Best Practices Guidelines
for using Remote Sensing for Food Security

Purpose: What information can you get from datasets derived from remote sensing?

Introduction

Datasets derived from satellite earth observation (EO) or remote sensing (RS) offer a cost-effective approach to data collection that supplements datasets from field collection. The number of datasets available from earth observation is rapidly growing. They enable scientists, policy makers and planners to observe changes over time, and to assess the extent to which the trends of these changes differ from historical baselines, offering a better understanding of the world.

Benefits

Satellite earth observation can be used as an independent source of information or in combination with field data collection. Major benefits are:

- Wide range of applications and potential users at multiple levels, from individual farmers to local/national/regional authorities and international organizations
- Integration with field data collection: satellite earth observation can improve sampling and support extrapolation or interpolation of field data points in space and time
- Robust (continuity) , consistent (independent of administrative boundaries), cost-efficient, and objective data collection
- Available in areas that are difficult to access

Considerations

The following considerations should be made when selecting data products derived from RS:

1. What is our area? Spatial coverage – remote sensing has greatly increased the areas of the globe where we can gather information, expanding into remote areas that would be difficult to collect on the ground and allowing the sampling of large areas at once.
2. How much detail do we need? Spatial resolution – resolution of data products can vary, from sub-meter pixels to 10 x 10km pixels. The ideal resolution can be determined by the size of the area under review and level of detail required.
3. How often do we need an update? Temporal resolution – the temporal resolution is the number of times a product is collected (e.g. daily, every 16 days, monthly, annually).
4. For which period do we need data? Temporal coverage – archived datasets allow us to see historical changes on earth, for example, in land cover or primary productivity using remote sensing. This can fill gaps in data that was not collected in the field in the past.
5. What is our budget? Cost-effective – Satellite earth observation can be very cost-effective as compared to field data collection. There are numerous remote sensing derived products that are freely available (see Table 1).

Verification

Just like a photograph, RS and RS-derived products can provide a lot of information without visiting an area in person. The caveat is that a photograph does not provide the same degree of information as visiting a place in person. For example, RS derived products can observe the status, trends, and changes of vegetation cover, but cannot explain the socio-economic drivers of variations in vegetation cover. Due to the above considerations on spatial and temporal resolution and extent, these datasets can be validated on the ground to ensure accuracy when used in a specific location.

The following considerations should be made when using RS-derived products:

1. Spatial resolution
    1.1. The resolution of the data product should meet a scale that is suitable for your work. With a fine spatial resolution, you can distinguish individual fields. With a coarser resolution, you can cover a larger area, but you can no longer distinguish fields. It is possible to collect measurements across various scales and integrate/upscale information. The tradeoff is generally one of cost and processing time – finer resolution products are generally more expensive and require more processing power to analyze.

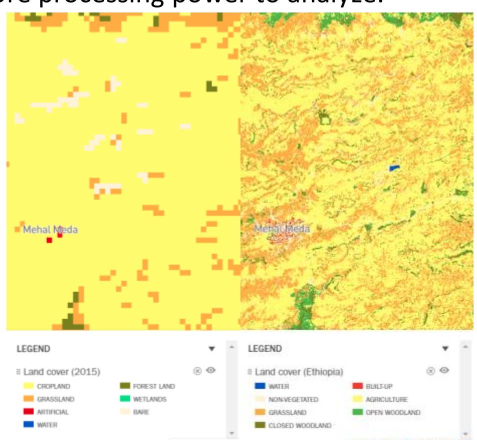

Figure 1: Demonstrating spatial resolution an example of an aggregated land cover from ESA-CCI (300m) (left) and customized land cover product (10m) derived from remote sensing analysis (right).

    1.2. Example 1 - The European Space Agency (ESA) offers annual land cover products with 37 classes at 300m resolution. While these data products have been validated, they may be too coarse if you are looking at small project areas where land cover is changing at a finer spatial scale. ESA also offers a 20m resolution land cover dataset, but this dataset is only available for 2015 and thus cannot be used to track change over time.
    1.3. Example 2 – Many climate datasets, including climate models, have a coarse spatial resolution (kilometers or more) but often a high temporal resolution (sometimes hourly or more). Changes in temperature are generally not drastic over space unless there are large elevational changes, but changes in temperature over time can be large. A finer spatial resolution dataset may not give more information in this case.
2. Temporal resolution

2.1. The appropriate temporal resolution is important to decide the frequency and time frame that is relevant for your work. Generally the higher the spatial resolution, the lower the temporal resolution, and vice versa.
2.2. To look at change of any kind, you will need at least two data products, collected or analyzed using the same methods, at different points in time for comparison.
2.3. Example 1 - if you are looking for land cover changes over time, the ESA land cover data product may be suitable to show national or regional-level changes annually. If you wanted to look at seasonal changes, you would need a land cover product that shows changes more frequently, either semi-annually or monthly. When looking at vegetation trends, you may be interested in change from year to year, but also in changes during each year, e.g. changes during the different growing seasons.

3. Method
    3.1. Many RS-derived products use modelling for analyses of RS datasets. Some of these models are based on physical principles, such as energy balance modeling to determine actual evapotranspiration. Others are more empirical and use ground truth data to train a model as used in supervised classification machine learning algorithms.
    3.2. Example 1 - Datasets like the ISRIC soil datasets, are modeled using soil samples that have been analyzed using the same methodology at the same lab at ICRAF. This ensures a standard approach was followed to collect and analyze the nutrients in the soil. The results of these analyses were used to train a model so that soil properties can be inferred even in areas where no ground data was collected.
4. Approach
    4.1. To obtain information using remote sensing, you have several possibilities:
        4.1.1. Do it yourself. This approach requires in-house expertise. This requires investments in hardware and software, although there are an increasing number of online options and tools such as Google Earth Engine and DIAS (https://www.copernicus.eu/en/access-data/dias processing) and Sen2Agri (http://www.esa-sen2agri.org/ land cover mapping tool).
        4.1.2. Use free, existing products. The Sentinel fleet and the Landsat program have unlocked a large amount of free, high quality and high resolution satellite data. You can download the raw imagery, but very often further processed products such as surface reflectance and higher-level products such as land cover maps and biomass production (https://wapor.apps.fao.org) are also available. These higher-level products require less expertise to utilize.
        4.1.3. Use dedicated portals, such as the one developed for this project: https://foodsecurityiap.resilienceatlas.org/.
        4.1.4. Work with partners. This eliminates the need for processing facilities, image interpretation and product development, but direct access to required information. This comes at a cost but could possibly be cheaper than setting it up from scratch.
5. Feedback
    5.1. Once you have selected and validated a product (see next section for more information on validation), there are three options:
        5.1.1. Use the product – Assuming the product is accurate and has the appropriate temporal and spatial resolution to fit the needs of your work.

5.1.2. Use the product, after re-running analysis using ground-truth data collected from field or to produce a product for your area of interest from existing analyses as described in Table 2.

5.1.3. Do not use the product – if the product is inaccurate or does not reflect the conditions on the ground in your area of focus.

Validation

To design and perform ground truthing of datasets there are several considerations essential to ensuring high data quality and relevance. The validation must avoid bias and measure uncertainty so that the characteristics of a dataset can be assessed.

1. Understanding performance characteristics
   Validating datasets helps to identify different types of possible errors in the data. The scale, age, and formatting of data can degrade data quality. The level of accuracy and precision depends on the application of the dataset. There are tradeoffs associated with collecting data at very high levels of accuracy or precision. These tradeoffs include:
   1.1. Cost

Validation will incur costs in both time and finances that must be incorporated into the available project budget. The investment in validation will ensure higher accuracy products.

1.2. Scale
- 1.2.1. Pixel scale – compares the product with an independently observed data at the same time and location
- 1.2.2. Whole product – the process of validation an entire remotely sensed product by temporal or spatial pixel-by-pixel (or sampling) product validation where observation and validation occur continuously or are obtained within a heterogenous region
- 1.2.3. High resolution – these products are validated using Modulated Transferring Function (MTF), radiation quality, geometric quality and ground pixel resolution.

1.3. Resolution
- 1.3.1. Higher resolution datasets will create higher level of detail required for validation, as noted above.

1.4. Precision vs. Accuracy
- 1.4.1. Trueness – estimate of systematic error (requires reference value)
- 1.4.2. Precision – the level of measurement and exactness of description
- 1.4.3. Accuracy/certainty – the degree to which information matches true or accepted values.

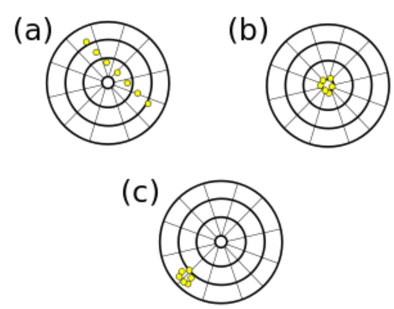

Figure 2. (a) Is neither precise nor accurate (b) is precision and accuracy (c) is precise but inaccurate.

Sampling framework for validation

1.1. Sampling methods - There are several sampling methods (Simple random sampling, stratified sampling, ordinary kriging spatial sampling, mean of surface with non-homogeneity (MSN)) where RS products can be validated.

   1.1.1. Example 1 – a stratified sampling (figure 3) allows for an equal representation of validation points within each land cover category, where points are randomly distributed across each land cover category proportional to the amount of land covered by each land cover category.

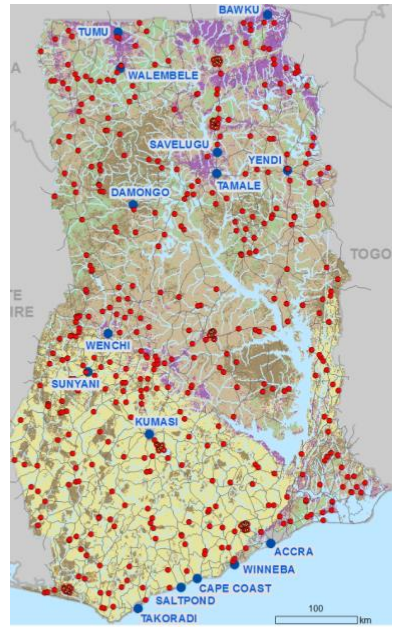

Figure 3. Example of a stratified sampling framework from the Vital Signs protocol

1.2. Sampling units

   1.2.1. Elementary sampling units (ESU) – capture the variability of the product across the study site; it can be determined from existing land cover, vegetation or surface reflectance map

   1.2.2. Secondary sampling units (SSU) – distributed across the ESU representing locations where measurements are recorded, these locations can be selected by various designs including fixed pattern, transect, random sampling.

1.3. Timing - The field data collection should be aligned to the satellite acquisition dates and preferably be within one week from the time the satellite collects the imagery. This time may change depending on the data product.

   1.3.1. Example 1 – if you are validating a specific crop type, you must visit during the growing season while the crop is still growing.

   1.3.2. Example 2 – if you are validating a product that models something that can change more frequently, e.g. water levels, the ground truth data may need to be collected as close to the time the RS product was collected as possible due to fluctuations in water levels.

1.4. Extent - The sampling design for ground-truthing measurements is determined by the footprint of the field measurements and the up-scaling process used to integrate the field measurements and high-resolution imagery.

1.5. Access – The ability to access your sites for validation should also be considered if you are going into the field for ground truthing.

   1.5.1. Example 1 – the sampling framework can be developed to be accessible near road networks

   1.5.2. Example 2 – if there are budget constraints, aerial imagery can be used for validation if the years of validation are available

If your project area for the GEF-Integrated Approach Programme for Food Security work could benefit from the use of customized remote sensing analyses, ground truthing/validation of datasets, interpretation of outputs or capacity building on the use of tools, please contact the HUB collaborative team at Rodrigo Ciannella <R.Ciannella@cgiar.org> and copy the general PCU email for the GEF-IAP-FS Project <GEFIAPFS.PCU@cgiar.org>.

Table 1. Freely available datasets with global or continental coverage

Indicator	Title	Spatial resolution	Temporal resolution	Coverage	Source / Notes	License	HUB Contact
Land cover	Land cover	300 m	Annual	All IAP countries, 1992 – 2015	European Space Agency Climate Change Initiative (CCI). Land cover, land surface seasonality products and open water bodies.	Freely available under CC by-SA 3.0 license	EO4SD - GeoVille
Land cover	Land cover (30 m)	30 m (10-20 m, where resolution of Sentinel data is available)	Years 1 and 4 of project	All IAP countries	Produced by CI in collaboration with regional partners. Both annual (two time points) and land cover degradation layers will be provided.	Freely available under CC by-SA International license	CI
Productivity	Above ground biomass production	250 m	Annually (2010-2016)	All IAP countries	FAO WaPOR	Freely available under CC by-SA 3.0 license	EO4SD – eLEAF
Climate	Actual Evapotranspiration	250 m	2010	All IAP countries	FAO WaPOR	Freely available under CC by-SA 3.0 license	EO4SD - eLEAF
Productivity	Gross Biomass Water Productivity	250 m	Annually (2010-2017)	All IAP countries	FAO WaPOR	Freely available under CC by-SA 3.0 license	EO4SD - eLEAF
Productivity	Land productivity	250 m, 8 km	Annual	All IAP countries, 2001 – present at 250 m, 1982 – 2015 at 8 km	Trends.Earth, produced following UNCCD SDG 15.3.1 GPG, and MODIS MOD13Q1-coll6 or AVHRR GIMMS. Broken into five classes consistent with UNCCD SDG 15.3.1 GPG	Freely available under CC by-SA 4.0 license	CI

Indicator	Title	Spatial resolution	Temporal resolution	Coverage	Source / Notes	License	HUB Contact
Soil properties	Soil organic carbon	250 m	Annual	All IAP countries, 1992 – 2015	Trends.Earth, drawing on ESA CCI, SoilGrids, produced following UNCCD SDG 15.3.1 GPG. Both annual and soil organic carbon degradation layers will be provided.	Freely available under CC by-SA 4.0 license	CI
Climate	Precipitation (current and historical)	.05°	5-day, monthly, annual, climatology	All IAP countries, 1981 – present	Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS). Derived change products will also be provided.	Public domain	CI
Climate	Precipitation and temperature (projected future)	.25°	Aggregated into projections for 2040-2060, and 2080-2100	All IAP countries	NASA Earth Exchange Global Daily Downscaled Projections, processed by CI into derived products.	Public domain	CI
Climate	Carbon emissions due to deforestation	30 m	annual	All IAP countries, 2000 - present	Trends.Earth, drawing on Hansen et al. (2013) Global Forest Change data, ESA CCI, Intact Forest Landscapes, IPCC Climate Zones, and IPCC GPG-LULUCF	Freely available under CC by-SA 4.0 license	CI
Food security	Famine Early Warning System (FEWSnet)	Polygon shapefiles	Quarterly	All IAP countries, except Burundi, Eswatini, Ghana or Senegal	USAID	Freely available under CC by-SA 4.0 license	NA

Table 2. Custom datasets in select IAP countries or project sites (please contact the Hub contact for more information).

Indicator	Title	Spatial resolution	Temporal resolution	Coverage	Source / Notes	License	HUB Contact
Agriculture	Irrigated areas	10 m	2017	Malawi	ESA EO4SD/DHI GRAS	DHI GRAS	EO4SD – DHI GRAS
Productivity	Biomass production	30 m	2013 (Ethiopia) and 2017 (Ethiopia & Burkina Faso); Monthly or Annually	Project areas for Burkina Faso/Ethiopia	ESA EO4SD/ eLEAF	eLEAF	EO4SD - eLEAF
Soil properties	Potential soil erosion risk (water based)	30 m	2017	Project areas for Burkina Faso/Ethiopia	ESA EO4SD/ GeoVille	GeoVille	EO4SD – GeoVille
Climate	Actual Evapotranspiration	30 m	2013 (Ethiopia) and 2017 (Ethiopia & Burkina Faso); Monthly or Annually	Project areas for Burkina Faso/Ethiopia	ESA EO4SD/eLEAF	eLEAF	EO4SD - eLEAF
Climate	Evapotranspiration deficit	30 m	2013 (Ethiopia) and 2017 (Ethiopia & Burkina Faso); Monthly or Annually	Project areas for Burkina Faso/Ethiopia	ESA EO4SD/ eLEAF	eLEAF	EO4SD - eLEAF
Productivity	Land productivity	30m, 250 m	2018	Trend 1999-2018 Project areas for Ethiopia at 30 m; trend 2001-2018 at national scale for Burkina Faso at 250 m	ESA EO4SD/DHI GRAS	DHI GRAS	EO4SD – DHI GRAS