Viewed from Above: An Learning Diary on Earth Observation

The-Huan Hoang

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Hello...

...from a novice to another!

Part I.

Making sense of Remote Sensing

1. Remote Sensing: To see the unseen

1.1. In summary...

Remote Sensing is the use of satellites, planes, drones, etc. as our aerial eyes, piecing together a portrait of our planet through light and data and revolutionising the way we understand and interact with it.

Sensors, well, 'sense' Earth in two ways: Some passively listen to sunlight reflected off our planet's surface (i.e., *passive sensors*), while others actively send their own signals and capture the echoes (i.e., *active sensors*). By that definition, the human eye is a type of passive sensors!

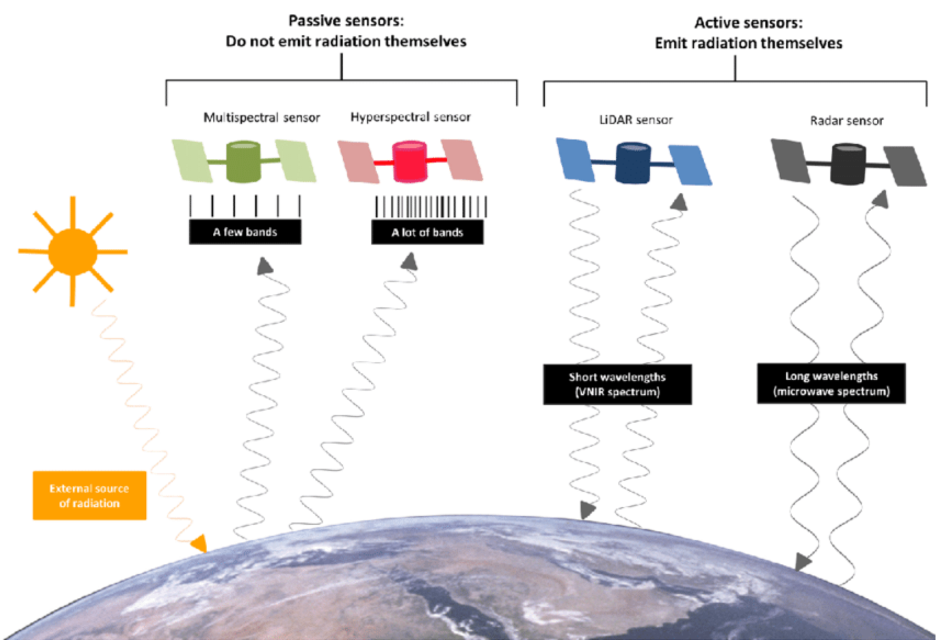


Figure 1.1.: Active vs Passive Remote Sensing (Earth Science Data Systems 2019).

These sensors interpret a fascinating language of light, both invisible and visible, known as the *electromagnetic spectrum.*

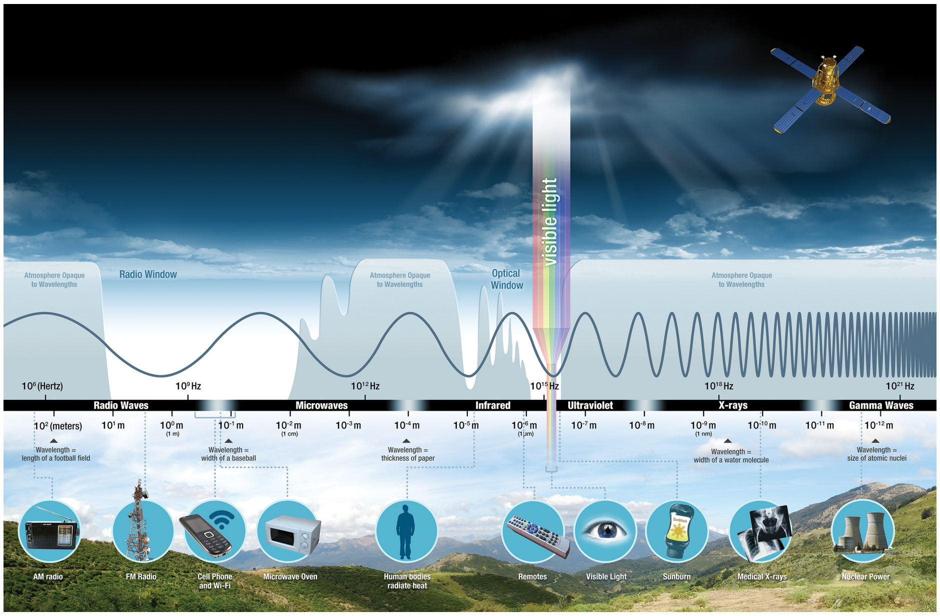


Figure 1.2.: The Electromagnetic Spectrum (EMS). Credit: NASA Science

Electromagnetic radiation moves as waves as perpendicular electric and magnetic field with a wavelength: `= c/v` where:

- = **wavelength**, distance between two crests
- `c` = velocity of light 3 x 10^8 m/sec
- `v` = frequency, rate of oscillation (full oscillations in a time unit)

Different materials reflect unique wavelengths in this spectrum, allowing us to identify them, like decoding DNA! More on this later…

But information that sensors receive isn't just about color. Remote sensing data has its own "resolution" recipe, encompassing:

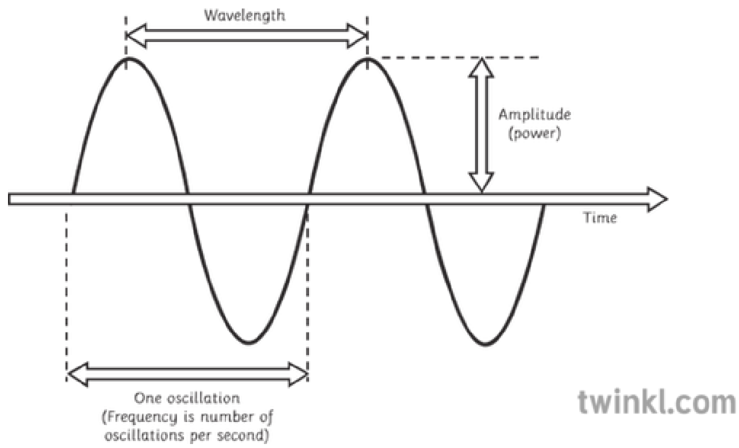


Figure 1.3.: Wavelength vs. Oscillation

- **Spectral:** How EMS bands (i.e., the range within the EMS) the sensor can hear, revealing more detail with each additional band.
- **Spatial:** The size of each pixel in the image, ranging from centimeters to kilometers, offering varying levels of detail.
- **Temporal:** How often the sensor revisits the same area, providing a dynamic view of changes over time.
- **Radiometric:** The range of brightness levels captured, painting a vibrant and accurate picture.

In reality, depending on the purpose, each sensor is equip to have better resolution of one type over the other. For example, sensors with a high spatial resolution of 5m (i.e., each pixel is 10x10 on the ground) will have lower spectral resolution (i.e., capturing only narrow range of the EMS) ("Remote Sensing, Satellite Imaging Technology | Satellite Imaging Corp" n.d.)

1.2. In practice...

Remote Sensing has many transformative applications in the realm of Urban Analytics. Think of it as an X-ray for cities, revealing hidden patterns and empowering informed decision-making by city planners, urban designers, and public officials to make swift and informed decisions to improve the lives of millions of urbanites.

Here are some examples

1. **Mapping Urban Growth:** By tracking changes in the built environment over time, we can identify sprawling suburbs, monitor urban expansion, and plan for infrastructure needs. Remote sensing data are particularly rich sources to train classification models to extract features and identify unmapped communities.

2. **Predicting Floods with Foresight:** Analysing land cover and terrain, it anticipates where water will flow, safeguarding communities from harm, while also estimating potential damage. Here is an example of how insurance companies can make use of such data to assess risk and process claims.

3. **Energy Efficiency:** Identifying heat island effects and understanding building energy consumption through thermal imaging empowers planners to design sustainable cities, and researchers to determine the best strategies to combat long term climate disasters.

This is just the beginning. Remote sensing is transforming the way we understand and manage our cities, paving the way for a healthier, smarter, and more sustainable urban future.

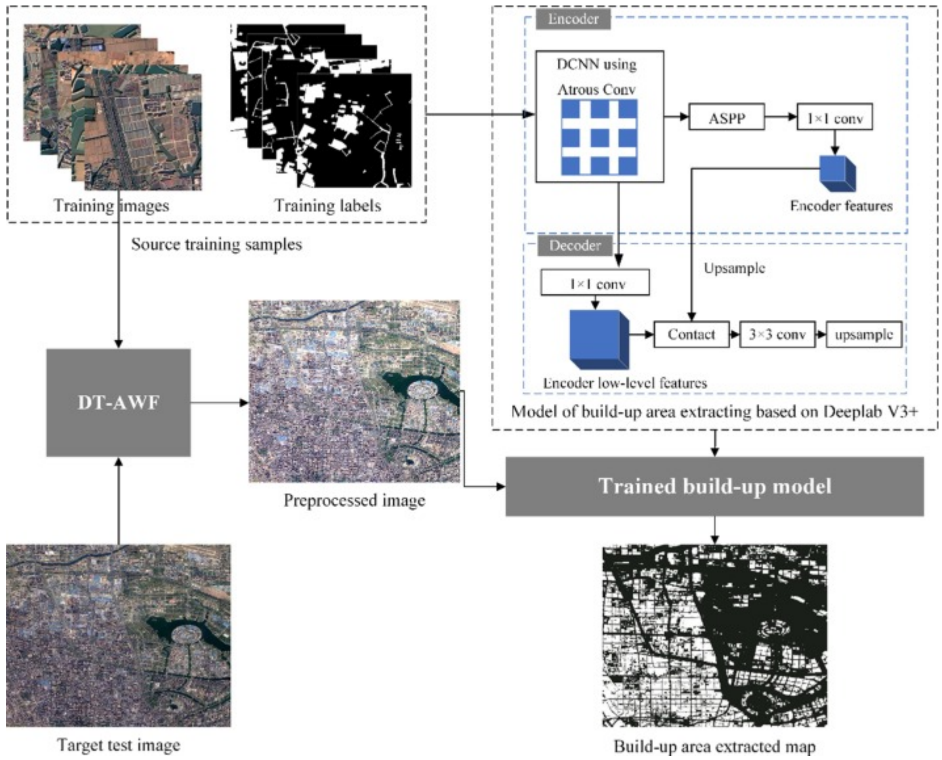


Figure 1.4.: Transferable built-up area extraction (TBUAE) framework to map urbanised areas (Wang et al. 2021)

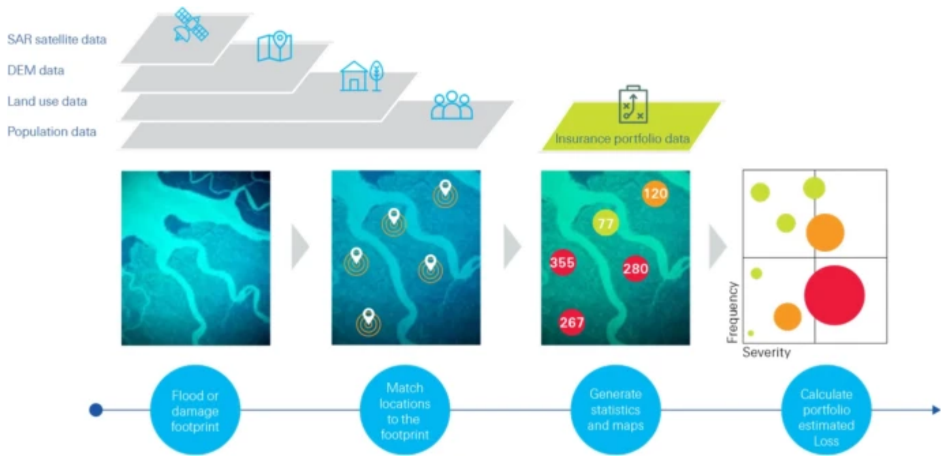


Figure 1.5.: Remote sensing data can be used to estimate flood extent, and to derive individual risk level damage estimates (Schumann et al. 2023)

1.3. In short...

My first foray into the world of Remote Sensing was eye-opening, to say the least. For the uninitiated, it is easy to assume that remote sensing purely means orthophotographic satellite images that one might see using platforms such as Google Maps, i.e., as if the only thing that sensors do were to snap a simple photo of the planet like a phone camera.

In reality, it unlocks unseen depths of data beyond mere human perception, less high-resolution photographs and more spectral signatures, where each pixel holds a universe of information. Building a true-color composite from all these layers (so that our eyes can see) was like seeing the world through a brand-new lens.

I am particularly excited to get started with Google Earth Engine later on as the primary gateway to access the wealth of remote sensing data

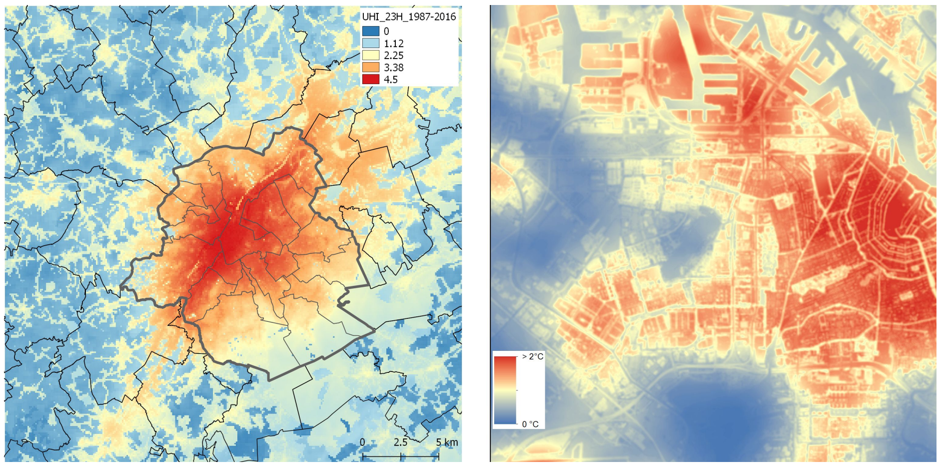


Figure 1.6.: **Left:** Average 2m air temperature at 23h (moment of max UHI) during all summer months (June-August) of the years 1987- 2016. **Right:** UrbCLIM output field downscaled to 30-m resolution showing the average daily maximum urban heat island (UHI) intensity for a part of the city of Amsterdam. ("DestinE for Human Heat Stress: ECMWF Use Case to Tackle Urban Heat Islands" n.d.)

and analytics with more ease in order to solve specific problems facing our world today.

2. A peek into the LiDAR technology

Or, how to make self-driving cars a reality

Having understood how sensors work in theory, we can now shift our view to appreciate how one of them in particular, LiDAR (**Li**ght **D**etection **a**nd **R**anging), is deployed in practice and can benefit us in an emerging sector: *Autonomous Vehicles.*

3. Corrections and Enhancements

3.1. In summary...

Raw data coming from sensors are rarely immediately usable without being corrected for various interferences and effects. Here is

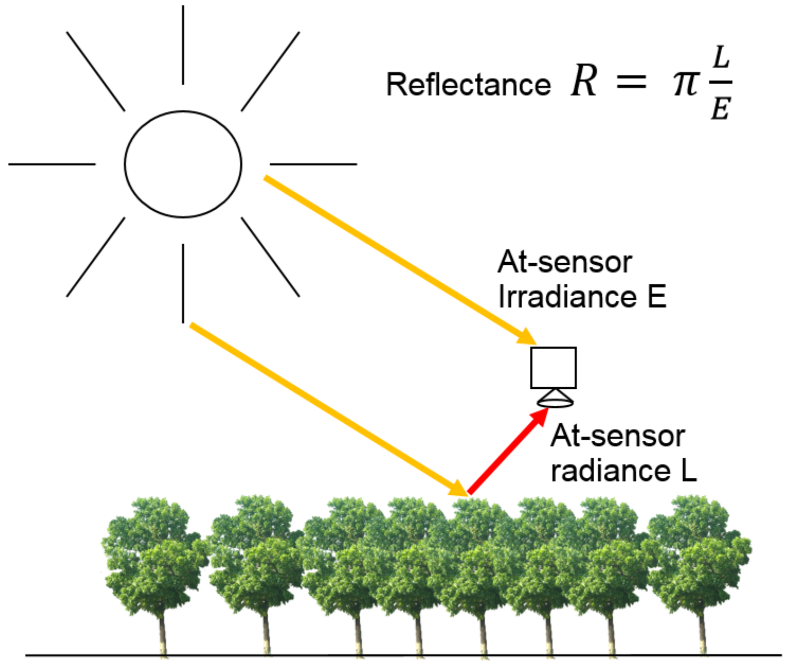
1. Geometric correction
2. Atmospheric correction
3. Topographic correction
4. Radiometric correction

3.1.1. Radiometric and Atmospheric corrections

These processes describe translating raw light data from the sensor into 'true' information on the surface's reflectance property, without interference from the light source and the atmosphere.

- **Radiometric calibration** is the conversion from raw Digital Number to Spectral Radiance via a linear transformation $L_\lambda = Bias + (Gain * DN)$. Radiance most often has units of watt/(steradian/square meter)
- **Atmospheric correction** involves the next step:
  - **TOA Radiance-to-Reflectance** correction removes effects of the light source (e.g. the sun) by calibrating radiation going down (irradiance) and up (radiance). TOA Reflectance still

has the effect of the atmosphere and the surface material. If irradiance = radiance, we call this *hemispheric reflectance*



– **TOA-to-BOA Reflectance** correction removes effects of the atmospheric conditions, leaving us with just data on the surface materials. If shadows and directional effects on reflectance have been dealt with, we get what is called *true reflectance*, if not then it is called *apparent reflectance.*

Atmospheric correction deserves out attention considering the effect of atmospheric scattering on the final results. Absorption and scattering create the haze which reduces the contrast, and can creates the "adjacency effect", whereby radiance from pixels nearby mixed into pixel of interest. There are several types of atmospheric correction:

1. **Relative:** normalise intensities of different bands within a single image, or from many dates to one date. This can be done via *Dark Object Subtraction (DOS)*, *Empirical Line Correction*, or *Pseudo-invariant Features (PIFs)*
2. **Absolute:** change digital brightness values into scaled surface reflectance. We can then compare these scaled surface reflectance values across the planet, through *atmospheric radiative transfer models* (i.e. summer, tropical). To perform this correction, we also need local atmospheric visibility and image altitude. There are many tools for this purpose:
   - Paid: ACORN, FLAASH, QUAC, ATCOR
   - Free: SMAC, Orfeo Toolbox

Finally, atmospheric correction to obtain true reflectance is not always necessary, for example, for classification of a single image, working on composite images, etc.

3.1.2. Geometric and topographic corrections

Subsets of Georectification

3.2. In practice...

3.3. In short...

Figure 3.1.: Example of LEDAPS atmospheric correction. (a) Top-of-atmosphere (TOA) reflectance composite (bands 3,2,1) for Landsat-7 ETM+ image of San Francisco Bay (July 7, 1999); (b) Surface reflectance composite.

Part II.

Resources

Glossary: Demystifying jargons

- **Digital Number (DN) :** raw brightness data captured by sensors without having units for efficient storage
- **Radiance :** how much light the instrument sees in meaningful units but still have effects of light source, atmosphere and surface material. Also known as Top of Atmosphere (TOA) radiance
- **Reflectance :** a property of a material, it is a ratio of the amount of light leaving a target to the amount of light striking it. Its calculation is performed on radiance corrected data. Typically this comes as surface (BOA) reflectance but can also be Top of Atmosphere (TOA) reflectance if the atmospheric effect on radiance has not been accounted for.
- **Radiometric calibration :** the process from converting DN to Radiance `L =Bias+(Gain*DN)`
- **Dark object subtraction (DOS) :** A relative Atmospheric correction technique. Searches each band for the darkest value then subtracts that from each pixel. This is appropriate when the visible bands have increased scattering vs. longer wavelengths. Also known as, Histogram Adjustment
- **Pseudo-invariant Features (PIFs) :** A relative Atmospheric correction technique. Assume brightness pixels linearly related to a base image (linear regression) and adjust the image based on the regression result
- *Atmospheric radiative transfer models.*

References

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