My Research: Remote Sensing

Leland Pierce, Nov 2021

Forest Modeling and Inversion

I mostly use Synthetic Aperture Radar (SAR) in order to estimate parameters of forests:

species

density

height

But I also use LIDAR and Optical data.

Outline

1. What can Remote Sensing do?
2. What is Remote Sensing?
3. How does Radar Remote Sensing work?
4. Using Models to Understand Forests
5. Industry

1. What can Remote Sensing do?

Weather Prediction

Global Climate Modelling

Resource Management:

groundwater, logging, crops, urbanization

857 active remote sensing satellites as of Oct 2020

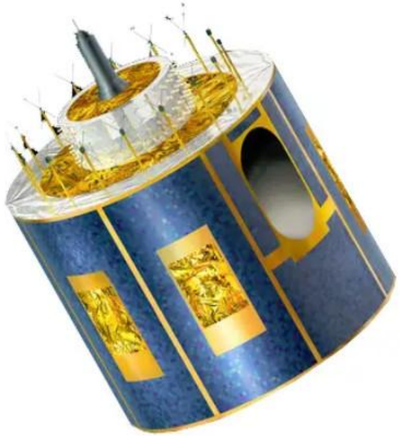
Weather Satellites

National Oceanic and Atmospheric Administration Satellite (NOAA)

NOAA satellites enable us to get a complete view of weather and environmental conditions around the world each day.

Image Credit: NASA

METEOSAT



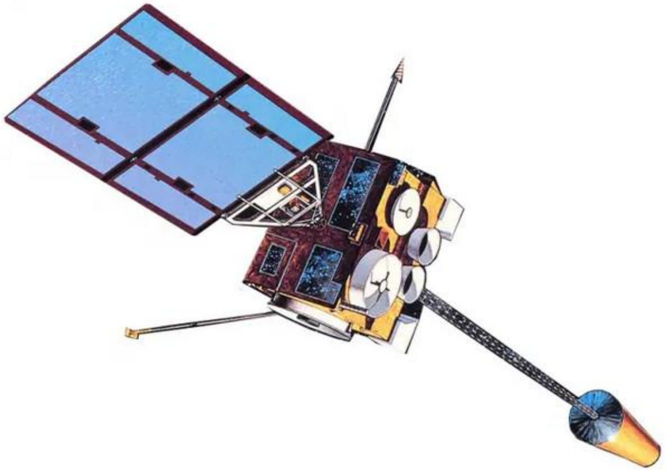
Meteosat is the geostationary observer in Europe and Africa. By beaming images of Europe's weather every 15 minutes, it's ideal for weather forecasting.

Image Credit: ESA

(gisgeography.com)

Weather Satellites

Geostationary Operational Environmental Satellite (GOES)



GOES knows weather. Since 1975, this geostationary squad of satellites are unsung heroes in forecasting our planet's weather.

Image Credit: NASA;

Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)

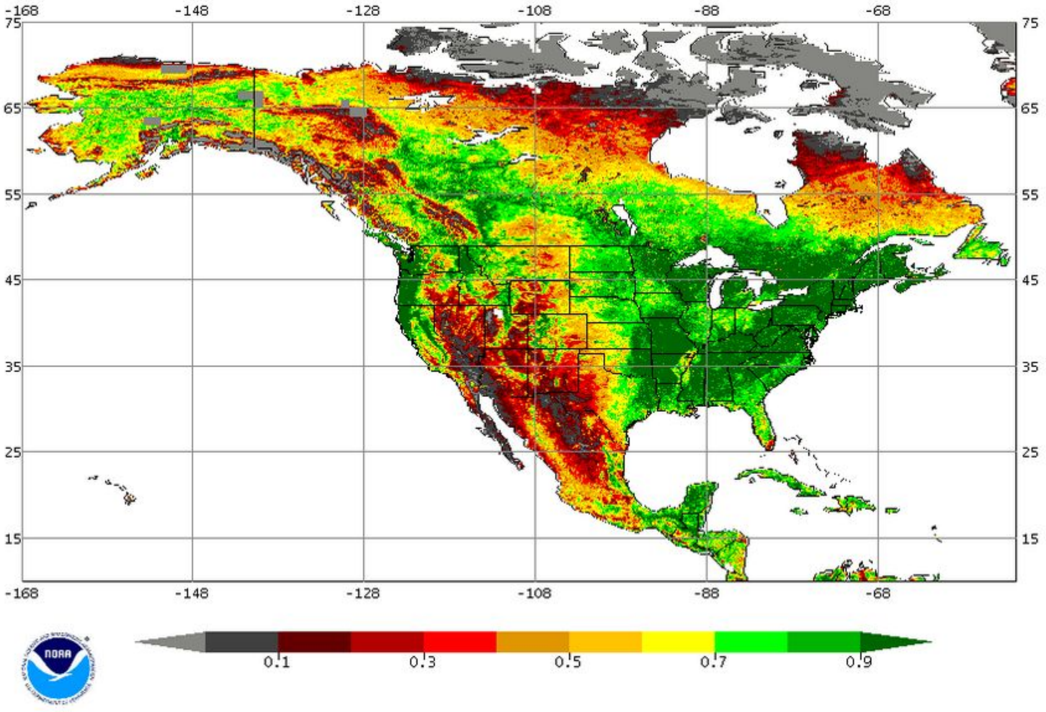
Using laser technology and a special sensor for cirrus cloud, CALIPSO graphs the vertical profiles of cloud structure.

Image Credit: NASA

(gisgeography.com)

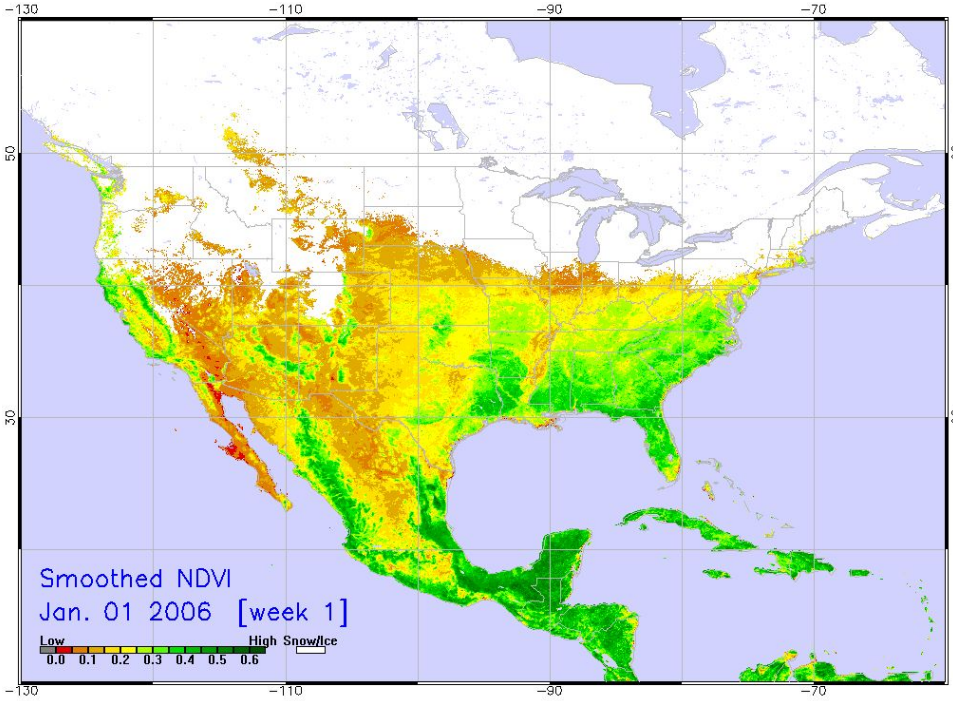
Weather Satellites

Green Vegetation Fraction



Weather Satellites

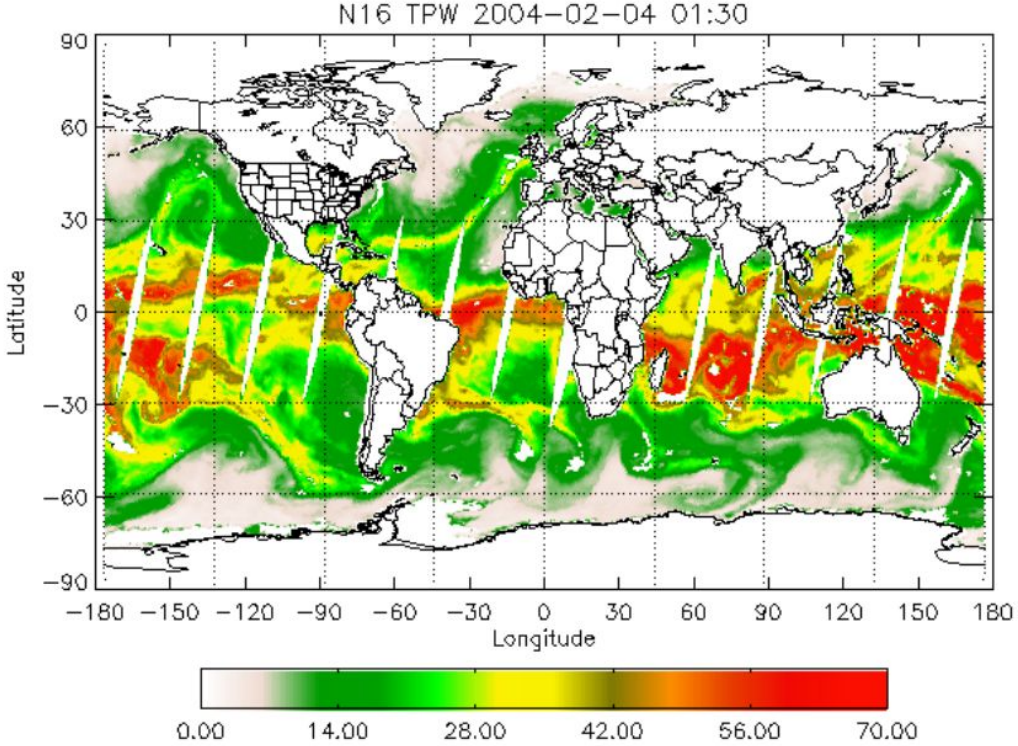
Green Vegetation Fraction



(noaa.gov)

Weather Satellites

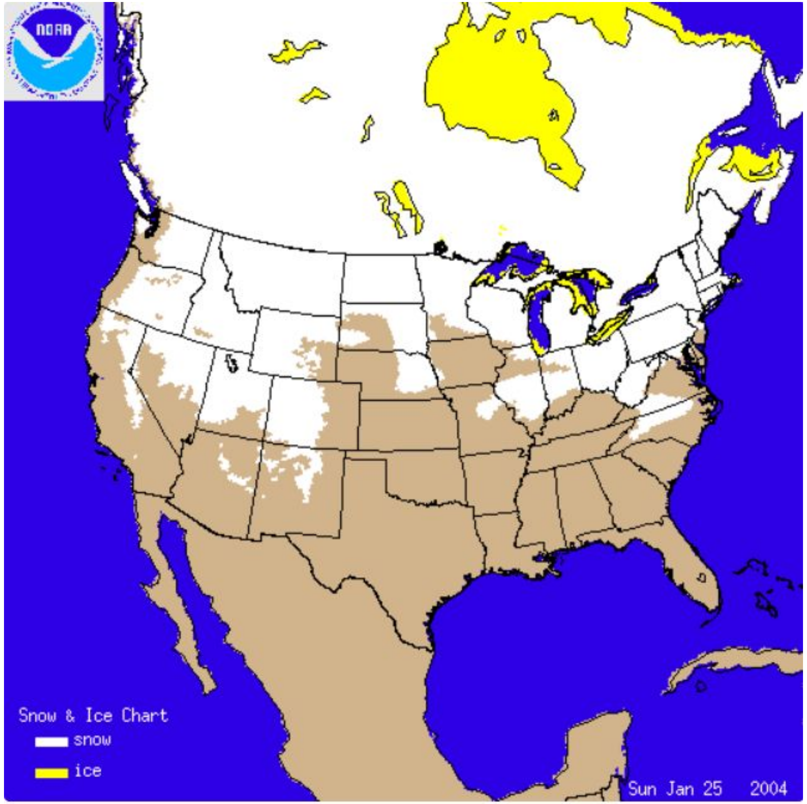
Atmospheric Moisture



(noaa.gov)

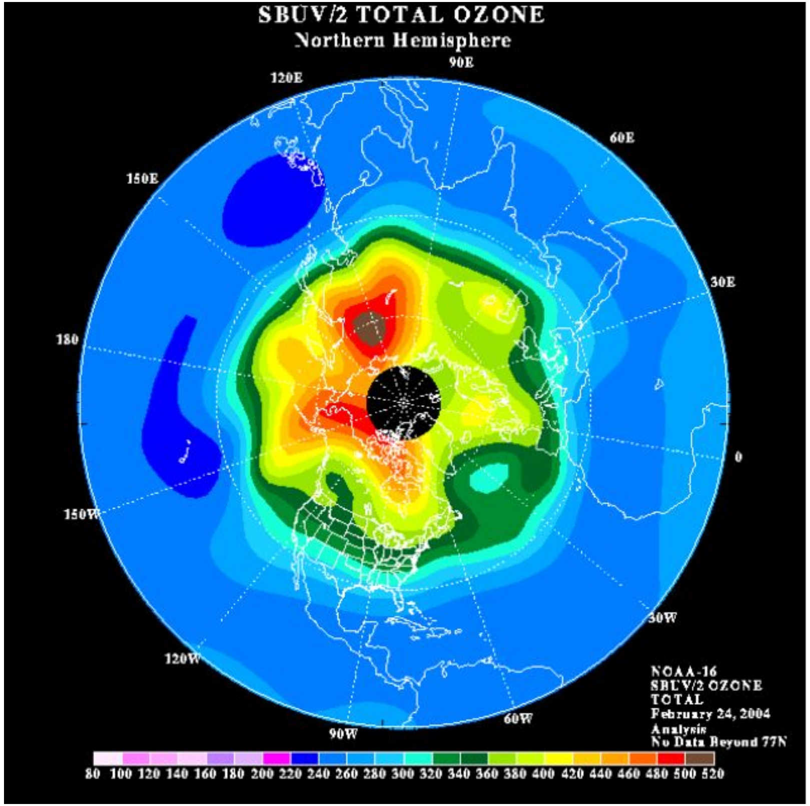
Weather Satellites

Snow and Ice



Weather Satellites

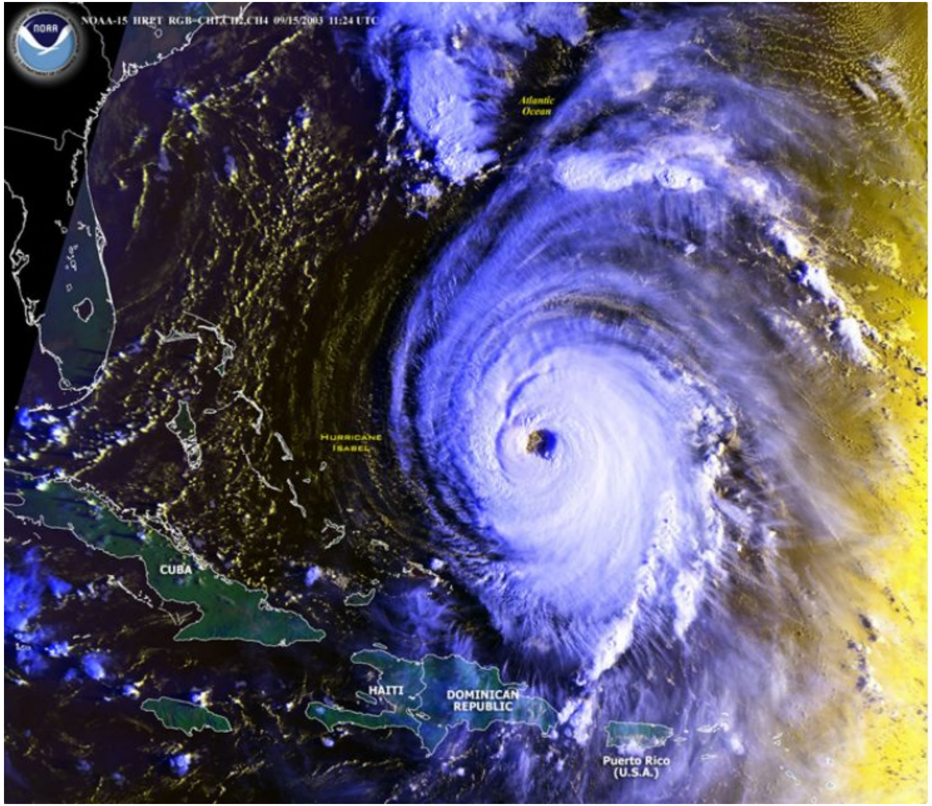
Ozone Concentration



(noaa.gov)

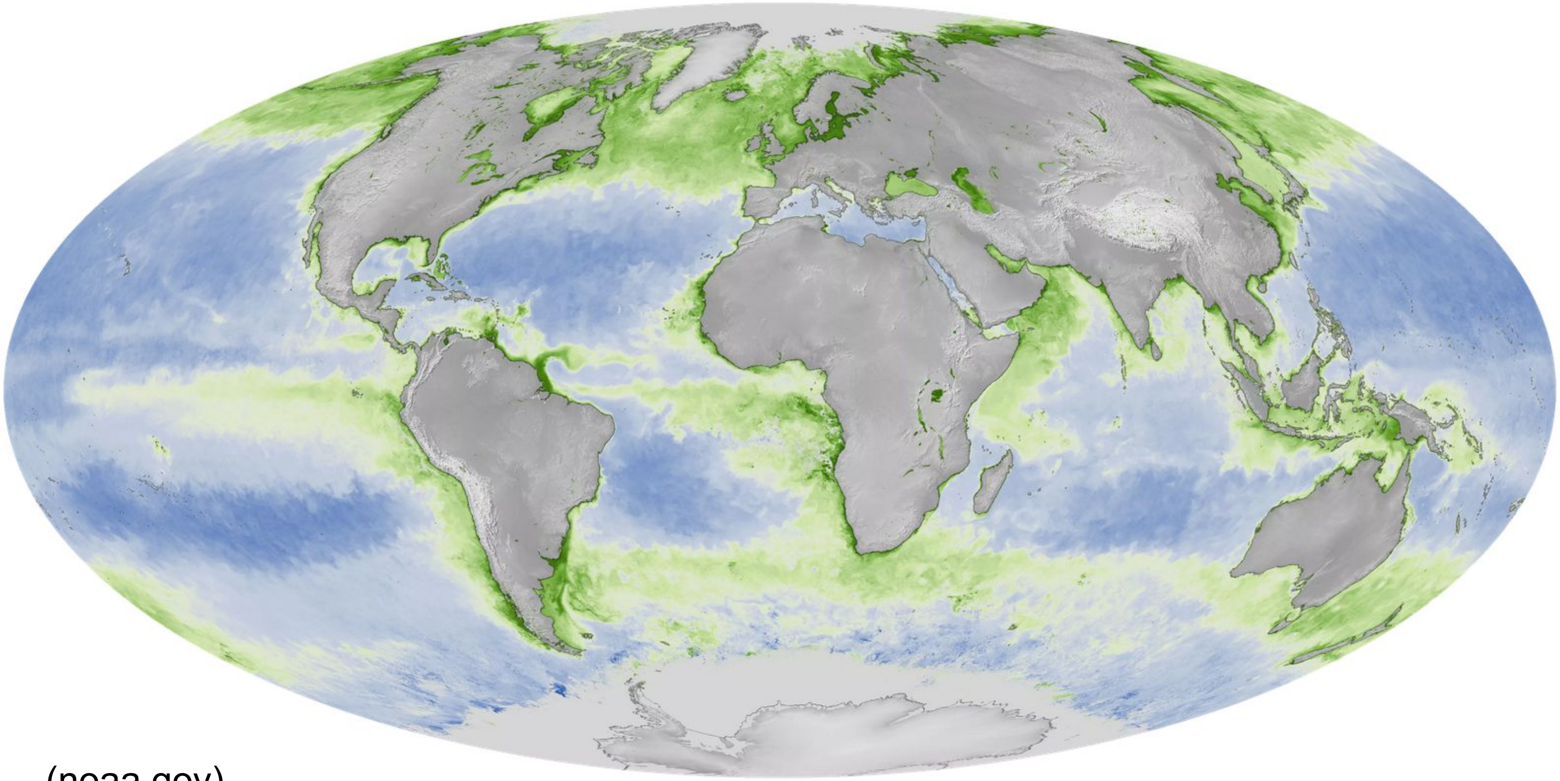
Weather Satellites

Clouds



Weather Satellites

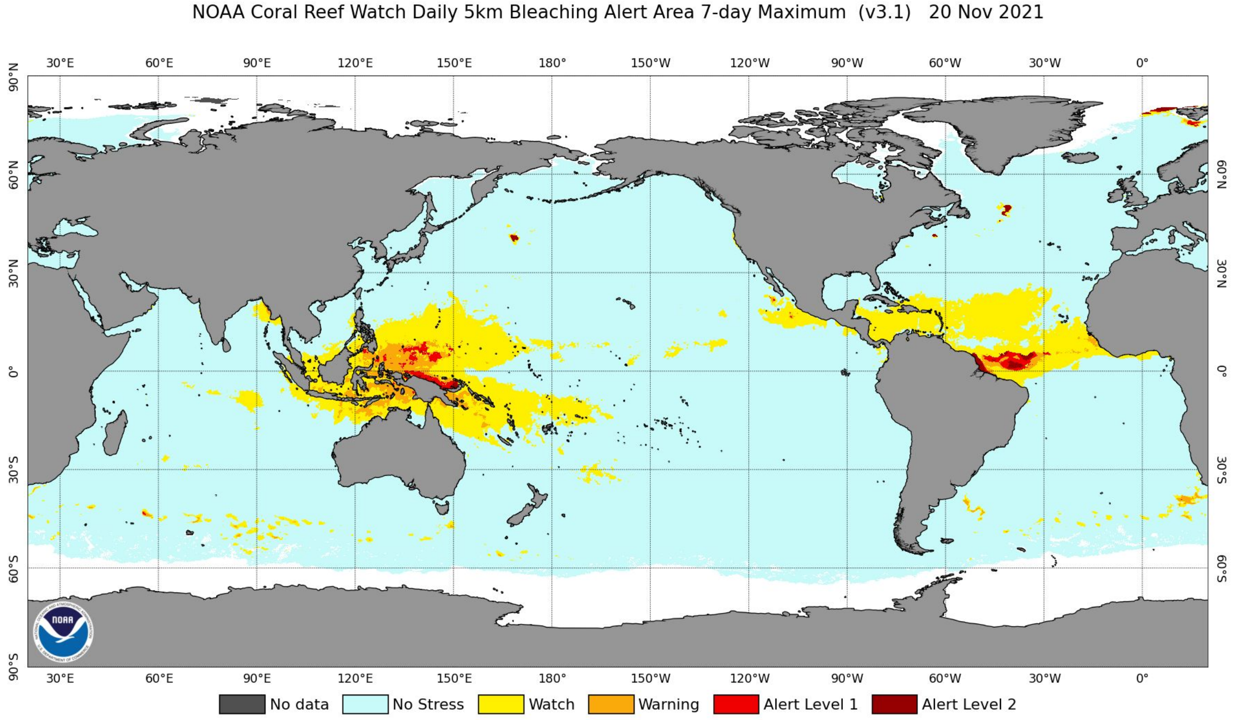
Chlorophyll Concentration



(noaa.gov)

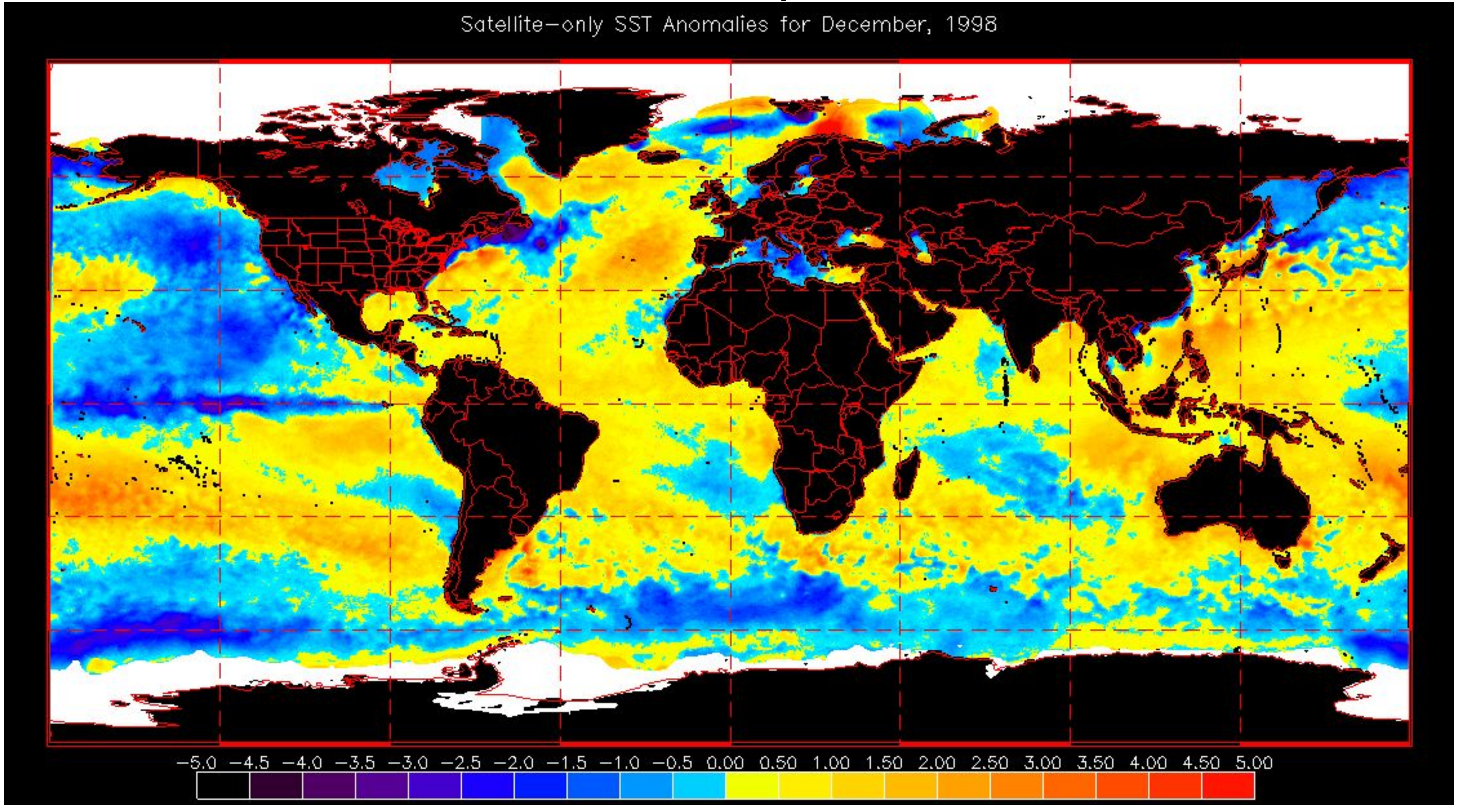
Weather Satellites

Coral Bleaching



Weather Satellites

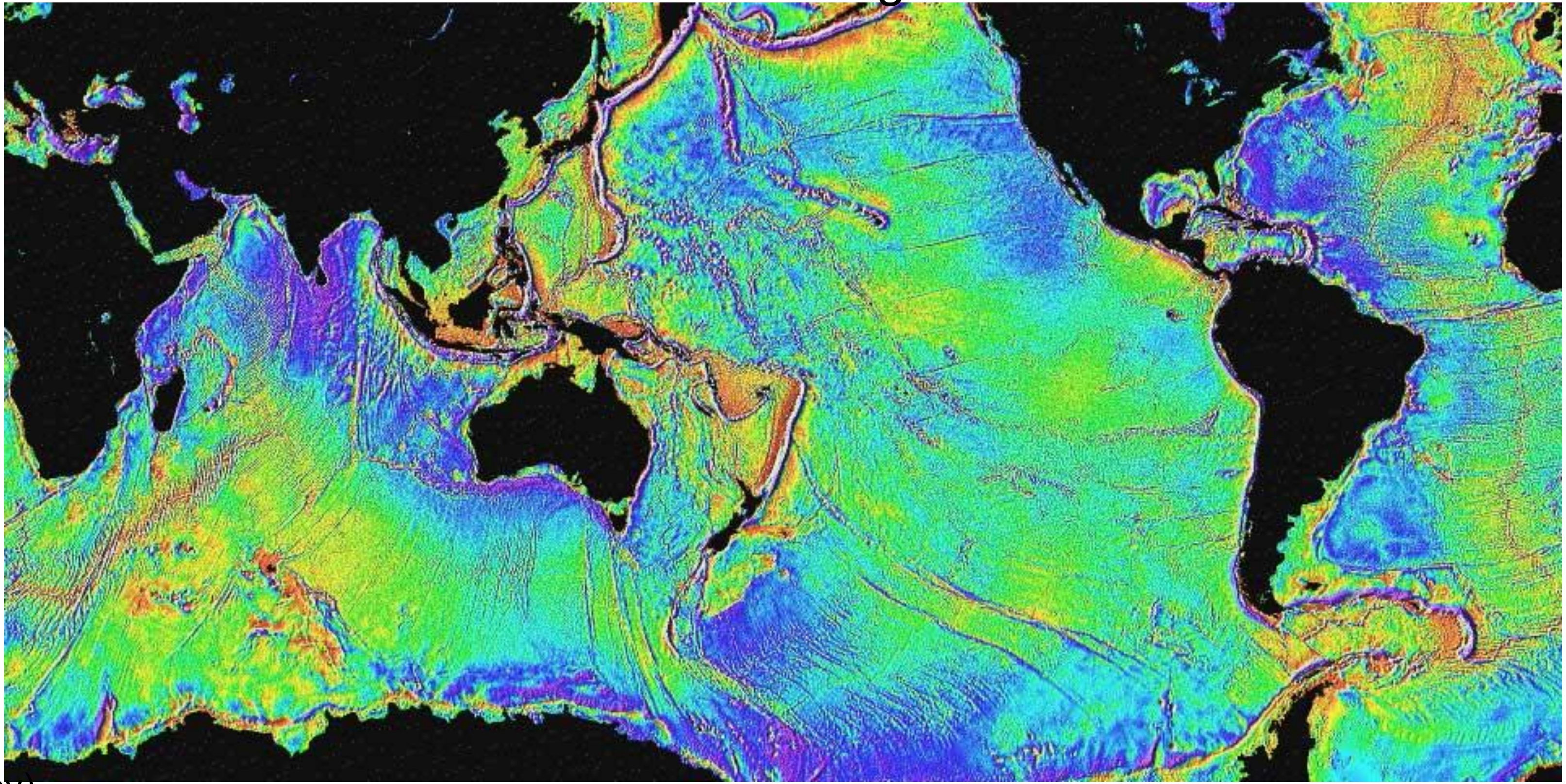
Sea Surface Temperature



(noaa.gov)

Weather Satellites

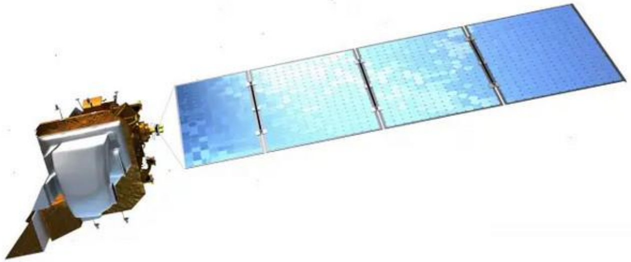
Sea Surface Height



(noaa.gov)

Optical Satellites

Landsat



Landsat's incredible long-lived legacy has archived Earth's history for over 40 years. With countless applications, it even found the **island Landsat in Canada**.

Image Credit: NASA

Sentinel

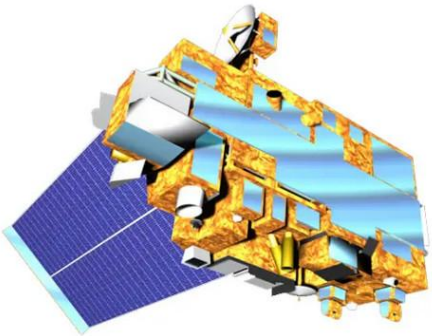
As part of the **Copernicus Programme**, Sentinel's fleet of 6 missions is a game changer. Specifically, **Sentinel-2** is a clear upgrade to Landsat, except that it's missing the thermal band.

Image Credit: ESA

(gisgeography.com)

Optical Satellites

Terra



As part of NASA'S multi-talented A-Train fleet, **Terra** is the jack-of-all-trades For example, ASTER models terrain, **MODIS** classifies land cover and MOPITT monitors air quality.

Image Credit: NASA

Project for On-Board Autonomy (PROBA)

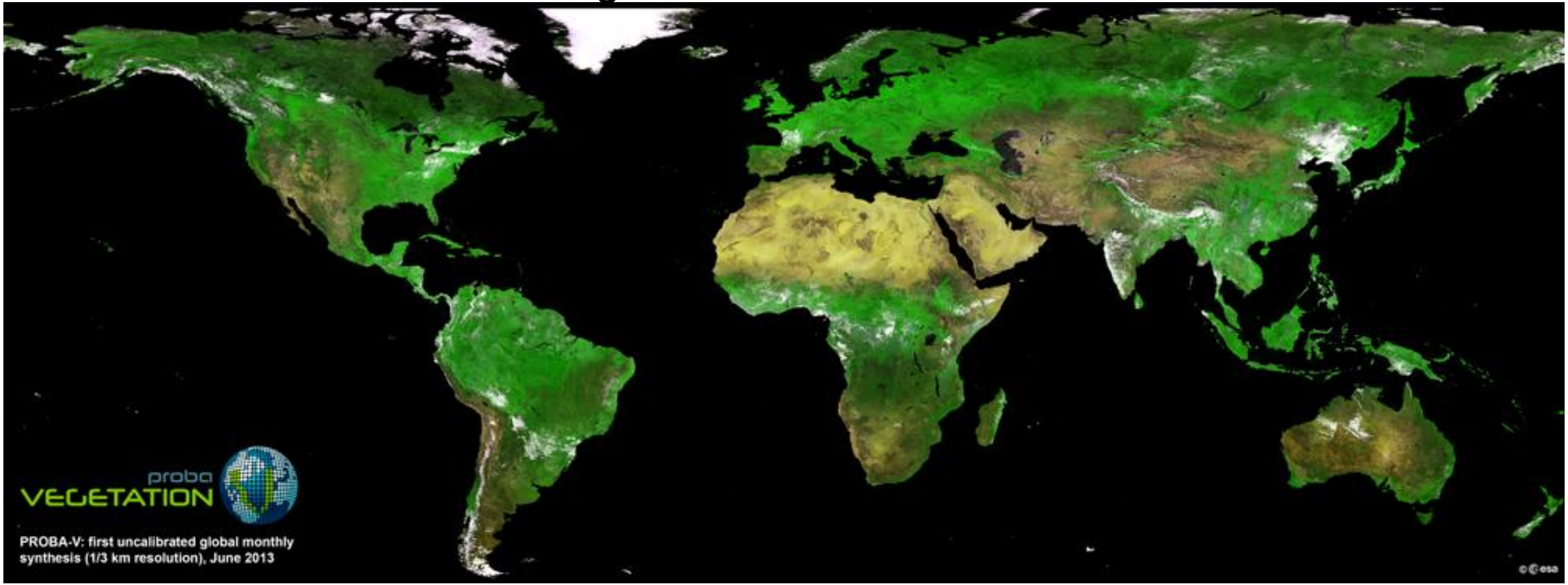
PROBA is a micro, cube-looking satellite with 30-meter hyperspectral data. Using its dextrous viewing angles, the **PROBA satellite** produced the world-renowned global vegetation archive.

Image Credit: ESA

(gisgeography.com)

Optical Satellites

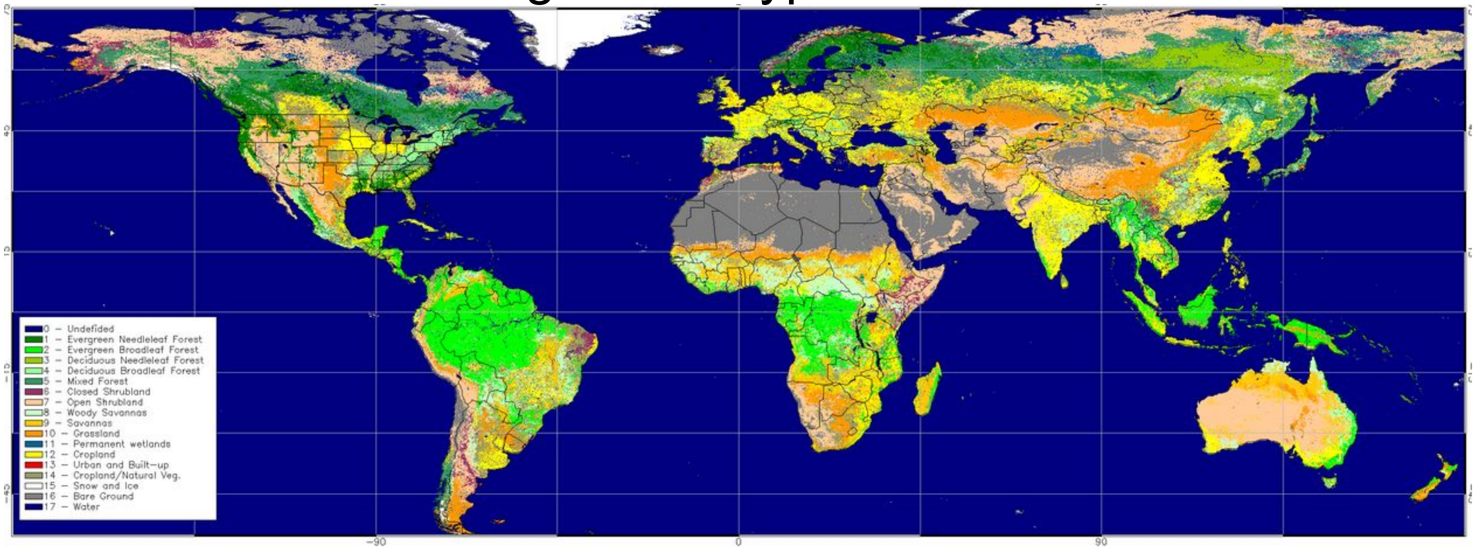
Vegetation Color



(proba-v)

Optical Satellites

Vegetation Type

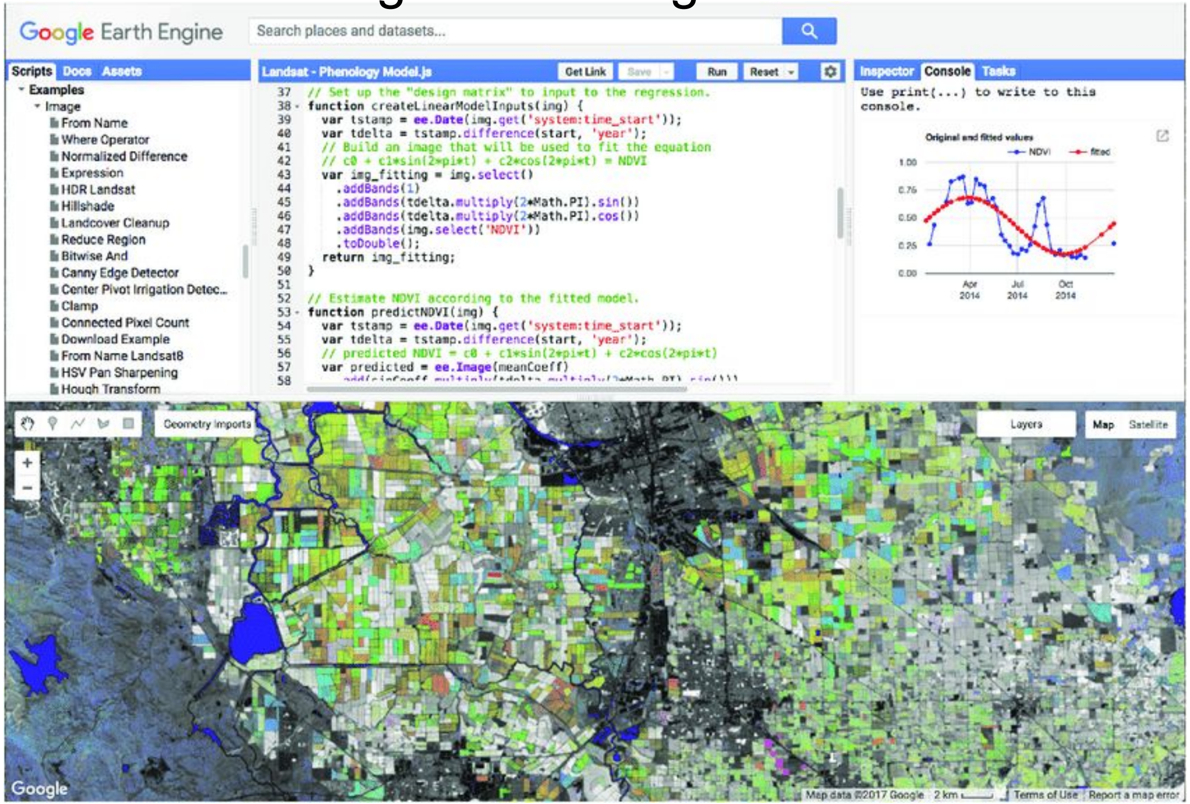


0 - Undefined
1 - Evergreen Needleleaf Forest
2 - Evergreen Broadleaf Forest
3 - Deciduous Needleleaf Forest
4 - Deciduous Broadleaf Forest
5 - Mixed Forest
6 - Closed Shrubland
7 - Open Shrubland
8 - Woody Savannas
9 - Savannas
10 - Grassland
11 - Permanent wetlands
12 - Cropland
13 - Urban and Built-up
14 - Cropland/Natural Veg.
15 - Snow and Ice
16 - Bare Ground
17 - Water Bodies

(landsat)

Optical Satellites

Google Earth Engine



Optical Satellites

40cm resolution

(maxar)

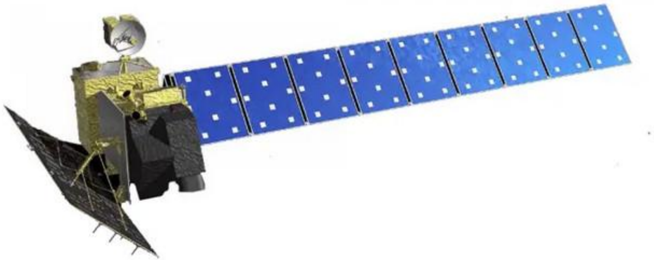
Radar Satellites

RADARSAT

Radarsat-2 is Canada's space radar monitoring mission. As part of the **Radarsat Constellation Mission**, 3 C-band satellites will hone in on the Great White North's land mass.

Image Credit: © Canadian Space Agency

Advanced Land Observation Satellite (ALOS)

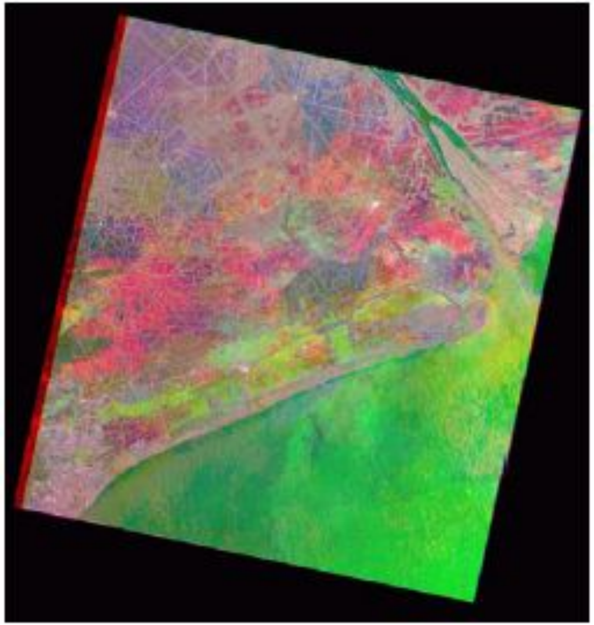


ALOS-1 sculpted the world's most precise elevation model at 5-meter resolution. Now, ALOS-2 has several upgrades such as L-band PALSAR radar and stereo mapping (PRISM).

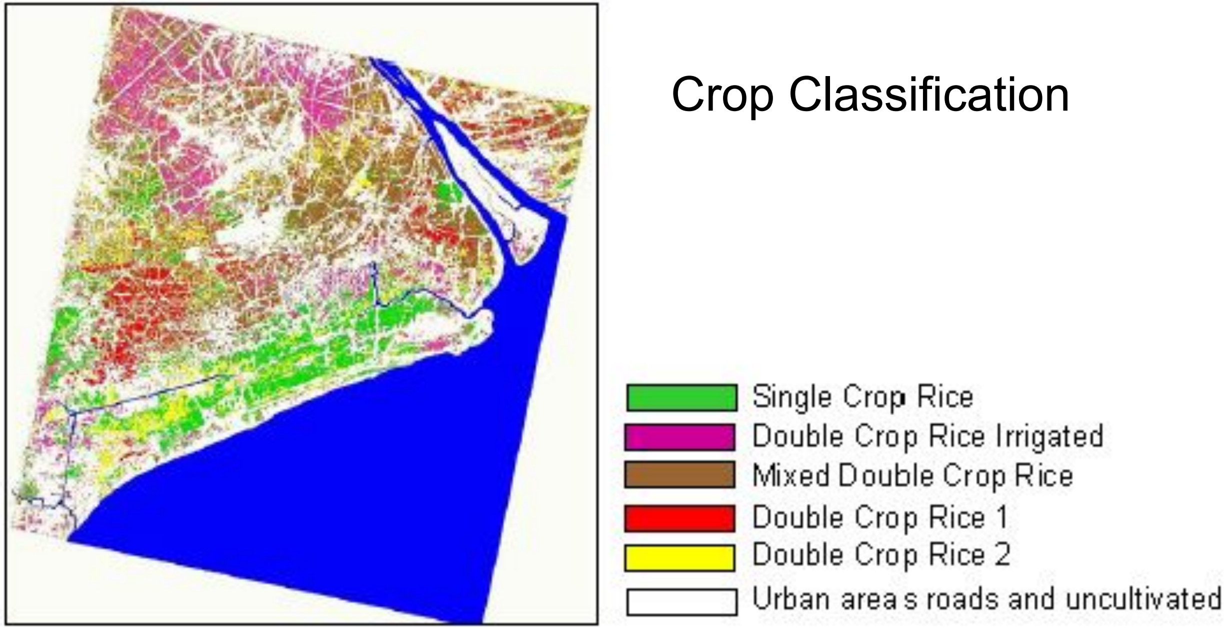
Image Credit: JAXA

(gisgeography.com)

Radar Applications

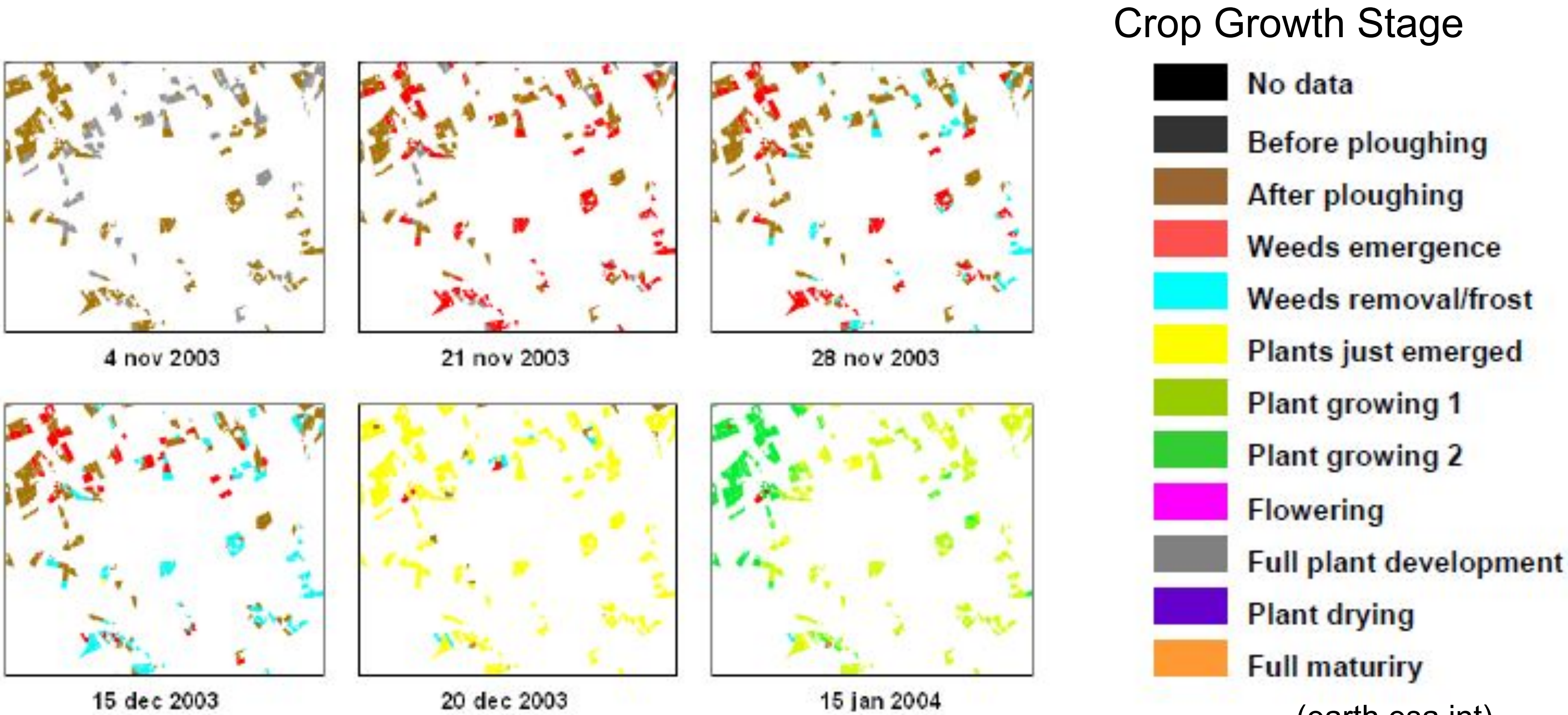


Crop Classification



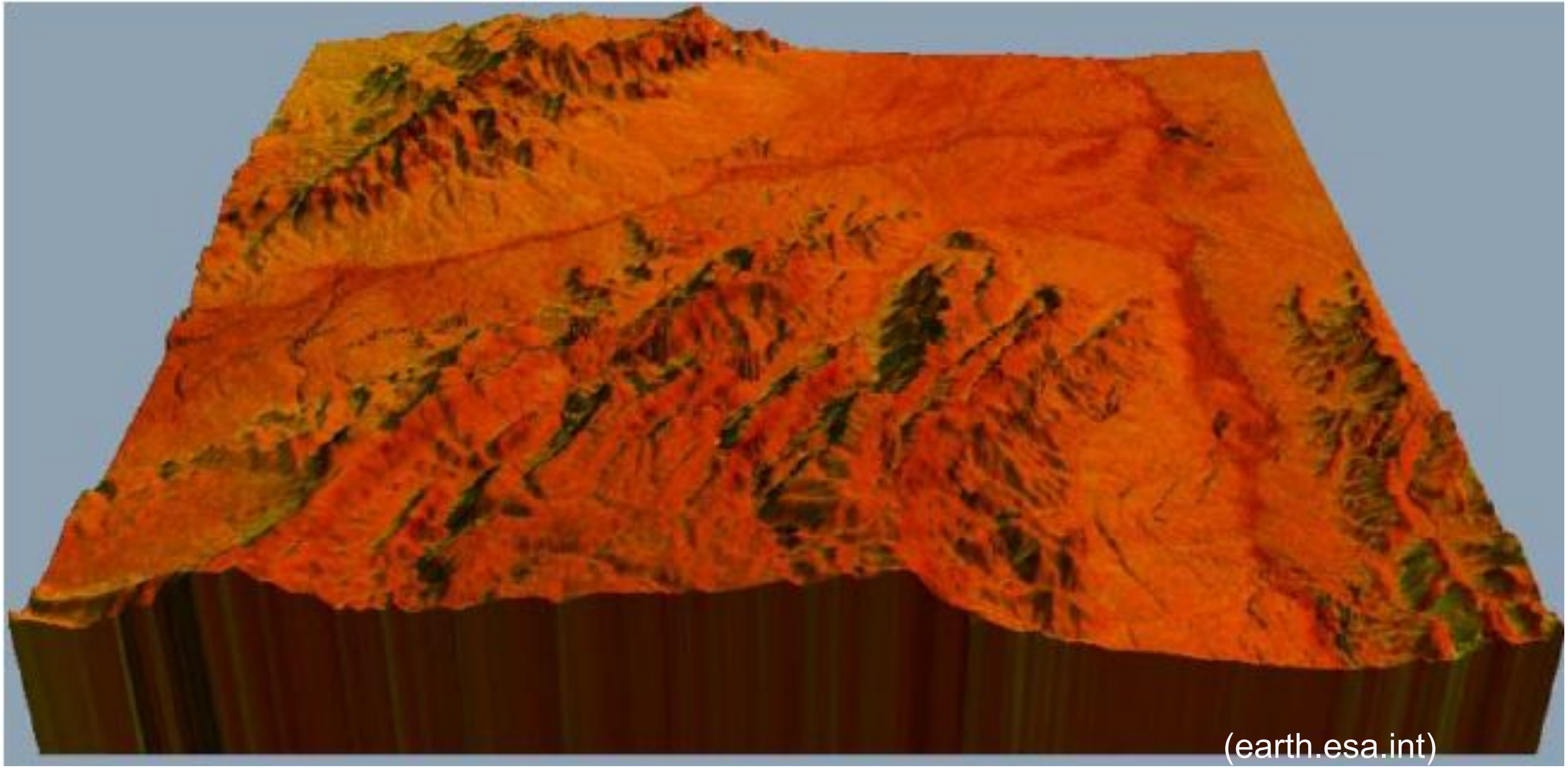
(earth.esa.int)

Radar Applications



(earth.esa.int)

Radar Applications: elevation

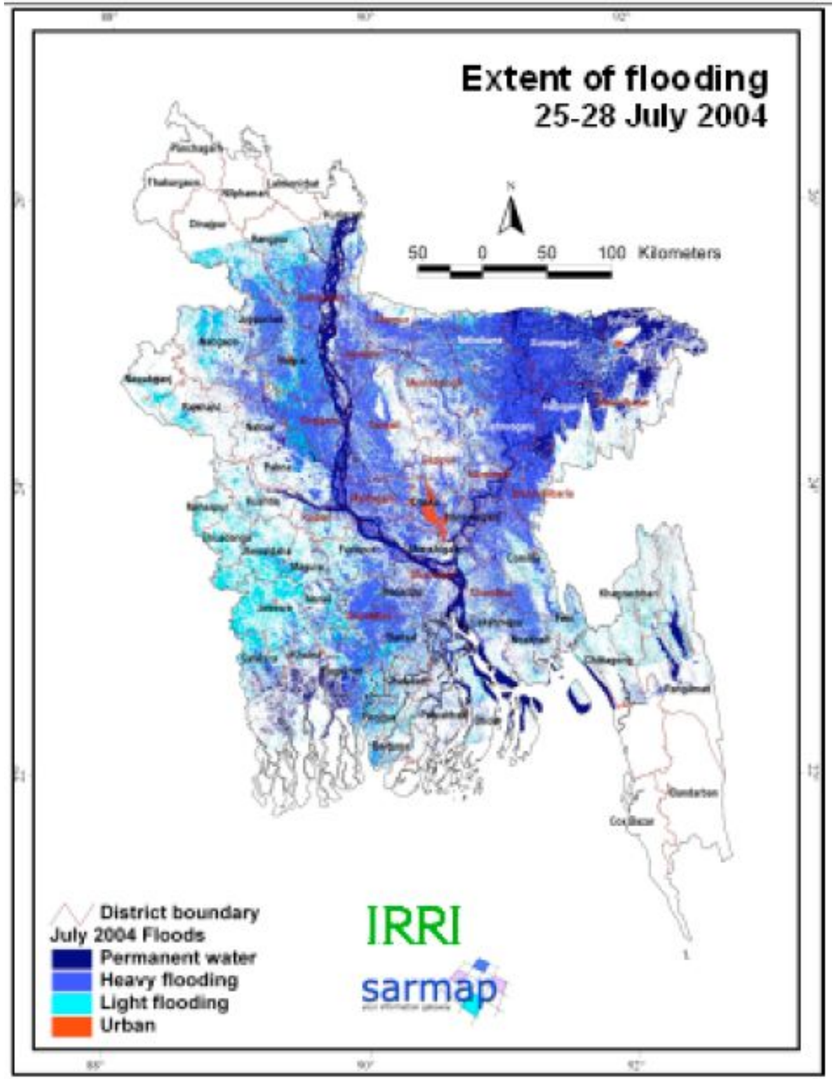


(earth.esa.int)

Radar Applications

Flooding: water= the areas where there is little backscatter.

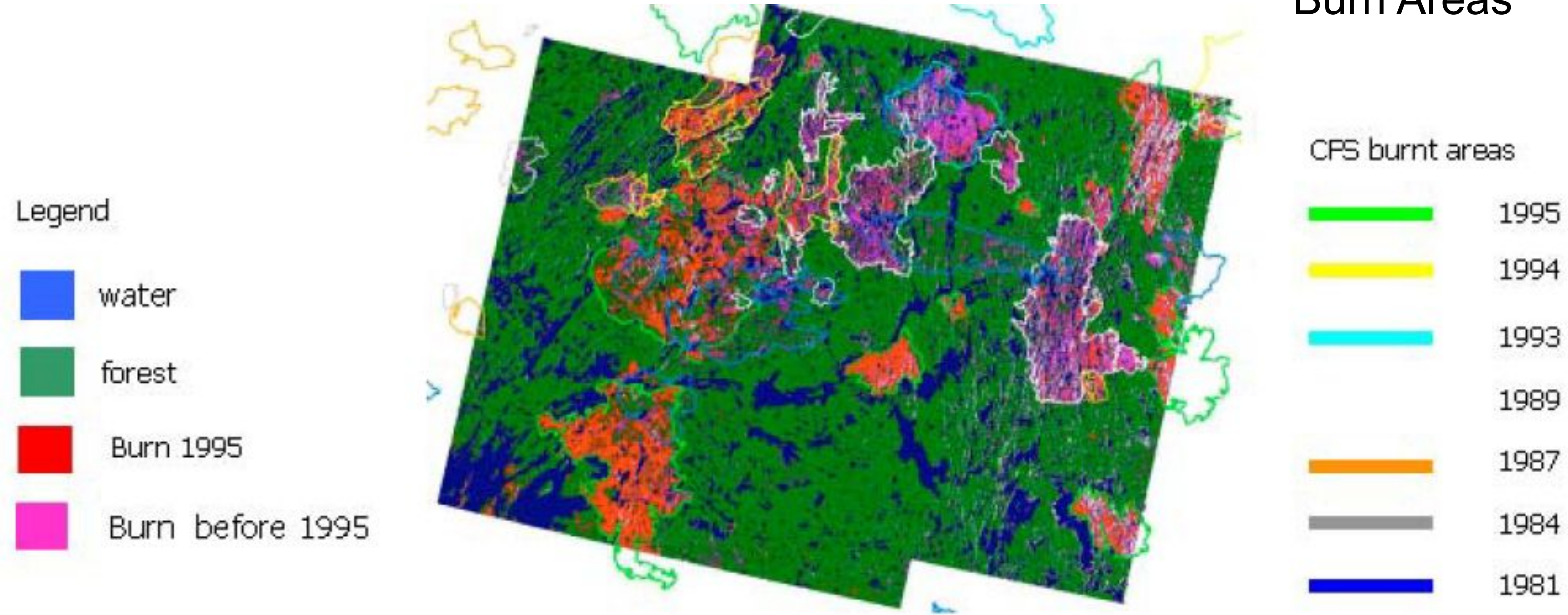
Compare with pre-flooding images to map extent.



(earth.esa.int)

Radar Applications

Burn Areas



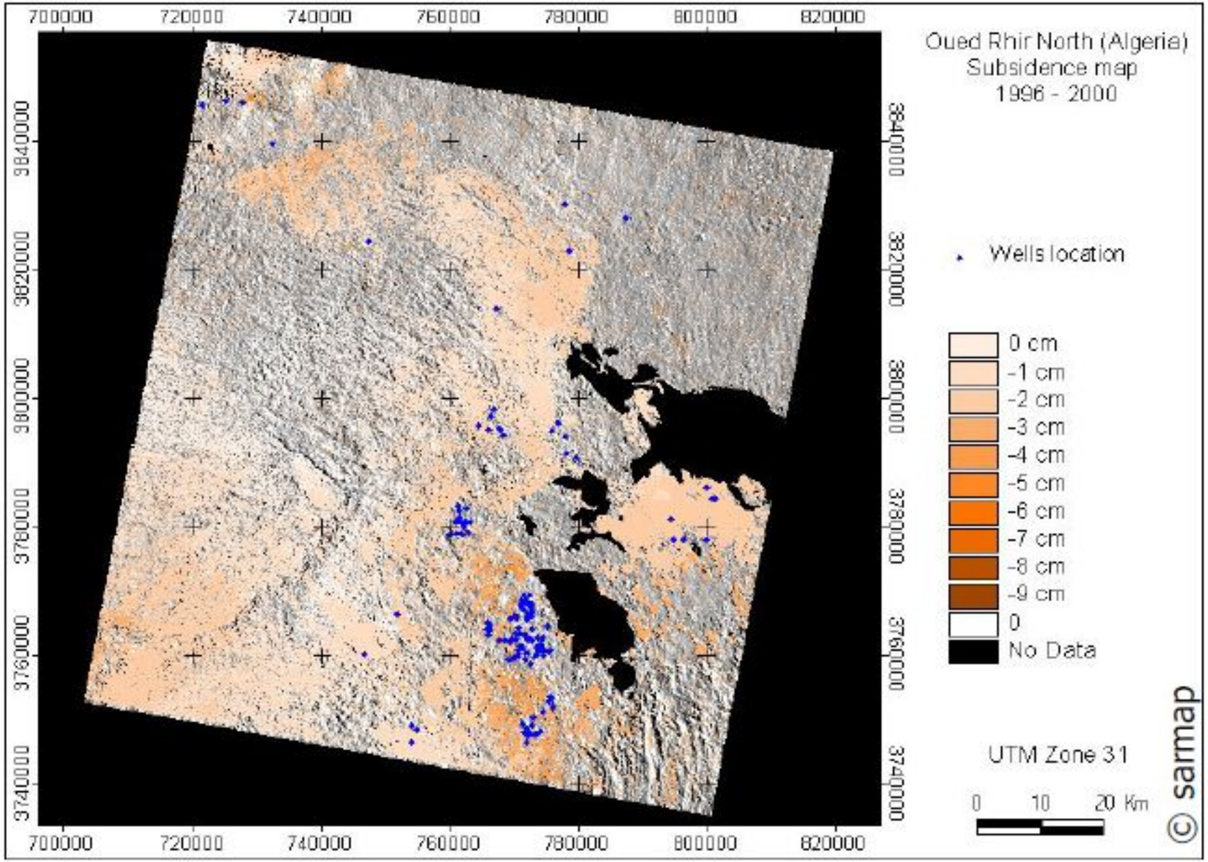
(earth.esa.int)

Radar Applications

Land Subsidence

uses differential interferometry

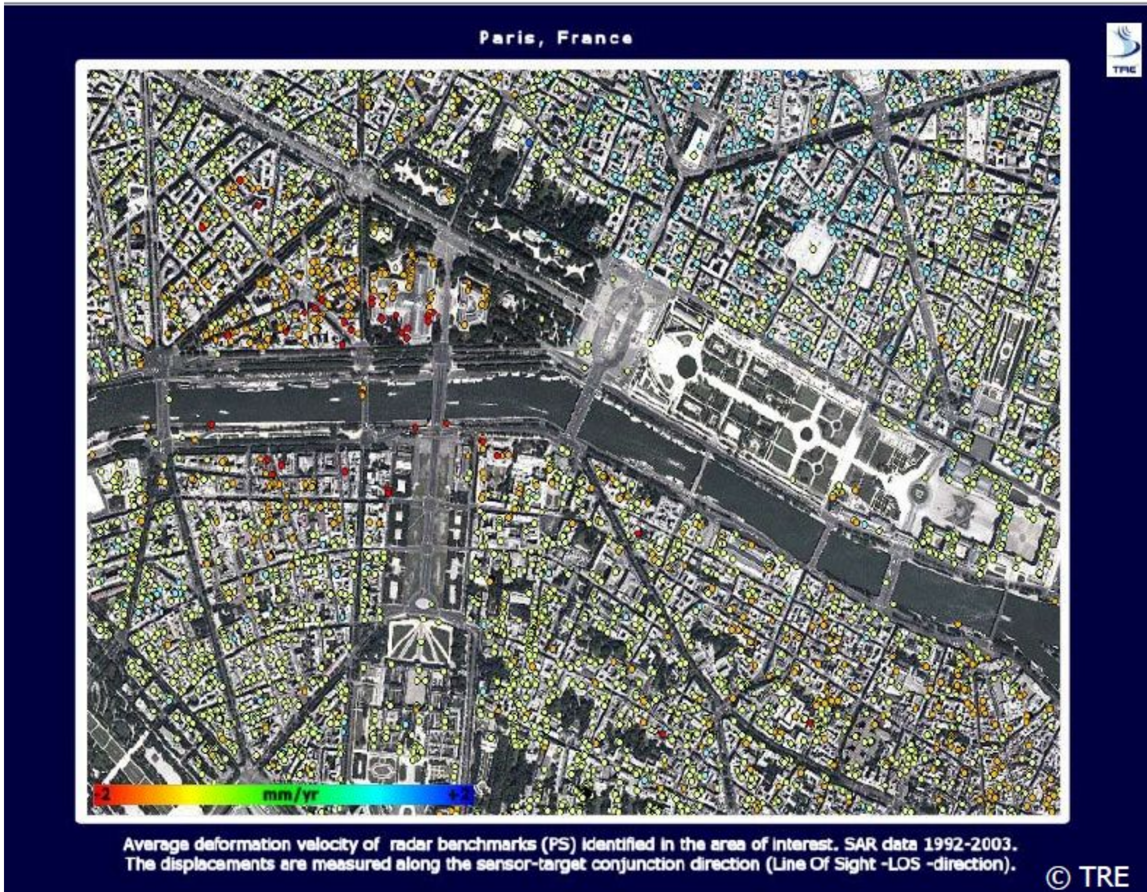
(earth.esa.int)



Radar Applications

Urban Mapping:

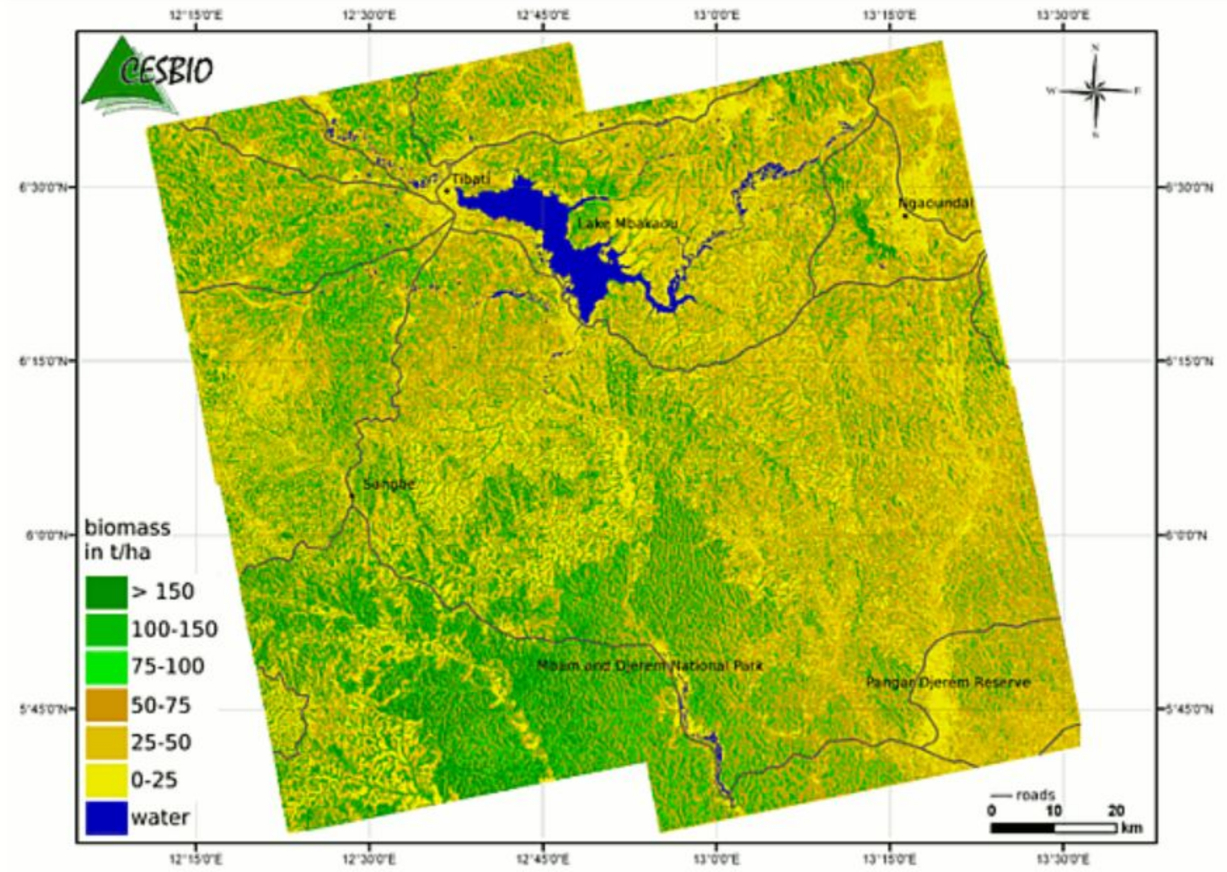
Paris, France



(earth.esa.int)

Radar Applications

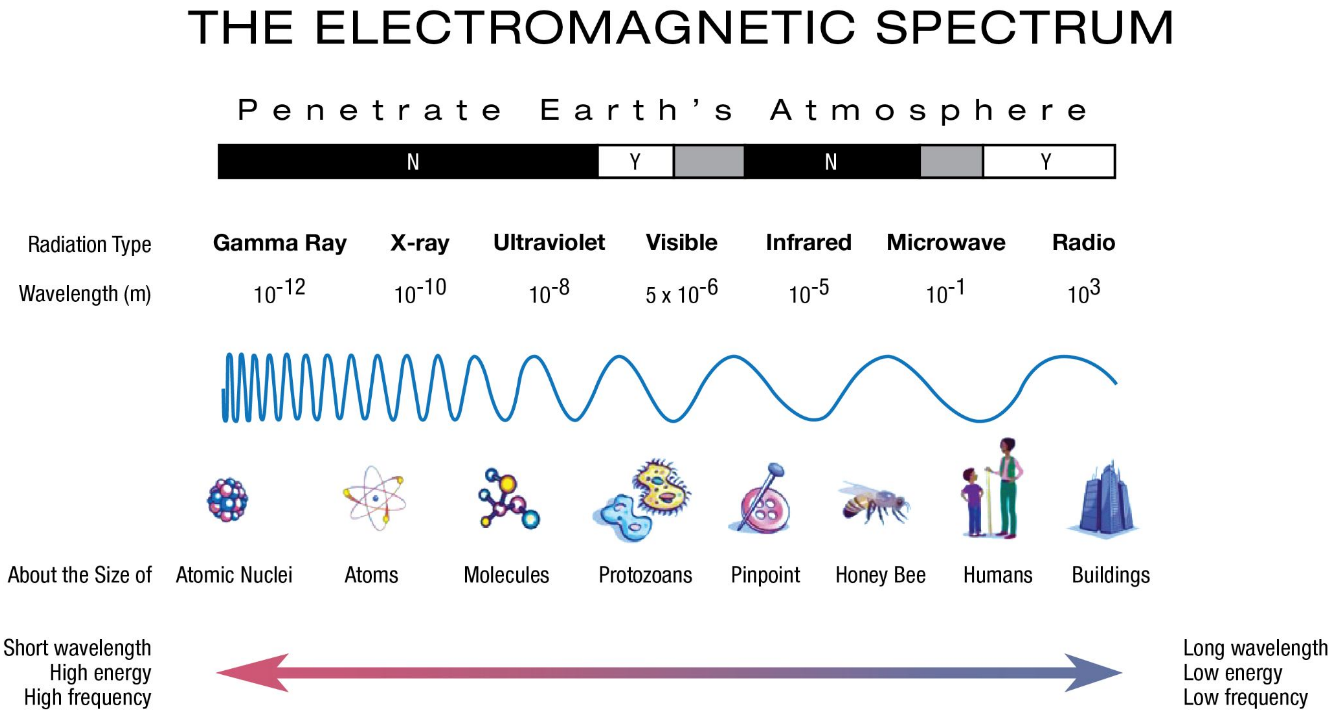
Forest Biomass



(www.reddaf.info)

2. What is Remote Sensing?

99% of Remote Sensing uses electromagnetic radiation



(mynasadata.larc.nasa.gov)

2. What is Remote Sensing?

Two main categories of sensor:

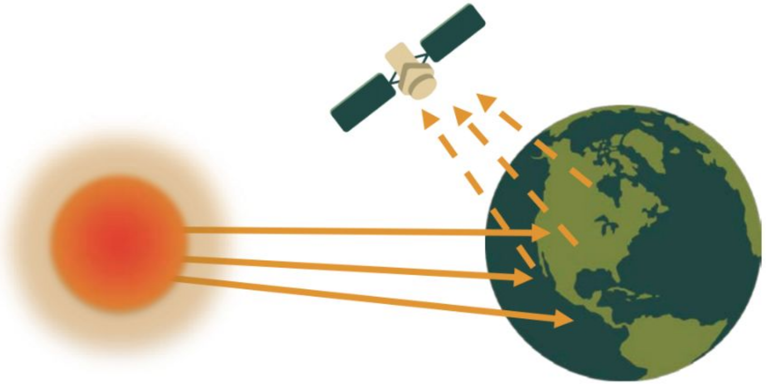
- Optical
- Microwave

Because the atmosphere does not absorb these frequencies

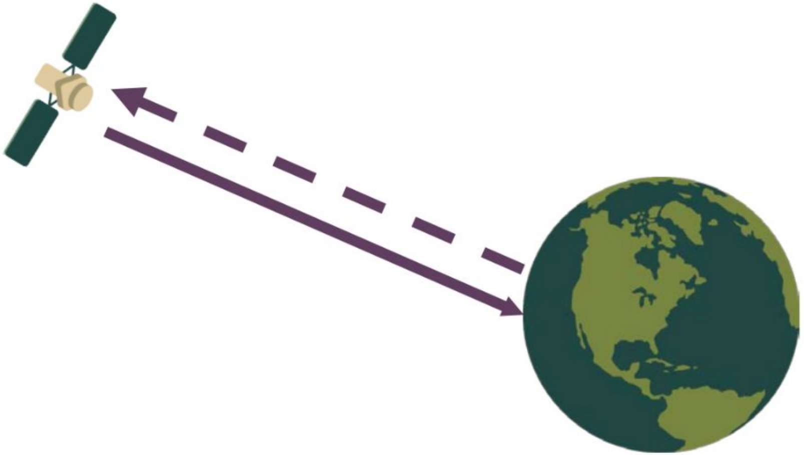
The technology used for each are very different

2. What is Remote Sensing?

Most Optical Sensors look at reflected sunlight



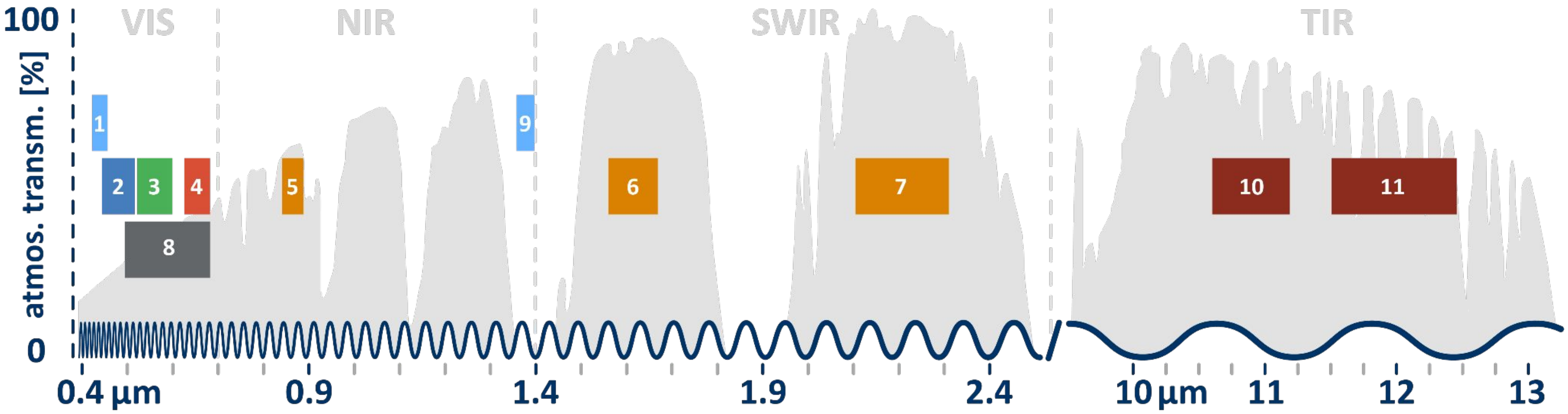
Radar Sensors look at a reflected radar pulse



(nasa)

2. What is Remote Sensing?

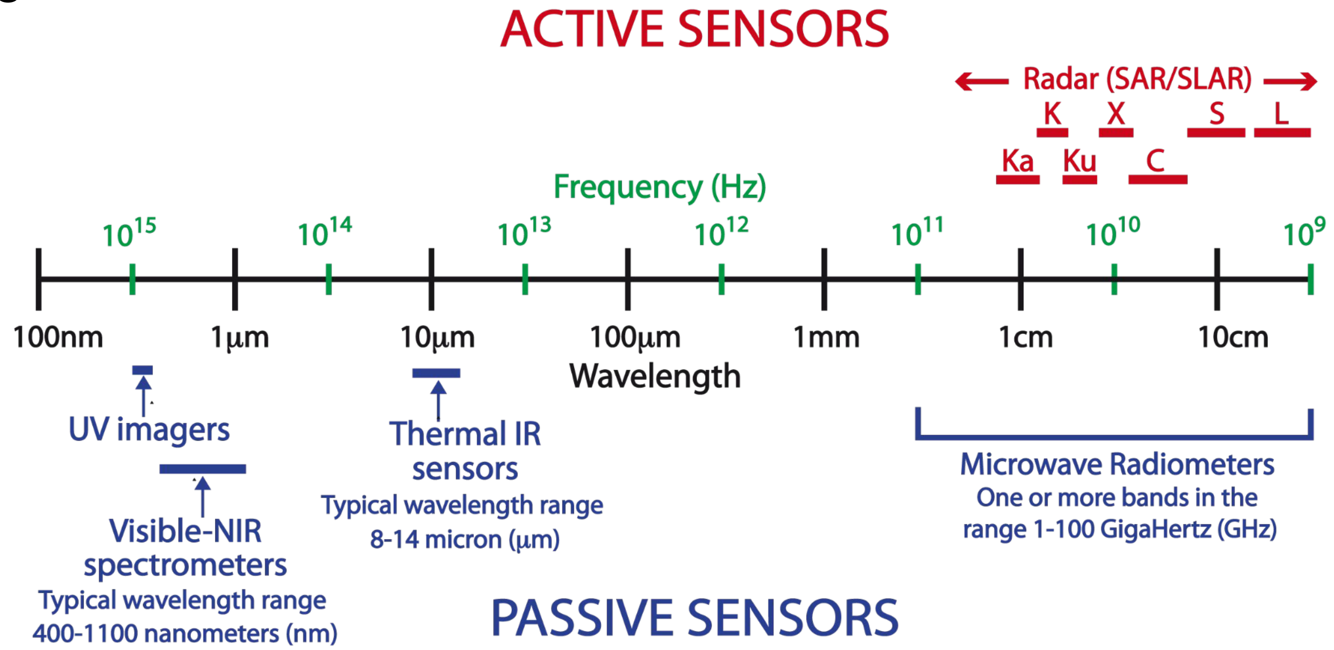
Optical Sensors record reflectance in a number of different wavelength bands:



(fu-berlin.de)

2. What is Remote Sensing?

Radar Sensors also can record in multiple frequency ranges



(seos-project.eu)

2. What is Remote Sensing?

Resolution and Accuracy

Image resolution: 40 cm to 30 meters to 100+ meters
Temporal repeat: 1 day to many months

SNR: 100's

Calibration of each sensor is required in order to obtain accurate and repeatable data

2. What is Remote Sensing?

Data Volume

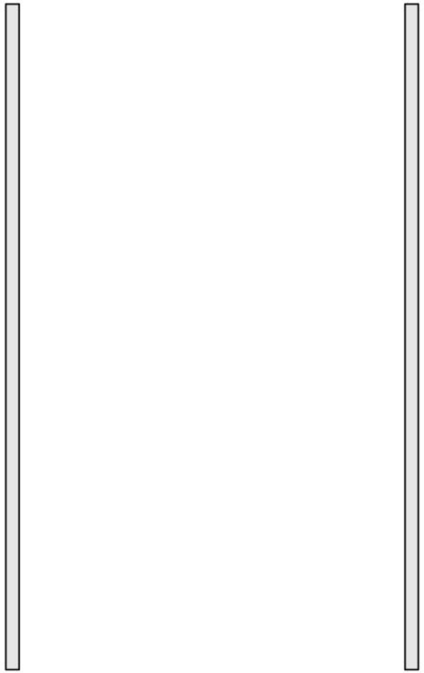
Daily rate: all sensors produce several-hundred TB of data

Storage: just the US: stores hundreds of thousands of TB per year.

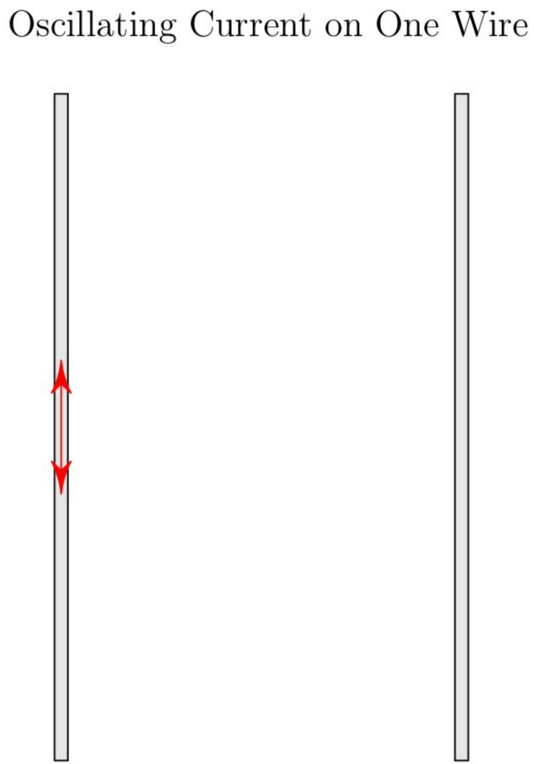
3. How does Radar Remote Sensing work?

Electromagnetic Interaction

Two Conducting Wires

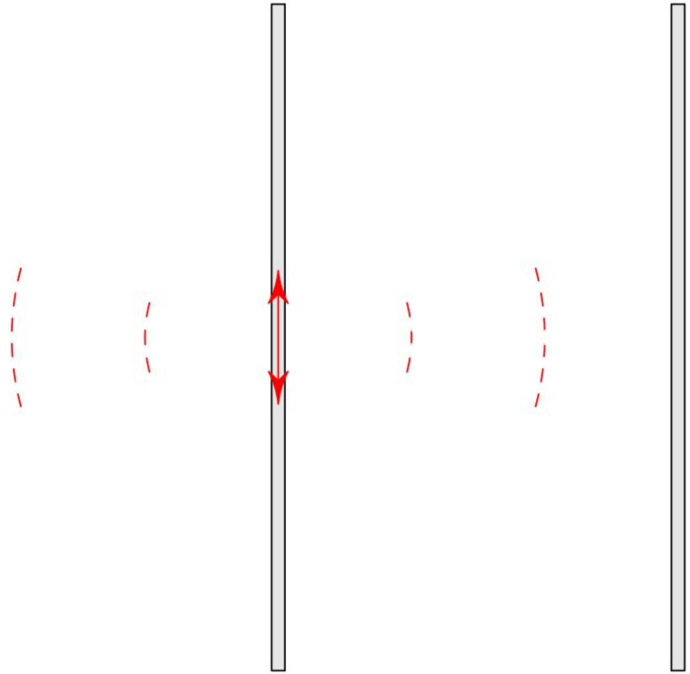


Electromagnetic Interaction

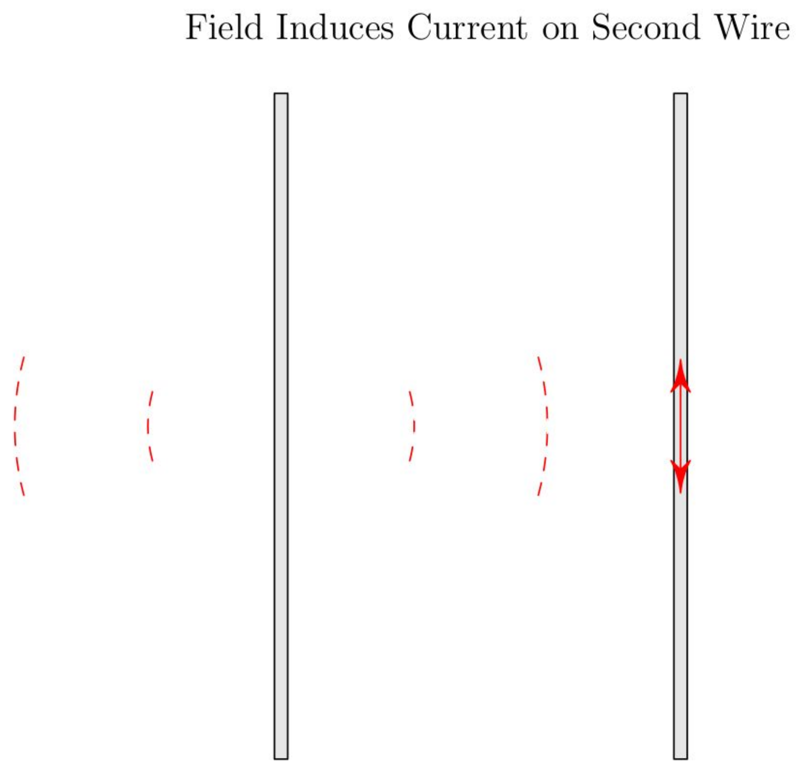


Electromagnetic Interaction

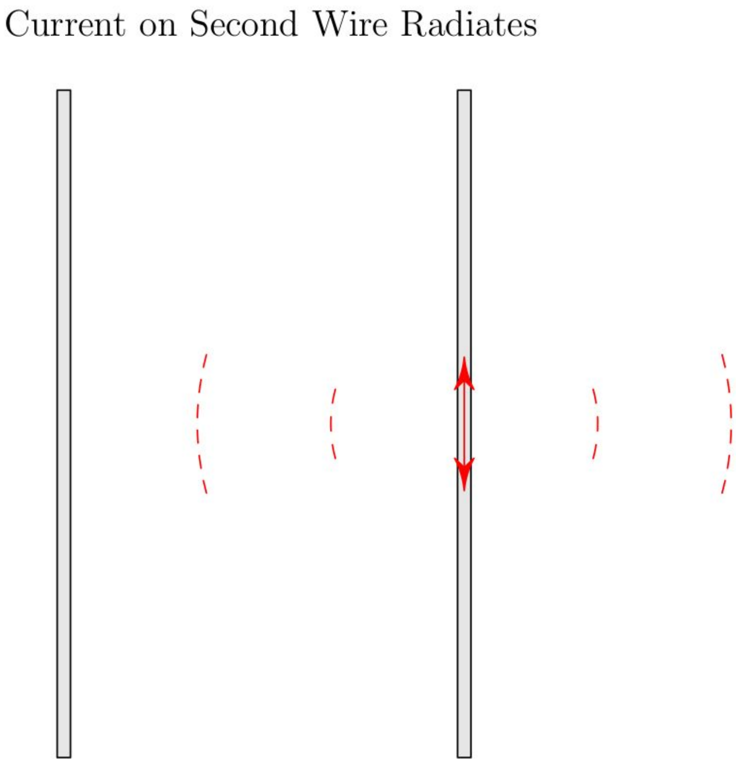
Radiated Field Propagates in All Directions



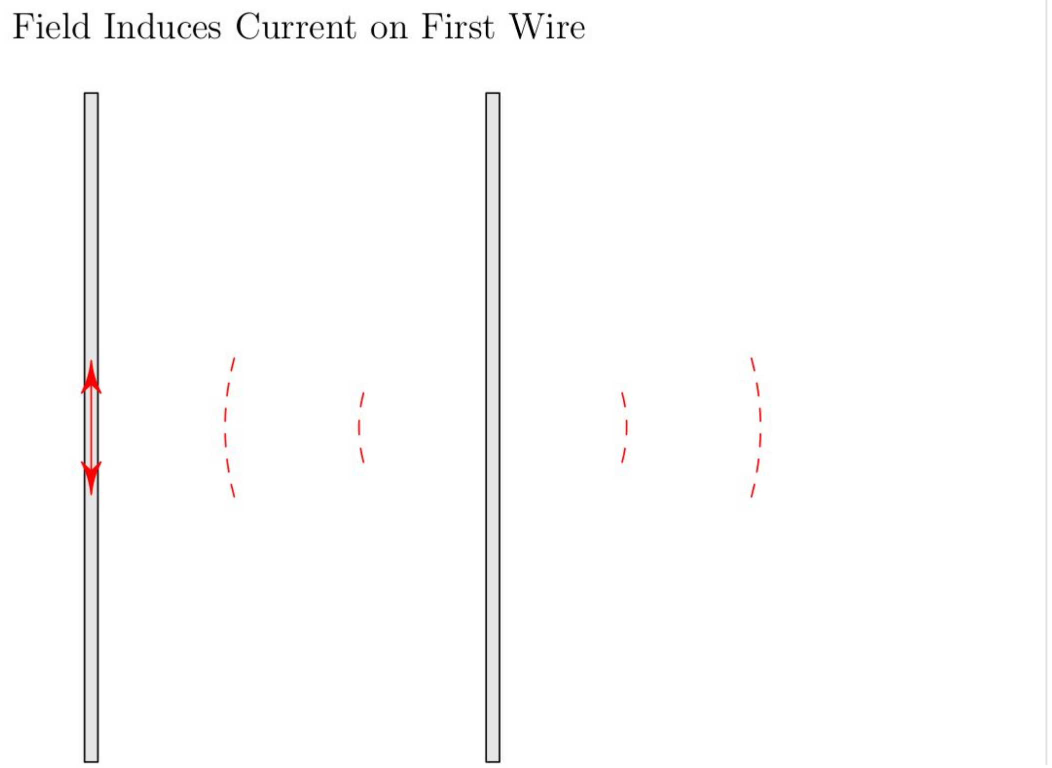
Electromagnetic Interaction



Electromagnetic Interaction

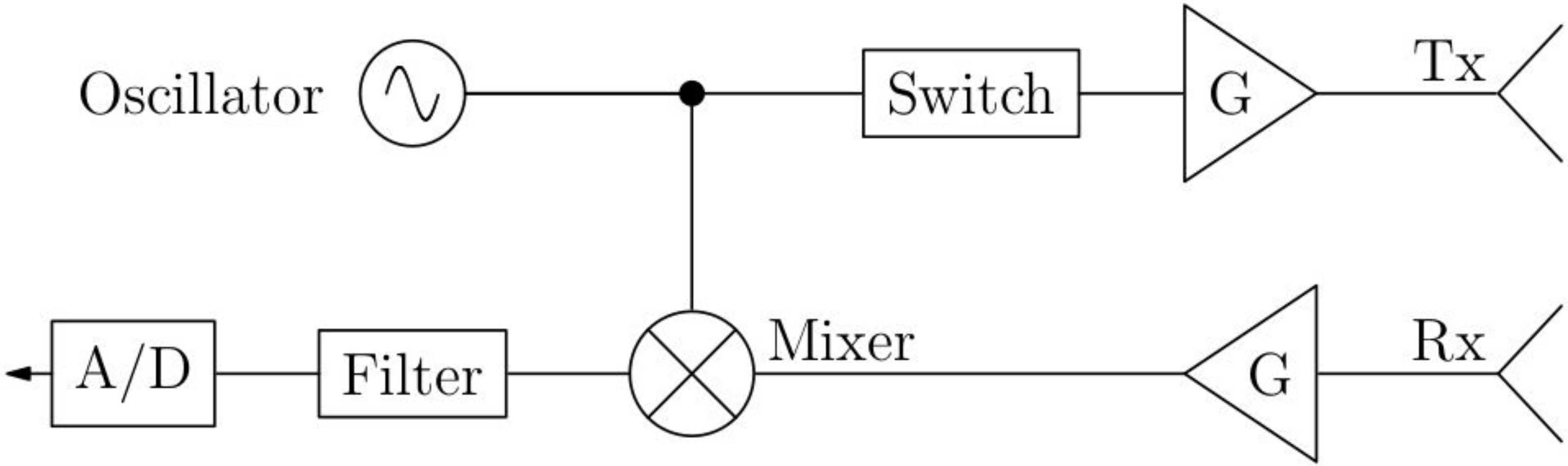


Electromagnetic Interaction



Radar Block Diagram

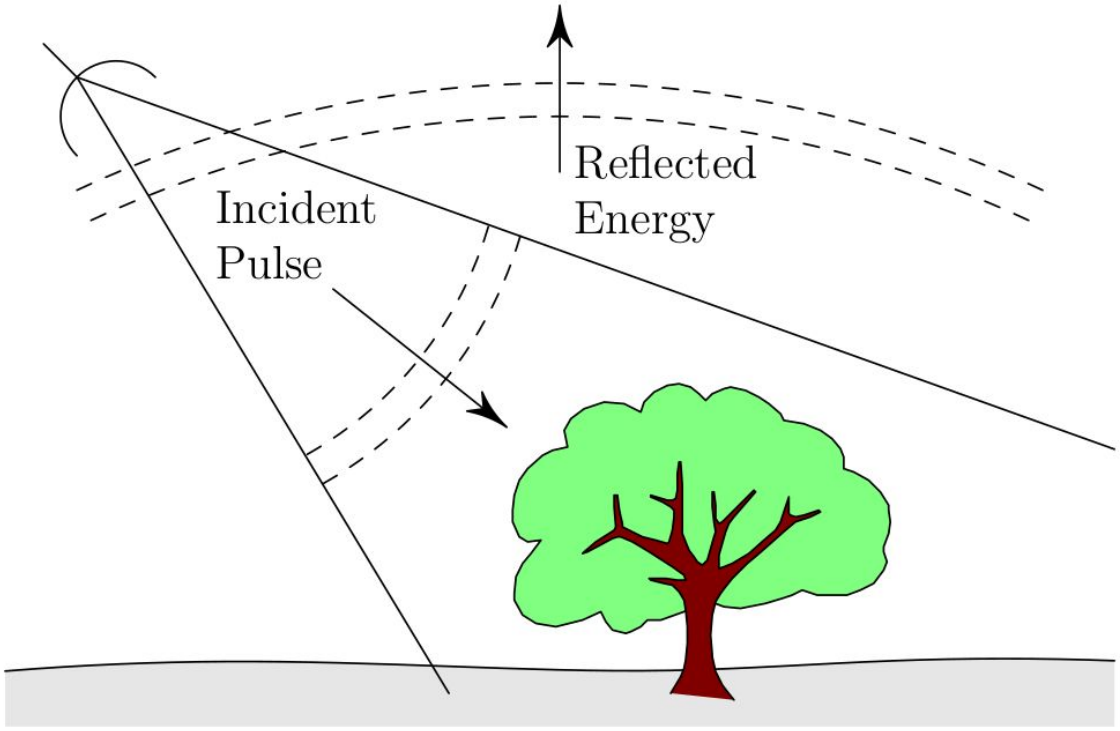
A Radar is a system for generating such a field and measuring the reflected field:



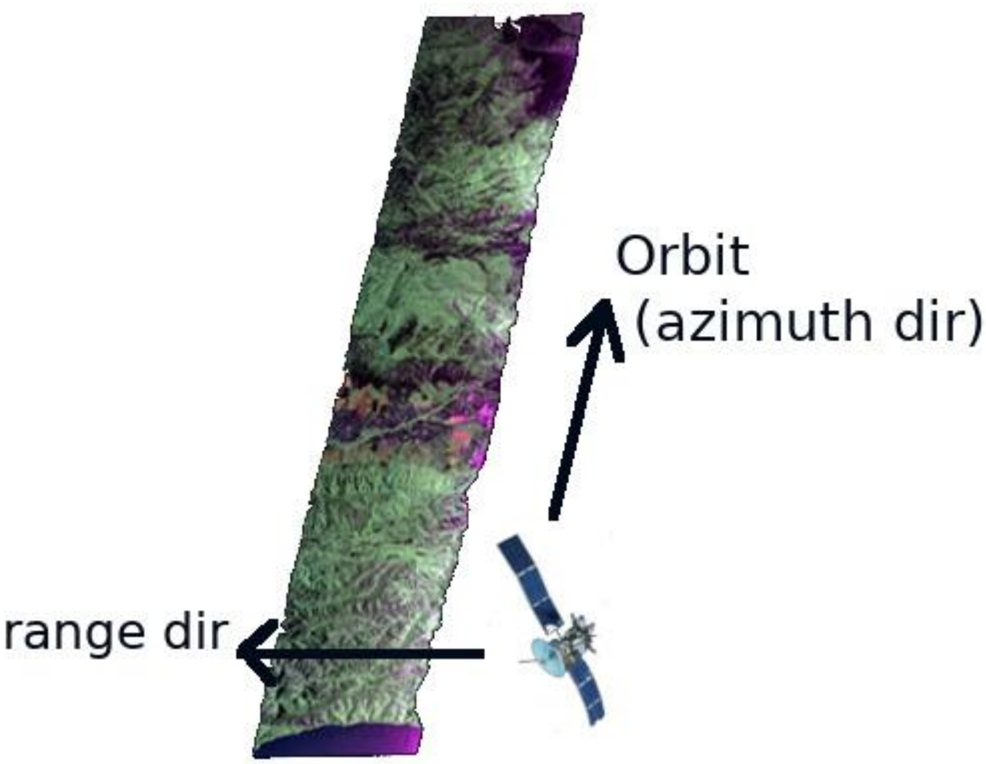
(digital control circuitry not shown)

Typical Sensing Scenario

Radar on an airplane or a satellite looks down upon the Earth:



SAR Image Coordinates



Noise

Thermal Noise limits the radar's performance:

$$V_{rms} = \sqrt{4RkTB}$$

R - Resistance, Ohms

k - Boltzmann's constant, Ws/K

T - Temperature, K

B - Bandwidth of voltmeter, Hz

Noise

Typically this noise is on the order of micro-volts.

What transmit power is needed to overcome this noise on receive?

Lose power on transmit like $1/R^2$

Lose power again on the way back up, like $1/R^2$

Usually means a **transmit power of Kilo-Watts for a Signal-to-Noise ratio of about 100**

Speckle Noise

The signal reflected from each ground target:

$$V = A \cos(\omega t + phi)$$

The signal recorded at the sensor:

$$V = A_1 \cos(\omega t + phi_1) + A_2 \cos(\omega t + phi_2) + ...$$

So when looking at the same spot on the Earth from a slightly different orbital location, the phases are all different, so the V can be completely different.

Voltage can vary from 0 to a large number: this causes speckle noise.

Speckle Noise

Turns out that the probability distribution for the noise gives a standard deviation equal to the mean.

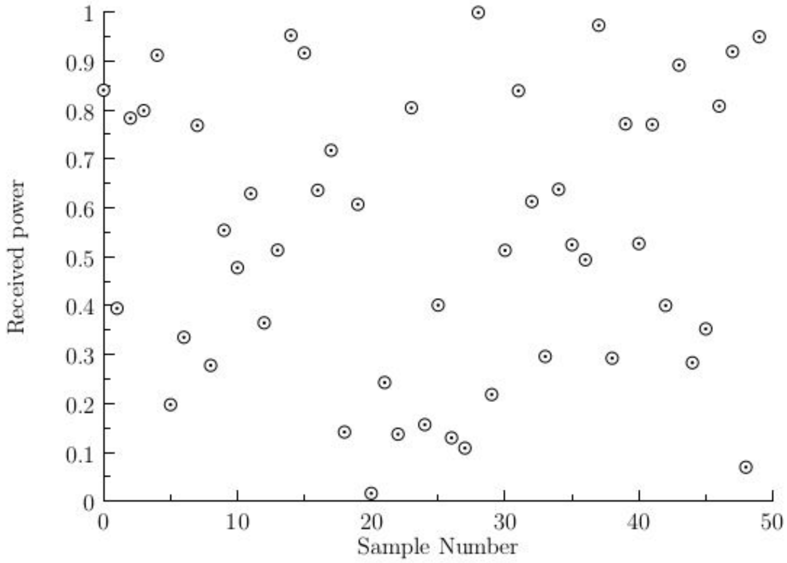
This is not the familiar "gaussian noise".

It's much worse.

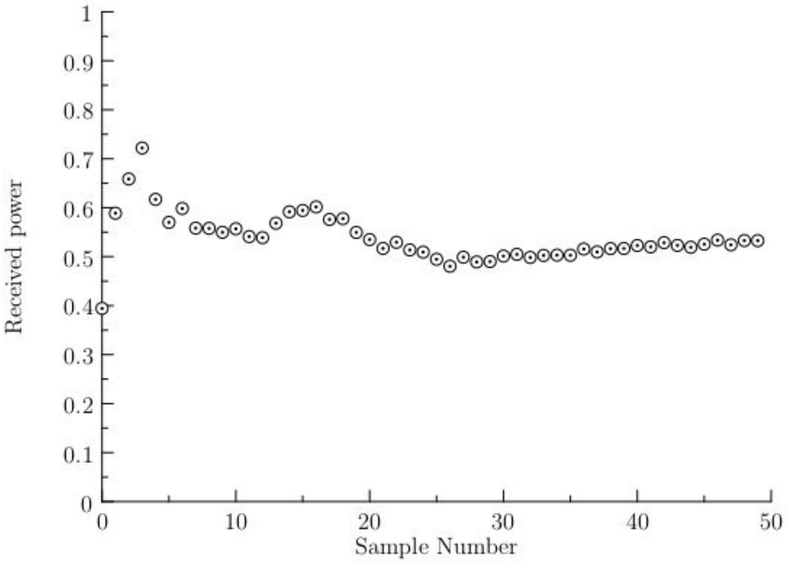
Best way to remove: average independent samples

Speckle Noise

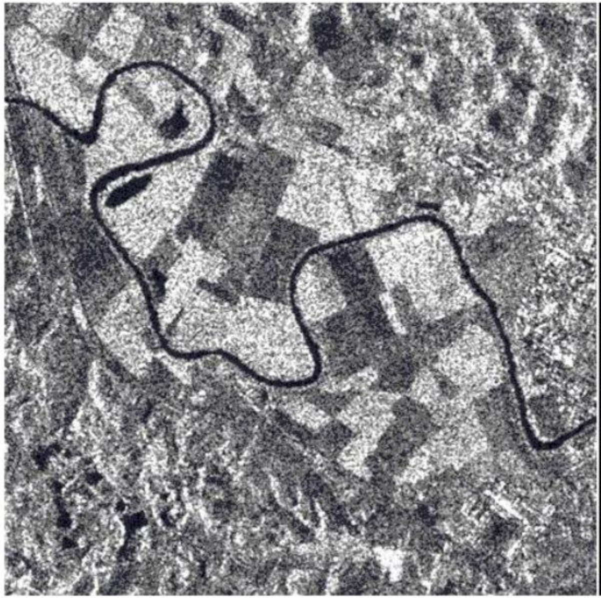
Speckle Mitigation: Example



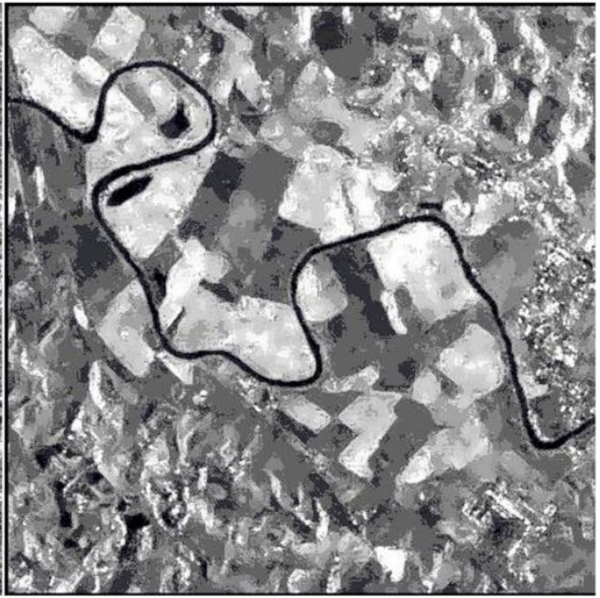
average ⟹



Speckle Noise



SAR image with speckle

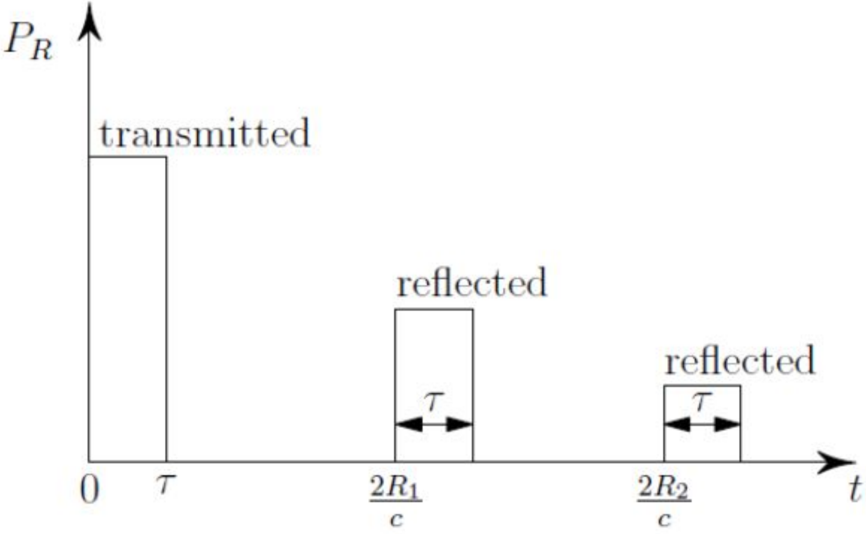


Despeckled SAR image

(http://earth.esa.int)

Range Resolution

Range Resolution: 2-target case:



Transmitted pulse with width τ and two received pulses.
Define range resolution as the spacing between 2 targets such that the two returned pulses start to overlap:

$$2 R_1 / c + \tau = 2 R_2 / c$$

Range Resolution

Range Resolution: 2-target case:

range resolution = $c\,\tau / 2$

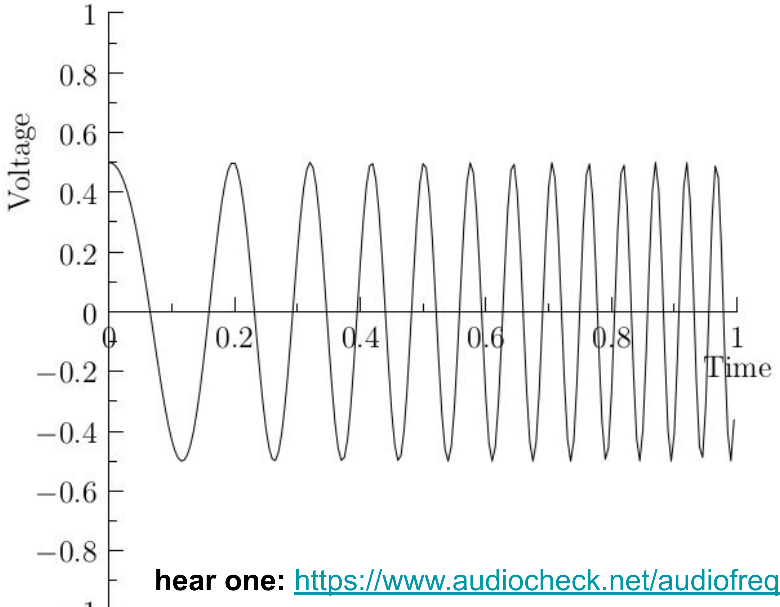
However, cannot make pulse width (τ) too short,

or transmitted power will be too small to overcome thermal noise.

Range Resolution

Instead of transmitting a constant-frequency pulse, send a **frequency-chirped pulse** instead:

$$\text{chirp} = V(t) = \cos(\omega t + \Omega t^2)$$



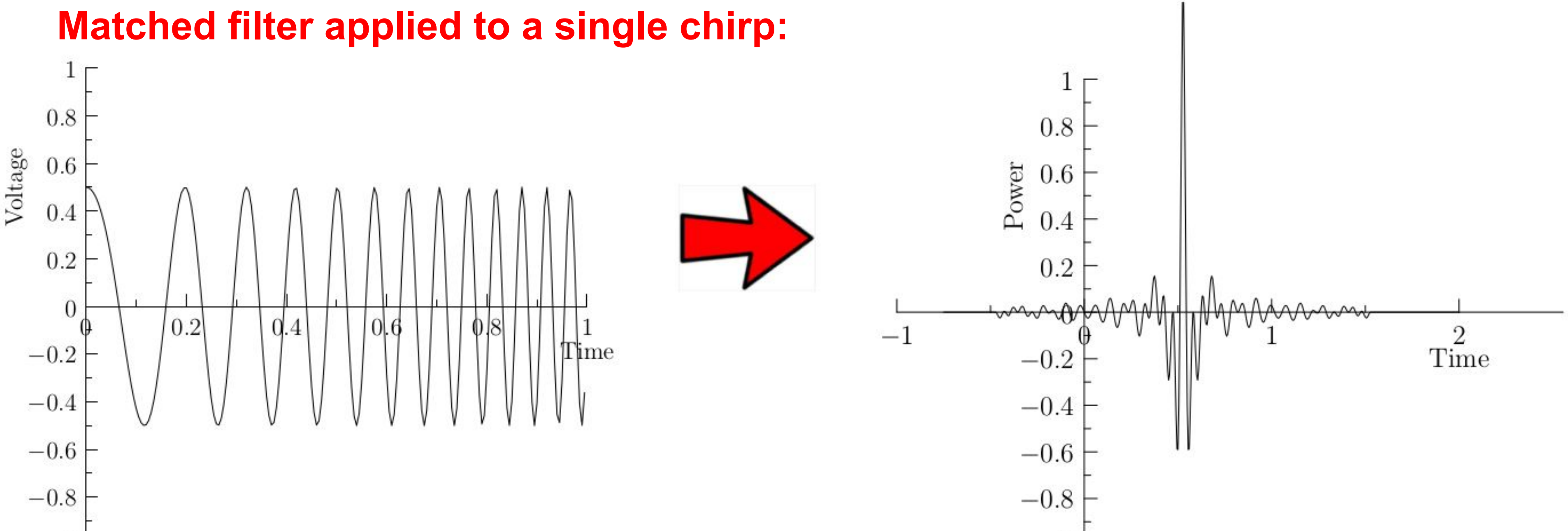
hear one: https://www.audiocheck.net/audiofrequencysignalgenerator_sweep.php

Range Resolution

Process the received signal with a matched filter:

$$\text{processed signal} = \int \text{signal}(t') \, \text{chirp}^*(t - t')dt'$$

Matched filter applied to a single chirp:



Range Resolution

Because we processed the received signal with a matched filter:

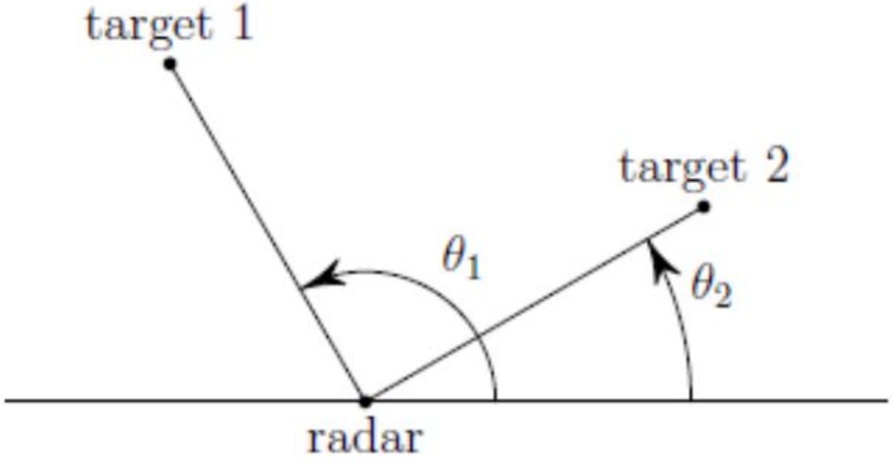
range resolution = c / (2B)

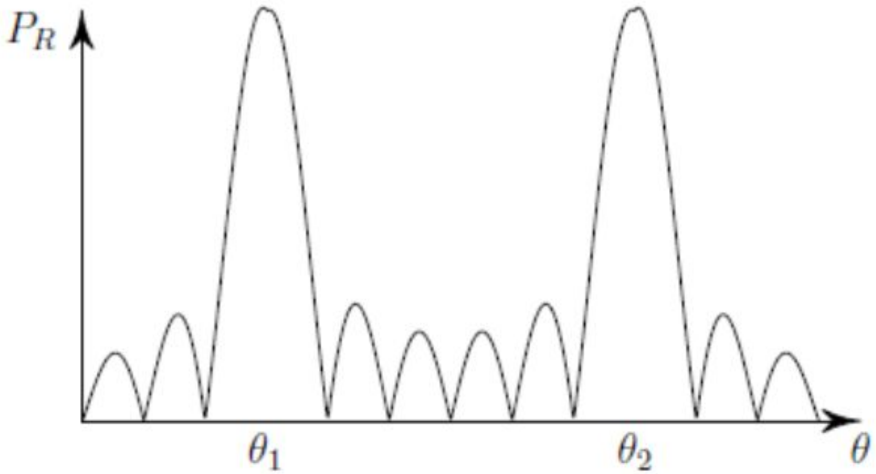
where B is the bandwidth of the chirp.

- Independent of pulse width.
- Can now choose pulse width to satisfy power, or other system constraints.

Azimuth Resolution

Antenna Pattern determines when targets at different angles overlap:

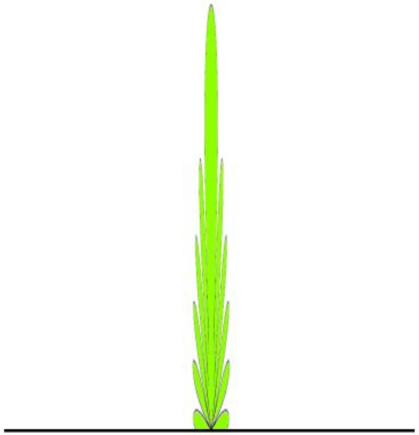




Azimuth Resolution

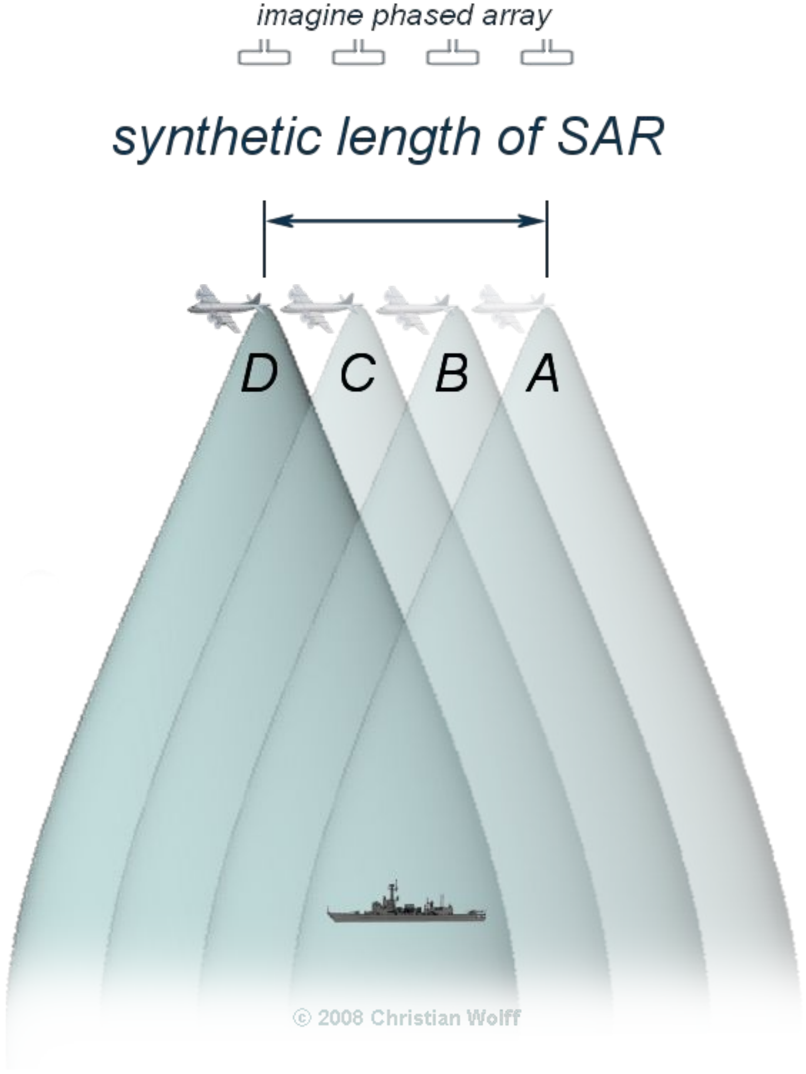
Used "phased arrays" to produce a narrow beam:

An array of 5 separate antennas, showing their single-antenna beams.



The composite antenna beam for the whole array.

Azimuth Resolution



(radartutorial.eu)

Azimuth Resolution

Create a phased array by **processing** the data from each orbital position as if its a component of a giant phased array in space.

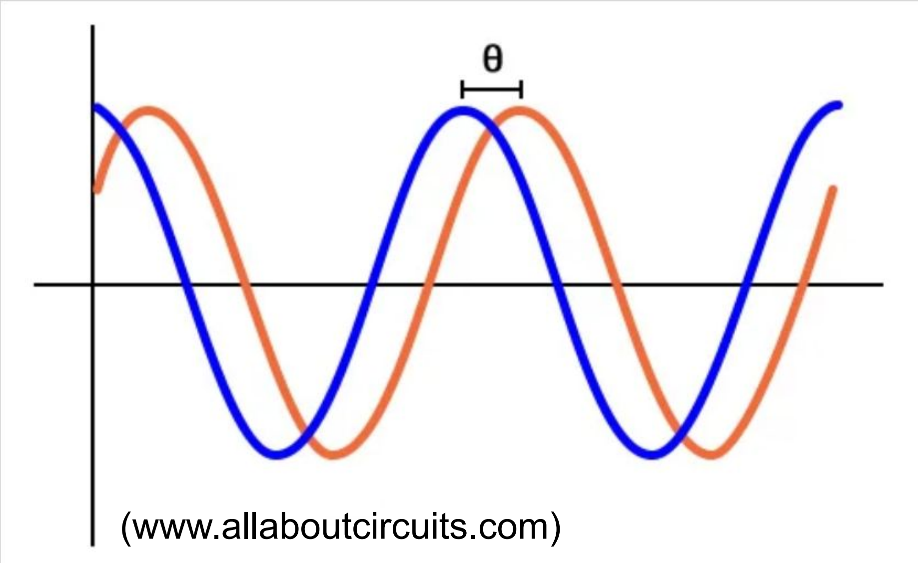
This is where the term "Synthetic Aperture" comes from, where the orbital length is the "aperture" of the phased array.

SAR Images are complex numbers

Each pixel in a SAR image has an Amplitude and Phase

Result of comparing the received sinusoid with a reference sinusoid:

- amplitude ratio
- timing for phase



(www.allaboutcircuits.com)

SAR Images are complex numbers

Amplitude and phase of a SAR image:

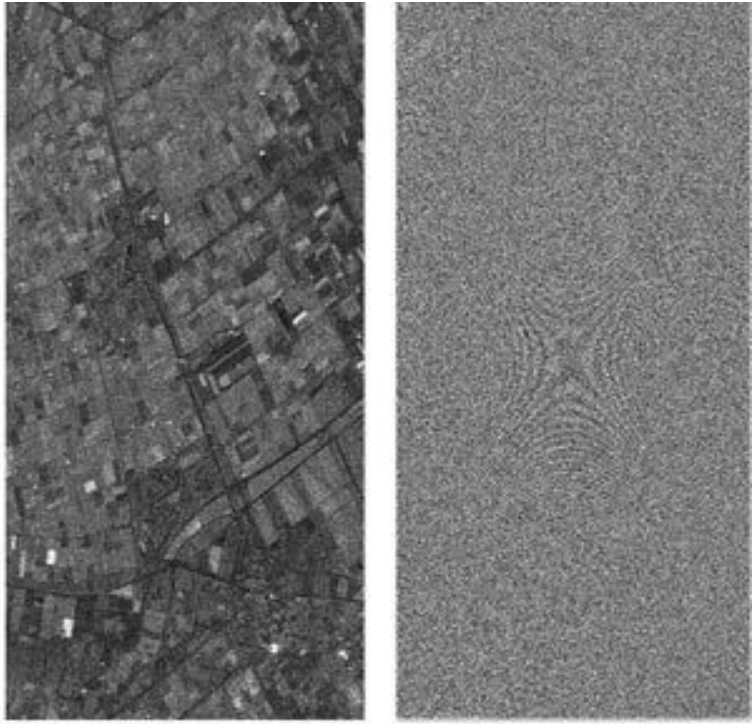
The phase looks like noise.

But it isn't.

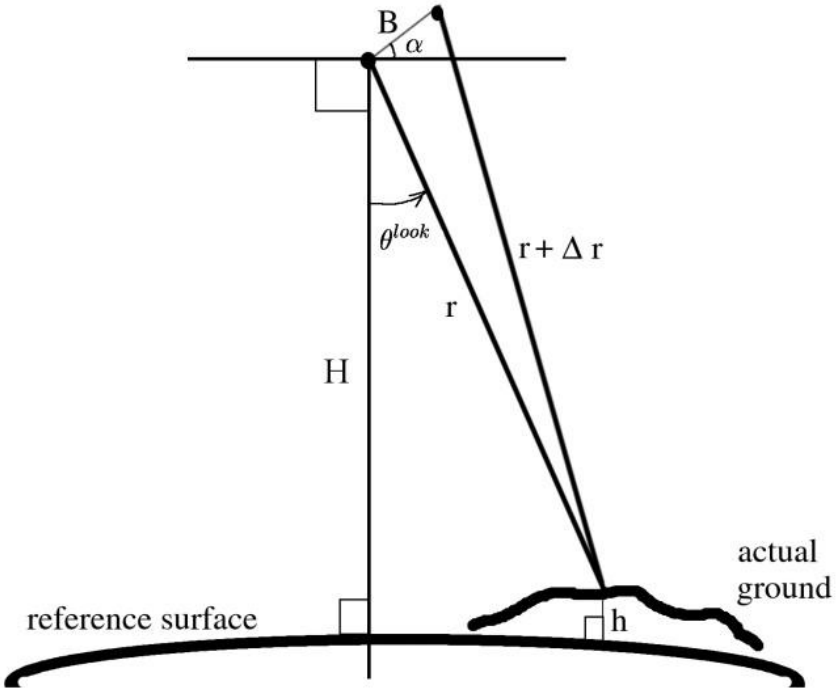
It's used in Interferometric SAR:

The phase difference between 2 images of the same area can be used to get distance.

https://www.reddit.com/r/glitch_art/comments/27qcp6/are_synthetic_aperture_radar_sar_images_welcome/



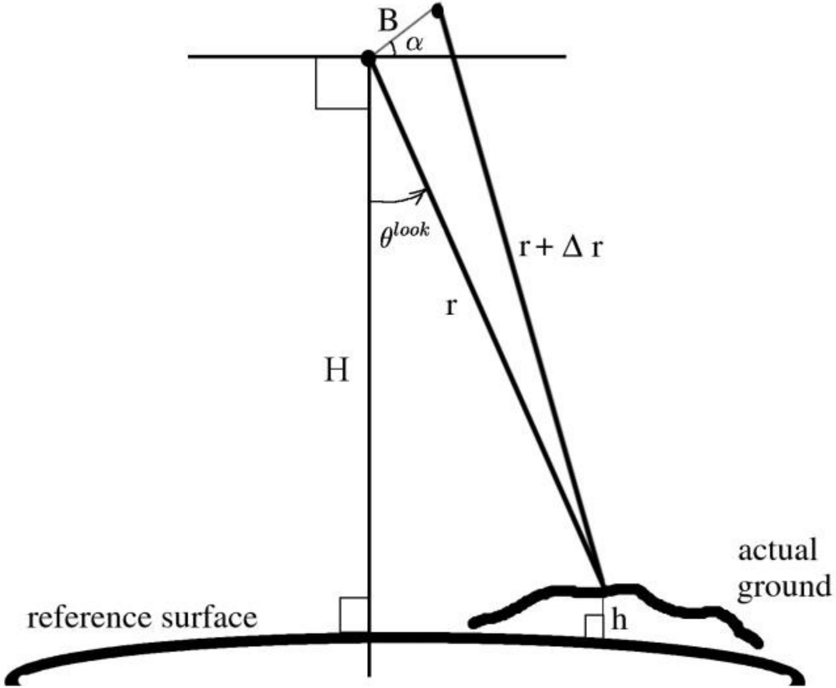
Geometry of Interferometric SAR



- Start with 2 sensors looking at same spot on the ground.
- These sensors have a separation, B, and an angle α, defining their relative positions.
- Relative to the ground, these sensors have a height, H, above some reference surface.
- A point on the ground is at a particular range and incidence angle from each sensor.

The unknown height, h, of the point on the ground is what we want to solve for.

Geometry of Interferometric SAR



- Assume know both ranges, and baseline. Solve for the look angle using law of cosines:

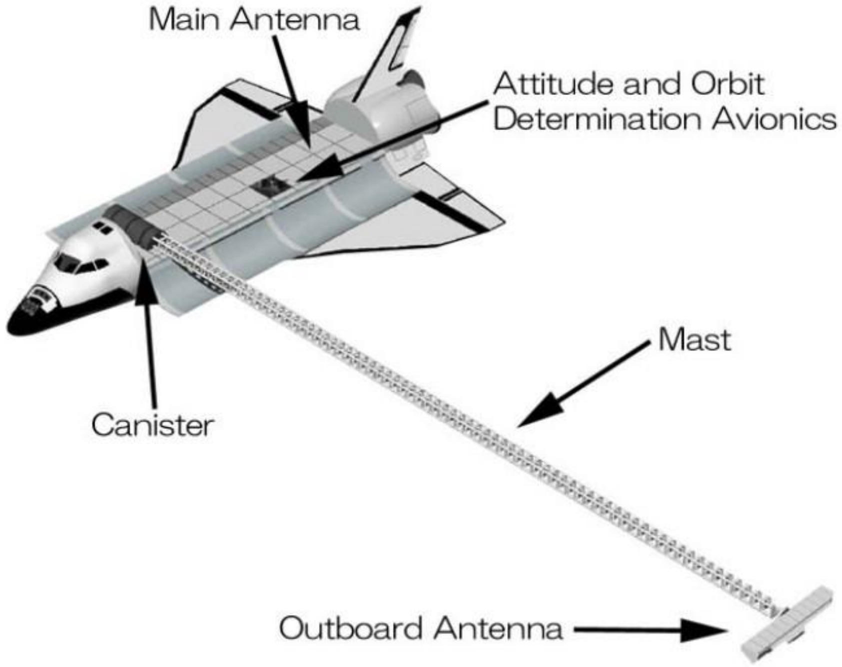
$$(r + \Delta r)^2 = r^2 + B^2 - 2Br\cos(\beta)$$

where $\beta = \alpha + (\pi/2 - \theta^{look})$.

After solving for θ^{look} we can calculate h:

$$h = H - r\cos(\theta^{look})$$

Example: SRTM



Frequency: 5 GHz

Resolution: 6-30 m range and az

Orbital Height: 225 Km

Swath Width: 20-100 Km

Boresite: 40 degrees

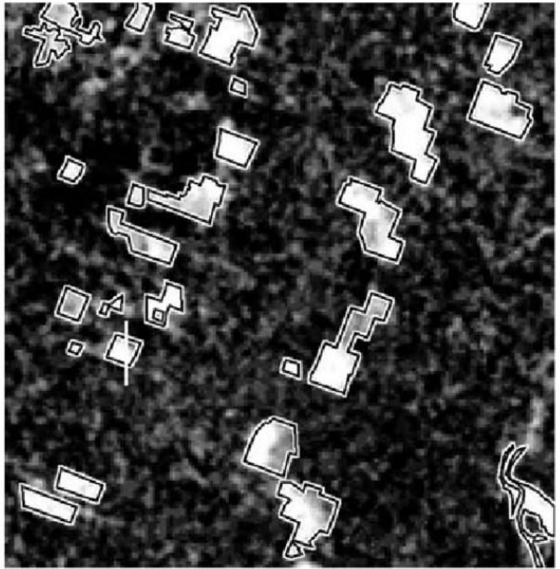
(http://southport.jpl.nasa.gov)

Example: SRTM

On the left: an airphoto, with forest stands outlined.

On the right: SRTM elevation map: showing that the forests are taller than the surrounding land.

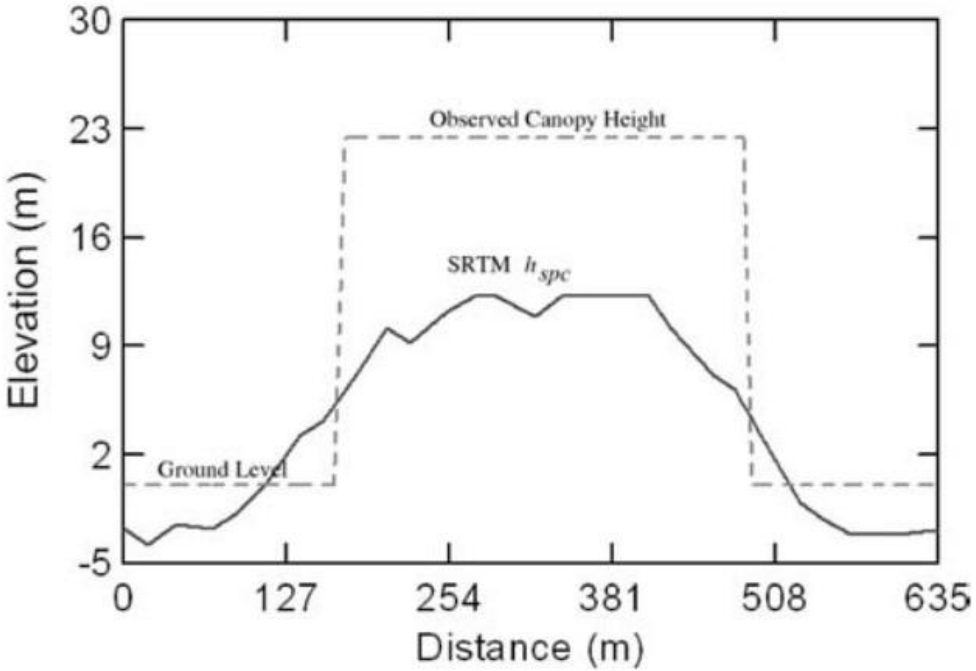
airphoto



SRTM elevations

Example: SRTM Forest Height Estimation

One slice through the dataset showing the correspondence of the SRTM data and the known forest height.



Since the radar scatters from within the canopy:

Equations that take into account the **species** and forest **density** are used to estimate the **forest height**.

Example: Height and Biomass Estimation

From Josef Kellndorfer:

4. Using Models to Understand Forests

Fractal Tree Model

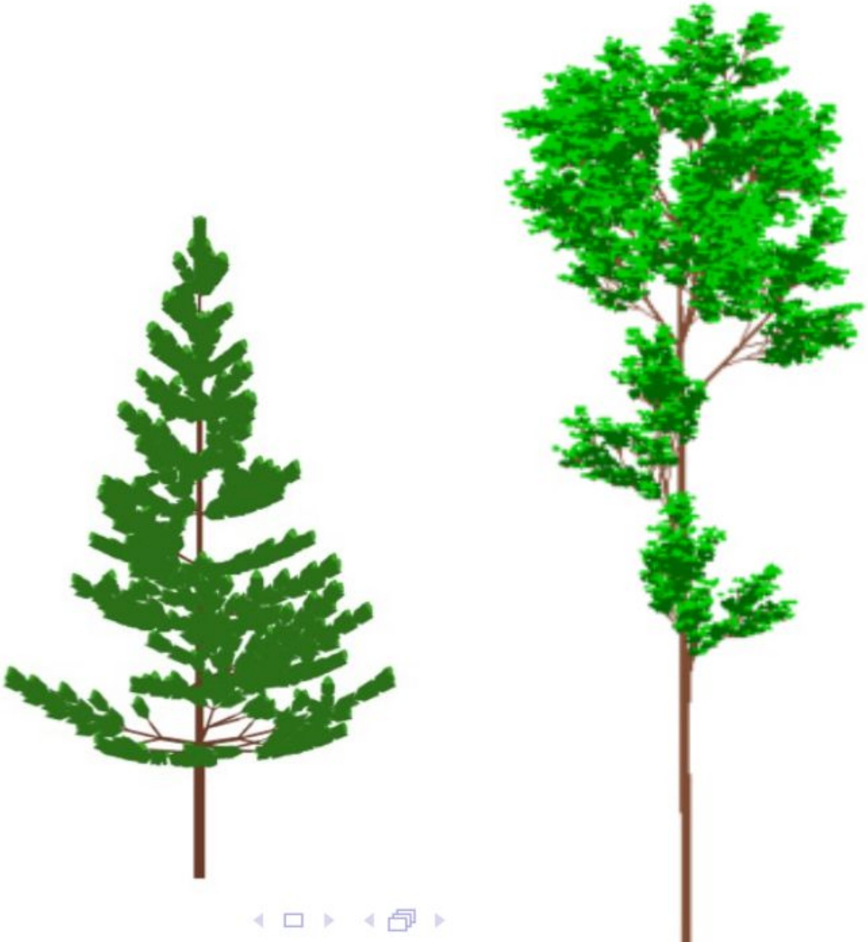
Model developed in late 1990’s.

Fractal pseudo-random trees.

Use Lindenmayer System:
string-rewriting rules are used to generate realistic branching structures, with needles and leaves.

Each species of tree has its own set of rules so it looks realistic.

Both coniferous and deciduous trees can be modeled.



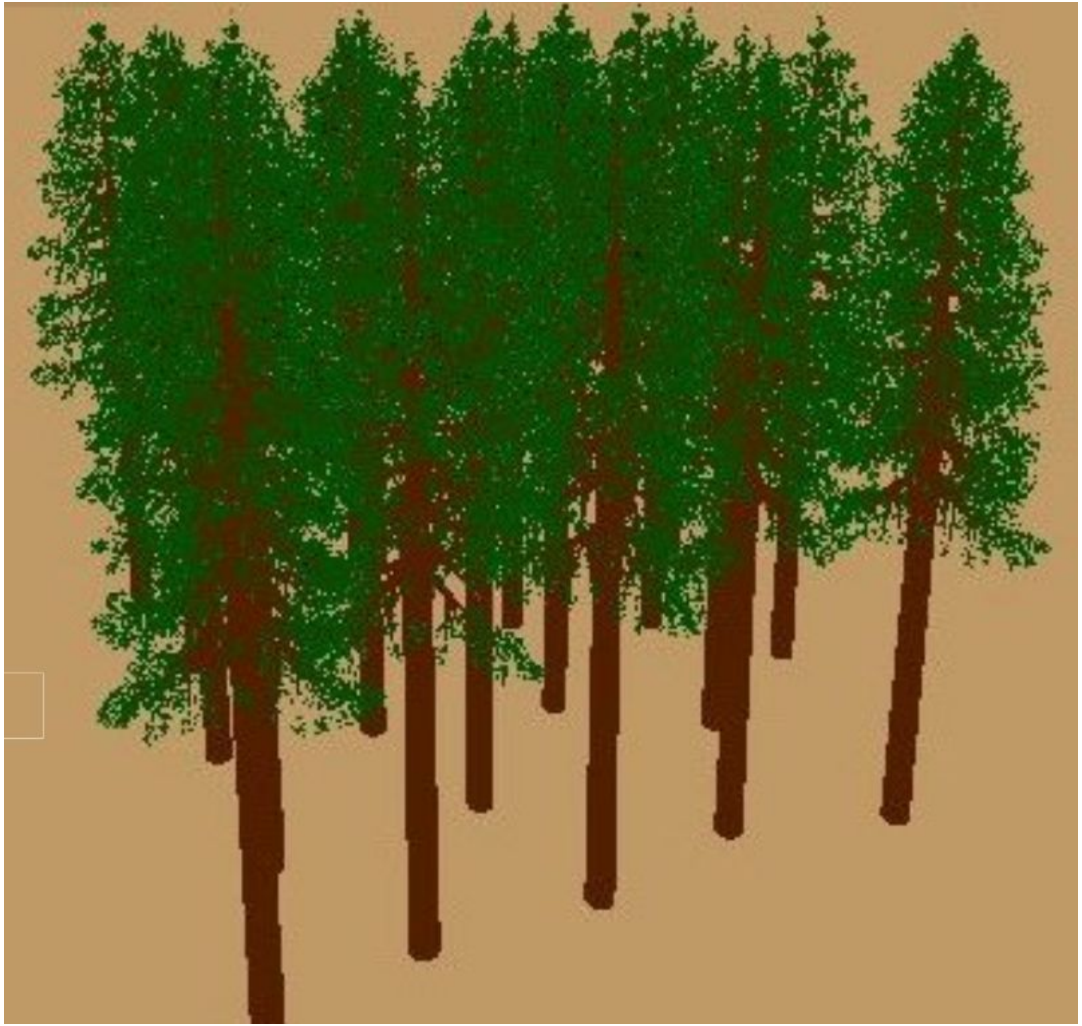
Forest Model

Forest Attributes:

- Biomass
- Tree Species

Tree Attributes:

- Height
- Crown Diameter
- Height to live crown
- Trunk Diameter



Parameter Estimation Idea

We don't have IFSAR, only SAR

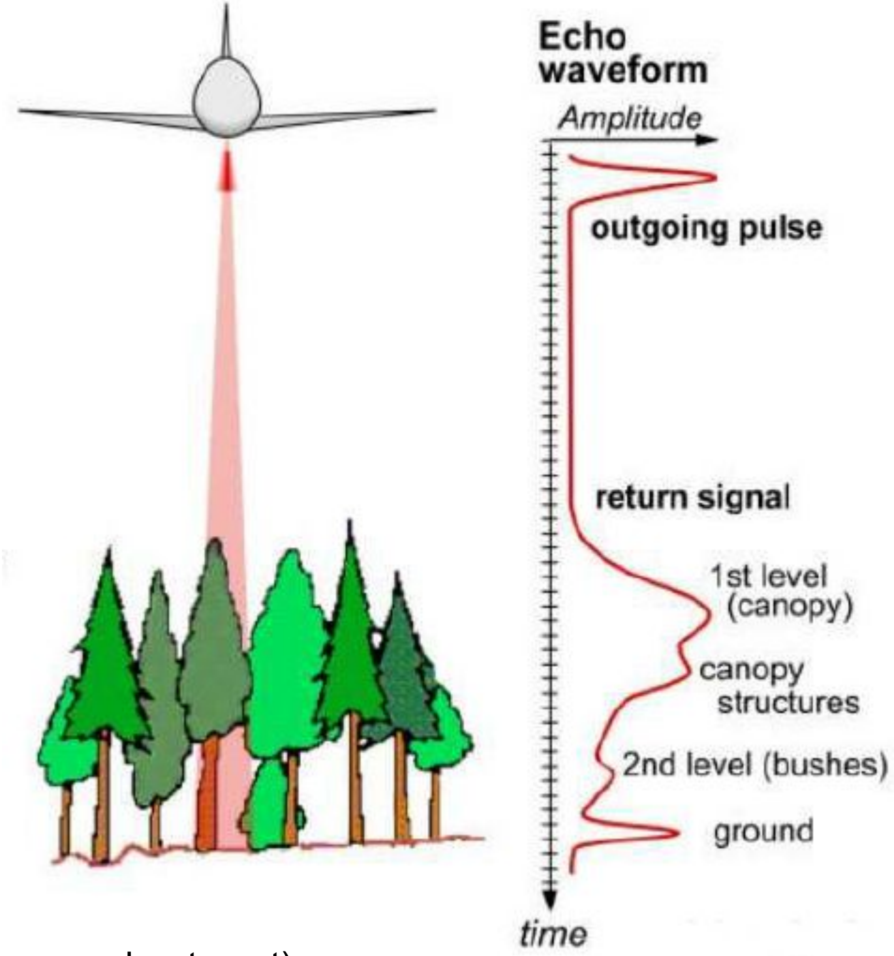
Combine with LIDAR and Optical for more information

Use simulator that covers all 3 sensing modalities

LIDAR Sensing

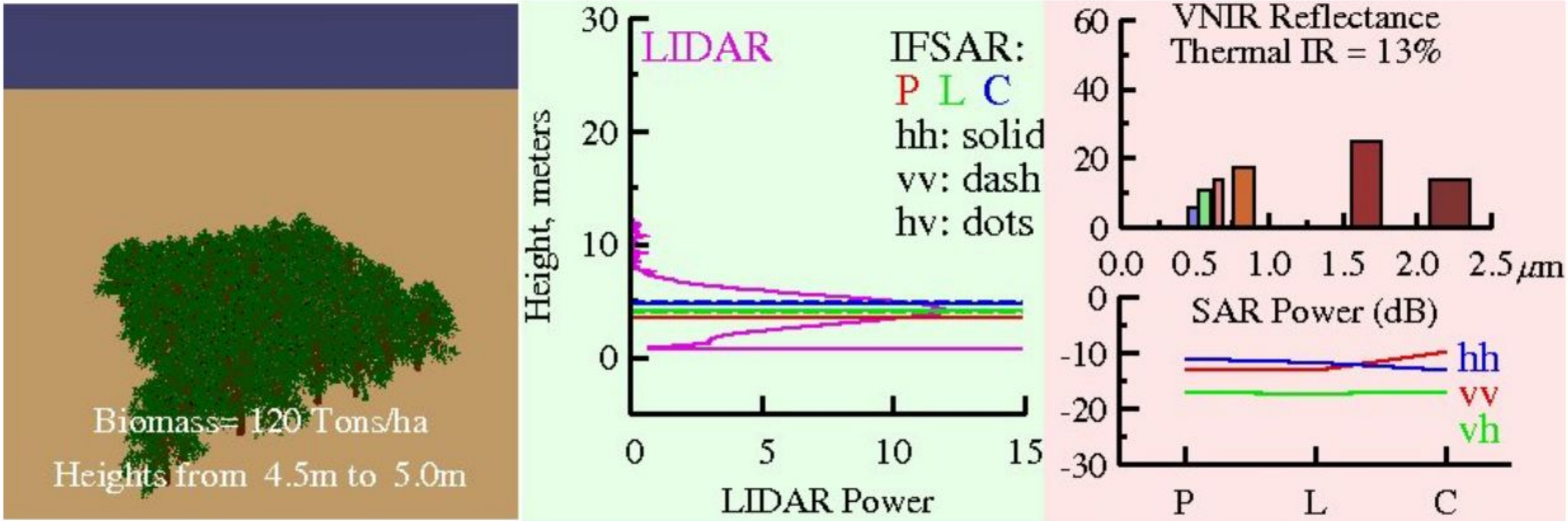
Transmit a short laser pulse

Record reflected amplitude vs.time

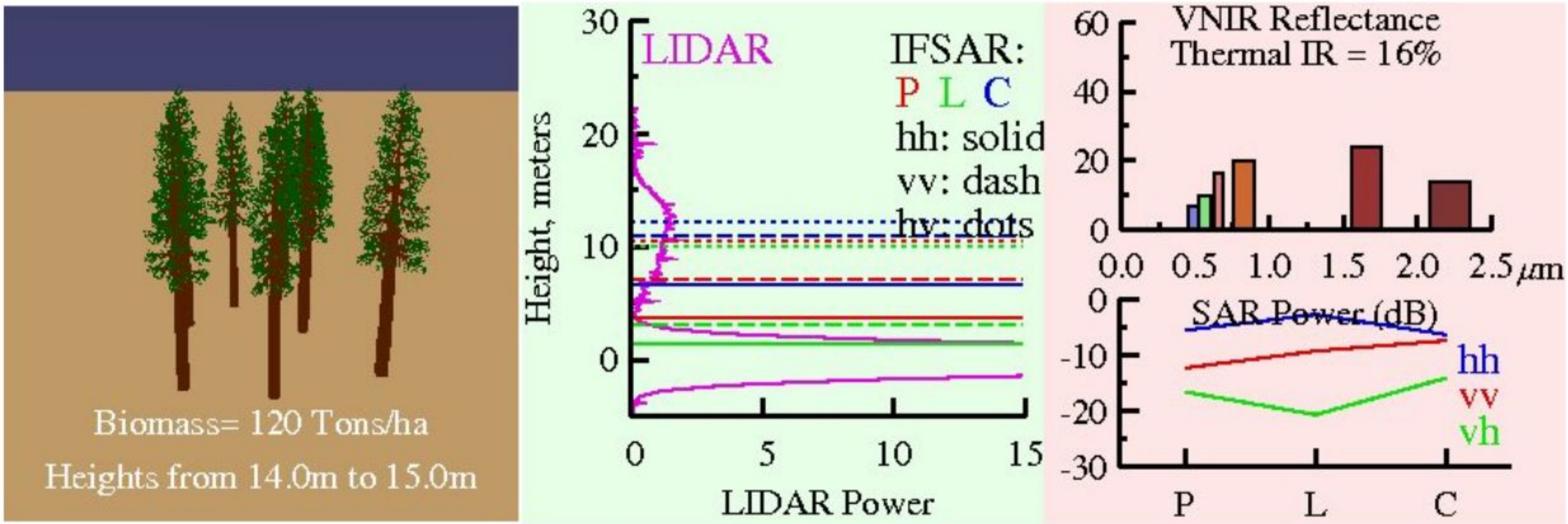


(researchgate.net)

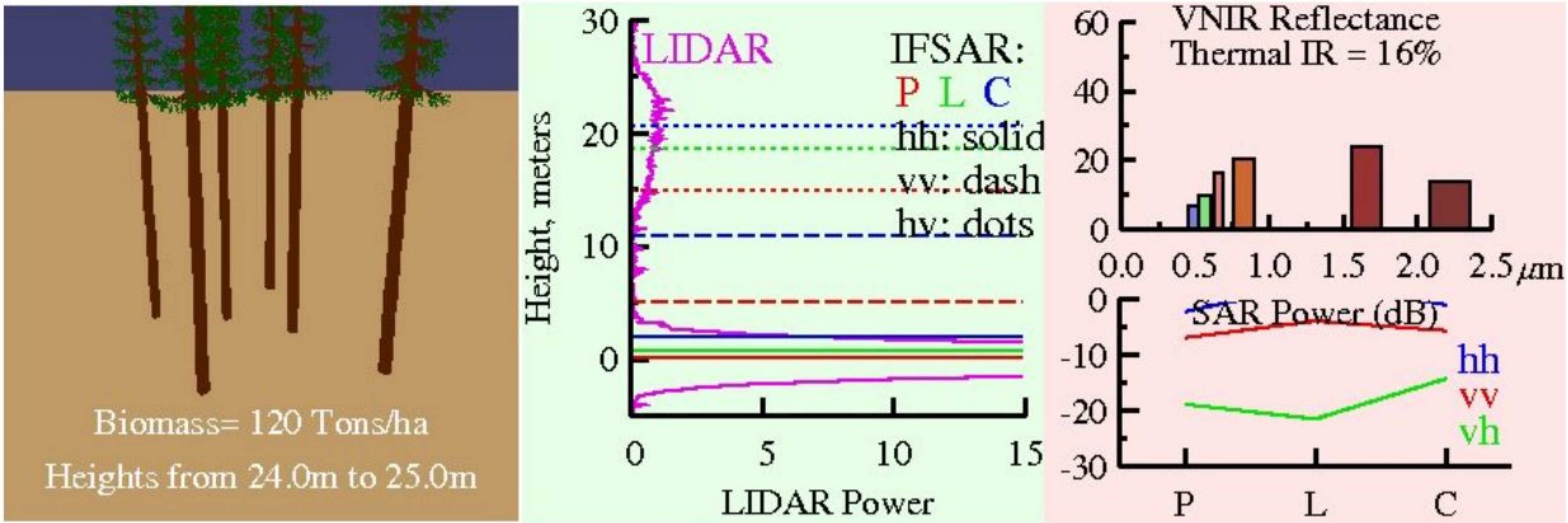
Short Trees


Biomass= 120 Tons/ha
Heights from 4.5m to 5.0m
LIDAR
IFSAR:
P L C
hh: solid
vv: dash
hv: dots
Height, meters
30
20
10
0
0
5
10
15
LIDAR Power
VNIR Reflectance
Thermal IR = 13%
60
40
20
0
0.0 0.5 1.0 1.5 2.0 2.5 μm
SAR Power (dB)
0
-10
-20
-30
hh
vv
vh
P L C

Medium Trees

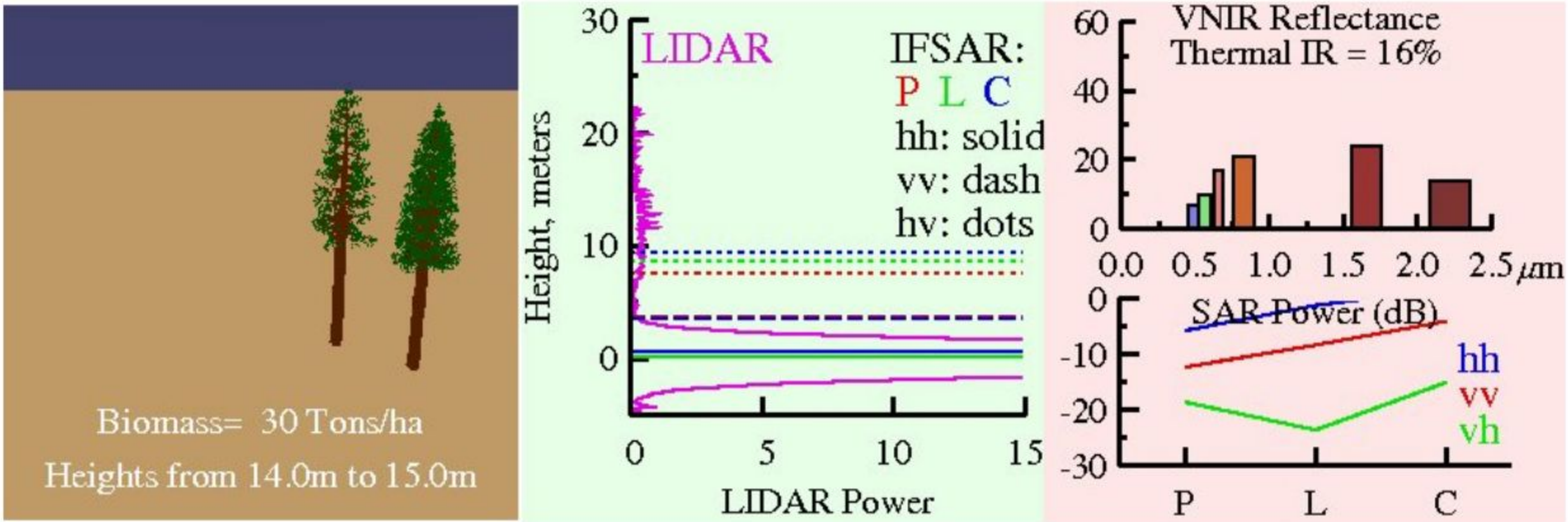


Tall Trees



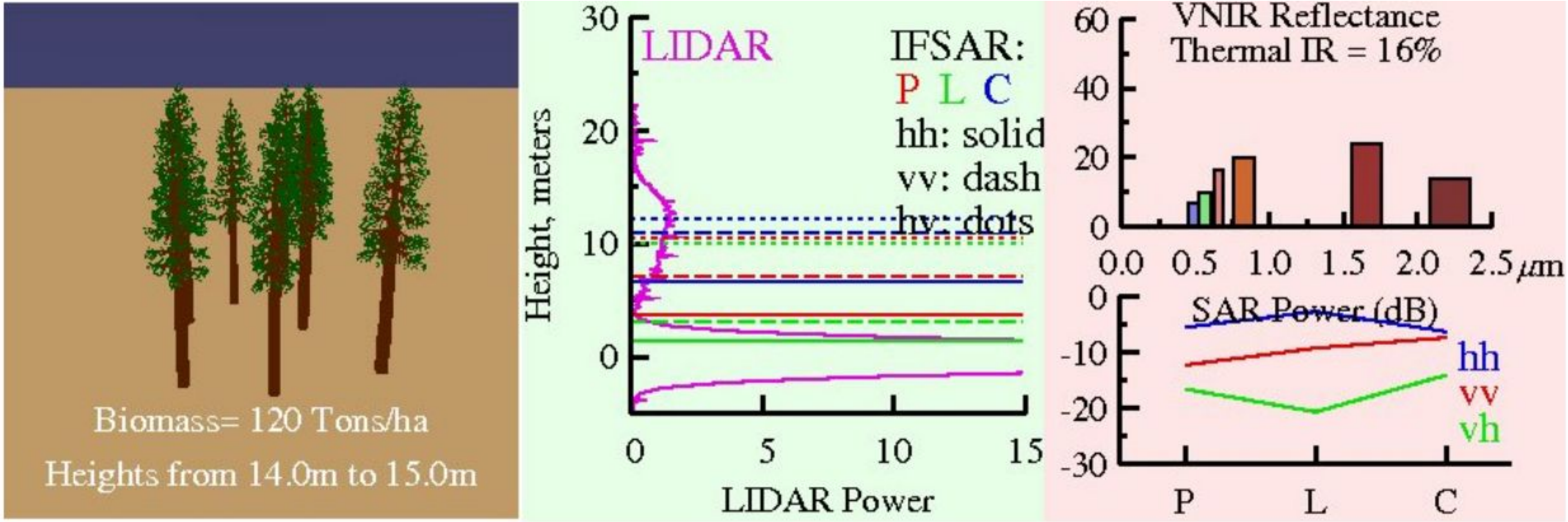
Biomass= 120 Tons/ha
Heights from 24.0m to 25.0m
LIDAR
IFSAR:
P L C
hh: solid
vv: dash
hv: dots
Height, meters
LIDAR Power
VNIR Reflectance
Thermal IR = 16%
0.0 0.5 1.0 1.5 2.0 2.5 μm
SAR Power (dB)
hh
vv
vh
P L C

Low Biomass

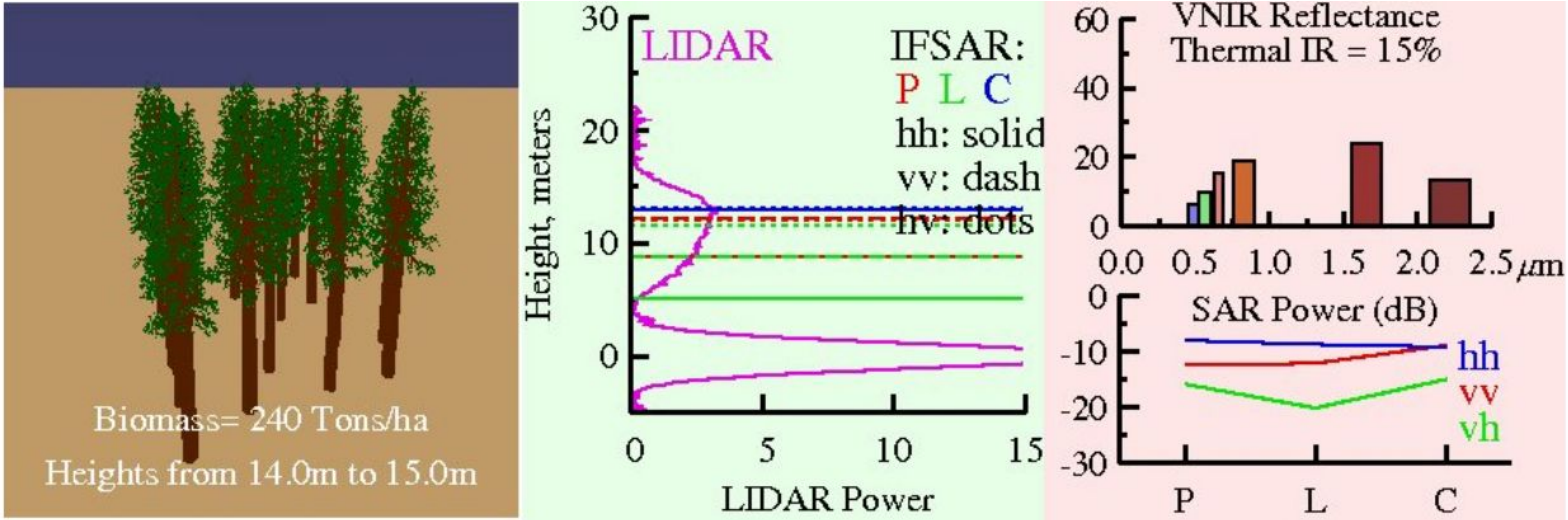


Biomass= 30 Tons/ha
Heights from 14.0m to 15.0m
LIDAR
IFSAR:
P L C
hh: solid
vv: dash
hv: dots
Height, meters
LIDAR Power
VNIR Reflectance
Thermal IR = 16%
SAR Power (dB)
hh
vv
vh

Medium Biomass

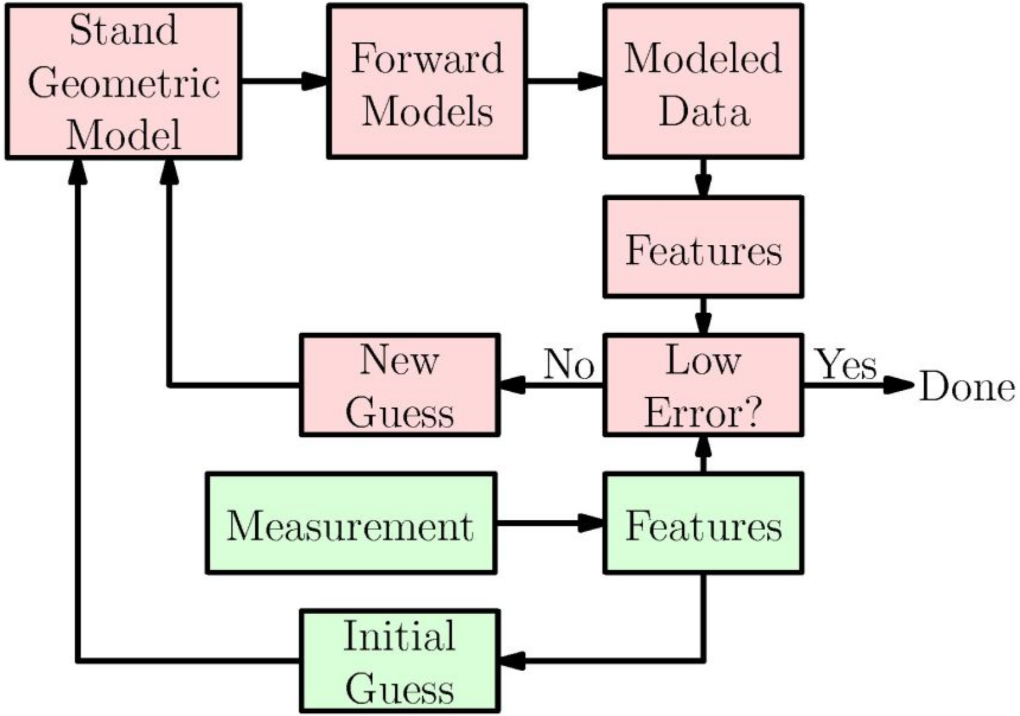


High Biomass

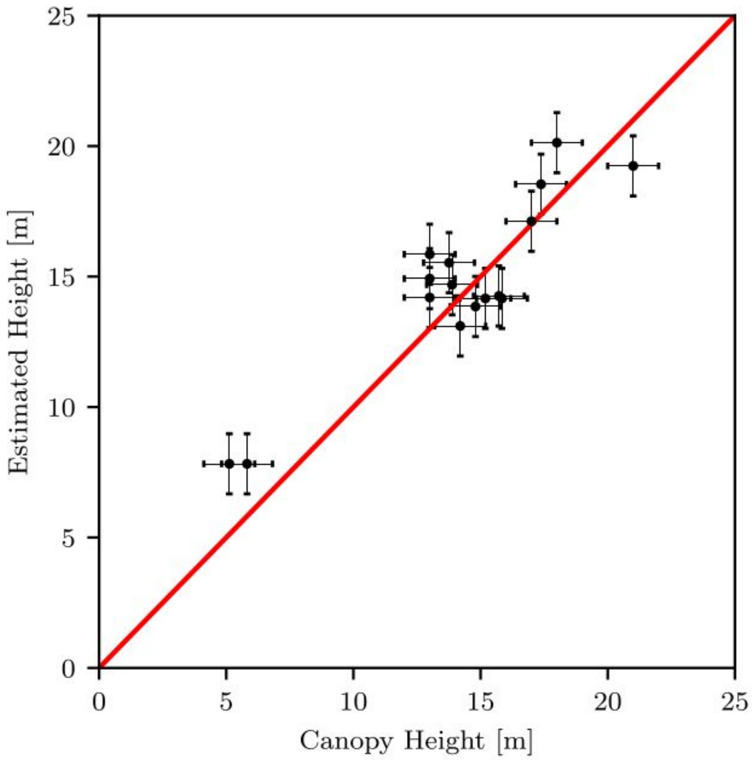


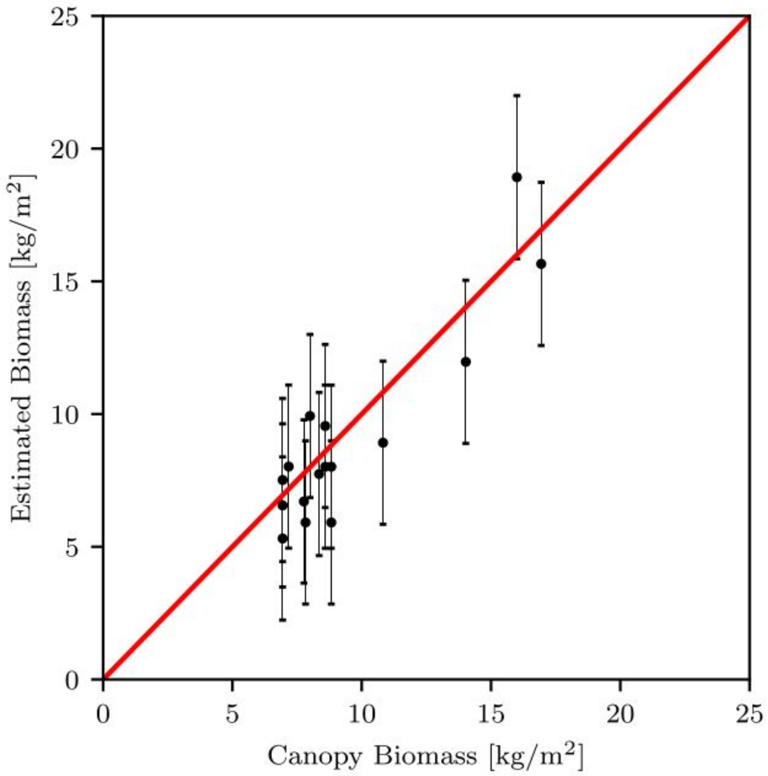
Parameter Estimation Procedure

One possible way of using modeling for parameter estimation:



Estimation Results





5. Industry

Lots of companies building and launching their own satellites

This includes SAR and Optical/Hyperspectral

Lots of other companies specialize in processing the data to provide data to other companies

Lots of new jobs

Areas for relevant classes:

- Wireless
- Embedded
- Optics
- Signal/Image Processing