INF-GEO 4310

Introduction to optical imaging and remote sensing

Anne Solberg (anne@ifi.uio.no)

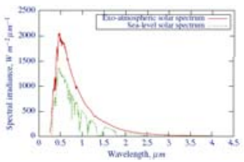
Introduction to optical imaging
Satellites, orbits and repeat cycles
Optical remote sensing

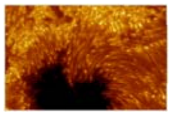
Literature:

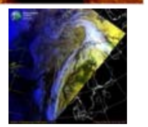
- Introduction to imaging
  http://www.uio.no/studier/emner/matnat/ifi/INF-GEO4310/h13/undervisningsmateriell/imaging-kap1.pdf
- Glossary for remote sensing terms:
  http://www.ccrs.nracn.gc.ca/glossary/index_e.php
- Tutorials:
  http://www.ccrs.nrcan.gc.ca/resource/index_e.php#tutor
  Only Chapters 1-2.

Introduction to imaging

- Contents of "Introduction"
  - Passive and active imaging
  - Spectral distribution of radiation
    - Planck's equation
    - Wien's distribution law
    - Spectral emission and spectral irradiance
    - Atmospheric absorption
  - The color of images
    - Color perception
    - Pseudo-color
    - False-color images







Imaging

- Imaging is a process that produces an image of some part of our surroundings.
- Rendering a mathemathical function is not considered to be imaging, but visualization.
- The image that is produced may be projected onto a screen for viewing, or it may be captured on film or some digital detector matrix for storage and processing.

Image not created by imaging

Image dimensions

- Image may be a 2-D matrix of intensity values.
- 2-D images at several wavelengths => 3-D image.
- Time-instances of 3-D image => 4-D image.
- 3-D medical image (US, CT, MR, PET) or seismic
  - 3-D image at several frequencies => 4-D image
  - 4-D image at several instances in time => 5-D image.

Images or coefficients?

- Stored data is not necessarily an image.
- May be a matrix of transform coefficients
  - may later be transformed into an image.

- Imaging may occur
  - at wavelengths
  - using physical principles

  that are not part of our own visual system
  - the eye and the brain,

  giving images unobtainable by the naked eye.

Passive imaging

- Utilizes energy sources external to imaging system – usually naturally available sources.
- Either using image sources present in the scene, or letting source light up objects within the scene.
- Examples:
  - infrared (IR) imaging of
    - heat sources
    - leaks in a construction.
  - Astronomical images of
    - Visual, gamma, X-ray, UV,
    - IR, MW and radio sources.

High resolution passive image

Passive imaging of reflected radiation

- We image radiation reflected at a given wavelength, or absorbed and reemitted at a different wavelength.
- Different objects or different parts of the same object may have different absorption / reflection properties.
  - Highly absorbing objects look dark
  - **Spectral absorption determine color of object.**
- Reflection properties determine whether objects are
  - Mirror-like (specular reflection)
  - Matte surfaces (diffuse reflection).
- Orientation, shape and fine structure of surface, influence how the object is imaged.

Qualities of energy source

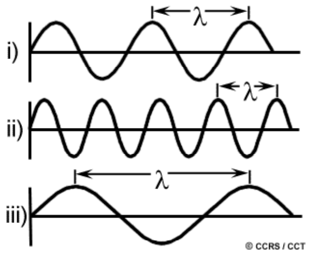
- Passive imaging depends on energy source.
- The most frequently used source is sunlight.
- Amount and color of light depends on
  - atmospheric conditions
  - elevation
  - local topography
  - time of day
  - time of year
  - position on Earth

Active imaging

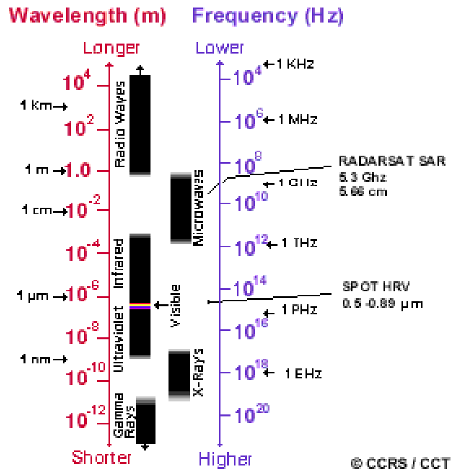
- We have to provide the energy, and then image radiation
  - reflected from the object
  - absorbed and re-emitted at other wavelengths
  - passing through the object
- Pros:
  - not hampered by unpredictable variations in natural light source
  - able to obtain images regardless of time of day or time of year.
- Examples:
  - radar, sonar and seismic
  - medical applications – microscopy (EM, laser, confocal, fluorecent)
  - medical applications - US, X-ray, CT, MR, PET

Electromagnetic radiation

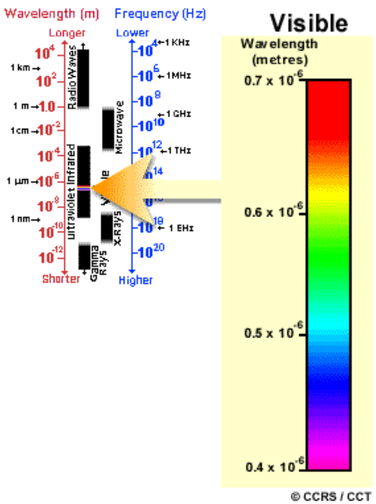
- c= λv
- c: speed of light (3x10^8 m/s)
- λ: wavelength
- v: frequency (cycles per second, Hz)



The electromagnetic spectrum



Visible region



Violet: 0.4-0.446 μm
Blue: 0.446-0.550 μm
Green: 0.500-0.578 μm
Yellow: 0.578-0.592 μm
Orange: 0.592-0.620 μm
Red: 0.620-0.7 μm

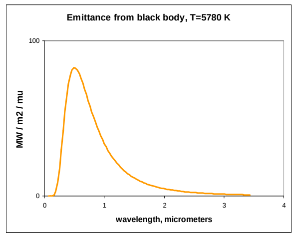
Planck's equation

- Energy emitted versus wavelength depends on temperature of source.
- Emitted energy varies according to Planck's equation

$$M(\lambda,T) = \frac{2hc^2}{\lambda^5}\cdot\frac{\pi}{e^{\frac{hc}{\lambda kT}}-1}$$

where
- λ is the wavelength (m)
- T is the temperature (K)
- h is Planck's constant = 6.6260693•10^{-34} Js,
- c is the speed of light = 2.99792458•10^{8} m/s,
- k is Boltzmann's constant = 1.38065•10^{-23} J/K
- M is the spectral emittance, given in W per unit area (m^2) per wavelength (m).

- The Sun behaves like a "black body" radiator with T ≈ 5780 K, peaking in visual part of spectrum.



Wien's displacement law

- Gives wavelength of maximum emission by a "black body"

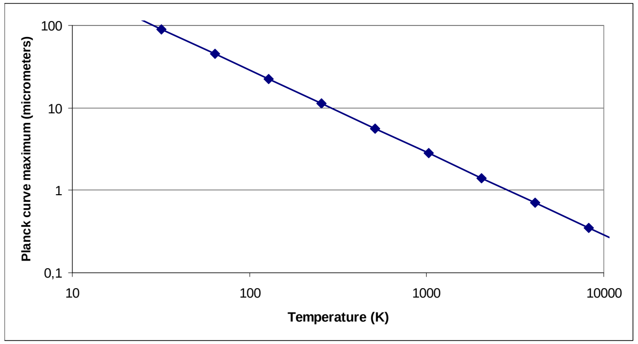
$$\lambda_{\max} = \frac{2897}{T}$$

λ_{max} is wavelength of maximum emittance, given in μm.

- The Sun's average surface temperature T ≈ 5780 K implies λ_{max} = 2897/5780 ≈ 0.5 μm = 500 nm.

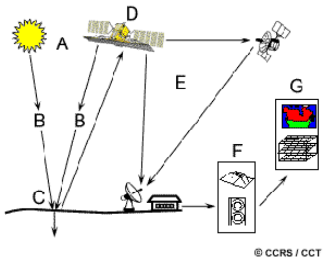
- Average temperature of the Earth's surface is about 287 K, emission spectrum peaks around 10 μm.

Log-log plot of Wien's law



Main principle for optical sensors

- A: An energy source illuminates the target.
- B: The energy travels through the atmosphere (and interacts with the atmosphere).
- C: Depending on both properties of the radiation transmitted and the target, parts of the energy will be reflected.
- D: The sensor on board record the reflected energy (after a second interaction with the atmosphere).
- E: The recorded signal is transmitted to the ground station.

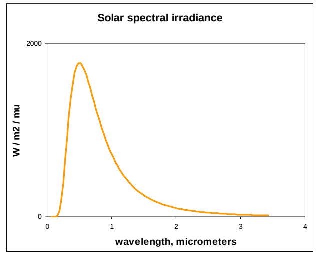


Exo-atmospheric irradiance

- Earth receives only a fraction of emitted solar radiation.
  - Energy from surface of Sun is spread out over sphere
  - radius equal to the distance of the Earth from the Sun.
  - Exo-atmospheric solar spectral irradiance, is given by

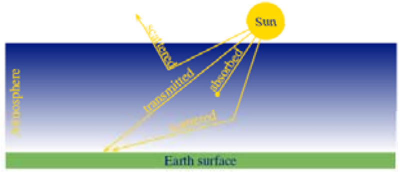
$$E_0(\lambda, T) = \frac{2hc^2}{\lambda^5} \cdot \frac{\pi}{e^{\frac{hc}{\lambda kT}} - 1} \left(\frac{r}{d}\right)^2$$

  - where
  - r is the radius of the Sun
    - r = 6.36 •10^8 m
  - d is the mean distance Earth – Sun
    - d = 1.5 •10^{11} m.
  - Irradiance curve is a scaled Planck curve

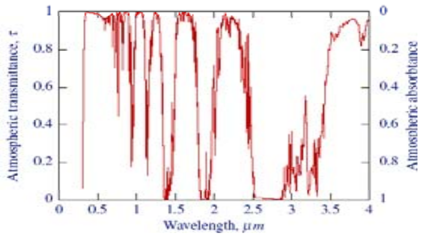


Atmospheric transmittance

- Only a part of the total exo-atmospheric solar irradiance reaches the Earth's surface.
  - Some is absorbed by gases and particles in the atmosphere
  - Some is scattered back out to space by aerosols and clouds



- Transmittance of the standard atmosphere when light travels vertically down through the atmosphere to sea level.
- Note :
  - strong UV absorption
  - IR absorption bands



Path length through atmosphere

- Direct solar radiation incident on a horizontal surface

$$I_{direct} = E_0 \tau^m \cos(\psi)$$

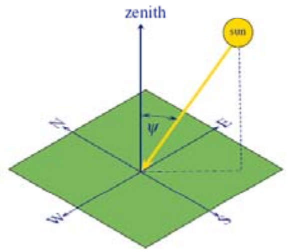
  - where τ is the atmospheric transmittance, *m* is the air mass and *ψ* is the solar zenith angle
- The air mass at sea level, *m*, is given by

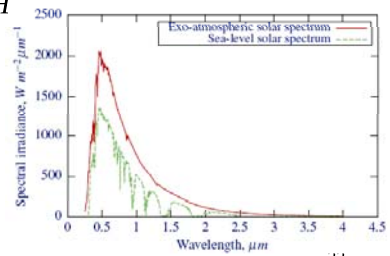
$$m = \cos^{-1}(\psi)$$

- The solar zenith angle, *ψ*, is given by

$$\cos\psi = \sin\phi \sin\delta + \cos\phi \cos\delta \cos H$$

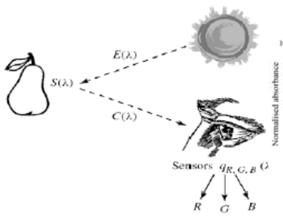
  - where *φ* is the geographical latitude of the site
  - *δ* is the solar declination angle
    δ = -23.4° cos(360(*D* +10)/365))
    where *D* is the day of year.
  - *H* is the hour angle of the Sun,
    given by H ≈ 15(12-h),
    where h is the local solar time in hours.

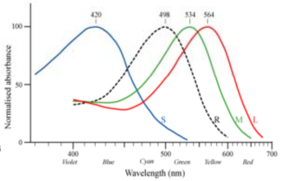




Color of images

- Light from the Sun, having a spectral distribution E(λ) falls on object.
- Surface of object has a spectral reflection function S(λ).
- Light entering the eye is detected by the three cone types,
  - each having a spectral sensitivity function, q(λ).
- CIE-defined RGB primaries:
  - Blue=436 nm, Green=546 nm, Red=700.0 nm,
  - and standard light sensitivity curves for the three color components.
- Three analog signals expressing a three-channel image by integrals:





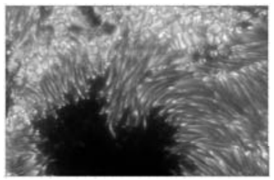
$$R = \int E(\lambda)\, S(\lambda)\, q_R(\lambda)\, d\lambda$$

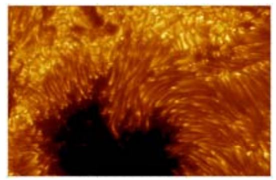
$$G = \int E(\lambda)\, S(\lambda)\, q_G(\lambda)\, d\lambda$$

$$B = \int E(\lambda)\, S(\lambda)\, q_B(\lambda)\, d\lambda$$

Pseudo-color images

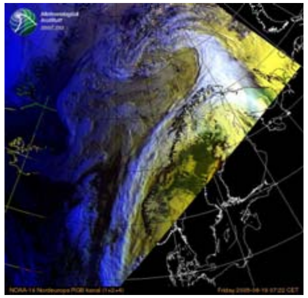
- Are single-channel (graylevel) images where a color has been assigned to each graylevel.
- Example: Sunspot image.
  - Monochromatic filter gives graylevel image.
  - Lookup-table maps each graylevel to an RGB-value.
- Used extensively in many imaging modalities!



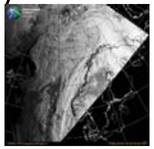


False-color images

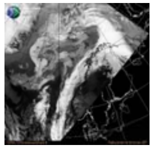
- We have graylevel images from three wavelengths.
- Assign each of them to the primary colors in (RGB), even though wavelengths do not correspond to (RGB).
- The result is an image of the observed scene using colors that are different from those actually observed.
- Ex.: NOAA AVHRR
- Three images:
  - 580-680 nm
  - 725 – 1 000 nm
  - 1 030 – 1 130 nm
- displayed as RGB (435, 546, 700 nm)



Channel 1+2+4 as RGB



Channel 2



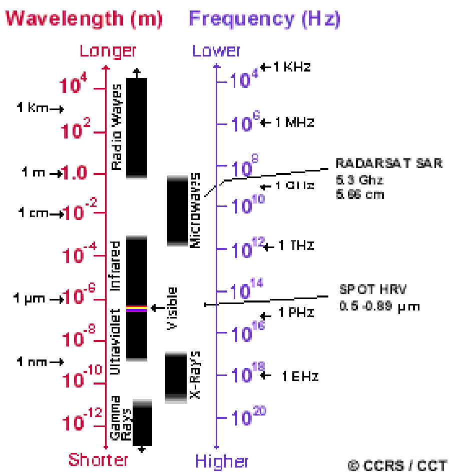
Channel 4
4

What is remote sensing

- Remote sensing is the science of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing that information.

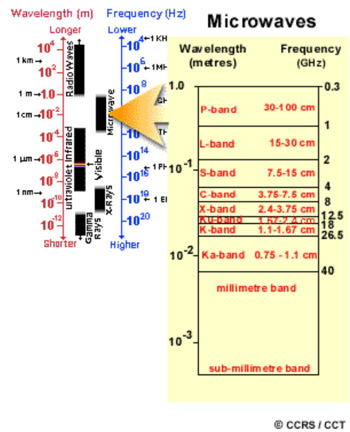
- Sonar and seismic sensors acquire information from distant sensors, but this is not called remote sensing.
- The term remote sensing is normally only used when imaging using electromagnetic energy from airborne or spaceborne sensors.

The electromagnetic spectrum



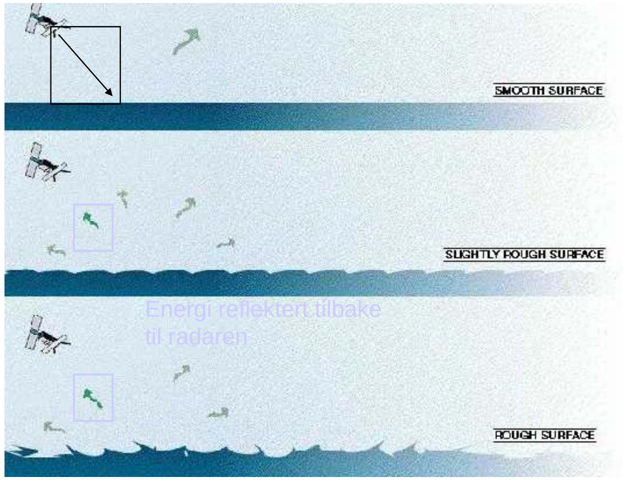
Microwave region – radar imagery

- Microwave sensors transmit a microwave signal (active sensor)
- Images can be aquired at night and in clouded sky.
- The reflected signal is determined by:
  - Surface roughness
  - Dielectric properties of surface (temperature, moisture content etc.)
- This will be covered in the radar lecture.



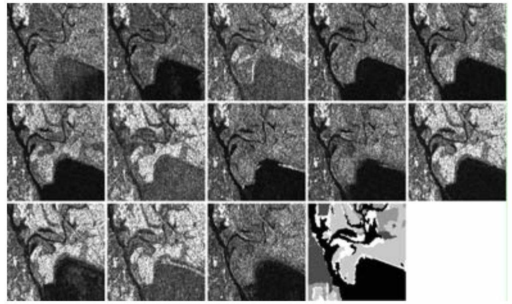
Radar imaging

Transmitted energy



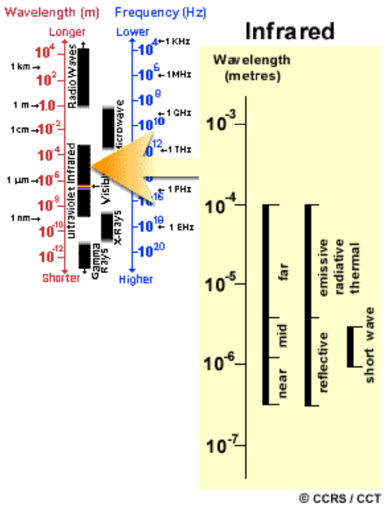
Radar image from Kjeller

SAR image from 17.10.91



A time series of SAR images from august to November. Changes in backscatter signal strength are due to changes in soil structure/tilling temperature and soil moisture.

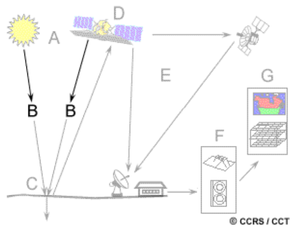
The infrared region

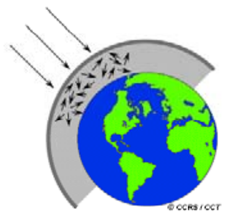


Energy emitted by the earth itself (surface temperature)

Reflected sunlight

Interaction with the atmosphere





- Only parts of the solar irradiance reaches the surface of the Earth.

Two effects:

- Scattering: particles or gas molecules cause redirection of the electromagnetic radiation.
- Absorption: molecules absorb energy at various wavelengths.

From optics lecture: Planck's equation and the sun as an energy source

- Energy emitted versus wavelength depends on temperature of source.
- Emitted energy varies according to Planck's equation

$$M(\lambda,T) = \frac{2hc^2}{\lambda^5} \cdot \frac{\pi}{e^{\frac{hc}{\lambda kT}} - 1}$$

where
- λ is the wavelength (m)
- T is the temperature (K)
- h is Planck's constant = $6.6260693 \cdot 10^{-34}$ Js,
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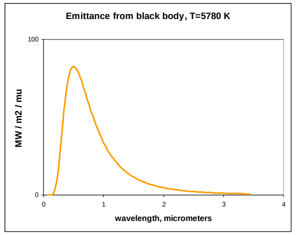


- The Sun behaves like a "black body" radiator with T ≈ 5780 K, peaking in visual part of spectrum.

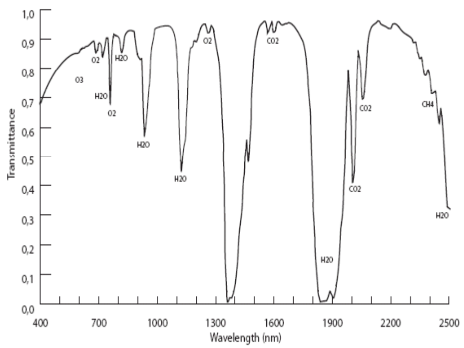
Reflection

- Reflection occurs when a wave hits the interface between two dissimilar media,
  - at least part of the wave returns into the medium of origin.
- Common examples:
  - reflection of rays of light
  - reflection of surface waves
    - Surface waves in a pool of water
    - Sound waves reflected as echo from a wall
- Reflection may be
  - Specular: occurs on a blank mirroring surface that retains the geometry of the beams of light.
  - Diffuse: occurs on a rougher surface, not retaining the imaging geometry, only the energy.

Reflectance

- The ratio of reflected power to incident power, generally expressed in dB or %.
- Reflectance varies with the angle of incidence.
- Reflectance varies with wavelength.
- Surface reflectance is often divided into
  - diffuse reflectance
  - specular reflectance
- In climatology, reflectance is called albedo.
- Also important in computer graphics.

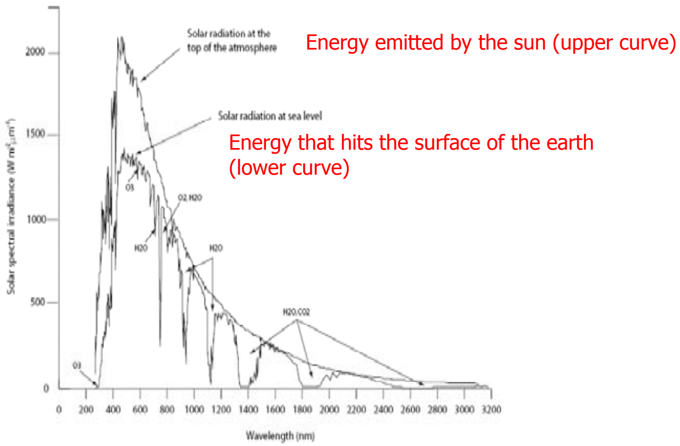
Wavelengths absorbed by the atmosphere



Energy in the visible (and infrared) part of the spectrum is affected by atmosphere absorbtion.

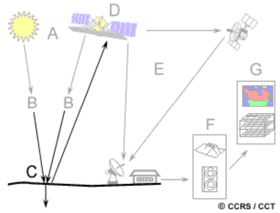
The microwave region is mostly unaffected by the atmosphere.

Solar radiation on the ground vs. above the atmosphere



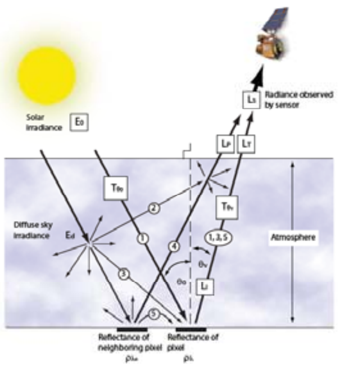
Radiation – target interactions

- I: incident radiation
- A: energy absorbed by the target
- T: energy transmitted through the target
- R: energy reflected

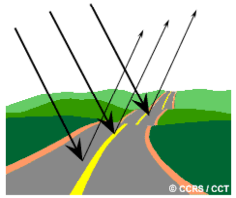


Radiance, reflectance etc.

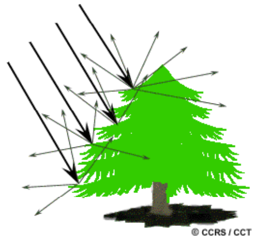
- Irradiance: energy submitted by the sun
- Reflectance: how the object reflects different wavelengths
- Radiance: the measured reflected energy received by the satellite
- Radiance measures can be converted to reflectance if the atmospheric conditions are known (called atmospheric calibration)



Specular and diffuse reflection



Specular from smooth surfaces



Diffuse reflection from rough surfaces

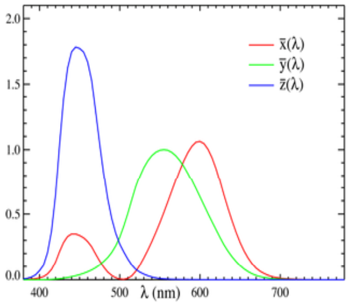
- A target reflects diffuse or specular depending on its roughness in relation to the wavelength.
  - Microwave (5cm) imaging of ocean ripples: rough
  - Optical: nm wavelengths

The RGB camera

- Three types of detectors sensitive to R, G and B wavelength bands.
- Let the spectral distribution of the light that enters the camera be C(λ).
- Three numbers detemines the value of the measured color.

$$c_i = \int C(\lambda)\, a_i(\lambda)\, d\lambda, \quad i = r, g, b$$

- These 3 numbers are stored in a 3-band image.

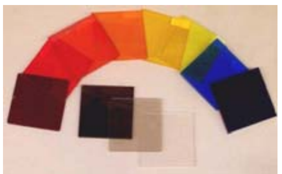


Introducing multispectral images

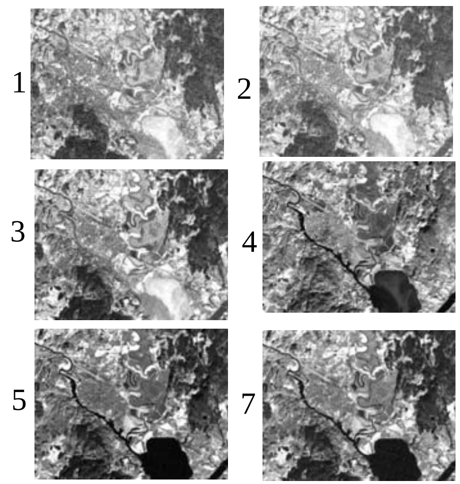
- A **multispectral image** is one that captures image data at specific frequencies across the electromagnetic spectrum.
- The wavelengths may be separated by filters or by the use of instruments that are sensitive to particular wavelengths, including light from frequencies beyond the visible light range.
- Spectral imaging can allow extraction of additional information the human eye fails to capture with its receptors for R, G and B light. It was originally developed for space-based imaging.
- A remote sensing, multispectral (>3 spectral bands) and even hyperspectral (>15 spectral bands) are commonly used.

Optical filters

- Optical filters are devices that selectively trasmit light of different wavelengths.
- They can be made as plane glass or plastic devices that are dyed or have interference coatings.
- They can be made as bandpass filters that only transmits certain wavelengths.
- They can cover either the infrared, ultraviolet, or visible part of the spectrum.
- An IR filter can give night-time images.
- Regular cameras often have UV-blocking as photographic film is sensitive to ultraviolet but the human eye is not, making photographs look different from the scene visible to people.



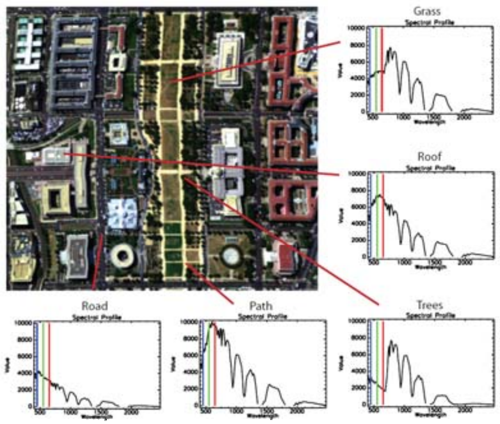
What can different wavelengths see – an example from a Landsat satellite image



1	Blue	0.45-0.52	Max. penetration of water
2	Green	0.52-0.60	Vegetation and chlorophyll
3	Red	0.63-0.69	Vegetation type
4	Near-IR	0.76-0.90	Biomass
5	Mid-IR	1.55-1.75	Moisture/water content in vegetation/soil
6	Thermal	10.4-12.5	Temperature (lower spatial resolution)
7	Mid-IR	2.08-2.35	Minerals

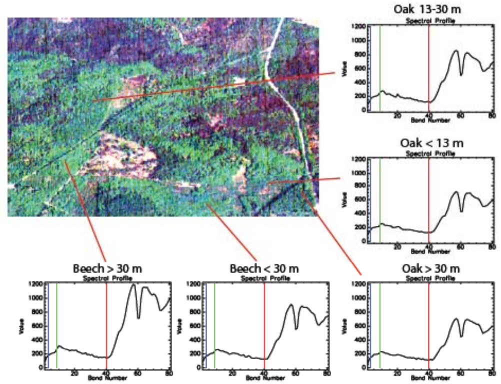
EXAMPLE: The power of many spectral bands – radiance for different classes

- Common factor: water absorbtion bands.
- The black curves are measured radiance fron a hyperspectral sensor.
- The red, green and blue bars indicate the response if we only had a RGB camera.
- It is clear that have more spectral bands gives additional information as we get the curve shapes and can discriminate between more ground cover classes.



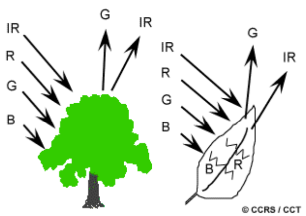
Example: vegetation spectra

Typical for vegetation: red edge (large rise in reflectance)

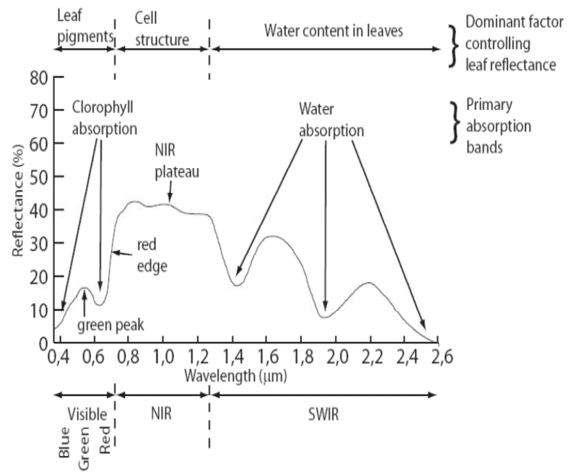


Why are leaves green?

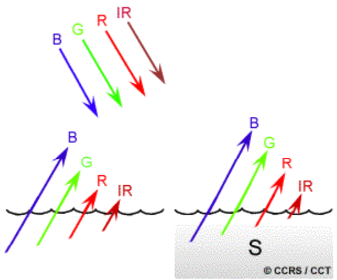
- Remember: an object has a reflectance function
- Chlorophyll absorbs radiation in red and blue wavelengths but reflects green wavelengths.
- ”Autumn colors”: less chlorophyll present, less absorption, appear red or yellow.
- Infrared region: sensitive to vegetation health.



Imaging of vegetation



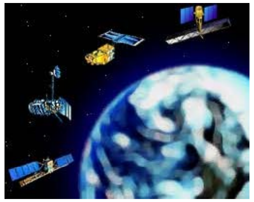
Why is water blue?



- Longer wavelengths are absorbed more than shorter wavelengths.
- Water thus looks blue or blue-green, and dark higher wavelengths.
- Algae contains chlorophyll, absorbs blue and reflects more green, making the water appear more green.

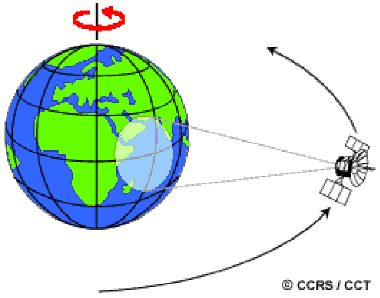
Sensor platforms

- Aircrafts:
  - Advantage: high resolution possible.
  - Disadvantage: normally expensive, low coverage, platform unstable (cause geometrical errors)
- Satellites:
  - Advantages: stable orbits, can cover large areas, not too expensive (once the satellite is launched)
  - Disadvantage: satellite overflight time fixed, limited spatial resolution.



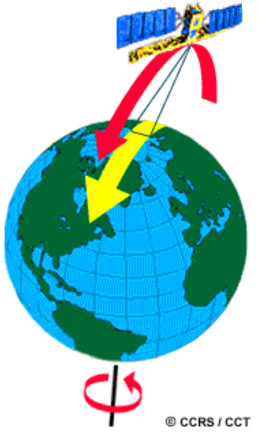
Geostationary orbits

- Orbit: the path that a satellite follows.
- Geostationary orbit: the satellite views the same part of the surface at all times.
- Height: 36000km
- Rotate at the same speed as the earth.
- Types of satellites:
  - Weather
  - Communication



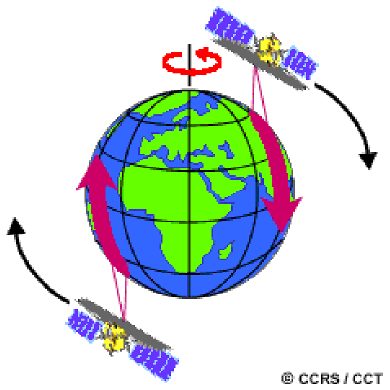
Polar orbits

- North-south directed orbit.
- Orbit called polar because it has an inclination angle close to 90 degrees relative to the equator.
- As the earth rotates (west-east), they will eventually cover the entire surface of the earth.
- Coverage depends on latitude, good towards the poles.
- We have ascending and descending passes.
- Height: typical 800km (80-2000km)
- Typical speed: 8km/s
- Typical time pr. rotation: 90m



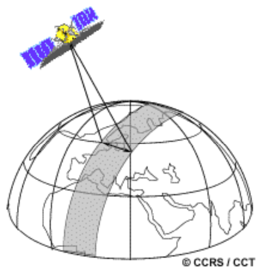
Ascending and descending passes

- Ascending pass: from north to south
- Descending pass: from south to north.



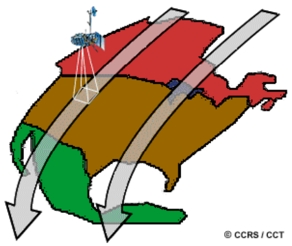
Satellite swaths

- The swath is the footprint, or the area a satellite sees when it passes an area.
- Swaths (for polar orbits) go from pole to pole.
- Earth rotation makes us able to image different longtitudes.
- Swath widths can vary from 10 to 500km.

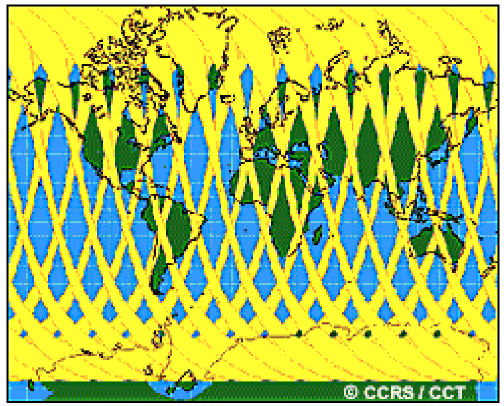


Orbits and repeat cycles

- One cycle will cover one swath.
- The next cycle will cover a different swath due to the rotation of the earth.
- During one day, a number of swaths will be covered.
- After n days, the satellite will be back to exactly the same swath as the first. n is called the repeat cycle.
- Complete coverage of the earth is collected during a series of cycles.



Example - Coverage during one day

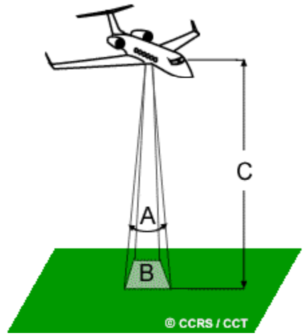


Sun-synchronous orbit

- They will cover a certain area at a constant time of the day called local sun time.
- At a given latitude, the position of the sun on the sky will be the same for each time an image is taken over an area.
- This helps analyzing time-series of images.
- Height: 600-800km.
- Rotation time: 96-100 min.
  - 96min: 15 rotations per day.
- Inclination angle: 98°
- Two main orbit types:
  - Noon/midnight
  - Dawn/dusk: the satellite always sees the sun and can charge solar panels. Combined optical/radar satellites can image during the night.

Spatial resolution, pixel size and scale

- The distance from the satellite sensor to the ground affects spatial resolution for optical sensors.
- The optics inside the camera/lense also affects this by varying the focal length.
  - Greater focal length means more details.
- Instaneous Field of View (IFOV): the cone (A) that the sensor sees at a given point.
- The area on the ground covered at a timepoint is the spatial resolution or pixel size.
- We can see homogeneous objects with size equal to or larger than this.
- Smaller features are sometimes detectable (e.g. roads or bridges)



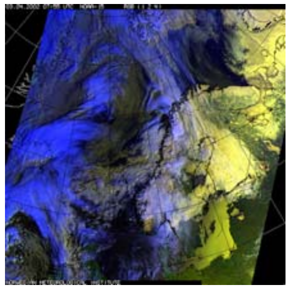
Example – 30m pixel size

Roads/bridge still visible

Note: beware of Windows smoothing effect in displaying images

Three main types of resolution

- Low-resolution sensors
  - Pixel size 100m-1km, wide swath, cover large areas.
- Medium resolution
  - Pixel size 10-30m, regional coverage, medium wide swath.
- High resolution
  - Pixel size 0.5-10m, small swath

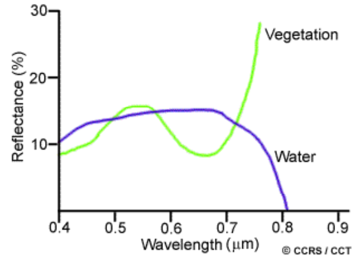


Low resolution NOAH AVHRR

Example – high resolution image

Spectral resolution

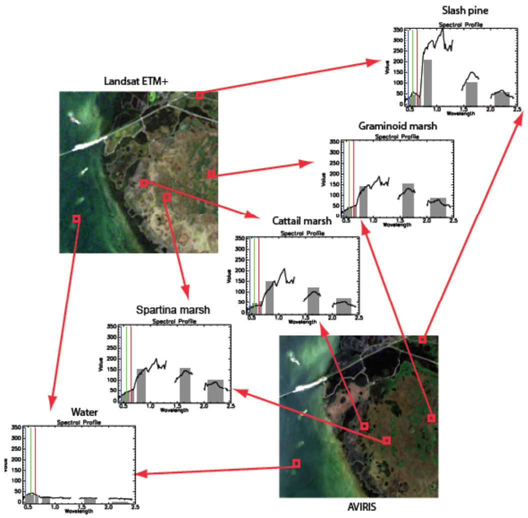
- Each material on the ground has a certain spectral response, a curve that characterize the reflectance over different wavelengths.
- The number of spectral bands of a sensor determines its spectral resolution. In addition, the width and location of each spectral band must be defined.



Multispectral vs. hyperspectral sensor

Multispectral:
<15 spectral bands, often broad bands

Hyperspectral:
30-200 narrow spectral bands



Discriminating between ground cover types

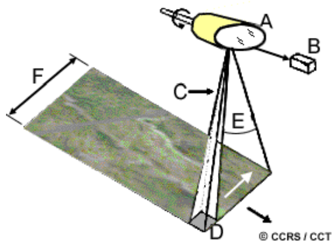
- Materials that have different response over a long range of wavelengths are easy to discriminate.
- Materials that are similar (e.g. different tree species) are difficult to discriminate with a small number of spectral bands, but can be identified using hyperspectral sensors.

Radiometric resolution

- How many bits used for representing the reflectance of one pixel defines the radiometric resolution.
- Common data types:
  - Bytes (0-255)
  - 12 bit
  - 16 bit
  - Float or complex

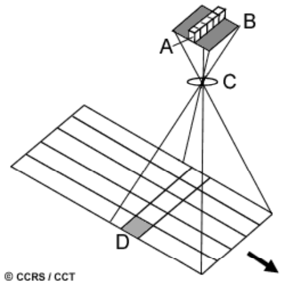
Multispectral scanning – Across-track scanners

- Scan in a series of lines using a rotating mirror. The movement of the sensor builds up several lines in the along-track direction.
- A set of detectors measure the energy in different wavelenghts.
- IFOV and the altitude determines the ground resolution.
- The angular field of view (E) determines the width of the swath (F).
- Aircraft sensor sweep 90-120°, satellites 10-20°
- Geometrical errors can be seen towards the edges of the swath.



Multispectral scanning – Along-track scanners

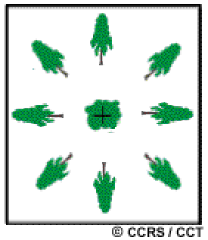
- A line of detectors image the across-track lines.
- They are called pushbroom scanners.
- Each individual detector measures the energy for one resolution cell (D).
- A separate line array measure each spectral band.
- Compared to across-track scanners, they see a given area for a longer time.

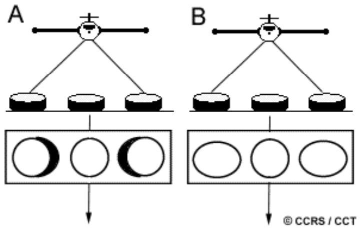


Geometric distortion

- Due to the 3D nature of the object being imaged, geometrical errors will occurr. Common types are due to:
  - Perspective of the sensor optics
  - Motion of the scanning system
  - Motion and instability of the sensor platform
  - Platform altitude, attitude and velocity
  - Terrain relief
  - Curvature and rotation of the Earth

Illustration of geometrical effects





Relief displacement

Relief displacement

Tangential scale distortion (across-track scanners)

Weather satellites/sensors

- GOES (Geostationary Operational Environment Satellite).
- Views 1/3 of the Earth in one image.
- Several satellites view different parts of the world.

NOAA AVHRR

NOAA AVHRR Bands

Band	Wavelength Range (µm)	Spatial Resolution	Application
1	0.58 - 0.68 (red)	1.1 km	cloud, snow, and ice monitoring
2	0.725 - 1.1 (near IR)	1.1 km	water, vegetation, and agriculture surveys
3	3.55 -3.93 (mid IR)	1.1 km	sea surface temperature, volcanoes, and forest fire activity
4	10.3 - 11.3 (thermal IR)	1.1 km	sea surface temperature, soil moisture
5	11.5 - 12.5 (thermal IR)	1.1 km	sea surface temperature, soil moisture

Height 830-870km.
Two satellites, cover the earth every 6th hour.
Swath width: 3000 km.

Landsat

- A series of satellites (Landsat-1 1972, currently Landsat-7)
- Height 700km, repeat cycle 16 days, swath width 185km.
- Spatial resolution: 30m (120m thermal band)

TM Bands

Channel	Wavelength Range (µm)	Application
TM 1	0.45 - 0.52 (blue)	soil/vegetation discrimination; bathymetry/coastal mapping; cultural/urban feature identification
TM 2	0.52 - 0.60 (green)	green vegetation mapping (measures reflectance peak); cultural/urban feature identification
TM 3	0.63 - 0.69 (red)	vegetated vs. non-vegetated and plant species discrimination (plant chlorophyll absorption); cultural/urban feature identification
TM 4	0.76 - 0.90 (near IR)	identification of plant/vegetation types, health, and biomass content; water body delineation; soil moisture
TM 5	1.55 - 1.75 (short wave IR)	sensitive to moisture in soil and vegetation; discriminating snow and cloud-covered areas
TM 6	10.4 - 12.5 (thermal IR)	vegetation stress and soil moisture discrimination related to thermal radiation; thermal mapping (urban, water)
TM 7	2.08 - 2.35 (short wave IR)	discrimination of mineral and rock types; sensitive to vegetation moisture content

SPOT

- Height 830km, repeat cycle 26 days.
- Two modes: panchromatic (10m)and multispectral (20m).
- Swath widt 60km.

HRV Mode Spectral Ranges

Mode/Band	Wavelength Range (µm)
Panchromatic (PLA)	0.51 - 0.73 (blue-green-red)
Multispectral (MLA)	
Band 1	0.50 - 0.59 (green)
Band 2	0.61 - 0.68 (red)
Band 3	0.79 - 0.89 (near infrared)

Hyperspectral sensors

- CASI (Compact Airborne Spectrographic Imager)
  - Spectrometer: 288 spectral bands from 0.4 to 0.9 µm.
  - Airborne sensor.
- Hyperion:
  - Spaceborne sensor.
  - 242 spectral bands.
  - Pixel size 30m.

Characteristics of some hyperspectral sensors

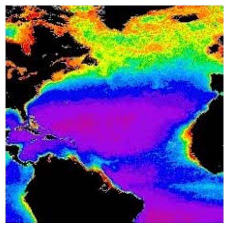
Table 1.1: *Summary of characteristics of some hyperspectral sensors*

	AVIRIS [2]	HYDICE [3]	ROSIS [4]	DAIS 7915 [5]	HYPERION [6]
Platform	airborne	airborne	airborne	airborne	spaceborne
Design altitude (km)	20	6	10	1-6	705
Spatial res. ($m \times m$)	20	3	5.6	3-20	30
Spectral res. (nm)	10	4-14	4-12	15-900	10
Spectral coverage (nm)	380-2500	400-2500	430-846	400-12600	400-2500
Number of channels	224	210	81	79	242
Dynamic range (bits)	12	12	12	15	12
Pixels/line	614	320	167	512	256
Swath width (km)	11	1	0.935	1.5-10.2	7.7

Marine sensors – Coastal Zone Colour Scanner

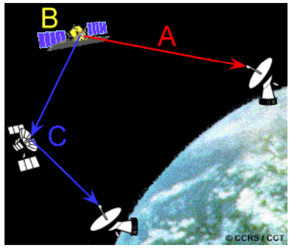
CZCS Spectral Bands

Channel	Wavelength Range (µm)	Primary Measured Parameter
1	0.43 - 0.45	Chlorophyll absorption
2	0.51 - 0.53	Chlorophyll absorption
3	0.54 - 0.56	Gelbstoffe (yellow substance)
4	0.66 - 0.68	Chlorophyll concentration
5	0.70 - 0.80	Surface vegetation
6	10.5 - 12.50	Surface temperature



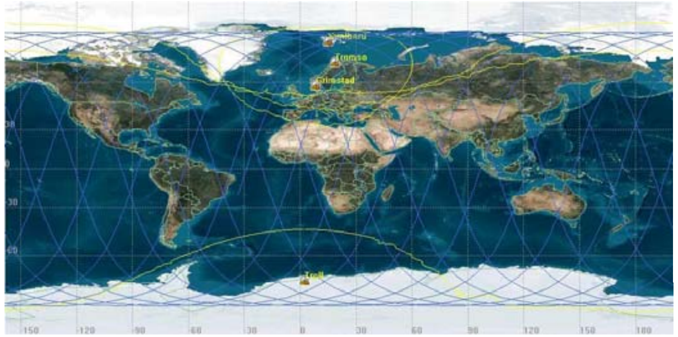
Data reception, transmission and processing

- Data can be transmitted to the surface only when a ground station is in the line of sight. Data can also be recorded and stored onboard the satellite and downloaded later.



Kongsberg Satellite Services

- Ground stations in Tromsø, Svalbard and Grimstad
- …. And now also in Antarktis



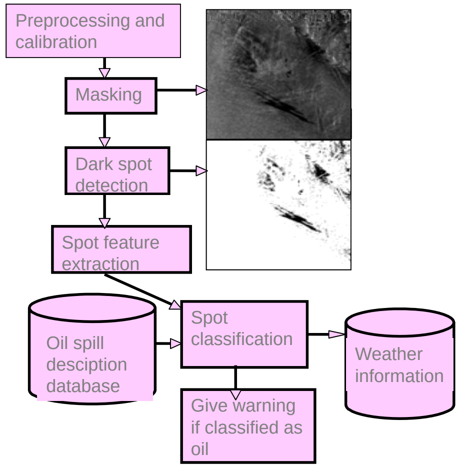
Applications

- Examples of application project that are run in Norway follows on the remaining slides.

Oil spill monitoring

Three main parts:

- Spot detection
- Spot feature extraction
- Spot classification
  - Decide oil spill or look-alike based on a statistical model for oil in different wind conditions and of different shapes



Cultural heritage – detection of ancient monuments

Relics of buried ancient monuments may in some cases be detected in agricultural fields due to changes in soil chemistry, drainage, etc.

Infrastructure detection in very-high resolution imagery

- Detection of buildings, roads and other infrastructure in very-high resolution imagery
- Pattern recognition in 2D and 3D
- Relevant for map construction, map revision and disaster monitoring

Detection of objects (buildings and roads)

Traffic monitoring by satellite

- ESA project to evaluate satellite image analysis for generating traffic statistics
- Using Quickbird imagery (0.6 m pan)
- Main challenges arise in urban areas with buildings and trees occluding the road
- Road markings are equally a challenge
- Customers are road authorities

Snow mapping for Statkraft

- NOAA AVHRR imagery acquired at Tromsø satellite station (KSAT)
- Satellite data transfered within one hour to Statkraft in Oslo
- SnowStar performs fully automated processing into map products: Geocoding, cloud detection, snow cover retrieval (% SCA) and generation of maps and statistics (drainage areas, regions, Norway, Nordic countries)
- All products available 1,5 hour after satellite acquisition