An overview of available satellite data and services

EO4SD consortium, presented by Rolf A. de By (ITC, University of Twente)
The consortium of EO4SD – Agriculture and Rural Development

The Netherlands

Service provision

Data integration

Capacity development

Denmark

Austria

Belgium
Remote sensing

... is the science of acquiring information about the Earth's surface without actually being in contact with it.

A: Source of energy
B: Interaction with atmosphere
C: Interaction with earth surface
D: Recording energy
E: Transmission, reception, processing
F: Analysis
G: Application
Ready for take-off

- To get there, first steps are:
  - identify observation requirements
  - build sensor & design satellites
  - get rocket to send each satellite into a (pre-defined) orbit
Space: a busy place

In 1957, Sputnik 1, the first ever satellite, was launched into space by the Soviet Union.

Since then, 7,900 satellites were launched into space.

In 2017, there were 4,635 satellites orbiting our planet.

There were 357 satellites launched in 2017 alone.

In the next 3 years, 1,300 satellites will be launched.

Infographics from https://spaceoneers.io
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Infographics from https://spaceoneers.io

Status on 31-7-2017

WHO OWNS THEM?

U.S.A: 803 satellites (46%)
CHINA: 204 satellites (11%)
OTHERS: 589 satellites (34%)

Russia: 142 satellites (8%)

~215 European (12%)

Infographics from https://spaceoneers.io
Copernicus programme

- The world's largest single earth observation programme, directed by the European Commission in partnership with the European Space Agency (ESA).

- Headed by the **European Commission** (EC)
  - Acting on behalf of the European Union, setting requirements, managing the services

- in partnership with the **European Space Agency** (ESA)
  - Provision of 30 satellites (**Sentinels**) for the operational needs, space segment & ground segment.

- Objectives:
  - Global, continuous, autonomous, high quality, wide-range EO capacity.
  - Providing accurate, timely and easily accessible information for, a.o. improving the management of the environment, understanding and mitigating the effects of climate change, and ensure civil security.
Long-term (decadal) continuous, consistent data
Copernicus dedicated missions: Sentinels

<table>
<thead>
<tr>
<th>Mission</th>
<th>Description</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sentinel-1 (A/B) – SAR imaging</td>
<td>All weather, day/night applications, interferometry</td>
<td>2014/2016</td>
</tr>
<tr>
<td>Sentinel-2 (A/B) – Multi-spectral imaging</td>
<td>Land applications: urban, forest, agriculture,... Continuity of Landsat, SPOT</td>
<td>2015/2017</td>
</tr>
<tr>
<td>Sentinel-3 (A/B) – Ocean and global land monitoring</td>
<td>Wide-swath ocean color, vegetation, sea/land surface temperature, altimetry</td>
<td>2016/2018</td>
</tr>
<tr>
<td>Sentinel-4 (A/B) – Geostationary atmospheric</td>
<td>Atmospheric composition monitoring, trans-boundary pollution</td>
<td>2021/2027</td>
</tr>
<tr>
<td>Sentinel-5 precursor/ Sentinel-5 (A/B) – Low-orbit atmospheric</td>
<td>Atmospheric composition monitoring</td>
<td>2017/2020/2027</td>
</tr>
<tr>
<td>Sentinel-6: Jason-CS (A/B) – Altimetry</td>
<td>Sea-level, wave height and marine wind speed</td>
<td>2020/2023</td>
</tr>
</tbody>
</table>
Copernicus constellation deployment schedule
Official Sentinel website

- [https://earth.esa.int/web/sentinel/home](https://earth.esa.int/web/sentinel/home)
Sentinel-1: launched April 2014 and April 2016

- Constellation of two satellites (A & B) in the same orbital plane (180° phased in orbit)
- C-Band Synthetic Aperture Radar
- 7 years design life time (up to 12 years)
- 698 km height, 6-day repeat cycle for constellation

- Applications:
  - monitoring sea ice zones and the arctic environment
  - surveillance of marine environment and security (e.g., oil spill monitoring, ship detection, wind, wave, current monitoring)
  - monitoring of land surface motion (subsidence, landslides, etc.)
  - support to emergency/risk management (e.g., flooding, etc.) and humanitarian aid in crisis situations
  - mapping of land surfaces: forest, water and soil, agriculture, etc.
Sentinel-1: SAR acquisition modes

- Multiple modes
- But consistent observations at same mode
**Sentinel-1 observation scenario**

- Sentinels are operated via a pre-defined background observation plan published ahead of every repeat cycle as kml format at: https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1/observation-scenario

![Sentinel-1 Constellation Observation Scenario: Mode - Polarisation - Observation Geometry](image)

- Europe covered systematically every cycle, ascending and descending passes, IW mode, Dual polarisation
- HH-HV or HH polarization for the monitoring of polar environments, sea-ice zones
- VV-VH or VV polarization for all other observation zones

Source: Foumelis (2017)
Sentinel-2: launched June 2015 and March 2017

- 2 satellites operating in **twin configuration, 5-day revisit***
- **13 spectral bands** (VIS–NIR–SWIR spectral domains)
- Spatial resolution: 10 m / 20 m / 60 m
- Sun-synchronous orbit at 786 km (14.3 revolutions per day), with local time on descending node (LTDN) 10:30 AM
- **MultiSpectral Instrument**: pushbroom
- 7 years design life time (up to 12 years)
Sentinel-2 spectral bands

overlaid with Landsat 8 OLI* bands

*NASA Landsat Data Continuation Mission, Operational Land Imager
Sentinel-2 observation scenario

Regularly published online in kml format:
https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2/acquisition-plans

- High Revisit (10 days) at the equator with one satellite - 5 days with 2 satellites (2-3 days at mid-latitudes)
- Sentinel-2 systematically covers all land surfaces (56° South latitude - 84° North latitude)
- Europe & Africa systematically covered on every orbit
- The rest of the world within a certain time interval: currently 30 days, will be progressively reduced over the coming months to reach 10 days.

Source: Foumelis (2017)
Sentinel-2 data products

L2a BOA reflectances are generated at users’ side by a processor running on ESA’s Sentinel-2 Toolbox.

L2a BOA reflectances are provided now over Europe.

Systematic processing and online dissemination of all Level-1c Products available from the Sentinel Data Hubs.

Sentinel 2 Toolbox – L2b Biophysical Products
- **LAI**: Leaf Area index
- **FAPAR**: Fraction of Photosynthetically Active Radiation
- **CCC**: Canopy Chlorophyll Content
- **CWC**: Canopy Water Content

L1c Product Tile Composition

Source: Foumelis (2017)
Sentinel-2 timeliness

The *Payload Data Ground Segment* will process all data up to Level-1C within 100 minutes after satellite downlink.
Sentinel-3: launched February 2016 and April 2018

- 7 years design life time (up to 12 years)
- OLCI: 300m resolution for 21 spectral bands
- Intended continuity with SPOT-VEGETATION and Proba-V
- Revisit: ~1 day (with 2 satellites)
Sentinel-3 mission profile

Operational Oceanography & Global Land Application

**Optical Payload**
- **OLCI** (Ocean and Land Color Instrument)
- **SLSTR** (Sea and Land Surface Temperature Radiometer)
- Data continuity of the Vegetation instrument (on SPOT4/5), Enhanced fire monitoring capabilities

**Topography Payload**
- **SRAL** (Synthetic Radar Altimeter)
  - Sea surface topography data
- **MWR** (Micro Wave Radiometer)
- **POD**
  - Precise Orbit Determination

Source: Foumelis (2017)
Sentinel-5P TROPOMI instrument

- Tropospheric monitoring instrument
- Launched October 2017

Global CO distribution

NO$_2$ distribution – 22/11/2017

Bali SO$_2$ distribution
Air pollution over Delhi in India was captured by the Copernicus Sentinel-5P mission on 10 November 2017.
First ozone retrievals of Copernicus Sentinel-5P show the closing of the ozone hole over the South Pole during November 2017.
Tropomi examples

Elevated absorbing aerosols – caused by fires – in the atmosphere off the west coast of the US on 12 December 2017.
Sentinel data access

Complete, free and open access to Sentinel-1, -2 and -3 data from moment of in-orbit review.

https://scihub.copernicus.eu/

Restricted access for Copernicus Service Projects

https://cophub.copernicus.eu/

For international partners with established EC agreements

https://inthub.copernicus.eu/

Development of cloud infrastructure Europe (DIAS)


External parties

USGS Earth Explorer

https://earthexplorer.usgs.gov/

Google Earth Engine

https://earthengine.google.com/

Amazon Web Services

http://sentinel-pds.s3website.eu-central-1.amazonaws.com/
Sentinel: support tools

- SNAP: Sentinel Application Platform
  - SAR toolbox (S1TBX)
    - Handling and post-processing of Sentinel-1 data
  - High-resolution optical toolbox (S2TBX)
    - Sentinel-2 multi-spectral data processing
  - Medium-resolution optical toolbox (S3TBX)
    - Sentinel-3 OLCI and SLSTR
- Developer forum
  - Requirements for the common platform
  - Platform roadmap
  - Coordinate horizontal activities

- Downloadable from: http://step.esa.int/main/download
Copernicus services

- Besides image data, some derived products are freely available
- Six thematic areas:

  - Atmosphere (CAMS)
  - Marine Environment (CMEEMS)
  - Land (CLMS)
  - Climate Change (C3S)
  - Emergency Management (EMS)
  - Security

- The Land theme has four components:
  - **Global**
    - Provides a series of bio-geophysical products on the status and evolution of the land surface at global scale at mid and low spatial resolution
  - **Pan-European**
    - Provides information about the land cover and land use (LC/LU), land cover and land use changes and land cover characteristics
  - **Local**
    - Focuses on different hotspots, i.e. areas that are prone to specific environmental challenges and problems
  - **Reference data**
    - All of the Copernicus services need access to in-situ data in order to ensure an efficient and effective use of Copernicus space-borne data
• Vegetation products
  ▪ Most 300m-1km resolution
  ▪ Proba-V (Sentinel-3)

https://land.copernicus.eu/global/
Copernicus/Sentinel: additional tools

- Sen2Agri toolbox
- http://www.esa-sen2agri.org/
- Based on € 1.5M ESA project
  - Local to national operational agricultural monitoring

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Produce high resolution EO products suitable for Agricultural Monitoring from local to national scales
Processing chains validated over a wide range of cropping systems around the world

Download and process Sentinel-2 and Landsat 8 dense time series without any effort
Cutting-edge image processing methods are performed automatically over your region and monitoring period

Access through a Graphical User Interface
System to be installed on a Linux server but easily accessible and configurable on a graphical user interface through your favorite web browser

Free and Open source system under GPL license
Based on Orfeo Toolbox and SLURM

Data privacy
Field data and products can be processed and stored locally
Background on reflectance and time series analysis
Vegetation reflectance

- green vegetation
- dry soil
- water

Visible, near-infrared, shortwave-infrared
Reflectance dynamics of vegetation

Vegetation stress: decay of a *Ficus benjamina* leaf

- 10 min. time step, total duration 8 hrs
- y-axis is reflectance plus reflected transmittance

Bartholomeus & Schaepman (2004)
Feature space – changes in reflectance

Changes in reflectance

Sentinel-2 imagery – False Color Composite (NIR, red, green)
Area west of Erbil
Vegetation indices

• Dimensionless radiometric measure that indicates the relative abundance and activity of green vegetation
  ▪ or moisture status of vegetation

\[
NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}}
\]

\[
NDWI = \frac{\rho_{NIR} - \rho_{SWIR}}{\rho_{NIR} + \rho_{SWIR}}
\]
Vegetation index time series

Behaviour of wheat over time.
Temporal information as input to classification

- Various crops may have similar reflection at single moment in time
- Use the fact that their cropping calendar is different to distinguish them
- Or understand frequency of multi-cropping

*Nguyen et al, 2012. Mapping the irrigated rice cropping patterns of the Mekong delta, Vietnam, through hyper-temporal SPOT NDVI image analysis. IJRS 33: 415-434*
Medium resolution sensors

<table>
<thead>
<tr>
<th>sensor</th>
<th>platform</th>
<th>spectral range</th>
<th>number of bands</th>
<th>resolution</th>
<th>swath width</th>
<th>repeat coverage</th>
<th>launch</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVHHR</td>
<td>NOAA POES 6-19</td>
<td>VIS, NIR, MWIR</td>
<td>5</td>
<td>1100m</td>
<td>2400km</td>
<td>12 hours</td>
<td>1978</td>
</tr>
<tr>
<td>AVHRR</td>
<td>METOP</td>
<td>VIS, NIR, SWIR, MIR</td>
<td>5</td>
<td>1100m</td>
<td>2400km</td>
<td>12 hours</td>
<td>2007</td>
</tr>
<tr>
<td>SEAWIFS</td>
<td>Orbview-2</td>
<td>VIS, NIR</td>
<td>8</td>
<td>1100m</td>
<td>1500km</td>
<td>1day</td>
<td>1997</td>
</tr>
<tr>
<td>VEGETATION</td>
<td>SPOT 4, 5</td>
<td>VIS, NIR, SWIR</td>
<td>4</td>
<td>1100m</td>
<td>2200km</td>
<td>1day</td>
<td>1998-2014</td>
</tr>
<tr>
<td>MODIS</td>
<td>Terra/Aqua</td>
<td>VIS, NIR, SWIR, TIR</td>
<td>36</td>
<td>250-1000m</td>
<td>2330km</td>
<td>&lt;2days</td>
<td>1999</td>
</tr>
<tr>
<td>MERIS</td>
<td>ENVISAT</td>
<td>VIS, NIR</td>
<td>15</td>
<td>300m</td>
<td>1150km</td>
<td>&lt;3days</td>
<td>2000</td>
</tr>
<tr>
<td>Suomi NPP</td>
<td>VIIRS</td>
<td>VIS, NIR, SWIR, TIR</td>
<td>22</td>
<td>375m</td>
<td>3040km</td>
<td>1 day</td>
<td>2011</td>
</tr>
<tr>
<td>PROBA-V</td>
<td>PROBA-V</td>
<td>VIS, NIR, SWIR</td>
<td>4</td>
<td>300m</td>
<td>2250km</td>
<td>1 day</td>
<td>2013</td>
</tr>
<tr>
<td>SENTINEL 3</td>
<td>OLCI</td>
<td>VIS, NIR, SWIR</td>
<td>21</td>
<td>300m</td>
<td>1270km</td>
<td>&lt;2 days</td>
<td>2016</td>
</tr>
</tbody>
</table>
Why medium resolution?

• Very frequent coverage
  ▪ capture seasonal variation
  ▪ clouds

• Free global imagery
  ▪ cover large areas at low cost and reasonable data volumes

• Long consistent time series
  ▪ variability/trends & link to climate
Drawbacks of medium-resolution

• Fields or vegetation patches are often smaller in size
• Spectral information comes from multiple surfaces
  ▪ makes interpretation more difficult
Composite products

- Combine multi-day acquisitions in a single product
- ‘Best observation’ per pixel → suppress clouds

MODIS surface reflectance for 10x10° tile in East Africa
Example analysis

length of growing period (LGP, in days)

trends in LGP (1981-2011)

Drought analysis through vegetation anomalies

NDVI June 2011 vs. mean (’98-2010)

Bay (Somalia)
CNDVI and rainfall for AfriCover: continuous small fields

- Rainfall 2011
- NDVI 2011
- Rainfall average
- NDVI average

EARTH OBSERVATION FOR SUSTAINABLE DEVELOPMENT
Agriculture and Rural Development
More on drought monitoring: FAO E-learning

- “Remotely Sensed Information for Crop Monitoring and Food Security – Techniques and methods for arid and semi-arid areas”

1 Introduction
2 Remote Sensing Data for Crop Monitoring
3 Data Sources and Products
4 Rainfall and NDVI Anomaly Maps
5 Rainfall and NDVI Seasonal Graphs
6 Crop Status Analysis Throughout the Crop Season
7 Introduction to Yield Forecast
8 Communicating Results
9 Data Management of Remote Sensing Images
10 Required Software Functionality
Several other learning resources exist

- For example:
  - Open online courses from ESA:
    https://earth.esa.int/web/guest/education-and-training/moocs
  - ESA Research and User Support (RUS):
    https://rus-copernicus.eu/portal/
  - NASA applied remote sensing training (ARSET):
    https://arset.gsfc.nasa.gov/
  - FAO E-learning on Management of Spatial Information:
  - FAO E-learning on multi-temp RS for agricultural monitoring:
  - ...
  - ITC Faculty of Geo-information Science and Earth Observation:
    https://www.itc.nl/
      - MSc, PhD, short courses, online courses, tailor-made trainings
To remember

• Many image types exist:
  ▪ One difference is spatial resolution
    • Finer resolution: more spatial detail
    • Coarser resolution: more temporal detail

• Many applications require frequent observation throughout season
  ▪ coarser spatial resolution = shorter revisit
  ▪ increasingly more options at finer resolution
  ▪ radar offers possibilities also when cloud cover is persistent (not shown in detail now)

• Time series: monitoring what is happening
  • in season
  • between years (variability, trends)

• Copernicus / Sentinels are provided great new opportunities
  • Image types / resolution / frequency / long-term observation commitment

• Such data helps to deliver key environmental information to support planning, implementation, monitoring, and assessment of projects
  • How may it serve your needs?
For more information

http://eo4sd.esa.int/agriculture

http://eo4sd.esa.int/