative positioning, showing the primary importance of that requirement. The coloured areas provide the proposed requirement for the different resolutions, although in all three domains more resolution is always appreciated.

Another conclusion from the interviews and workshop is, that there is a great trust and faith in technological advancements in space technology and satellite data in particular: The user community still expects new and disruptive applications from the Earth Observation domain. But, as mentioned above, the user community has no hooks and handles to tune these developments towards their own goals. This offers however opportunities for industry to fill a void between the (mostly) government lead programmes with free and open data, and the more stringent information needs. Companies like Planet, Airbus, Maxar and many others develop new space vehicles, new sensors, but most importantly also more customer focussed data channels towards the so-called "Analysis Ready Data" that will find their way to users quite easily. Even those companies, however, could make other choices when an organised user group could offer them perspectives.

The way information is “distilled” from data has changed significantly in the past decade. The processing of raw data into Analysis Ready Data (ARD) is becoming more and more standardised and more automated. Constructions of mosaics, cloud removal and other pre-processing has become a computer’s job. This way it is much faster, however, the investigative data analyst will find these methods sometimes delivering less than optimal quality. And then, from ARD to information, artificial intelligence has taken over from humans, or is at least helping humans in faster and better interpretation. This changing way of creating information out of data has an impact on the data itself too: producing computer-processable data streams is becoming a dedicated new way of working.

4.2 Data access and infrastructure

In general, it's understood that user uptake should improve and that several mission and downstream segment related aspects play an important role. This is a multi-faceted question as the lack of uptake has several reasons.

Firstly, for both users and experts in the field, many satellite data and products thereof are available which are unknown to them. Sometimes also users are familiar with data products, but they are unaware of the exact specifications of the products. As a result, throughout the expert interviews and the workshop, it was emphasized that experimenting and interaction between users, service providers and value-adders, but also between upstream and downstream entities, should be increased. This should create the missing link and helps experts from non-remote-sensing fields to come in contact with the possibilities that satellite data provides. There are many ways to achieve this, but important ones are: low thresholds in experimenting with new satellite data, facilitating the access to data and improving the quality of metadata, and lastly, creating networks for users to share their multidisciplinary experiences.

Secondly, organising an investment fund to finance experiments and even space instruments could be a way for the land-agri-food domain to have a voice within the space-industry. Similar to the meteorological sector and the meteo-satellites, the land-agri-food sector could help develop technologies that are tailormade for the sector itself. Such a fund could be financed by contributions from important land-agri-food stakeholders and user groups as well as governmental investment funds.

Thirdly, most stakeholders still see the price of commercial satellite images as something that impedes their embrace of the technology. Before exploitation, testing must be done. However, when the technical specifications of free alternatives aren't sufficient for the application, these tests can be too costly for many stakeholders.

Fourthly, satellite data is in some cases not adequate enough to fulfil all needs of users.
Principally, many users require cloud-free data (sometimes in mosaic form for larger regions), (cheaper) higher spatial and temporal resolutions, and more hyperspectral possibilities. Some of these issues can be solved by new space instruments, while others are drawbacks inherent to satellite data.

5 Recommendations

In order to continue on some of the conclusions, a number of suggestions ('recommendations') are made to provide fertile ground for elaborating on the study results.

5.1 User conference

The study revealed that there is a great interest within the large community of users and developers to exchange on information needs, application developments and data usage stories. Existing meetings and workshops often have an international character, which is also appreciated, but that offers less room for more in-depth interaction between peers. A dedicated EO user conference in the Netherlands should be a way to facilitate this need and could also be a stage for further elaboration on user needs.

5.2 Interaction with space scientists and developers

Although not for every user, but there is a significant group of users that would appreciate a more intense interaction with scientists and developers in the space segment. There are opportunities to develop more co-designed solutions, if users could get more understanding of the space constraints, and vice versa. Better communication between space sector and user could reveal the information needs in a better way. Here, a task for universities and NSO is sought to facilitate this more intense meeting of minds.

5.3 Room for experimentation

Users indicate that they would appreciate to better understand upfront what new systems could bring and prepare for their value streams. New instruments or improved ones could for instance be mounted on High Altitude Long Endurance drones (HALEs), to mimic the potential capability of a new space mission. By organising a field lab where this could take place, users are better suited to prepare and maybe even to improve the missions' characteristics to suit their application purpose, and hence improve the value of the instrument. New satellite instruments could and should be used for innovative applications, tasks and monitoring in particular. Also, there should be more room to play and experiment with technologies, products and applications – possibly hosted by providers. This would not only give more awareness of the added value of sensors, but also give insights in the practical application of HALE drones in an agri-food context.

A dedicated experimental area, with abundant in-situ measurements could facilitate the development of new instruments. A campaign like AGRISAR in the '80s of last century would be of great value still and could also attract international attention as *thé* experimental field lab where new sensors should be tested.

5.4 Association of agri-food satellite data users

There is an interest between several user communities to unite and organise themselves, in particular in the agricultural domain where precision agriculture, food security, agricultural activity monitoring and more, are very satellite-soaked applications. A union or association of agri-food satellite data users could be established. Here developments could be evaluated, and user demands could be defined regularly.

This association could engage itself in setting priorities for investments and investigations and it could even connect to an investment fund. Connecting two very distinct yet very connected domains, that of high-tech and space tech, with agri-food would be a great accelerator under further development in this field.

In the Netherlands, two initiatives have been recognised for the involvement of the agricultural sector, being BioScope BV, a subsidiary of farmers organisation LTO Bedrijven, and Geo4A BV, a business deeply connected to the potato breeding sector.

6 Lessons learned

In this section the results of this study are presented that can be classified as 'lessons learned'. The points listed below are more generic findings that provide feedback on how satellite data and space applications are generally perceived and how the space sector is observed.

First of all, there is an important notice that space applications in agri-food are in the majority of cases an add-on, a nice-to-have, that improves processes or applications. Space data is not a "need-to-have". The study shows many useful applications, but the envisaged users have managed without space data and would be able to continue doing so. Satellite data is not yet a "basic necessity" of users in many themes. Exceptions to this are, for example, land use and agricultural monitoring, where without satellite data the work would be disproportionately more difficult. On the other hand, for some subjects such as soil monitoring and soil dynamics, already existing satellite data isn't widely used yet – even though satellites would have a clear added value. More awareness could create a better foundation for this higher 'need-to-have' perspective. And more crossovers should be encouraged.

Another element that stood out is that many applications that have been developed are not demand- and user driven developments. The demand side of innovation is still underdeveloped. This doesn't mean that representants of the agricultural sector are not consulted: in many projects and satellite developments, users have been interviewed and their needs are inventoried, but without exception on the initiative of the high-tech and aerospace sector, not on agricultural sectors' initiative.

The satellite development is ongoing and new missions and sensors are defined day by day. At this moment many people are hopeful that hyperspectral sensors and thermal sensors will ignite a new era of satellite capabilities, also in the land-agri-food domain. The promise of these sensors is that it will bridge the gap between technology and information needs by the users. But both hyperspectral and thermal are not yet in space in operational missions. In agriculture, the type of platform is not relevant, therefore these sensors could be easily mounted on drones and HALEs to serve as proxies for satellite missions.

Talking about drones and HALEs: these are currently underexploited platforms for more and intense experimentation, with shorter cycles than the average space mission. Also, the space industry should make more effort to collaborate with the aerial industry, providing more integrated and multimodal platforms for better user satisfaction.

Space technology, sensor developers and service providers focus too much on data quality and forget the service quality. Users don't just look at the data and its quality, but at the whole picture about how data is offered as a service. It is therefore not just about the instrument, but how the instrument contributes to the information need and how this information is disclosed. This also includes aspects such as data delivery, processing and application in processes. Many users don't know what's available.

All in all, the domain of land-agri-food can make more and better use of satellite data, in particular when new sensors, missions and services arise that fill in the user requirements mentioned.

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8 Annexes

ANNEX I: Factsheet – Agricultural soil and water management

Theme description

This theme only covers soil moisture with respect to irrigation and agriculture, because general water and water management issues are covered in previous NSO studies by Deltares.

Soil quality and soil moisture have obviously always been an important topic for agri-food, as plants and crops are rooted in soil. Soil sciences have become even more prominent starting in the 90s in Australia, Africa and US because of land erosion and degradation. There is also a long history of remote sensing to monitor different soil characteristics, which always has the problem of shallow penetration, therefore only getting information of the soil surface, rock and plant material. For agriculture, a total soil profile of one meter is important, so still field work is needed. However, new techniques of radar and signal analysis are being developed. Soil is also an important theme with strong relations with other themes in this study, for example, there are strong links with precision agriculture, climate change, biodiversity and sustainability.

In North-western Europe, soil erosion is not a big issue, but soil structure, -quality and -fertility is prominently important. This is even more the case due to the renowned link with the emission and storage of greenhouse gasses in and out of soil. Also, there is a large emphasis on prevention and mitigation of soil biodiversity loss, because this is interlinked again with plant and also fauna biodiversity.

For prevention of degradation, erosion and climate adaptation, soil action plans (EU Soil Strategy, issued 2021) came into place. These aim to protect, restore and promote the sustainable use of terrestrial ecosystems, sustainably managing forests, combating desertification, stopping and reversing land degradation and stopping the loss of soil biodiversity. So, it has crossovers with agriculture, nature conservation, climate change and biodiversity. Moreover, also the effect of droughts and floods on soil and anthropogenic contamination are tackled.

A second aim where soils come in is carbon sequestration, not only by conserving it in forests and other vegetation, but also by carbon farming in the soil. The idea is decennia old, but the practical development has been booming for 3-5 years, because of present CO_2 sequestration goals.

Because fresh water is expected to be scarcer and at the same time more needed in the future due to climate change and the rising population, action plans on irrigation and water conservation helped by earth observation are increasingly important. Related to climate change and soil are also floods, landslides, impacts of sea level rise and subsidence of soil surfaces.

In the field of soil quality and degradation there are various sub-themes:

- Depletion of nutrients,
- Soil organic matter,
- Erosion, (wind, water and bad land use and management),
- Soil compaction,
- Sealing,
- Salination,
- Contamination (heavy metals, pesticides and medicine residue etc.).

Deltares (2019) performed a comprehensive survey on the state-of-the-art remote sensing of soil variables. It provides an overview of the gaps and possibilities of monitoring soil properties and soil degradation processes worldwide. Highest maturity of sensing (according to that report) has been achieved in soil moisture assessment and crop residue. The least developed were found to be assessment of soil organic carbon, biodiversity and salination.

Overview most important challenges

Moisture and water management

Soil moisture monitoring – also interconnected with climate system and climate change – has experienced strong advances in the last decades, but for agriculture it is still considered not accurate enough. Therefore, it is still very important to improve the soil moisture assessment by RS techniques – this is consequentially the number one priority according to many experts. Of course, this also relates to drought monitoring. As in some areas in the world dry spells are becoming more frequent and severe and drinking water is getting scarcer, there is high interest in general fresh water supply assessment and better estimates of fresh water in ice and snow layers. This is secondarily again related with the general climate system.

For climate adaptation there is also an interest for an opposite effect, namely excess water resulting in flooding and upstream and downstream development in rivers and streams.

Soil and crops

For this category crop health and soil health is directly important for sustainable food security for future generations. For this, crop growth monitoring has taken great advances in the recent decade. There is a strong relation with soil moisture and evaporation monitoring. Crop health monitoring with RS is a highly appreciated topic but still in its infancy. Soil health monitoring has high priority, but experts don't have much faith in adequate remotely sensed solutions in the near future. Related to this, also assessment of soil suitability for tillage, sowing, planting or ploughing is important. This could also help contractors optimise their service, work quality and planning. Another topic is assessing emissions of GHG, more accurate, more specific and on the origin of trace gases, also to validate carbon credit systems, (see also the Climate Mitigation factsheet). Further, there is also increasing interest in assessment of the chemical build-up of soils and pollutants. For example, salination (of soil, but also inland water reservoirs and streams) is causing production loss in coastal regions of the Netherlands and other areas in the world. Again, experts' faith in a breakthrough is lacking. Also, mechanical and physiological properties come into focus. However, experts do not show much faith in the aid of RS for soil compaction and sealing in the near future. This is estimated to be a problem in 50% of soils in the Netherlands. Soil surface temperature is mainly monitored at 1km spatial resolution but there are huge spatial differences, and it is a major factor for growth processes, and also spread of diseases.

Main Stakeholders:

- Government and waterboards: international: JRC Soil, national: RVO, UVW, RIVM, ISRIC
- Farmers
- Large research centres: Deltares, ITC, Eurofins, STOWA, HLB, Irriwatch

General technical demands from users

- Higher resolution, for many applications 5m resolution is needed, for precision agriculture 1m is minimum. For disease monitoring, 1m resolution can be helpful, but for real impact cm level would be needed according to experts,
- More revisit days, most users would prefer 1 Sentinel image per day (first priority),
- More bands in the multispectral sensing, especially in the SWIR region,
- Some experts have high expectations of radar techniques to uncover and monitor more features of the soil; others say the data processing is too difficult or even unsolvable.
- Being able to reliably measure soil characteristics at 30cm – in accordance with IPCC Reporting obligations – would be ground-breaking.

ANNEX II: Factsheet – Ecology and biodiversity

Theme description

The relationship between living organisms and their physical environment, also known as ecology, has been greatly affected by human activities. Biodiversity, a subdiscipline of ecology that entails the biological variety and variability of life on Earth, has been of particular interest in societal and scientific discussions. It's no mystery why. An abundance of ecological issues such as the fastest known extinction rate of species, mass deforestation, an increase in global carbon footprint, climate change, and land-, water- and air pollution, have put the resilience of ecological systems to the test. As these systems wane, their importance to the overall health of the planet and its inhabitants has become more evident. Understanding the spatio-temporal aspects of these issues can provide a better understanding of high priority areas and help maintain these systems.

These issues are occurring at a range of spatial and temporal scales. With this in mind, the added value of Remote sensing (RS) and Geo-information science (GIS) research to monitor ecology and biodiversity has become clear and is currently in full swing. Thanks to faster revisit times, sensors in new (hyper)spectral ranges, higher resolutions and the sheer quantity of worldwide historical data, RS (often in combination with machine learning techniques) has been a wonderful addition to the ecologists' toolbox. Yet, this research is mostly used for applications unrelated to the agri-food industry. Most ecologists use RS and GIS to monitor issues related to forestry and habitat changes – issues dealing with larger-scale objects. Besides the use of GNSS to monitor the movement of larger animals, RS and GIS for the more nitty-gritty ecology on the smaller, individual organism scale, is still relatively untreaded ground.

Overview most important challenges

The bridge between ecology and remote sensing is still relatively unexplored. While RS specialists mostly focus on the technologies and processes that make remote sensing possible, the ecologists address methods to study the various issues that plague natural systems. Although not all ecologists' issues are relevant for remote sensing, we focus on those that are detectable, or can be aided, by space-based remote sensing.

Several measures that are relevant to ecology and biodiversity can be retrieved through remote sensing. Based on nearly 120 remote sensing biodiversity products, Table 2 shows a list of variables that are essential for ecologists, as well as their relevance to the agri-food sector.

Table 2: Essential biodiversity variables that can be informed by remote sensing and are relevant for agri-food. Based on Skidmore et al. (2021).

Class	Remote sensing biodiversity products relevant for agri-food
Species population	Species diversity
	Population density
Species traits	Green-up (start of season)
	Senescence (end of season)
	Peak season (max of season)
	Leaf dry matter content
	Plant specific leaf area
	Gross primary productivity
	Net primary productivity

	Leaf area index
	Plant composition (Chlorophyll, NPK, polyphenols, lignin, cellulose, carbohydrates)
Community composition	Taxonomic (species diversity/richness)
	Percentage of species which grow or occur together
Ecosystem structure	Land cover (vegetation type)
	Fraction of vegetation cover
	Above-ground biomass
	Vegetation height
	Plant area index profile (canopy cover)
Ecosystem function	Evapotranspiration
	Fraction of absorbed photosynthetically active radiation (FAPAR)
	Ecosystem soil moisture
	Carbon cycle (sequestration, below- and above-ground biomass and carbon)
	Biological effects fire disturbance (direction, duration, abruptness, magnitude, extent, frequency)
	Biological effects of irregular inundation
	Biological effects of pest and disease outbreak

These specific variables can be placed in a larger context that dictates what the challenges and tasks are that we, as a society, should undertake. Focussing on the agri-food sector, ecologists deal with four main subjects: crop species traits, crop community composition, ecosystem structure and ecosystem function. For the first, common ecological task deal with the differentiation of crop species, phenology, plant growth and production, and the general health and composition of the crops. Secondly, for crop community composition, focus goes to the composition of different species in an area (e.g., flower and herb rich pastures, intercropping, species detection), monoculture and polyculture analysis, and the effect of invasive species. Thirdly, ecosystem structure is relevant in the agri-food sector as it deals with above-ground biomass, types of habitats within agricultural fields, vegetation height, canopy cover, ecosystem fragmentation and effects of climate change such as desertification. Lastly, ecosystem functions deal with evapotranspiration, FAPAR (fraction photosynthetic radiation), soil moisture, the carbon cycle, and the effects of disturbances by fire, inundation, droughts, pests and diseases.

Experts are also interested in monitoring biodiversity loss. Geo-data can help by observing the direct and indirect drivers of biodiversity loss. For example, by monitoring the herb-richness of grasslands, number of tree species in a forest, variability in habitat structures, in-soil and above-ground moisture. However, currently much discussion regarding biodiversity is opinionated because ‘how much biodiversity is enough?’ is not easy to objectively answer. However, by having baseline studies, this could lead to average values which could help the discussion. Experts think that satellite data can help in creating these baseline values.

It’s expected that future problems will relate to identifying and monitoring smaller species using remote sensing. Also, more precisely monitoring micro-climates and how these relate to species living therein.

Stakeholder overview

With an increased interest in biodiversity, this subject is in the scope of interests of various stakeholders. The main stakeholders are:

- Governmental bodies: these organisations need biodiversity data in order to control the state of the environment and to be able to report to EU biodiversity goals.
- Research organisations: biodiversity research using remote sensing focusses on identifying species (flora and fauna) and monitoring these in space and time more accurately.
- Environmental organisations: by having a good insight in the state of biodiversity, these organisations can use biodiversity data for PR and/or as evidence to pressure parties to discuss environmental issues.
- Farmers and farmer cooperatives: as farmers should adhere to national and EU biodiversity policy, it's interesting for farmers to know what the state of biodiversity is in their farms. With such information, farmers can apply measures to increase biodiversity.

General technical demands from users

To precisely monitor biodiversity, a spatial resolution of <=10cm would be ideal. However, already <1m would be of great help to identify larger objects. Hyperspectral imaging is also wanted to distinguish individual species and the general heterogeneity of fields more easily. However, users would then also need to understand the hyperspectral images, and training datasets should be available.

More accurate soil moisture estimations are also great indicators of biodiversity. Users would prefer a spatial resolution <=5m, however, 10m resolutions are also fine. The critical aspect then becomes making these soil moisture estimations accurate and preferably absolute.

Concerning height measurements such as InSAR and LiDAR, higher accuracies are wished for. The higher the spatial resolution the better, if resolutions comparable to airborne LiDAR data would be possible (approximately 20 points per m^2) that would be ground-breaking. However, in a practical sense, identifying canopy height of individual trees would be great.

Coupled to all these demands are also demands on the temporal resolution. All users expressed a preference to more frequent (at least daily) cloudless images. For animal monitoring, such as cattle, having more frequent data would allow agencies to check if cows are being let out frequently enough.

ANNEX III: Factsheet – Food security

Theme Description

Accurate and up-to-date information on food supply and demand are essential components to support policies on food security, including market interventions and famine mitigation. Since the 80s of last century satellite data gained an important role for agricultural monitoring. The European Commission initiated the Monitoring of Agricultural ResourceS (MARS) programme in the mid-80s as one of the first operational monitoring programmes with satellite data – using both high-resolution data on selected sites and low-resolution data for continental oversight. And since 1988, the Food and Agriculture Organization of the United Nations (FAO) has been using data from low-resolution satellites to monitor rainfall and vegetation conditions over large areas. These data are provided operationally in near real-time through the FAO's Africa Real Time Environmental Monitoring Information System (ARTEMIS). The core concept of food security monitoring is agri-ecological modelling: On a regional scale, planted area and weather data are the main driving factors behind seasonal differences in yields. Earth Observation is used to monitor the resulting crop growth, mainly through vegetation index tempo-spatial analysis. In this way, also unexpected deviations can be identified, also called Anomaly Hot Spots. Integration of Earth Observation and weather data can indicate these hot spots and identify potential causes, like droughts.

In 2011 the Group on Earth Observations (GEO) initiated the GEO Global Agricultural Monitoring Initiative (GEOGLAM) to operationally deliver EO based services that are making a difference for commodity market stability and food security and early warning. The purpose of GEOGLAM is to increase market transparency and improve food security by producing and disseminating relevant, timely, and actionable information on agricultural conditions and outlooks of production at national, regional, and global scales. It achieves this by strengthening the international community's capacity to utilize coordinated, comprehensive, and sustained Earth observations. GEOGLAM continues to respond to evolving policy information needs. It is now working on more quantitative metrics and broadens its scope to monitoring of the UN's Sustainable Development Goals (SDGs). In that sense, GEOGLAM is defining a set of Essential Variables for agriculture, biodiversity and climate. (Source: earthobservations.org).

Overview most important challenges

Food security monitoring with Earth Observation is a well-established application. The focus on EO is on 1) cropped area; 2) cropping season indication (timing, earliness etc.) and 3) vegetation density. In order to link those EO data to tonnes of harvested product, often a comparison to earlier seasons on a regional base is made. EO then serves to indicate anomalies and deviations from normal season patterns. To translate agricultural production to food security, other information is important to integrate e.g., existing stocks and prices and other market information.

The biggest challenge in food security is to make estimates quantitative, in particular to predict end of-season harvests. This requires linking EO parameters to yields, but that relationship has a certain saturation, and the last (most relevant) part of the prediction requires better information on e.g., cultivars used, the so-called harvest index, harvest conditions etc.

Stakeholder overview

Public organisations:

- The most relevant stakeholders are national and multi-national governmental organisations that are concerned with food security. The FAO of the United Nations is the most prominent organisation. For us also the European Union and its scientific institute the Joint Research Centre are relevant. Other similar governmental organisations are USAID, Worldbank, African Development Bank and others;
- The European Commission, having an interest in food security for member states but also for neighbouring regions, is an important stakeholder for funding and developing EO tools for food security. It's Joint Research Centre (JRC) is operating the MARS system and the dedicated anomaly hotspots of agricultural production: https://mars.jrc.ec.europa.eu/asap/;
- Group on Earth Observation, GEO, is a governmental network, including academics, data providers and other. They organise funding from different sources, for instance through the Horizon Europe programme – where specific funding is conditional to supporting GEO's mission and the GEO System of Systems (GEOSS);
- Dutch government / NSO: the programme Geo 4 Agriculture and Water (G4AW) is a NSO lead programme to develop innovative tools to improve food security in developing countries;
- Wageningen University and Research is a large player in this field;
- ITC / University of Twente: has a long history in food security programmes and earth observation;
    - Other academic institutions have expertise and participate in different projects.

Private organisations:

- There are many value adders active in the field of food security. In the Netherlands companies such as TerraSphere, Sarvision, Neo, Hydrologic, ClimateImpact, Irriwatch, RHDHV, Arcadis and many others are active in this domain;
- More soil and agrifood related companies, such as Future water, Agrocares and others are also contributing to food security projects.

General technical demands from users

An important demand from this domain is data continuity as it depends on time series of data to calculate anomalies, cropped areas and seasonal dynamics. It requires in particular to capture the start of the growing season, which is by nature a difficult thing for areas in the world that have 'rainfed' agriculture, as the season start is often rainy and therefore very cloudy. The abundance of SAR data from Sentinel-1 is a major asset for food security monitoring.

Of course, also in this theme every enhancement in resolutions is well appreciated.

ANNEX IV: Factsheet – Land use and land development

Theme description

First, the definitions. Land cover concerns what is physically *on* the field (e.g., grassland, forest). *Land use* consists of the modification, ordering and management of land in general – the functional description of areas and how these areas lie within a socio-economic context. In other words, how land is used by entities (e.g., grassland for agriculture or a golf course). *Land development* on the other hand, consists of the actual physical alteration of land to fulfil certain needs. This can also be seen as *measures*.

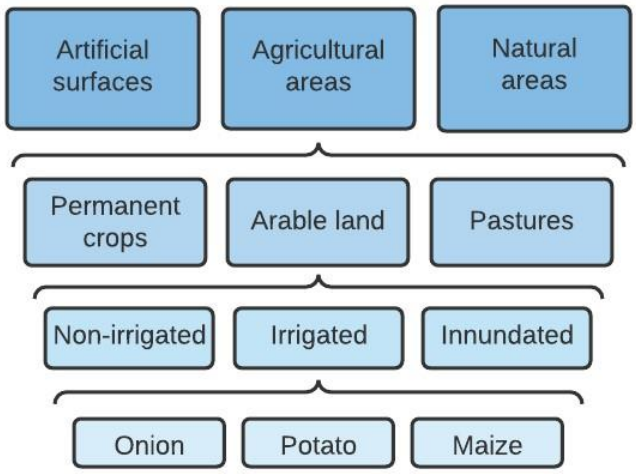

Figure 5: Difference in scope of land cover classification.

In the context of agri-food, this theme demands accurate and up-to-date information in order monitor, report, verify (MRV) and strategize on the best use of land resources. Traditionally, land management MRV was done through field measurements and/or manual, trust-based, reporting. Remote sensing has given land managers unequivocally useful tools to improve their MRV methods. Founded in 1985, the CORINE programme (CO-oRdination of INformation on the Environment) produced a global land cover database using satellite imagery for 1990, 2000 and 2006. The LGN (*Landelijk Grondgebruikbestand Nederland*; en: Country-wide Land Use File Netherlands) has been mapping The Netherlands based on satellite imagery and additional data since 1986 every three to five years, and annually since 2018. Ideally, new remote sensing technologies can keep this trend going and help manage and govern land in more efficient, precise and sustainable ways. Another important player is the European Commission and the EU Green Deal's climate ambitions. To monitor the sequestration and release of carbon in countries; land use, land use change and land measures are essential data. Therefore, Member States must deliver *activity data* (which shows land use and change) on a yearly basis. It is expected that this data must also be *geographically explicit* in the near future.

Overview of most important challenges

As land use and land use change is a rather broad subject, the issues related to it are many and varied. These issues are therefore tackled by various types of organisations simultaneously. Yet, in essence, land managers use and need remote sensing for two main reasons: classification of areas and detecting change in time.

Classification tasks include the differentiation of what can be found *in* the area, what the *borders* of the area are and what has *happened* in the area. For the first case, land classification is an important use. Here, areas are divided into different classes which can vary in scope (Figure 5). These type of classification tasks can help users explore common themes such as habitat fragmentation, area-specific goals (e.g., 20% area must be nature), planted crops, crop rotation, arable land capability, etc. But also, less common themes can be explored, such as measuring the amount of combustible material in forests to estimate the severity of forest fires, waterlogging sensitivity, sedimentation and land use surrounding rivers, etc. The second case related to the *border* of areas, include cadastral documentation (especially lacking in developing countries) and effects of land use from one area on the other (e.g., contamination of nature due to agricultural use). The last case relates to monitoring what (agricultural) measures have occurred on the area (e.g., mowing, ploughing, planting, etc.). As these measures generally occur in a timespan of one day, it's challenging to actually measure the exact moment it has happened. As such, the effects of the measure are generally monitored.

Change detection tasks add the temporal dimension to remote sensing data. Understanding changes over time is essential for monitoring and gives information on possible trends, efficacy of policies, and can even give insights to predict future changes. Change detection tasks are thus essential for many users. For example, by understanding changes in land use due to desertification, one can predict food security in certain areas. Also, carbon sinks and sources can be monitored, erosion and land degradation can be examined – giving policy makers the tools to counteract these negative trends.

Land use and -development never functions in a vacuum. It will always be linked to some degree to the physical environment, climate, ecology, agronomy, socio-economic and cultural needs, resources and politics. As such, it's impossible to evaluate the use of remote sensing technology as something that only concerns land use and -development. However, experts did have two main points of focus:

1. Monitoring carbon emissions and sequestration: to fight climate change, sequestering carbon and reducing emissions is essential. The role that land management can have herein is becoming increasingly relevant. As this is also important within EU policy, many experts need ways to more easily monitor carbon and land use change. Member states are expected to deliver *geographically explicit* datasets – amongst others, for afforestation and deforestation.
2. Effect of land use on biodiversity: biodiversity can be affected by the way land is managed. An increased focus on preserving biodiversity and sustaining healthy ecosystems, must be coupled with ways to more easily measure biodiversity. Besides classifying and monitoring species, this also involves measuring how intensively agriculture is being done.

Looking further into the future (10+ years), experts could not say what the challenges would be. The consensus among experts was that the issues would not be related to the information needs, but to what decision makers would do with the information at hand.

Stakeholder overview

Land is, for very obvious reasons, essential for people. As such, its management is interesting for everyone. However, only a few stakeholders can have a tangible effect on land and can be seen as *acting* stakeholders within land management. These acting stakeholders are the ones that use data related to land management and can be summarised as follows:

- Governmental bodies: besides national land management, EU-wide policies also require land use data.
- Cadastral organisations: using satellite information is interesting for cadastral organisations as it removes the need to go to the fields themselves – or using more expensive aerial imagery.
- Research organisations: most research focusses on the issue of monitoring land use and land use change by remote means – in service of the national and EU policies.

- Environmental organisations: Land use and land use change are essential variables that contribute to carbon emissions and sequestration.

General technical demands from users

In general, higher spatial, temporal and spectral resolutions are desired. However, one of the main bottlenecks is not having frequent nation-wide cloudless images. Although nation-wide mosaics exist, these are composited of images that lie too far apart in time for some uses. Also, there is a need for at minimum three of such mosaics per year: two between May and August, and one in the winter months. Besides more frequent cloudless mosaics, a higher temporal frequency is also desired to monitor land measures such as grassland mowing.

Higher spatial resolutions (<10m), in combination with more hyperspectral possibilities, would be useful to better identify land cover. However, according to some, the current resolution of 10m is high enough for most European purposes due to the larger parcel sizes – the data is available, it's simply not used well yet. Conversely, when dealing with smaller parcels in e.g., African countries, a spatial resolution of <2m is desired.

More hyperspectral possibilities are desired, but this desire is not always founded on concrete knowledge of what is possible. Experts expect that hyperspectral imaging can be of great help in discerning land use intensification (e.g., grassland composition), but there are uncertainties as to how accurate this would be – these uncertainties are exacerbated when taking into account that hyperspectral imaging might not necessarily be of high spatial resolution.

For forestry, a range of parameters need to be estimated. E.g., forest type and tree species, age class distribution, dead wood, etc. However, a number of limitations still remain when trying to collect this data. Firstly, data is not well harmonised – in spatial, temporal and radiometric sense. Secondly, extending remote sensing data with in-situ data is deemed as time intensive and costly by experts.

ANNEX V: Factsheet – Precision agriculture

Theme description

Precision Agriculture (PA) is a farming management concept based upon observing, measuring, and responding to inter- and intra-field variability and needs in crops, and to variability and needs of individual animals with the use of digital techniques. A more condensed and popular definition is: "PA is doing the right thing, *in the right place,* at the right time, in the right way" (Blackmore, 2005). The PA farming management paradigm aims for optimising outputs and improving the efficiency of inputs – ideally making every phase of farming more sustainable, from seed to product. PA helps the farmer make the right decisions to reach these goals.

Figure 6: Vision on Precision Farming by ZLTO (Presentation Precision Agriculture 2.0, Corné Kempenaar, WUR)

The satellite data provides information on moisture content, soil quality and nitrogen and chlorophyll-content in the crop. Applications to accurately assess soil organic carbon, to detect pests, weeds and severe weather damage are still under development. In the Netherlands, the government and the agricultural business community are jointly promoting precision agriculture through the Precision Agriculture Program (NPPL).

For precision farming to become general practice, adequate data assessment, data processing and variable rate application (VRA) machinery and equipment is needed. There are still large advancements to make in temporal and spatial resolutions of satellite imagery. In many cases more research and data analysis is needed to get desired information on crop health and growth. Also sometimes more indices are needed like NDVI to analyse multiple cause – single effect issues, like plant stress. In this case plant stress can be caused by very high temperatures, drought, disease and/or mechanical damage.

Carbon farming could be an endorsement and incentive for precision farming, but for that also the SOC measurement has to improve and cheapen, and the still immature carbon credit system has to get viable and scientifically and socio-economically feasible.

Overview most important challenges

For Precision Farming still a lot lies in technical down-to-earth challenges instead of RS information. General trend is on nearby sensing in combination with remote sensing. There are many technical elements happening and needed in the interface topic of Chapter 3. There are large advances in online sensors, faster mobile networks and better and faster interfaces.

Regarding the required main applications accurate soil moisture and crop health monitoring are important. This is already addressed in paragraph 3.3.2. Soil moisture monitoring is also interconnected with climate system and climate change which is further elaborated in Annex VII.

In this respect there is a high demand for pest and disease monitoring and especially assessment in an early stage. From literature and spoken experts this is not expected in the next decade.

Stakeholder overview

Accurate positioning is very important, so GNSS providers and navigation systems are key. But also, government is very important because sustainability regulation stimulates or even demands for precision farming, because the individual plant health is the overall goal. In the Netherlands NPPL and WUR are important for research on precision farming

Also, very important in this paragraph, are sensor providers and variable rate techniques. Many research institutes and universities and SMEs work on decision support systems to optimize plant growth and cultivation measures. Providers of Farm Management Systems are important for development of decision support.

To combine all data and use this almost real-time for cultivation tasks, asks for a fast and reliable mobile internet network.

Other stakeholders are already covered in other factsheets, of which 5.2 about soil and water management is the most important.

General technical demands from users

- Higher resolution, for many applications 5m resolution is needed, for precision agriculture 1m is minimum, for disease monitoring m level can be helpful, but for real impact cm level would be needed according to experts
- More revisit days, most users say 1 Sentinel per day (priority 1)
- More bands in the multispectral sensing, especially in the SWIR region
- Farmers would like exact positioning without expensive RTK systems. This means EGNOS etc. should have 1cm accuracy for precision farming.

ANNEX VI: Factsheet – Agricultural monitoring

Theme description

Satellite data for agricultural monitoring is considered an independent and truthful source of verification of agricultural land use and activity.

This theme has close links to Food Security, Land Use (Change) monitoring and Precision Agriculture, but it stands out in its application on remote and wall-to-wall identification of agricultural activity. One important user group for these data are the Paying Agencies of the Member States of the European Union, who by law are using Remote Sensing as a means to verify farmers claims for financial support. Satellite data has been used since the MacSharry reforms in 1992 to control the type of crop, the location and the size of the area on farmers application forms, as this was input to the amount of financial support. Satellite data is a technological alternative to the On The Spot Checks (OTSC) that Paying Agencies are obliged to do on 5% of the farms. Growing over the years, now 80% of these checks are done by Checks With Remote Sensing (CWRS), with varying percentages per Member State (European Court of Auditors, ECA). Now, with the Copernicus programme in place, the new Common Agricultural Policy (CAP) requires a transition from OTSC and CWRS on 5%, to an Area Monitoring System (AMS) on 100% of the beneficiaries (farms). The European Commission defined AMS as "a procedure of regular and systematic observation, tracking and assessment of agricultural activities and practices on agricultural areas by Copernicus Sentinel satellite data or other data with at least equivalent value". This AMS will be part of the Integrated Administrative Control System (IACS) in Member States, alongside the existing Land Parcel Identification System (LPIS) and Geospatial Aid Application (GSAA). The AMS will help to improve monitoring of the CAP's performance.

The AMS will monitor the features of interest that are of relevance to policies. Currently, agricultural and rural policies are in favour of smaller features, like buffer strips, unfarmed features and landscape elements. Also, nature-based farming introduces a higher crop diversification with strip-cropping, where the field is not uniformly sown in with one crop but has strips of 3-26 meters with different crops next to each other. Also, mixed cropping and herb-rich grassland practices are part of policies. In identifying, monitoring and rewarding these practices, better data is required.

Although capabilities of satellite-data improve almost every year, it is not (yet) feasible to collect all necessary data with satellites to monitor agricultural performance. Data integration, fusion, annotation and machine learning are required to provide a convincing story on agricultural activity. This is relevant as it is linked to payments, permits and penalties. Satellite data is not fully conclusive when it comes to auditable decisions. Hence additional ground truth, or in situ data is required. Figure 7 provides an overview of techniques used by Paying Agencies for administration and control.

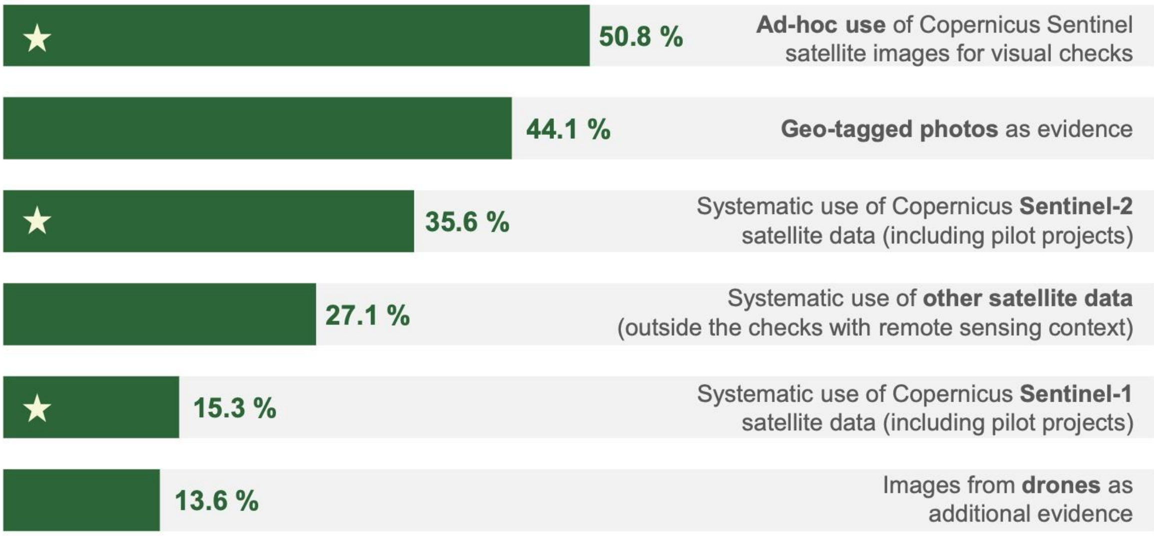

Figure 7: Technologies in use by Paying Agencies in executing administration and control on CAP support schemes. (Source: ECA, EU Finance).

As Figure 7 shows, a significant share of Paying Agencies is looking into geotagged photos to enhance or calibrate the satellite-based data. Processing and storing these images in conjunction with the satellite data is a challenge for many organisations.

Besides a change in data collection and analysis, the introduction of the AMS is also a change in governance. The European Commission aims with AMS to engage a dialogue between farmer and government agency about farm performance on obligations and requirements, aiming at where needed supporting farmers to achieve his goals because that is contributing to national goals.

In the context of the Green Deal and Europe's Farm-to-Fork strategy, Agricultural Monitoring has evolved from monitoring acreages and land use, into monitoring agri-ecological indicators. The indicator framework is still evolving but it becomes clear that more indicators are depending on multiannual data, hence requiring archives of harmonised data.

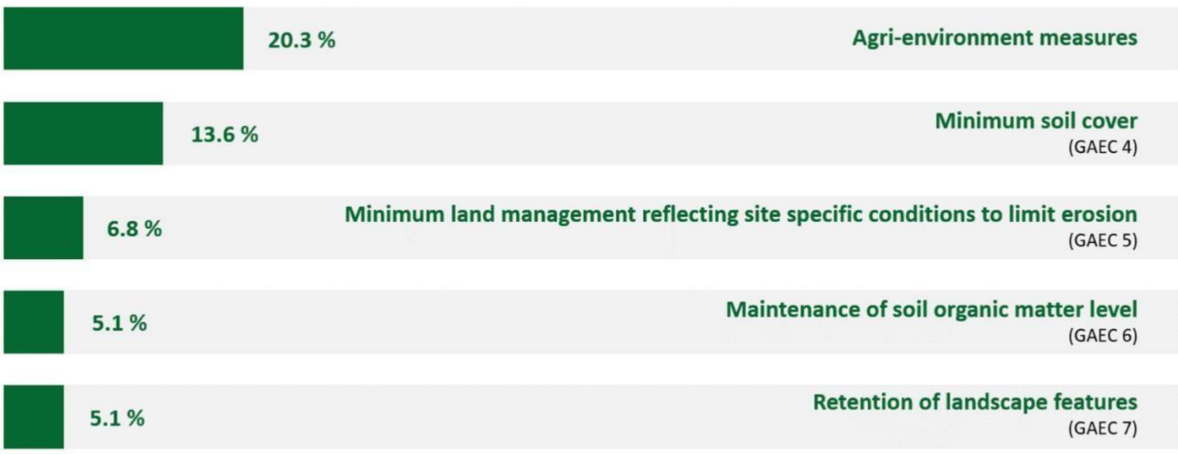

Figure 8: Candidate requirements to be monitored with satellite data by the PA's (GAEC = Good agriculture and environmental conditions) (source: ECA).

The CAP was an early adopter of satellite data for agricultural monitoring and more users have followed. New application domains arise, e.g., for insurances (index insurance, portfolio management, damage assessments), and for Carbon Farming: a new business model for farmers where farmers get paid for sequestrating atmospheric CO_2 in soils and thus delivering Carbon Credits to entities that want to compensate their emissions. Again, the monitoring is linked to payments and contracts.

Besides the nature and quality of the data, an important aspect of agricultural monitoring is the infrastructure and governance of the data. Where is data served, how is it made accessible to monitoring authorities and how can data be persisted (ensured), for instance to be used in audits or disputes on decisions based on these data.

Another very early adopter of satellite data for agricultural monitoring is the USDA, who is already from the mid-70s with Landsat data producing acreage estimations and yield predictions. Over the years this has been further evolved and also has led to the Group on Earth Observations Global Agricultural Monitoring Initiative (GEOGLAM).

Overview most important challenges

Current issues in Agricultural Monitoring are:

- New requirements include agri-environmental indicators, cultivation activity, and field-based performance analysis;
- More precise regulations also require the monitoring of smaller features / objects;
- This triggers new scientific challenges on how to use, combine and fuse sources to reach desired information;
- Increase in the use of Machine Learning techniques to analyse data;
- From mapping to monitoring: More focus on change and spatio-temporal aspects;
- From academic to administrative use: Higher reliability requirements.

Future issues in agricultural monitoring are:

- Introducing the auditing process to satellite data processing, as it will be more used as financial and legal proof;
- More integration and fusion of satellite data and in situ data to improve data quality, to provide training sets and augmentation of data;
- Coupling of agri-environmental indicators to farm management systems and precision agriculture data;
- Collection of in situ data as geotagged photos through drones and mobile phones;
- More use of hyperspectral data and integration of optical and radar data.

Stakeholder overview

Public sector / society:

- Paying Agencies: Tasked with the administration and control of CAP income support and agrienvironmental measures. Paying Agencies are the most relevant stakeholder for development of this theme;

- DG-AGRI: European Commission directorate developing directives and regulations related to the CAP including the use of EO for administration and control. Also providing technical guidance to national paying agencies and control agencies. The most influential stakeholder in this theme;
- National and Regional governments: Ministries, water boards and provinces and other administrations, in particular related to the agri-environmental indicators (biodiversity, soil, environmental aspects etc.) and policy monitoring. These type of stakeholders are strong influencers of this theme as they connect technical achievements in EO to policies and control activities.

Private sector:

- Farmers: the prime subject for this agricultural monitoring. Farmers are very much affected (controlled) but are not influential in the development of services and data needs;
- Insurance companies: Following technological advancements, these companies look for innovative possibilities to develop e.g. index insurances, using crop and soil related indices;
- Agricultural corporates: Monitoring the cultivation season and harvest progress (e.g. sugar beet harvest and logistics);
- Trading companies: Monitoring acreage and yields to anticipate on stocks and prices;
- Other suppliers and processors of agri-food production that want to have better market information on crops, season's progress and yields;
- Media: Information bulletins on changes and developments in agriculture.

Other:

- NGO's: in particular related to climate and environmental performance of agricultural land;

Value adders:

- Several value adding companies: Companies that deliver algorithms and datasets to different customers. To be specific:
    - Neo BV: Amersfoort based company serving the Dutch Paying Agency already for several years with relevant analyses on satellite imagery;
    - TerraSphere BV: Amsterdam based company working on agricultural monitoring on other continents using AI technologies;
    - Sinergise: Slovenian geospatial digital services company, developer of SentinelHub;
    - BioScope BV: farmers owned Wageningen based company delivering benchmarking solutions to farmers and agribusiness;
    - EO4Agri: GeoVille spinoff in Marknesse, developing tools for crop breeders in particular.

Research organisations:

- JRC: The Joint Research Centre of the European Commission is providing DG-AGRI with scientific backstopping on regulations, including the use of EO technology for monitoring agriculture and for administrating and controlling CAP measures;
- EEA: European Environmental Agency is developing and using data sets for monitoring agriculture and its impact on environment and climate;
- GEOGLAM: Group on Earth Observations Global Agricultural Monitoring Initiative, collaboration of research institutes and private sector parties to provide agricultural monitoring everywhere.

EO Science:

- Universities, space and data related research institutes: Large interest in Machine Learning techniques, coupling of EO data to deterministic models and experimenting with sensor types deployed on drones as precursor;
- ESA funded projects like SEN2CAP, SEN4CAP, etc.
- HE funded projects like NIVA, DIONE, ENVISION and many more.

Upstream:

- Satellite data providers: Responding to the changing requirements with new constellations, new sensors and new processing systems to provide analysis ready data.

General technical demands from users

Regulations, policies and other schemes are often inspired by technological advancements, and in return often follow the technological settings. Nevertheless, their general tendency is to want just more than what can be offered by EO, often through a misguiding overselling on the part of EO data suppliers.

In general, every advancement in terms of better resolution in space, time or spectrum is welcomed and absorbed. For agricultural monitoring, the current threshold requirements are:

- Identifying changes in agricultural land – preferably on daily accuracy.
- Identifying (changes in) small objects, e.g., small parcels (<0,2 ha), strips (< 3 m. width), treelines (<5 m. width) etc.
- Wall-to-wall monitoring.

ANNEX VII: Factsheet – Climate mitigation and adaptation

Theme description

Climate change is one of the biggest challenges facing the world. It is also considered essential to use Earth observations (EO) by Remote Sensing, as it has the capability to capture environmental and socio-economic data over a range of spatial, spectral and temporal resolutions on a global scale for this global problem. Within the EU there are two perspectives regarding goals: 2050 and 2030. 2050 is the goal year of the Climate Act, the agreement on the EU's target for emissions and storage. Fundamental to this target is that net emissions should be 0.0 for EU. From an analysis in recent years, a large part of the storage must come from forestry and agriculture. However, agriculture still has emissions. 2030 is an intermediate year with the interim target, -55%. net emission reduction target. We want to have more storage, but that is not possible. Storage capacity depends on physical, chemical and socio-economic factors. There are also developments at artificial carbon capturing, but this is costly.

In this factsheet only the relationships between agriculture and EO are outlined. Agriculture contributes a significant share of the greenhouse gas (GHG) emissions that are causing climate change – 13 % IPCC 2018, 17% OECD 2020 - directly through agricultural activities. In this way it is part of the problem but can potentially be an important part of the solution as well as GHG emissions can be mitigated or stored in soils, or by plants and trees. (OECD, 2020)

IPCC – the worldwide authority on climate change – started off in 1988, but it took quite a long time before climate change was statically proven by scientists and accepted and believed by the general public. Since the Kyoto Protocol (1997), An Inconvenient Truth (Al Gore, 2007) and the Paris agreement (2015) many national governments came into action. Most of them have developed Climate Action Plans in recent years, such as the Dutch National Adaptation Strategies (NAS) in the Netherlands.

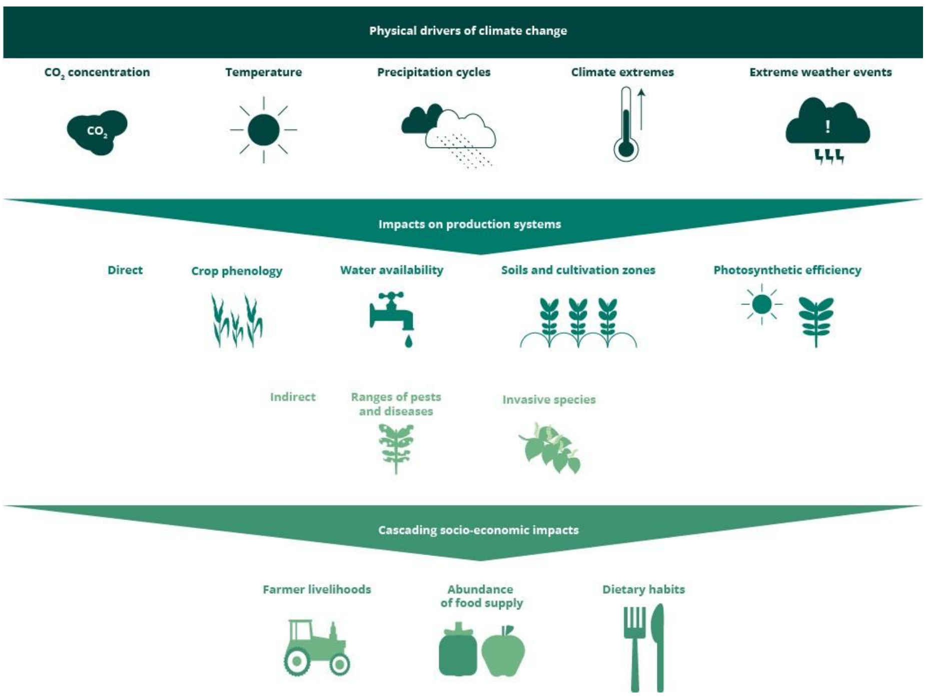

Figure 9: Overview of climate change causes and effects on agriculture, technically and socio-economically.

Climate change has caused challenges for the agricultural sector – and will continue to do so. Increases in temperatures, rainfall variation and the frequency and intensity of extreme weather events are adding to pressures on global agricultural and food systems. Climate change is expected to negatively affect both crop and livestock production systems in most regions, although some countries may also benefit from the changing conditions. The changing climate is also adding to resource problems, such as water scarcity, pollution and soil degradation.

For climate mitigation, GHG emissions worldwide have to drop significantly. By international accord even a 50-60% reduction is mandatory by 2050 compared to 1990 values to prevent more than 2 degrees average warming.

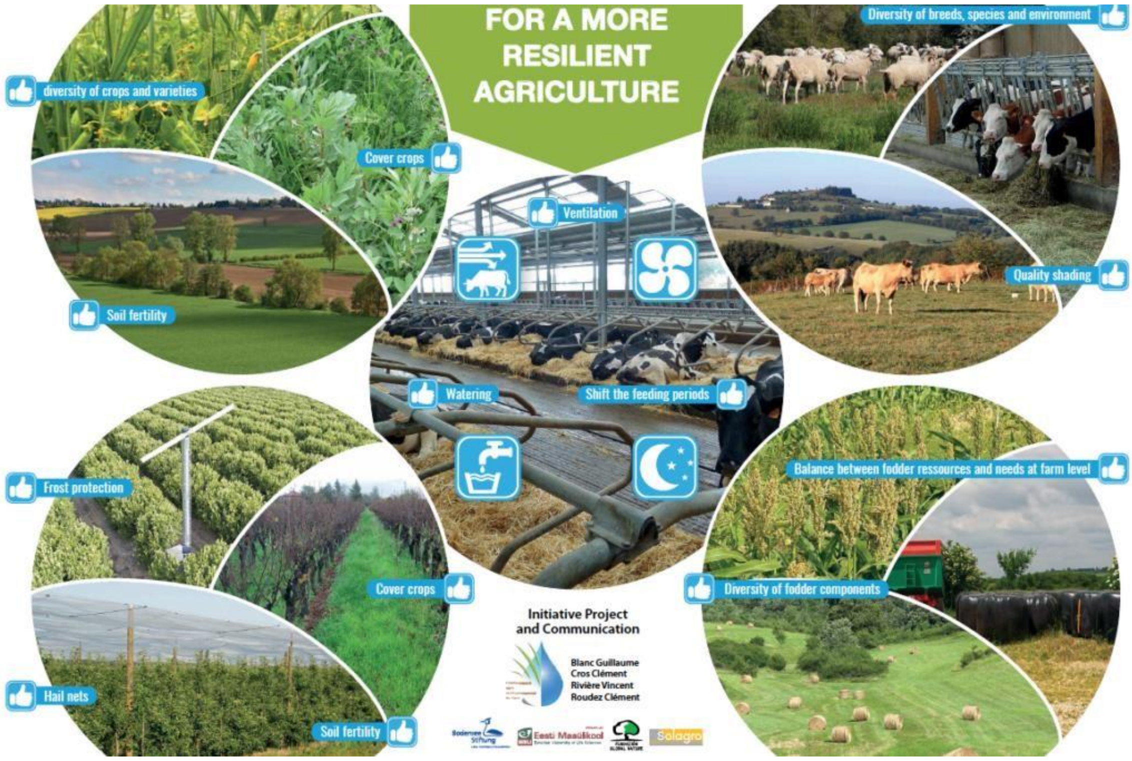

Figure 10: Items related to agriculture and climate mitigation and adaptation.

The main direct agricultural GHG emissions are nitrous oxide emissions from soils, fertilisers, manure and urine from grazing animals, and methane production by ruminant animals and from paddy rice cultivation. Both of these gases have a significantly higher global warming potential than carbon dioxide (300 times and 28 times respectively).

Therefore, the agricultural sector has to cut down on GHG emissions but also adapt to change practices in land management to mitigate climate change but also to become resilient against adverse climate effects

Main dangers for agriculture according to IPCC, FAO, USDA are:

1. Loss of yield due to extreme temperatures, rainfall, storms and soil degradation;
2. More extreme weather events, droughts, less water availability;
3. Shift in length of growing seasons;
4. More frequent pests and diseases;
5. Less sustainable rural areas, more poverty.

EU roadmap climate strategy

Overview most important challenges:

- Validation of emission data is still quite troublesome. Data from member states is checked by the EU Environmental Agency. They also have the task of validating with the approximate reports – here they can also use satellite images. They use satellites for Land use monitoring and land use change – they call this kind of data "activity data". They also look at what is on the land surface (living mass, harvested wood products, etc.).

- There are different categories and methods of reporting. Within one category (e.g., grassland), there are also different *management practices*. These management practices have different emission factors, you can choose from a couple of UNFCCC factors – where a preference exists for the higher tiers:
- Tier 1: Default factors.
- Tier 2: Member state should make their own factor (consistent with IPCC Guidelines). Based on empirical (field) research.
- Tier 3: Emission factor based on non-parametric models in combination with activity data: a model that takes information (e.g., rainfall, temp., animals, management practices, etc.). Using this Tier you can also inform farmers on what to do to improve their practices – which is an end-goal of sorts. Ideally, countries should report their emissions using Tier 3 systems. Sweden claims that everything is Tier 3.
- Many member states don't have the data, EU doesn't expect them to download it themselves, but someone needs to supply this data. Companies or research groups could do this.
- Satellite data can be 'fed' into the raw monitoring, but it needs to be broken down into the land changes and management styles – it should be quite nuanced. The link with the actual policies that should come out is also important!

Agricultural influence/connection with worldwide large climate impact: deforestation. The outcome of the latest climate conference in Glasgow 2021 gave that trees have to be monitored worldwide and deforestation has to stop as from now.

Main issues for the Netherlands: Fossil energy transition for horticulture and methane reduction in intensive animal husbandry. Also the water levels and conservation of heathlands and peatlands, because of prevention of GHG emissions.

Stakeholder overview

Climate mitigation and adaptation does involve all entities and therefore all stakeholders mentioned in the main document. But off course there are many different stakes and implications. Agricultural monitoring will also be used for monitoring climate regulations. In animal husbandry emissions of methane will have high priority in measures and monitoring. For horticulture the trend of zero emission will proceed and will probably become mandatory. For arable farming carbon sequestration, soil health, nutrient balance and reduction of inputs (pesticides and fertilizer) will be hot topics.

General technical demands from users

In this domain "water" has high impact on RS applications. Therefore, there is much expected on development of other methods – hyperspectral – for example. Radar applications show some fine results, but data processing proves difficult. Also, more bands, like the X band are asked for. Also, with respect to water the cloud impact on the quality of images has to be reduced and the automatic cloud detection (esp. very thin layer of cloud).

Also, here users demand higher temporal and spatial resolution. For many topics in agriculture daily new image would be preferable

Machine learning is much expected from. Atmospheric correction is troublesome, this could be done automatically with machine learning techniques. Also, machine learning techniques should be improved.

ANNEX VIII: Verslag workshop, studie satelliet instrumenten gebruikerswensen

16 maart 13.15-16.00 uur in SDG HUB NL Amersfoort (Stationsplein 16)

Deelnemers

Op locatie aanwezig, vertegenwoordigers van: ZuivelNL, WENR, Terrasphere, NEO, RVO, KNMI, ESA, Aeres NL, RIVM, LGN, Corine, AeroVision en NSO.

Aanleiding studie (Kees van Duijvendijk, NSO)

In 2022 vindt weer de ESA Ministerial Conference plaats. Nederland maakt daarin keuzes over de middelen voor de komende drie jaar. Dat geldt voor de Nederlandse bijdrage aan ESA, maar ook voor het nationaal budget. Het grootste deel van het budget gaat naar de ruimtevaart, dat wil zeggen, de zgn. "Upstream" partijen die voor het ontwikkelen van satellieten en satellietmissies staan. Er is vanuit die partijen, en vanuit het beleid, een sterke behoefte om aan te sluiten bij een toekomstige marktpotentie, het zgn. "Downstream" segment. De Netherlands Space Office (NSO), het agentschap dat in Nederland het ruimtevaartbeleid uitvoert en input levert voor het nieuwe beleid, heeft daartoe op zich genomen om die downstream gebruikersbehoefte beter in kaart te brengen. Deze behoeftestudies geven context vanuit gebruikersperspectief (vraagsturing): wat bestaat er al, wat zijn gewenste ontwikkelingen, en wat zijn de alternatieven voor ruimtevaart-instrumenten. Hiermee kunnen beter onderbouwde keuzes gemaakt worden voor verdeling van de middelen. Het komt in deze neer op het beter in kaart brengen van gebruikers, maatschappij en markt. Het gaat ook om innovatie en inspiratiewaarde. Er is een eerste serie studies geweest, over luchtkwaliteit, waterbeheer en waterkwaliteit. Dit is de eerste in de tweede serie, waarin ook 'emissies' en 'veiligheid' nader worden onderzocht.

Naast deze studies heeft NSO ook een survey uitstaan om beter inzicht te krijgen in de 'downstream' achterban.

Er wordt op dit moment vanuit NL geen instrument ontwikkeld de komende tijd. Vanuit Nederland wordt er wel bijgedragen aan "SPEXOne" dat bijdraagt aan NASA's PACE (Plankton, Aerosol, Cloud, Ocean Ecosystem) missie.

Toelichting studie (Sebastian Paolini van Helfteren, AeroVision)

Het doel van de NSO-studie betreft het identificeren en prioriteren van gebruikersbehoeften in het land-agri-voedsel domein – zowel voor nu als in de nabije toekomst. De behoeften worden geanalyseerd voor sectoren, zoals de wetenschap, overheid, en commercieel.

De studie is uitgevoerd op de volgende wijze. Eerst is het land-agri-voedsel domein in zeven thema's opgesplitst. Aangezien er veel overlap is tussen de uitdagingen in deze thema's, zijn de thema's vooral gebruikt ter onderscheid van de gebruikers. Over alle thema's en per afzonderlijk thema is een stakeholder analyse uitgevoerd. Vervolgens zijn per thema de gebruikers en hun behoeften onderzocht middels interviews. Hieruit zijn allerlei uitdagingen in de informatiebehoefte uitgekomen (zie Table 1 van het rapport). Na afloop van de workshop, worden alle resultaten geanalyseerd en wordt het rapport geschreven.

Doel van de workshop

De workshop heeft drie doelen. Allereerst heeft de workshop tot doel om de studieresultaten te valideren: *"zijn de workshop deelnemers het eens met de voorlopige resultaten van het onderzoek?"*. Het tweede doel is om de onderzoeksresultaten te prioriteren. De uitdagingen op het gebied van informatiebehoefte zijn legio en met deze workshop is een start gemaakt om hier orde in te scheppen:

“wat zijn de nice-to-haves en wat zijn de must-haves?". Het derde doel is het schetsen van een roadmap voor de toekomstige vraagsturing voor EO-instrumenten: *“wat moet er gebeuren om de doelen van het land-agro-voedsel domein te halen?”*. Met deze driedeling is de groep aan de gang gegaan.

Eerste deel workshop: Voorlopige uitkomsten studie

De projectgroep neemt kort de opgehaalde challenges op het gebied van informatievoorziening door met de deelnemers. In een eerste rondgang worden er geen omissies geconstateerd. Wat wel node gemist wordt is een maatschappelijk ethisch perspectief op het constant verbeteren van data en informatiesystemen: wie wil dit nou echt? En zijn er ook partijen die nadeel van deze ontwikkelingen ondervinden? Ook is de vraag of de beoogde instrumentatie bijdraagt aan de juiste maatschappelijke opgaven, waarin bijvoorbeeld een bias kan ontstaan omdat het ene wel (makkelijker/ beter) te meten is en het ander niet.

Als input voor het volgende deel van de workshop poneert het projectteam een aantal uitkomsten, ter validatie door de deelnemers:

Stelling: “Satelliet data is meestal een ‘nice to have’, niet een ‘must-have’”

Er zijn al vele succesvolle toepassingen van satellietdata in het domein van Land, Landbouw en Voedsel. Uit de gesprekken blijkt echter dat ook in die succesvolle voorbeelden, satellietdata in de meeste gevallen slechts een deel van de behoefte invult. Voor veel toepassingen is integratie met andere bronnen noodzakelijk of vormt satellietdata een aanvullende rol. De mate waarin de informatiebehoefte ingevuld is in succesvolle toepassingen van satellietdata wordt geschat op gemiddeld 65%, met een bandbreedte van 30% (satellietdata is een added-value) tot 100% (met training of calibratie kan satellietdata 100% van de informatiebehoefte vullen). Er zit wel veel verschil tussen de behoefte tussen de verschillende thema's. In veel toepassingen is satellietdata echter een add-on, een *nice-to-have*, waarmee processen of toepassingen verbeterd worden.

De deelnemers beamen dat satellietdata nog niet in veel thema’s een “eerste levensbehoefte” is van gebruikers. Uitzonderingen daarop zijn bijv. landgebruik en landbouw-monitoring, waarin zonder satellietdata de werkzaamheden onevenredig veel moeilijker zouden worden. Aan de andere kant bijvoorbeeld wordt satellietdata nog relatief weinig gebruikt voor het monitoren van soils and soil dynamics. Daar wordt de informatiebehoefte op andere manieren ingevuld, al zijn satellietdata een goede toevoeging om bijvoorbeeld (aanvullende) ruimtelijk dekkende analyses uit te voeren.

Stelling: “Vraaggerichte innovatie is tot nu toe gering”

De deelnemers vinden de stelling iets te scherp. Vanuit verschillende initiatieven worden (potentiële) gebruikers wel geconsulteerd. Het is vaak ook pas zinvol om commentaar te geven als er al iets is. De vraagsturing zoals die in andere domeinen gebeurd is, zoals bijv. defensie of in de meteorologie, wordt in het domein Land, Landbouw en Voedsel niet gezien. Men vindt het gebruikers-veld ook te breed, met name qua toepassingen kunnen er sterk verschillende eisen zijn. Bij het ontwikkelen van een instrument of missie gaat het vaak om trade-offs, omdat eisen soms niet te verenigen zijn. Een voorbeeld is de roep om grote scherptediepte, maar dan genoegen moeten nemen met minder hoge frequentie. Er zijn altijd compromissen.

Ook wordt geconstateerd dat in het bedrijfsleven, met name door de commerciële satellietdataproviders, wel degelijk scherp gekeken wordt naar welke data aan welke doelgroep geleverd kan worden. Het initiatief voor satellietdata of instrumentontwikkeling ligt nog steeds wel bij de ruimtevaart en haar ‘value adders’, maar in business cases speelt het gebruik een zware rol.

De deelnemers constateren, dat vraagsturing op satellietdata nog geen algemene praktijk is in dit domein, zoals bijvoorbeeld in defensie of meteorologie plaats vindt. In de meteorologie is dat onder andere mogelijk geworden doordat de internationale gemeenschap zich sterk verenigd had (al voor de satellieten in beeld waren) waardoor het ook makkelijker was om een sterke, eenduidige boodschap of wens te formuleren. Als we, zoals bij defensie en meteorologie, specifieke land-agri-voedsel satellieten willen hebben, moeten gebruikers zich meer organiseren. Dit is wel lastig want toepassingen zijn heel divers en minder uniform dan bij eerder genoemde domeinen.

Stelling: "De toekomst ligt bij hyperspectraal en thermisch"

In het hyperspectrale en in het thermische spectrum zijn heel veel ontwikkelingen waarin de deelnemers van de workshop veel vertrouwen hebben. Het zou voor validatie en ontwikkeling van business cases voor ruimtevaart ook erg nuttig zijn om dergelijke instrumenten met een droneplatform te demonstreren. Er is verder een grote behoefte aan spatiale en temporele resoluties waar satellieten voorlopig nog niet aan zullen toekomen, maar die zou kunnen worden ingevuld met drones. De aanwezigen constateren dat er eigenlijk nog veel te weinig interactie is tussen de 'airborne' en 'space' clusters van Remote Sensing. Overigens ook voor de integratie met andere sensoren die voor meer detail zorgen is nog te weinig aandacht binnen de ruimtevaart.

Er zijn wel zorgen om de verwerking, maar er worden verschillende voorbeelden genoemd waar de eerste processing en verwerking al op het spacecraft plaats vindt (Edge computing in feite).

Stelling: "Experimenteerruimte ontbreekt"

Deelnemers beamen dit allemaal. Vaak is de eerste kennismaking met satellietdata pas na lancering van een instrument. Het satellietdataportaal, ooit bedacht als pre-cursor voor de Sentinels van het Copernicus programma, was een voorbeeld van hoe gebruikers ex-ante kennis kunnen maken met de mogelijkheden van een nieuw instrument of programma. Echter, aan deze rol wordt niet veel aandacht meer besteed momenteel.

Stelling: "System- en Service Quality zijn even belangrijk als Information Quality"

Gebruikers kijken niet alleen naar de data maar juist naar het hele plaatje over hoe data als dienst wordt aangeboden. Het gaat dus niet alleen om het instrument, maar hoe het instrument bijdraagt aan de informatiebehoefte. Daar horen aspecten als datalevering, processing en toepassing in processen ook bij. Bovendien weten gebruikers niet wat er allemaal beschikbaar is – of hoe ze bij de informatie kunnen komen.

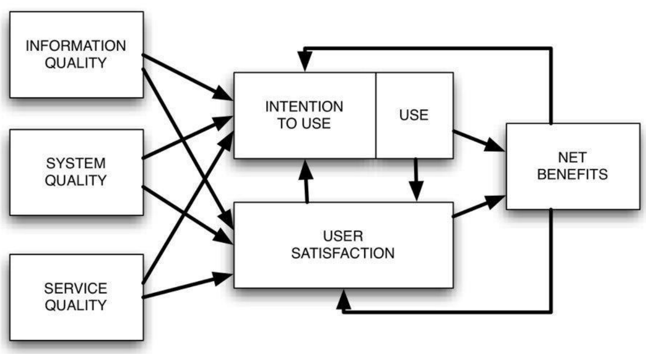

Figure 11: Relaties tussen Service, System en Informations Quality

De deelnemers merken op dat het belangrijk is om twee innovatiesporen te onderscheiden:

1. Échte vernieuwing: nieuwe sensoren/metingen die eerder nog niet konden – "high techinnovatie";
2. Toegankelijkheid tot informatie vergroten: Ervoor zorgen dat gebruikers makkelijker *zelf* geoinformatie kunnen gebruiken/toepassen. Nu kunnen maar relatief weinig mensen sommige dingen -> hoe zorgen we als geo-sector dat meer mensen het kunnen?

Veel gebruikers weten op dit moment niet wat er allemaal is. Omdat het niet in hun gezichtsveld is, weten veel gebruikers welke data er is enwat je met die data kan. Het zou nuttig zijn om dit soort kennis naar de gebruikers te brengen.
Ook doen deelnemers een pleidooi voor Continuïteit: bijv. Landgebruik in Europa is met 10 m resolutie goed te doen, laten we zorgen dat dat nog 30 jaar of langer geborgd blijft.

Tweede deel workshop: Van challenge naar aspecten van informatiebehoefte

In een tweede deel van de workshop werd de deelnemers gevraagd om een inbreng te leveren op de trade-offs en aan te geven welke aspecten van informatiebehoefte relevant(er) zijn. Tijdens een interactieve sessie rangschikten de deelnemers de verschillende challenges op vier aspecten:

- High Spatial Resolution: wat is de (toekomstige) eis op het ruimtelijk detail? Er zit nogal wat verschil in per toepassing. Maar er werd ook geconstateerd dat waar de 10 meter pixel van Sentinel-2 voldoende is voor landbouwmonitoring in Nederland, een dergelijke resolutie in Afrika in veel gevallen te grof is – overigens ook in andere Europese landen. Voor de vaak kleine percelen is 2 meter pixel of beter, vereist;
- High Temporal Resolution: Frequentere overkomst is voor veel (tijdreeks) analyses van belang, al was het alleen maar om de kans op een onbewolkte blik op de aarde te vergroten. Deelnemers noemen onder andere een versnelde lancering van de twee reserve Sentinel-2 satellieten om naar 4x per week overkomst te gaan (in grote delen van Nederland). Andere constellaties, o.a. Planet, laten mogelijkheden zien van hogere frequentie in het beter monitoren van land;
- Zero Latency: de tijd die zit tussen opname en beschikbaarheid voor analyse, wat voor sommige toepassingen kritieker is dan voor andere. Er zit een relatie natuurlijk tussen de opname frequentie en de tijdsvertraging: Frequentere monitoring heeft impliciet ook een lage latency vereiste. In de analyse verder zijn die ook bij elkaar gebracht.
- Interpretability: De mate waarin de data 'voor zichzelf spreekt' en gebruikers de gelegenheid geeft om eenduidige uitspraken te doen met de data. Dit aspect heeft ook overlap met de ruimtelijke en de temporele resolutie.

Deelnemers constateren dat er altijd een verlangen naar betere, snellere en specifiekere informatie zal blijven. De ruimtevaartsector moet dus blijven ontwikkelen, ook omdat alternatieven nog onvoldoende uitkomst bieden. Desalniettemin hebben de deelnemers de challenges op deze aspecten gerankt.

Derde deel workshop, voorgestelde roadmap en conclusies

De workshop, de gestelde doelen en vragen, wakkerden een breed gedeeld besef aan bij de deelnemers dat er weinig invloed en sturing op ruimtevaartinnovaties is vanuit het domein land, agro en voedsel. Dit neemt niet weg dat er wel ontwikkelingen zijn, zoals het Copernicus programma, die een grote impact hebben op de informatievoorziening. Maar hoewel daar wel gebruikers geconsulteerd worden, prevaleert het beeld dat gebruikers onvoldoende invloed hebben op de keuzes die gemaakt worden.

Om als ruimtevaartsector, met satellieten en satellietdata, relevanter te worden voor het domein landagro-voedsel is er behoefte aan verbetering van het instrumentarium, en aan verbreding van de mogelijkheden. De verbeteringen zitten vooral in het beter kunnen meten en monitoren aan het landoppervlak en met name meer aan specifiekere objecten en meer detail. Verbreding zit in nieuwe instrumenten in o.a. het thermische domein en in multi-platform concepten met bijvoorbeeld drones en HAPS (High Altitude Platform Station).

Bij de aanwezigen ontstaat een brede steun om als domein zich meer te verenigen. Door betere uitwisseling van ideeën, mogelijkheden en wensen wordt het ook makkelijker om een gezamenlijke agenda voor ontwikkeling van de informatievoorziening te schetsen. Gezamenlijk kan deze ook bij relevante partijen worden aangedragen om te zien hoe zij – zoals bijvoorbeeld de luchtvaart- en ruimtevaartsector – aan deze agenda kunnen bijdragen.

Voor het domein land-agro-voedsel ontbreekt ook een adequate experimenteerruimte, waar nieuwe instrumenten, nieuwe gebruikers en nieuwe toepassingen elkaar kunnen vinden en business cases kunnen worden uitontwikkeld. Zo'n experimenteerruimte moet bijvoorbeeld ook de grote behoefte aan kalibratie en validatie invullen, bijvoorbeeld door groots opgezette veldcampagnes met een langdurig karakter. Internationaal zou zo'n experimenteerruimte ook grote belangstelling genieten.

Er werd een suggestie aangereikt om met elkaar funding voor zo'n experimenteerruimte en vraagsturing te zoeken, onder andere wellicht bij het Nationale Groeifonds: een fonds gericht op publieke investeringen die bijdragen aan de economische groei op lange termijn. Succesvolle voorstellen moeten aantonen hoe de impact van deze voorstellen op het duurzaam verdienvermogen is, bijvoorbeeld door verhoging van de arbeidsproductiviteit of het creëren van nieuwe activiteiten. Daarnaast zijn er ook andere mogelijke fondsen of investeringsbronnen voor een dergelijke sturing.

De deelnemers zien veel heil om te beginnen om vaker en gestructureerd bijeen te komen, bijvoorbeeld in een verenigingsverband. Hiermee kan 'de gemeenschap' zich vormen en met elkaar strategische doelen formuleren en ontwikkelen.

Slot en borrel

In de workshop zijn de resultaten van de studie naar de informatiebehoeften in het domein land-agrovoedsel beoordeeld. De resultaten zijn bevestigd en waar mogelijk ook voorzien van kanttekeningen. Daarnaast hebben deelnemers een aanzet tot prioritering gegeven waarbij met name het monitoren met hogere frequentie (bijv. dagelijks) de belangrijkste bijdrage aan de informatiebehoefte levert, gevolgd door meer ruimtelijk detail en meer specifieke kenmerken van objecten.

De workshop leverde ook een begin van een agenda of roadmap op. Door beter en vaker de wensen of eisen vanuit de gebruikers kenbaar te maken, verwacht men om ook meer invloed en sturing op de ruimtevaartsector te krijgen om die instrumenten te ontwikkelen waar meer behoefte aan is.

ANNEX IX: Interviewees and workshop participants

Name	Organisation	Theme	Workshop
Gerard Hazeu	Wageningen Research	Land use and -change	Yes
Simon Kay	DG Clima	Land use and -change	
John van Aardenne	EEA	Land use and -change	
Hans Dufourmont	EEA	Land use and -change	
Louwrens van Keulen	ZuivelNL	Land use and -change, biodiversity	Yes
Arnoud Smit	Friesland Campina	Land use and -change, biodiversity	
Menno van Zuijen	Natuurmonumenten	Biodiversity	
Nico de Graff	Gemeente Amsterdam	Biodiversity	
Jan Buijs	GGD Amsterdam	Biodiversity	
Andrea van der Berg	Staatsbosbeheer	Biodiversity, Agro soil and water	
Fenny van Egmond	ISRIC	Agro soil and water	
Ton de Nijs	RIVM	Agro soil and water, biodiversity	Yes
Hans van Leeuwen	STOWA	Agro soil and water	
Gera van Os	Aeres Dronten	Agro soil and water, food security, precision agriculture	Yes
Wim Bastiaanssen	Irriwatch	Agro soil and water	
Jaap Schellekens	VanderSat	Agro soil and water	
Rutger Dankers	WUR	Agro soil and water, agricultural monitoring, precision agriculture, climate adaptation and mitigation	
Rogier van der Velde	Twente University	Agro soil and water, Climate adaptation and mitigation	
Gerbert Roerink	WUR	Climate adaptation and mitigation, agricultural monitoring, precision agriculture	Yes
Jos de Laat	KNMI	Climate adaptation and mitigation	Yes
Marc Middendorp	RVO	Agricultural monitoring	Yes
Marcel Meijer	RVO	Agricultural monitoring	
Eric van Valkengoed	TerraSphere	Food security/ Precision Agriculture	Yes
Ger Snijkers	CBS	Food security/ Agricultural monitoring	

Henk Janssen	NEO	Agricultural monitoring	Yes
Jeroen Verschoore	BioScope	Precision Agriculture	
Gennadii Donchyts	Deltares	Climate adaptation and mitigation, agro soil and water	