FAO work on geospatial applications for agricultural statistics

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Outline

❖ The Global Strategy to improve Agricultural and Rural statistics

❖ Use of remote sensing for agricultural statistics

❖ Monitoring agriculture drought with remote sensing data

❖ Earth Observation (EO) data for SDG monitoring

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# 1. The Global Strategy (GS) to improve Agricultural and Rural statistics

❖ *An international partnership*:
  o For strengthening capacity of developing countries in agri stats
  o Achieved its phase 1 (2013-2018) of implementation
  o Phase 2 (2020-2025) blueprint document is available:
     (http://gsars.org/wp-content/uploads/2018/12/GS-ACTION-PLAN-PHASE-2.pdf)

❖ *Three main components*
  o **Development of cost-effective methodologies at global level**
  o Provision of technical assistance
  o Provision of trainings at country level

Remote Sensing (RS) for agricultural statistics embedded into the overall programme of GS covering various domains
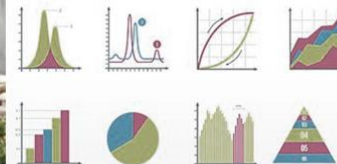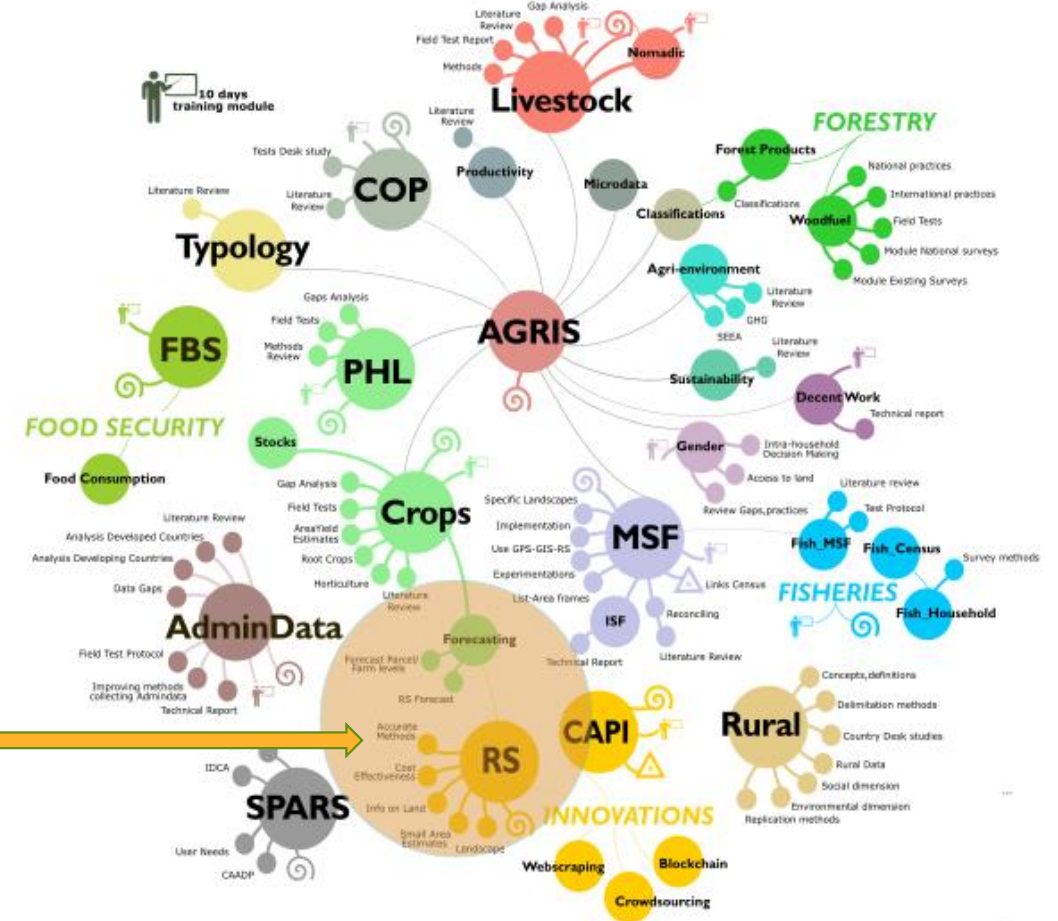
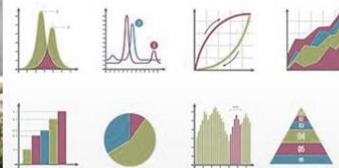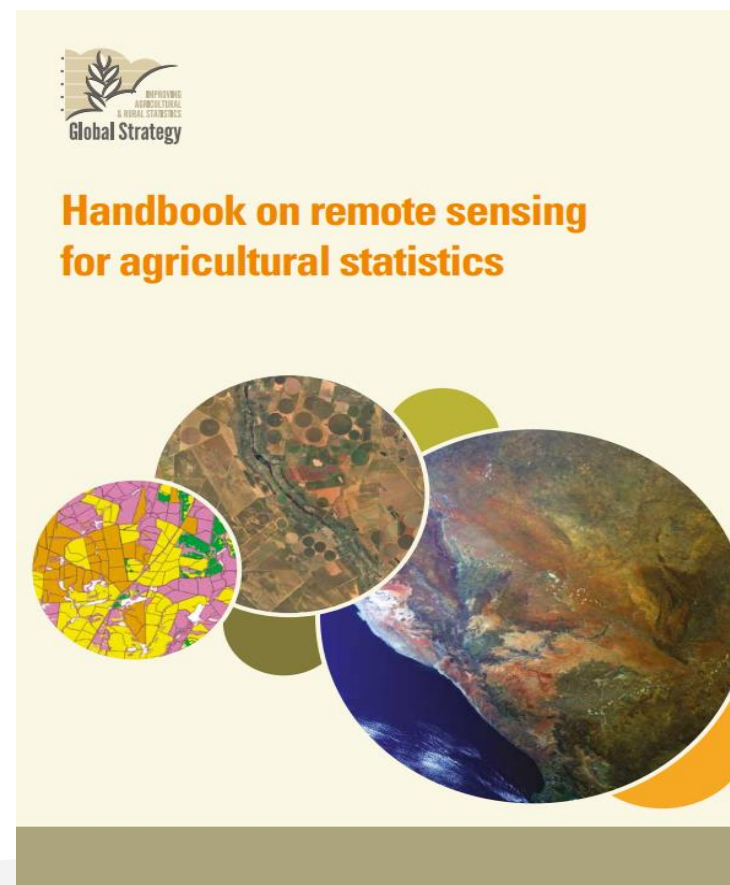Food and Agriculture Organization of the United Nations

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2. Use of remote sensing for agricultural statistics

Under GS-Phase 1: **a handbook on remote sensing for agricultural statistics (2017)** has been developed, covering:

o Efficient and accurate methods for using remote sensing

o Use of GPS, GIS and RS in setting up Master sampling Frames

o Spatial disaggregation and small-area estimation methods for agricultural surveys

o Cost-effectiveness of using RS for agricultural statistics

o Information on land cover in the context of agricultural statistics

(http://gsars.org/wp-content/uploads/2017/09/GS-REMOTE-SENSING-HANDBOOK-FINAL-04.pdf)
GS-Phase 2: Support countries in the use of RS for designing area frames

Handbook on remote sensing for agricultural statistics

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2. Use of remote sensing for agricultural statistics ...

Application 1: Land cover mapping and monitoring

- Land cover maps are often used to support stratification at the sampling design level

- A simple land cover map including a generic cropland category can significantly reduce the sampling variance:

  If a non-agricultural stratum covers one third of an area of interest, a reallocation of the sample on the remaining agricultural strata will provide a **relative stratification efficiency of 1.5 at almost no cost.**
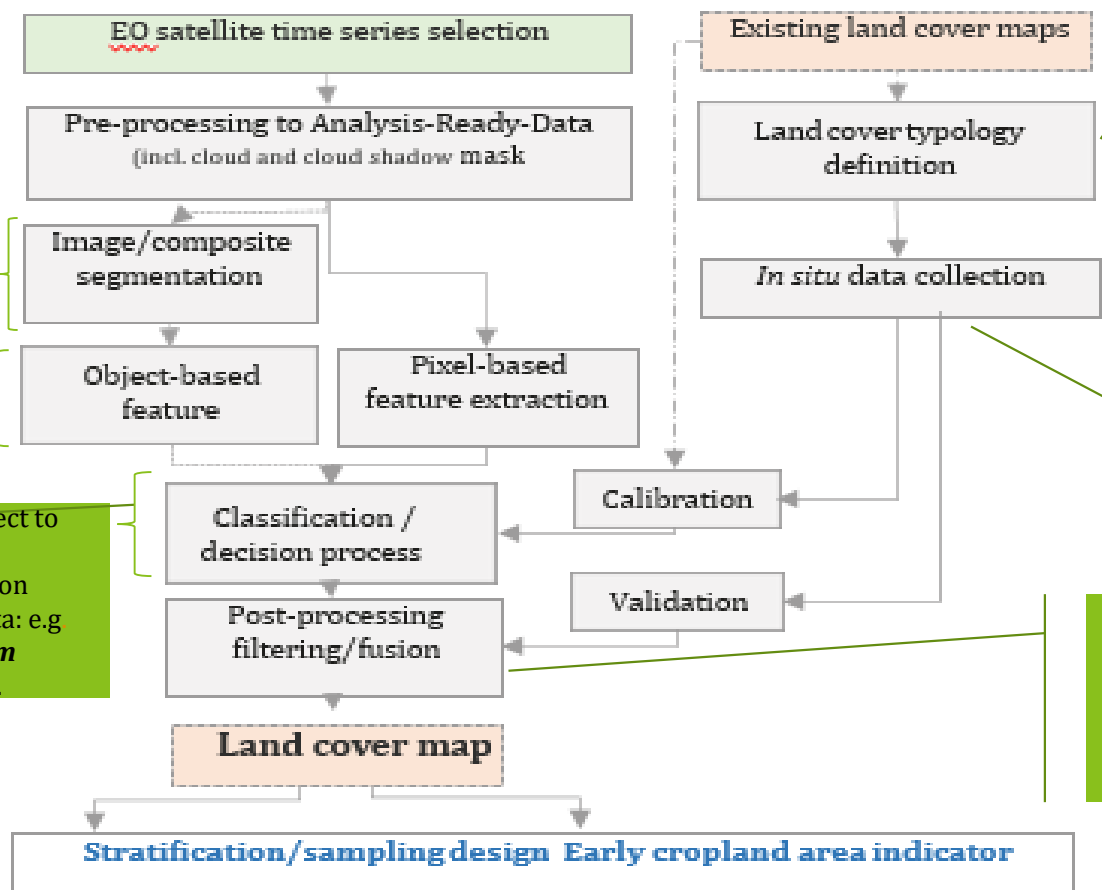
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2. Use of remote sensing for agricultural statistics …

Application 1: Land cover mapping and monitoring …
Generic workflow for land cover mapping from RS

Arable land: Land that is used in most years for growing temporary crops= growing temporary crops (12 months ref. period)+ land that would normally be so used but is lying fallow or has not been sown.
Cropland: Total of arable land + land under permanent crops
Agricultural land: Total of cropland + permanent meadows and pastures (land that is potentially cultivable but is not normally cultivated)
Land used for agriculture: Total of "agricultural land" + "land under farm buildings and farmyards"

Source: World Program for the Census of Agriculture 2020 (WCA 2020; Vol. 1, p. 82)

Other sources of information to support the classification process

```
EO satellite time series selection
        ↓
Pre-processing to Analysis-Ready-Data
(incl. cloud and cloud shadow mask
        ↓
Image/composite segmentation
        ↓
Object-based feature     Pixel-based feature extraction
                ↓
        Classification / decision process
                ↓
        Post-processing filtering/fusion
                ↓
            Land cover map
                ↓
Stratification/sampling design  Early cropland area indicator
```

Existing land cover maps
↓
Land cover typology definition
↓
In situ data collection
↓
Calibration
↓
Validation

Step 1: Discretize the land into pixels by satellite imagery if spatial resolution is not close or less than the size of the land cover elements to be mapped. Otherwise, go to extraction

Step 2: Extract land cover information

Step 3: Allocate every pixel or object to one of the classes of the land cover typology using different classification algorithms for satellite imagery data: e.g *Artificial Neural Network, Random Forests, Maximum Likelihood,* etc.

Step 4: Smoothing land cover map by correcting macroscopic errors and removes the salt-and-pepper effect induced by pixel-based classification, and merge outputs from the ensemble classifier.

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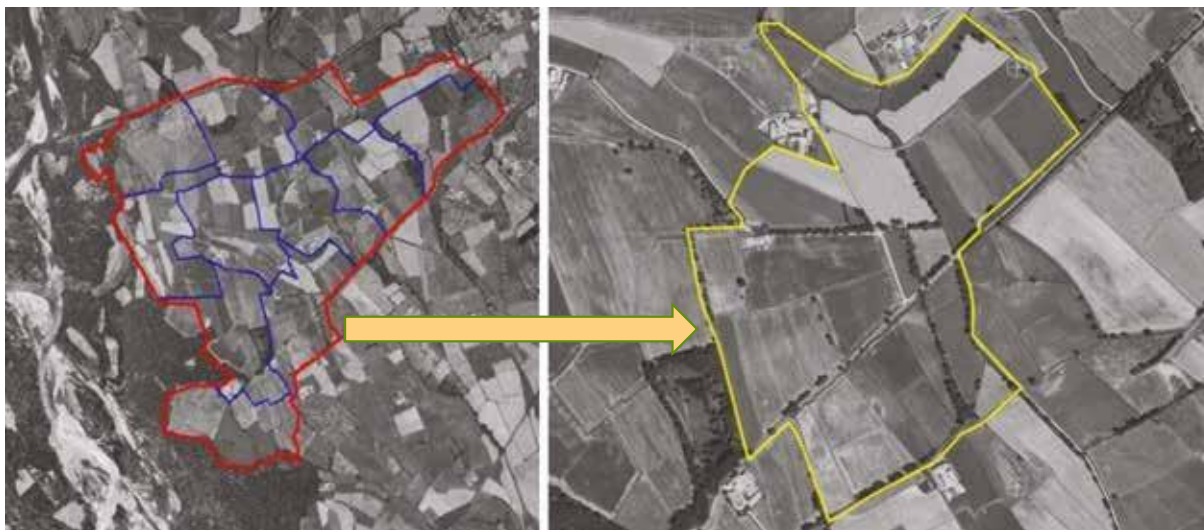# 2. Use of remote sensing for agricultural statistics ...

Application 2: Design of area sampling frames

Sampling units are geographic units: points, lines (transects) or polygons (segments):

❖ **Frames of segments with physical boundaries (rivers or roads)**

Old methodology (1930 USA), still operational.

The delineation of sampling units is based to a **large extent on photointerpretation**, despite the availability of crop classification layers (new tool for stratification). Another possibility to reduce the amount of photointerpretation is to select within a PSUs, a segment :

A PSU having physical boundaries and within which a segment is selected

Strong limitation: countries with small agricultural plots!

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2. Use of remote sensing for agricultural statistics ...

Application 2: Design of area sampling frames

❖ **Frames on regular grids**

Using a geometric grid on a given cartographic projection, usually square segments. RS provides a similar accuracy level as segments on physical boundaries at a lower cost


Overlay of a land cover map onto a sampling grid

If land cover or classified images are available it is possible to compute a crop area indicator for each cell of the grid which is useful to stratify the territory
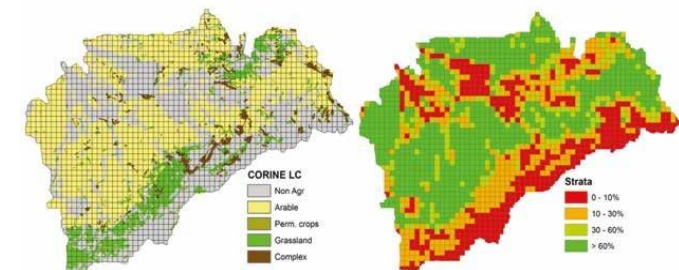
A sampling grid overlaid onto a high-resolution land cover map (left) and a derived stratification (right).
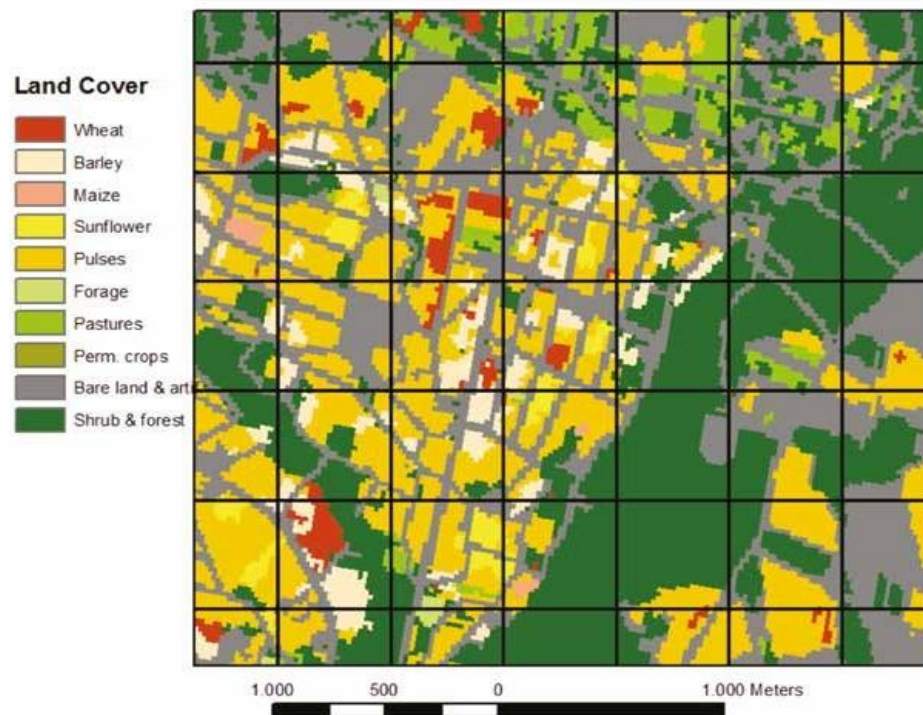
It can yield a relative efficiency of 2 for main crops
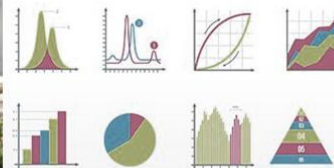
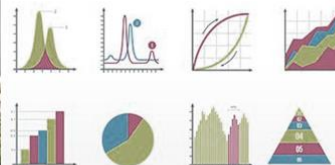# 2. Use of remote sensing for agricultural statistics ...

Application 2: Design of area sampling frames

❖ **Stratification on cropland maps or crop data layers**

A grid of square segments overlaid onto a classified image

The procedure remain the same: on each cell of the grid an indicator on arable land or cropland proportion is estimated

2. Use of remote sensing for agricultural statistics ...

Application 2: Design of area sampling frames
❖ Area frames of points

For area frames of (clustered or unclustered) points or segments with geometric shapes, satellite images are not necessary to define the sampling units, but may be essential for:

- Stratification, in particular when using a two-phase sampling for points with stratification based on photointerpretation of the first-phase sample; and

- Field survey documents: when the location of a point on the image fails to correspond to the location provided by GPS, it is preferable to give precedence to the image, which is more stable and traceable, especially if land cover change is an important target.
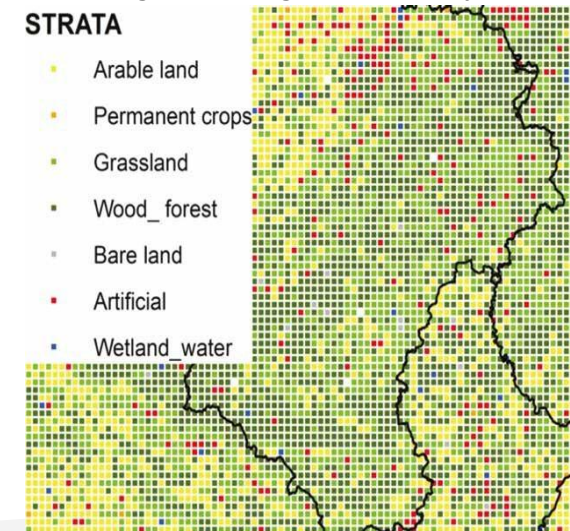

A regular grid of points on a square
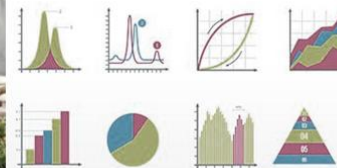segment for a two-stage sampling scheme.

Unclustered, however cost-efficiency may vary
according to travelling costs for surveyors

STRATA
- Arable land
- Permanent crops
- Grassland
- Wood_ forest
- Bare land
- Artificial
- Wetland_water

Stratified first-phase sample

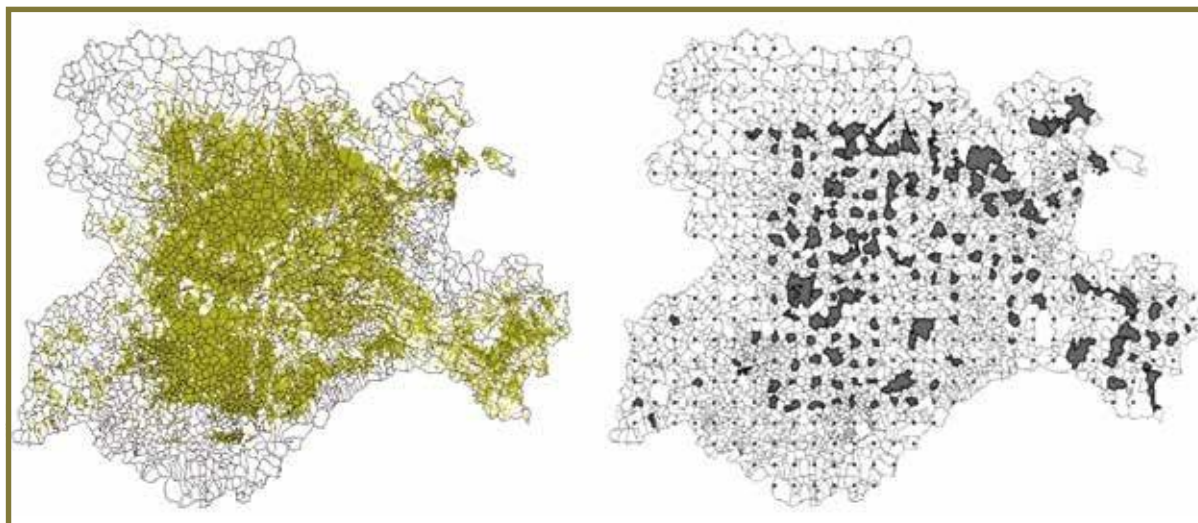**Food and Agriculture Organization of the United Nations**

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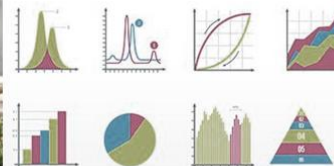# 2. Use of remote sensing for agricultural statistics ...

Application 2: Design of sampling frames
❖ List sampling frames

- The location of the farm is a huge problem!

- Using Enumeration Area (EA)'s as a first-stage sampling units on a GIS can be a solution:

  - EA's may be delineated on topographic maps, scanned and combined with images (for example Google Earth) , providing that quality of spatial resolution and orthorectification is compatible

  - Then, possibility for sampling of EA's with probability proportional to the area, and EA stratification using different possible approaches

Arable land distribution and a systematic sample of communes with a probability proportional to the area of arable land

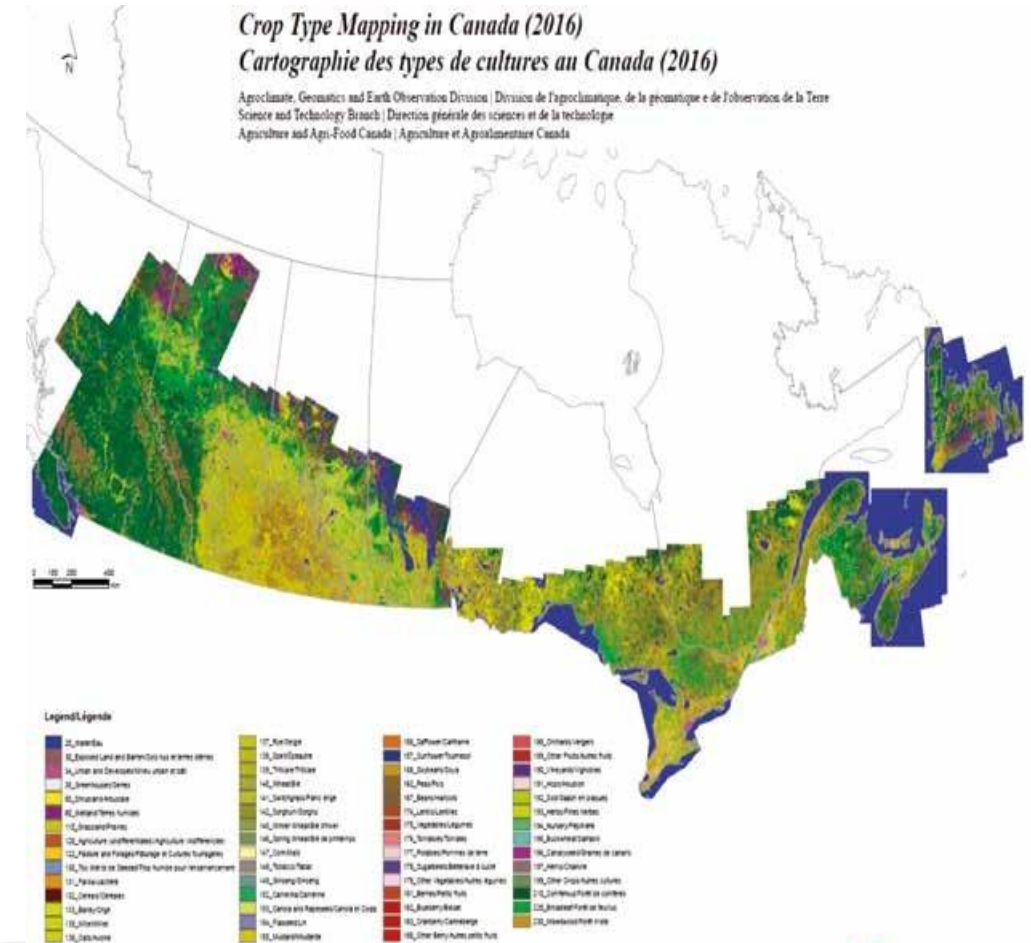Food and Agriculture Organization of the United Nations

2. Use of remote sensing for agricultural statistics …

Application 3: Crop data layers

- Crop Data layers are approaches used for *mapping field-level annual crops using satellite images*.

- In most cases crop maps are generated using supervised classification, requiring a quite complex process of operations and different <u>high-quality input data layers</u>:
    - Ground (in situ) data
    - EO data (optical, radar)
    - Ancillary data

- The methodology is well **adapted to large countries** where basic information (ground data and ancillary data is available), it remains a challenge for developing countries, particularly when plots are small.

Crop Type Mapping in Canada (2016)
Cartographie des types de cultures au Canada (2016)

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Application 4: Crop area and crop yield estimations

Area of interest for FAO in the near future.

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Cost-effectiveness ?

❖ Broadly two categories of costs in the use of remote sensing: costs of image, costs from data treatment (hardware, software, HR training)

❖ Costs have been reduced but still many issues in terms of staff availability and competence: GIS, image analysis, yield modelling, agrometeorology, soil science, crop science)

❖ High/medium/low resolutions images freely available in raw format and as derived products, only Very High Resolution needs to be purchased

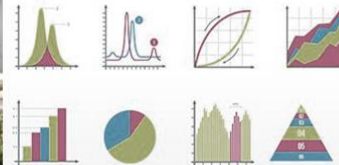**Food and Agriculture Organization of the United Nations**

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2. Use of remote sensing for agricultural statistics ...

Relative gains: Optimization of sampling design

❖ The major and cheaper use of remote sensing for statisticians!

❖ From images or existing maps: the important thing is to be able to create reference maps on which administrative limits can be located

❖ Two interesting cases:

  ○ China, Area Frame of the China's Bureau of Statistics in 10 provinces (1.6 M square Km at USS$ 75 000 for each province), approximately US$ 0.5/ square Km. This is **based on the classification of GF1 and ZY3 Chinese satellite imagery (with a resolution of 2 m).**

  ○ Haïti, Point Area Frame. **Use of a 50-cm resolution archive aerial photographs for establishing a point area frame.**

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3. Monitoring agriculture drought with remote sensing data

The ASI or Agricultural Stress Index represents the percentage of the "**cropped or grassland areas**" within each "**administrative region**", which are affected by "**drought**", as derived from "**EO-observations**" and defined over the course of the "**growing season**".
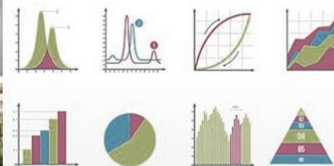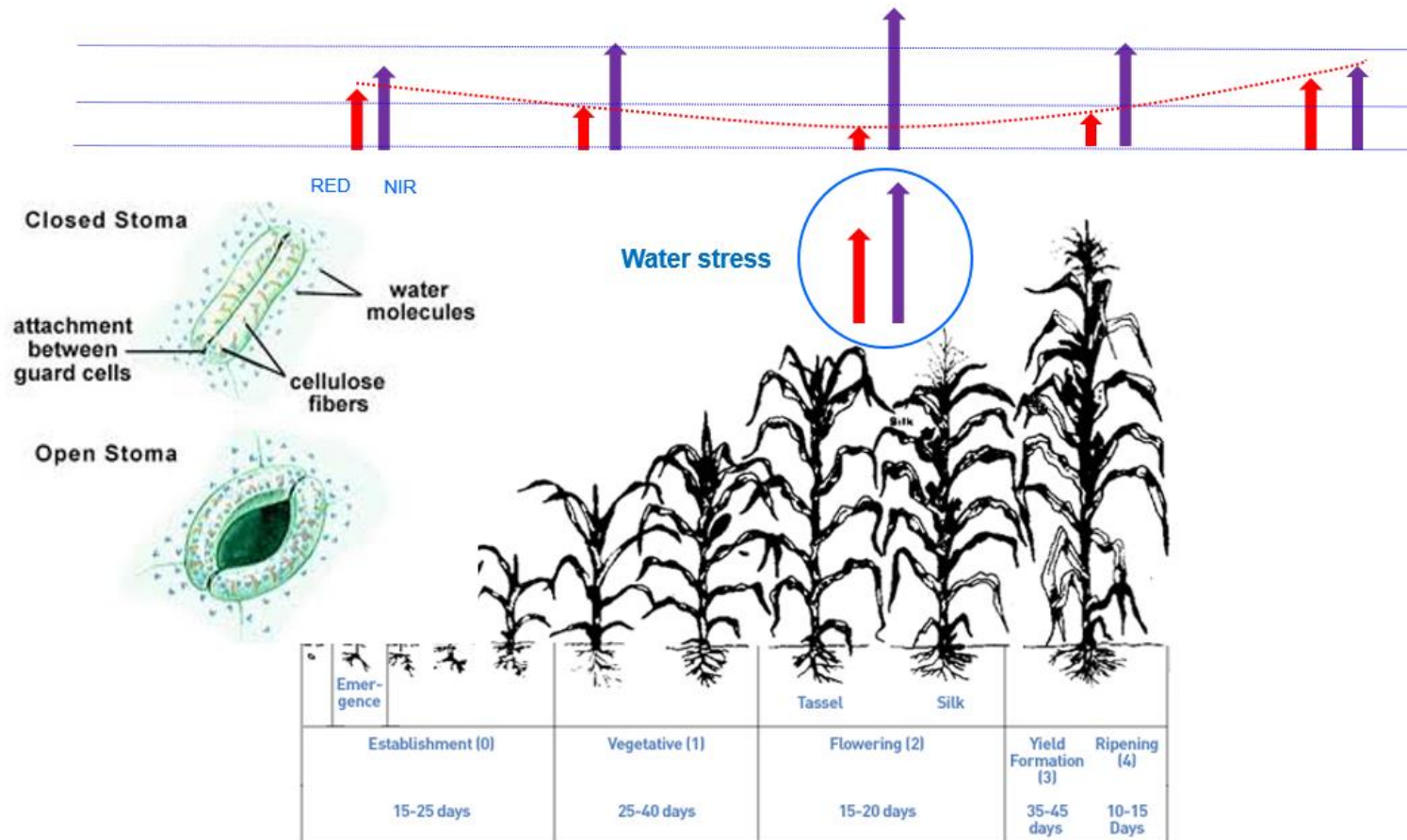
Methodological approach: Electromagnetic energy recorded by the sensor

3. Monitoring agriculture drought with remote sensing data ...

Vegetation Health Index

Agricultural Stress Index System is based on the Vegetation Health Index (VHI) (Kogan et al. 1995)

Vegetation condition index (VCI)

Temperature condition index (TCI)

$$VCI_i = \frac{NDVI_i - NDVI_{min}}{NDVI_{max} - NDVI_{min}}$$

$$TCI_i = \frac{BT_{max} - BT_i}{BT_{max} - BT_{min}}$$

Vegetation Health Index (VHI)

low VHI

$$VHI = a*VCI + (1-a)* TCI$$

high VHI

Weight w is fixed at 0.5 so VCI and TCI contribute equally
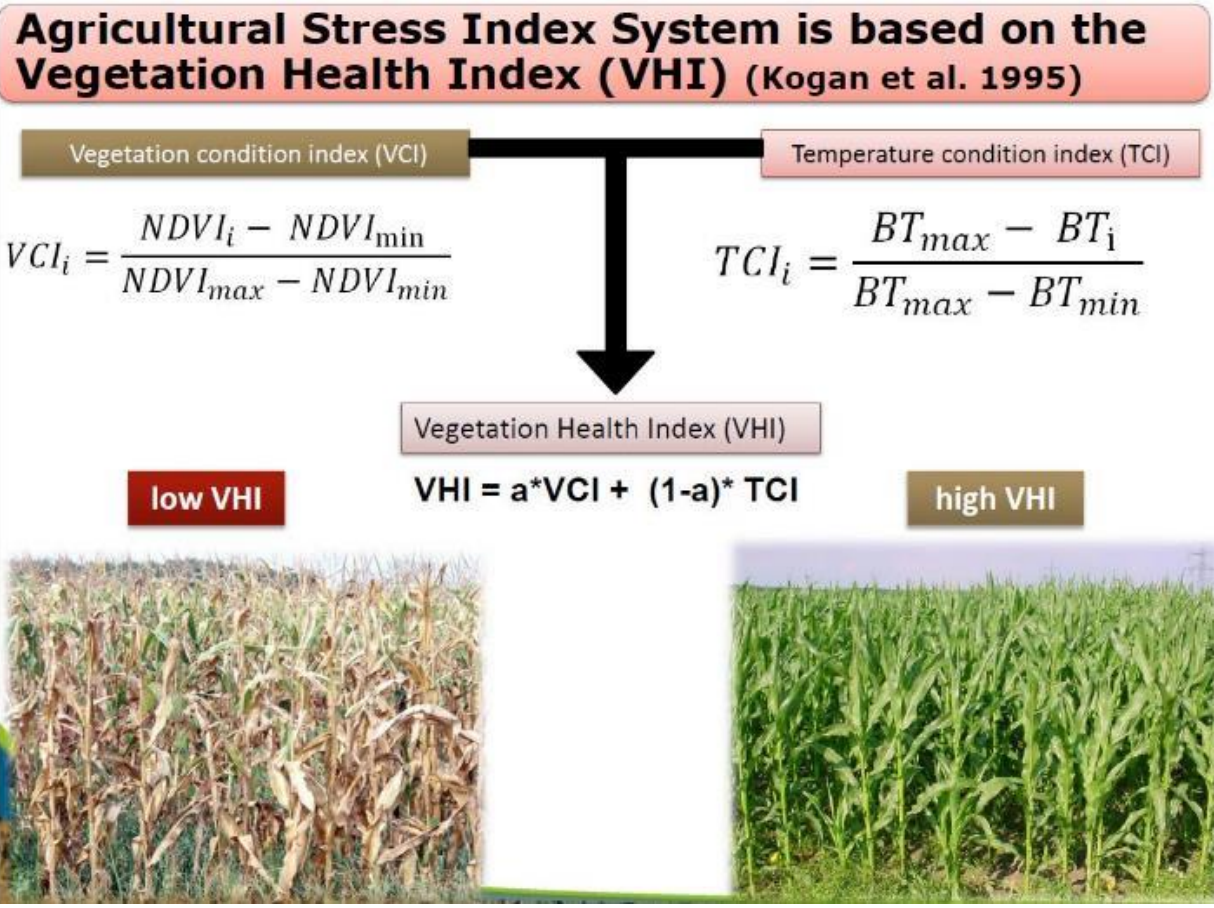
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3. Monitoring agriculture drought with remote sensing data ...

Earth Observation data

"EO-observations"

METOP-AVHRR
- Raw data from EUMETSAT
- Processing at VITO permises
- 10-daily at 1 km
- [2007-TODAY]
- Expected: continued delivery untill mid 2020's
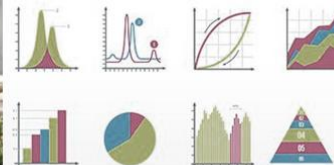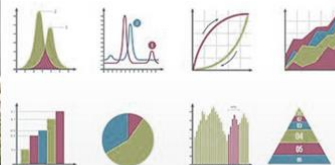- metops10.vito.be

NOAA-AVHRR
- Used in Rojas et al. (2011)
- In ASIS to extent METOP archive
- Center for Satellite Applications and Research (STAR)
- [1984-TODAY]
- Combination of different NOAA's
- Weekly at 16 km
- star.nesdis.noaa.gov

ASIS is based on imagery from the Advanced Very High Resolution Radiometer (**AVHRR**) sensor.

AVHRR is built on the National Oceanic and Atmospheric Administration (NOAA) and Meteorological Operational Satellite (METOP) satellites.

AVHRR on MetOp provides global imagery **twice a day**, at **1 km resolution** (at nadir), in the visible and infrared bands of the electromagnetic spectrum.

MetOp data are shared as decadal (S10) composites derived by the Flemish Institute for Technological Research (VITO) from the Earth Observation (EO) system METOP-AVHRR (**1 km resolution**, since March 2007) and **freely available** via the portal *metops10.vito.be/*.

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3. Monitoring agriculture drought with remote sensing data ...

Earth Observation data ...

NOAA - AVHRR

In order to extend the time series retrospectively, similar AVHRR composites, derived from subsequent NOAA platforms, were acquired for the years **1984 to 2012** from the portal of NOAA-STAR.

In contrast to METOP, these NOAA-composites have a **weekly frequency and a coarser resolution of 16 km**. The METOP-S10 series (starting in March 2007) is extended retrospectively (January 1984) by converting the NOAA-STAR composites (weekly, 16 km) to the METOP standards (dekadal, 1 km).

In both cases (METOP, NOAA) only the composite layers of **NDVI** (Near-infrared and red bands) and **BT4** were downloaded, because these are needed for **computation of the later anomaly indicators**.

3. Monitoring agriculture drought with remote sensing data ...

Methodological flowchart

Fill the missing values (caused by cloud and snow) by interpolated mean values

Composite layers of NDVI and BT4 were downloaded from *metops10.vito.be/* .

Maps indicating the number of growing seasons and their start and end dates are downloaded from *vito-eodata.be/*

Computation of images with the mean value of VHI:
(1) Dekadal mean VHI over the growing season (for early warning detection)
(2) Annual mean VHI over the growing season (to understand the evolution of drought over the long-period).

Based on time series of dekadal, 1 km composites covering 1984-2011; **3 output images:**

1- Per dekad long-term statistics (LTS) with the mean (LTA), minimum and maximum 1984 to 2011 of NDVI and BT4
2- NDVI and BT4 anomalies derived from the comparison of the actual scene with the LTS
3- VCI and TCI combined into the VHI

Fig. 4. Flowchart of the methodology for calculation of the Agricultural Stress Index (ASI). Source: Van Hoolst et al., 2016.

Underlying theory :
The **lower the observed VCI** (relatively low vegetation) and **the higher the TCI** (relatively warm weather), **the lower the VHI.**
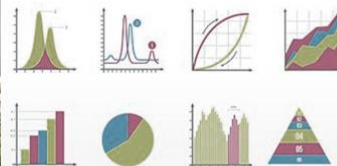
3. Monitoring agriculture drought with remote sensing data ...

Temporal aggregation

This picture illustrates the temporal integration for the annual VHI profile for a single season pixel. In this fictitious example, VHI and its averaged value (μVHI,y,s,t) gradually reduce to dekads 21–23, possibly **due to persistent drought stress**. Subsequently conditions improve (increase in VHI) and μVHI,y,s,t partially recovers. At the end of the green season – the entire period [SOS–EOS] is covered by μVHI,y,s,t – which now gives an overall evaluation of the growing season. This value is assigned to the yearly μVHI,y,s.
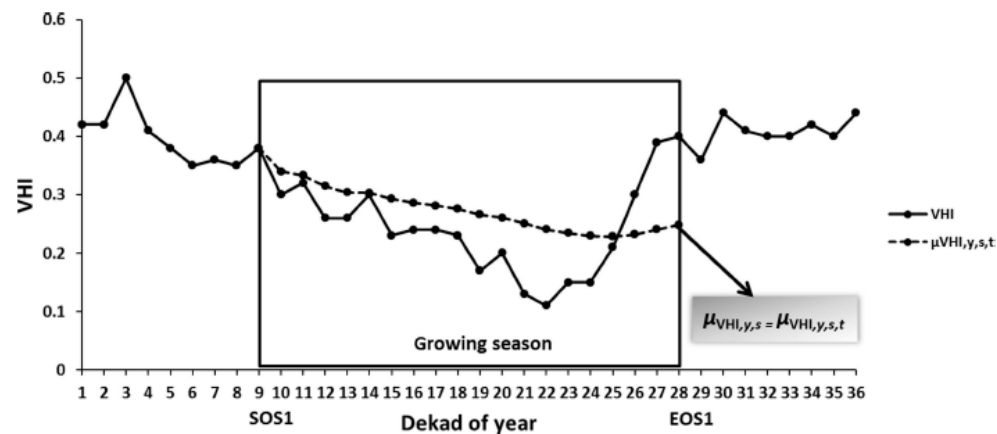
Figure 12. VHI profile of a pixel with a single growing season, and evolution of the derived temporal aggregate $\mu_{VHI,y,s,t}$, which is the mean of VHI over the dekads in the green season (starting at SOS1 and finally ending at EOS1). At the end (EOS1), the variable $\mu_{VHI,y,s,t}$ becomes equal to the static $\mu_{VHI,y,s}$, which relates to the entire year y.

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Spartial aggregation

ASI is computed as **the percentage of crop or grassland pixels** (following the above-mentioned AFIs) within each administrative region with µVHI below a certain threshold (currently set to 35%), and repeated for both seasons (s = 1,2). Thus, in contrast to previous indicators, ASI is an index that **works per region** and not per pixel.
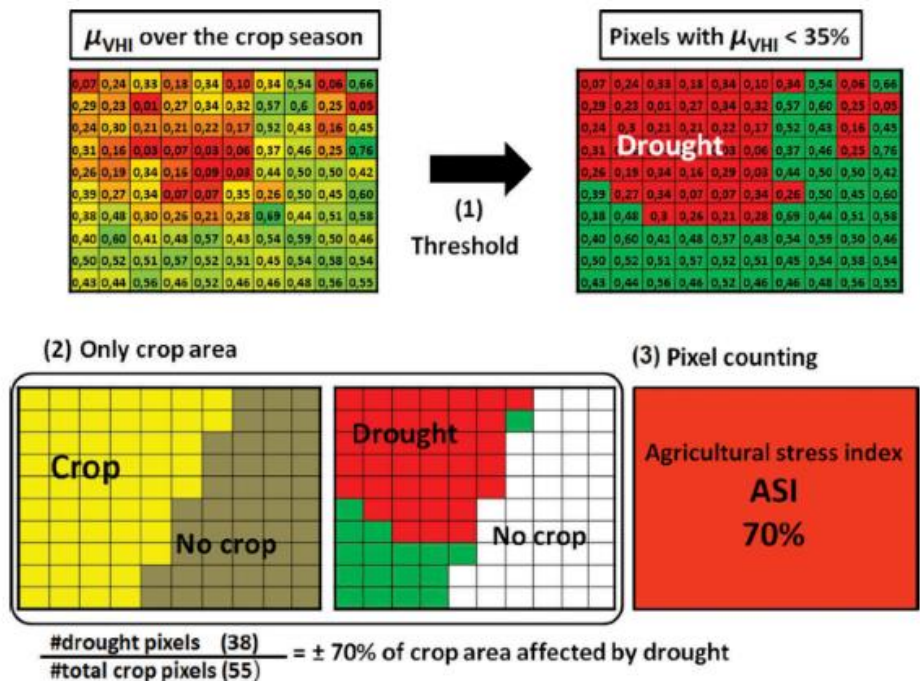

Figure 14. Illustration of ASI calculation for cropland in a fictitious administrative region with 10 × 10 pixels.

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3. Monitoring agriculture drought with remote sensing data ...

Country-Level ASIS

Based on the general methodological principles of ASIS at the global level, FAO has developed **a tool** to help countries monitor agricultural drought more accurately, by allowing the analysis parameters <u>to be adapted to each country's specific agricultural conditions</u>.

Country-level ASIS brings together in a single index the three dimensions that characterize a drought event

- ❖ INTENSITY – Different values of VHI are classified due to their intensity
- ❖ TEMPORAL and SPATIAL (similarly to global ASIS).
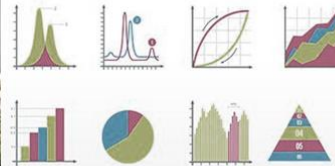
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3. Monitoring agriculture drought with remote sensing data ...

Country-Level ASIS

This tool differs from the global ASIS in the following ways:

- ❖ The VHI<35 threshold used in the global ASIS is adjusted and modified in the country-level version, with <u>thresholds being identified for each crop based on production statistics</u>;
- ❖ User-defined <u>land use and administrative units</u>;
- ❖ The tool enables the user to calculate, midway through the crop cycle, the probability that a specific pixel will be classified as drought-affected at the end of the cycle;
- ❖ The country-level ASIS uses crop coefficients (kc) to better model <u>water sensitivity</u> for each phenological stage of cultivation;
- ❖ the values of the Agricultural Stress Index (ASI) can be used as independent variables to <u>predict agricultural crop yields</u> by multiple regression.

Reference manuals for the tool:

Manual 1 – Data preparation: http://www.fao.org/3/ca2242es/CA2242ES.pdf
Manual 2 – Javatoolbox manual: http://www.fao.org/3/ca2247es/CA2247ES.pdf

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3. Monitoring agriculture drought with remote sensing data ...

FAO support to countries in this area:

FAO is ready to provide technical assistance to calibrate the tool, training people in the use of country-level ASIS and for the interpretation of the different vegetation indexes. During the training process the inter-institutional group will **be given the historical archive (1984-to the present).** Every 10-day FAO **will supply new satellite images** through the **file transfer protocol (FTP).**

The country must have **a computer with a 4TB hard drive as minimum** and it should be just **dedicated to monitoring agricultural drought**. The only software requirement is to have **Java**.

An advantage of country-level ASIS is that it analyses satellite data and generates early warning maps automatically

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4. Earth Observation (EO) data for SDG monitoring

Depending on the type of indicator, FAO is planning to use EO data and Geospatial analysis for one or a combination of the following statistical results:

Ind. Number	Indicator	Direct measure	Disaggregation	Survey design
2.1.1	Hunger		✔	
2.1.2	Severity of food insecurity		✔	
2.3.1	Productiviity of small-scale food producers		✔	✔
2.3.2	Income of small-scale food producers		✔	✔
2.4.1	Agricultural sustainability	✔ Support	✔	✔
5.a.1	Women's ownership of agricultural land			✔
6.4.1	Water use efficiency	✔ Support	✔	✔
6.4.2	Water stress	✔ Support	✔	✔
15.1.1	Forest area	✔	✔	✔
15.2.1	Sustainable forest management	✔ Support	✔	✔
15.4.2	Mountain Green Cover	✔	✔	✔

Direct measure
- o Zonal statistics
- o Pixel counting
- o Image classification

Disaggregation
- o dissymmetric mapping
- o regressions

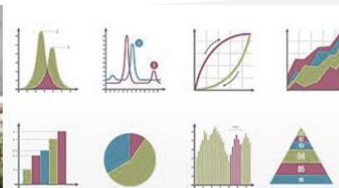Support agricultural survey samples design
- o Stratification
- o Area frames

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4. Earth Observation (EO) data for SDG monitoring ...

Expected deliverables the project include, but not limited to:

❖ Creating global EO database (based on the freely available EO data)
  ❖ Establish a baseline
  ❖ Conduct field visits to collect in-situ geo reference data that will be used for calibration
  ❖ Testing and validation of the EO data

❖ Developing guidelines and methodology that help countries utilize EO data to measure SDGs and data disaggregation
❖ Building the capacity of countries for effective use of the guidelines and methodology
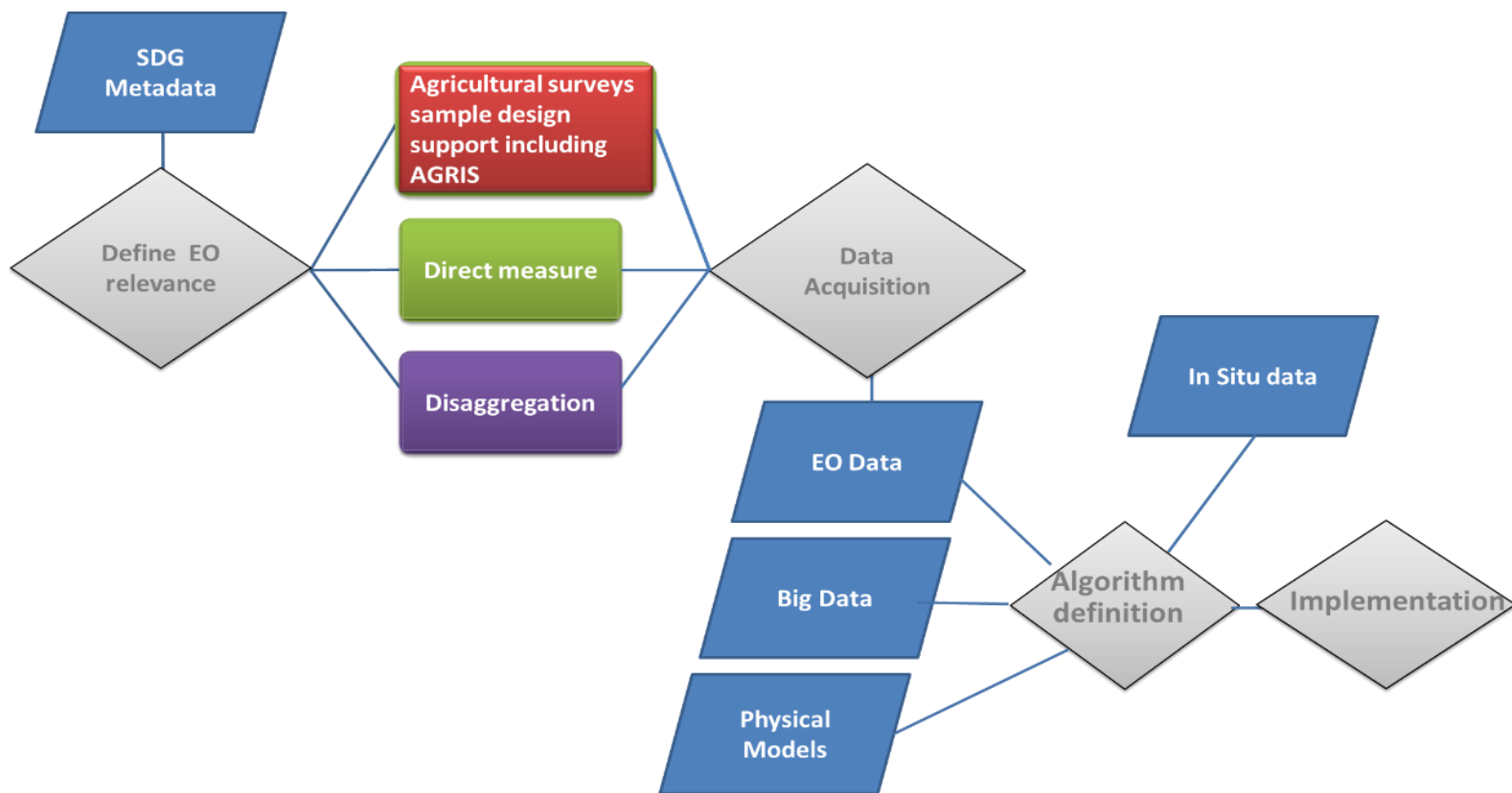
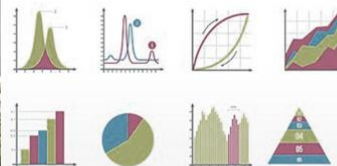Food and Agriculture Organization
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4. Earth Observation (EO) data for SDG monitoring ...

Project implementation approach

- ❖ Use of Public domain EO and/or products through cloud computing platforms and free EO/GIS tools.

- ❖ Use of local in-situ data collected in the field and managed by National Statistical Offices (NSOs) to validate EO products to improve accuracy of SDG indicators estimation and improve national EO products.

- ❖ Designing and implementing technical solutions in close collaboration with NSOs.

- ❖ Capacity building for countries implementing the project .

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Thank you !!!

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