Microwave RS Snow Products: Theory - Part I

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Definition of Remote Sensing

'Remote sensing' is, broadly but logically speaking, the collection of information about an object without making physical contact with it. (The term was coined by Evelyn Pruitt of the US Office of Naval Research in the 1950s.)

«… is the acquisition of information about an object or phenomenon **without making physical contact** with the object and thus in contrast to on site observation … »

[Campbell, J. B. (2002). *Introduction to remote sensing - 3rd Edition*. The Guilford Press]

What is Remote Sensing ?

"Remote Sensing is defined as the science and technology by which *characteristics* of objects of interest can be identified without direct contact"

Concept of Remote Sensing

Remote sensing is the **science of obtaining information** about objects or areas from a distance, typically from aircraft or satellites.

Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance from the targeted area.

Definition - What does *Remote Sensing* mean?

Remote sensing is the process of acquiring information about an object or phenomenon without making actual physical contact with it, as opposed to onsite observation or onsite sensing. This often requires the use of aerial sensor technologies such as those used in reconnaissance airplanes and satellites in order to detect and analyze objects on the Earth, usually on the surface.

Definition of Remote Sensing

Remote sensing is a way of collecting and analysing data to get information about an object without the instrument used to collect the data being in direct contact with the object.

Remote sensing is defined as the art, science and technology through which the characteristics of objects/targets either on, above or even below the Earth's surface are identified, measured and analysed without direct contact existing between the sensors and the objects or events being observed

The term remote sensing is often wrongly applied to satellite-borne imaging of the earth's surface only. Remote sensing is the common name for all methods used to collect data at a distance from the object under study by some kind of recording device.

"the art, science, and technology of obtaining reliable information about physical objects and the environment, through the process of recording, measuring and interpreting imagery and digital representations of energy patterns derived from noncontact sensor systems". (Cowell 1997)

Taken from: Introductory Digital Image Processing. 3rd edition. Jensen, 2004

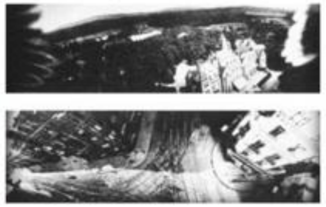
The **science of acquiring information about the earth** using instruments which are remote to the earth's surface, usually from aircraft or satellites.

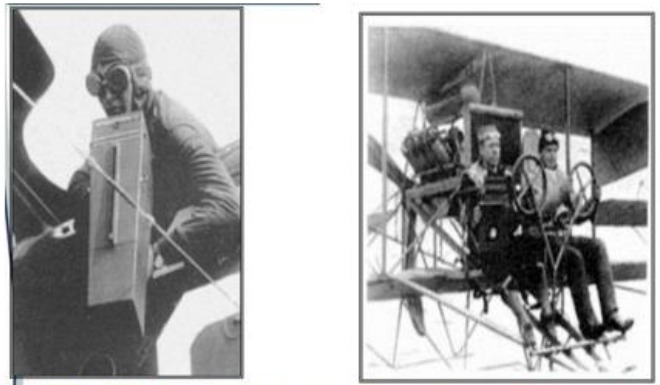
History of Remote Sensing

- 1858 - Gasper Felix Tournachon "Nadar" takes the first aerial photograph from a captive balloon from an altitude of 1,200 feet over Paris.

Boston from a captive balloon at 1,200 feet, October 13, 1860, James Wallace Black. This is the oldest conserved aerial photograph

- 1903 - The Bavarian Pigeon Corps uses pigeons to transmit messages and take aerial photos.





1914 - WW I provided a boost in the use of aerial photography, but after the war, enthusiasm waned

1946 - First space photographs from V-2 rockets.

1954 - U-2 takes first flight.

•EXPLORER-7 launched in 1959

• Carried Suomi radiometer measuring solar &terrestrial radiation (ERB study)

Major elements of Remote Sensing:

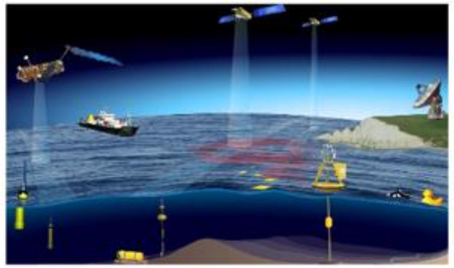
1. Platforms
2. Sensors
3. Targets
4. Information

Basic Principles of Remote Sensing

PLATFORMS

- Platforms refer to the structures or vehicles on which remote sensing instruments are mounted.
- The platform on which a particular sensor is housed determines a number of attributes, which may dictate the use of particular sensors.
- These attributes include: distance the sensor is from the object of interest, periodicity of image acquisition, timing of image acquisition, and location and extent of coverage.
- There are three broad categories of remote sensing platforms:

   a) ground based,
   b) airborne, and
   c) satellite.



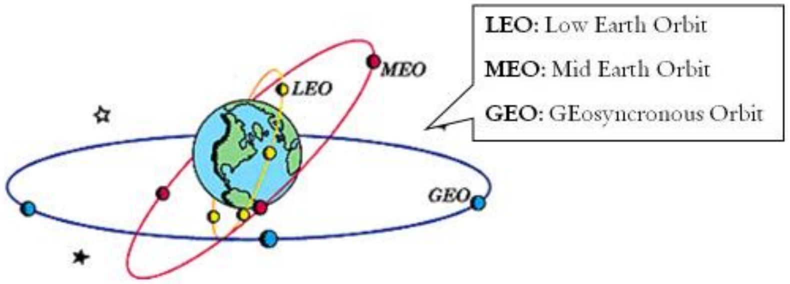
Basic Principles of Remote Sensing

PLATFORMS

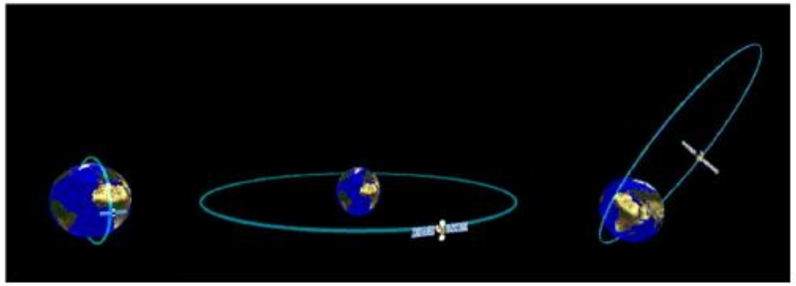
- Each space MISSION requires a specific orbit.

Mission	Type of orbit	Altitude	Period	Tilt
Communications Meteorological	Geostationary	35,786 Km (GEO)	24 hours	0 °
Earth Resources	Polar-synchronous	150-900 Km (LEO)	90 minutes	95 °
Navigation (GPS)	Semi-synchronous	20,230 Km (MEO)	12 hours	55 °
Space shuttle	Low orbit	300 Km	90 minutes	28.5 ° or 57 °
Communication Intelligence	Molniya	Perigee: 7971 Km Apogee: 45,170 km	12 hours	63.4 °

➢ **Circular** LEO, MEO, GEO



➢ **Elliptical**



Basic Principles of Remote Sensing

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SENSORS

- Remote sensing instruments are of two primary types—**active** and **passive**.

- **Active sensors**, provide their own source of energy to illuminate the objects they observe.
  - An active sensor emits radiation in the direction of the target to be investigated.
  - The sensor then detects and measures the radiation that is reflected or backscattered from the target.

- **Passive sensors**, on the other hand, detect natural energy (radiation) that is emitted or reflected by the object or scene being observed.
  - Reflected sunlight is the most common source of radiation measured by passive sensors.

Active sensors:

- Laser altimeter
- Lidar
- Radar
- Ranging instrument
- Scatterometer
- Sounder

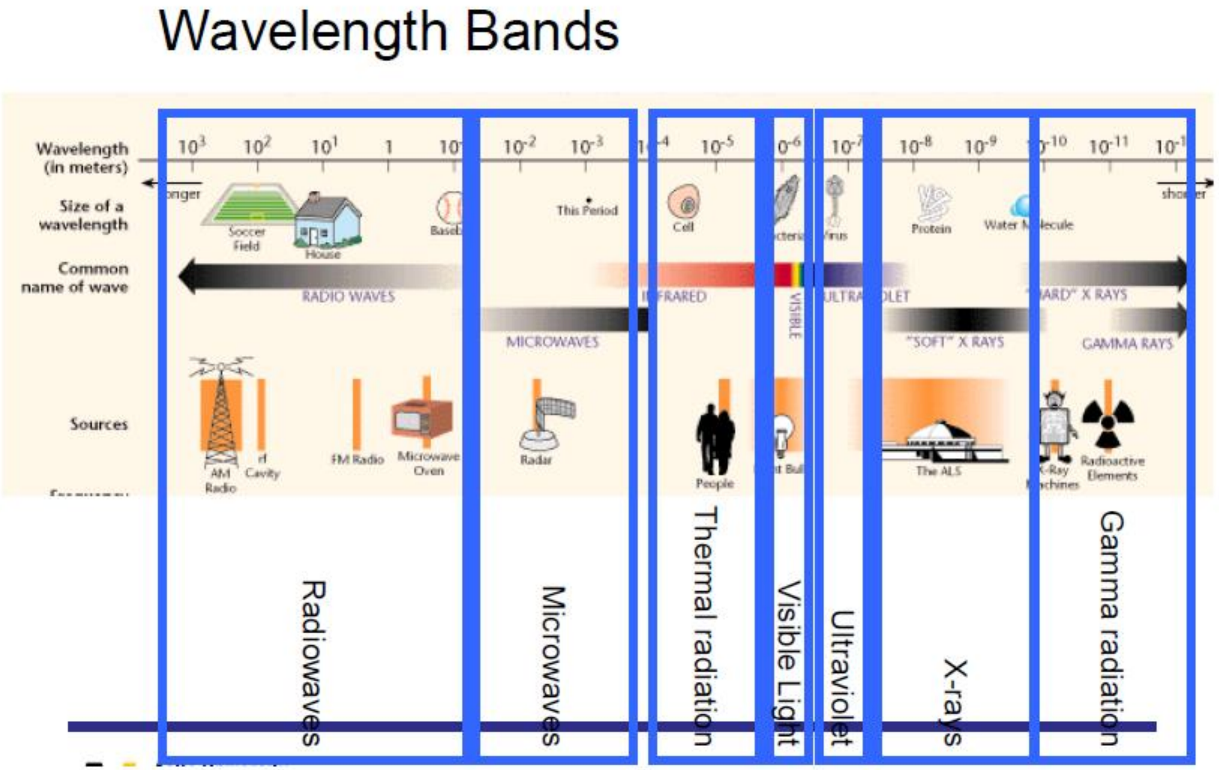
Passive sensors:

- Accelometer
- Hyperspectral radiometer
- Imaging radiometer
- Radiometer
- Sounder
- Spectrometer
- Spectroradiometer

Basic Principles of Remote Sensing

SENSORS

- Visible and Reflective Infrared Remote Sensing
- Thermal Infrared Remote Sensing
- Microwave Remote Sensing



Basic Principles of Remote Sensing

TARGETS

- Remote sensing techniques are implemented in function of what needs to be observed.
  - For instance, orbit parameters are related to monitoring requirements.
  - The Earth can therefore be observed at different scales.
  - Taking a photo with camera-distance determines scale of target
  - To have a picture of the Earth as a whole disk, the satellite has to be further away from the planet.
  - Targets will determine which sensors and their specifications will be needed.

Basic Principles of Remote Sensing

INFORMATION

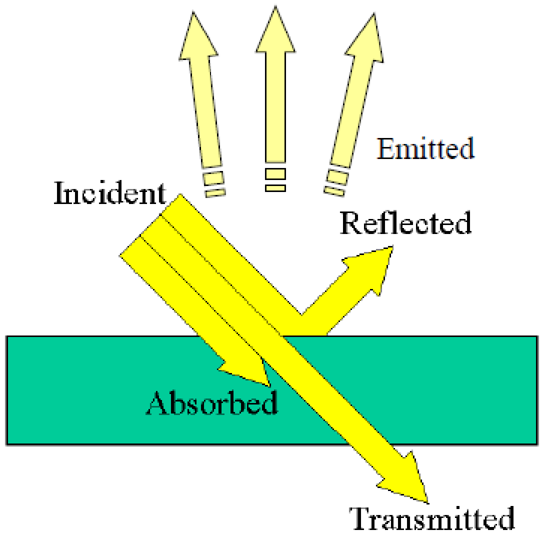
- In remote sensing, it is very important to understand the data provided by sensors in order to interpret them properly.

Interaction of EM Radiation with Matter

Remote sensing is based on these interaction mechanisms:

- Reflection
- Transmission
- Scattering
- Emission and Absorption

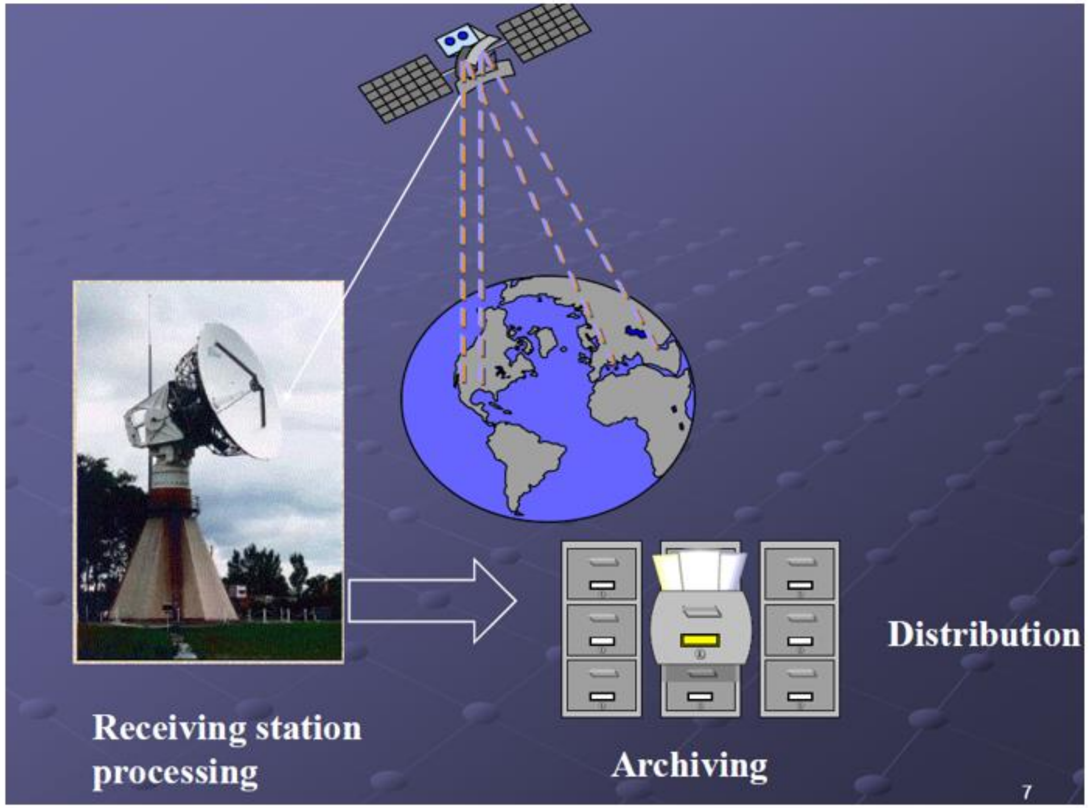
These mechanisms convey information about the target to the measuring instrument



Basic Principles of Remote Sensing

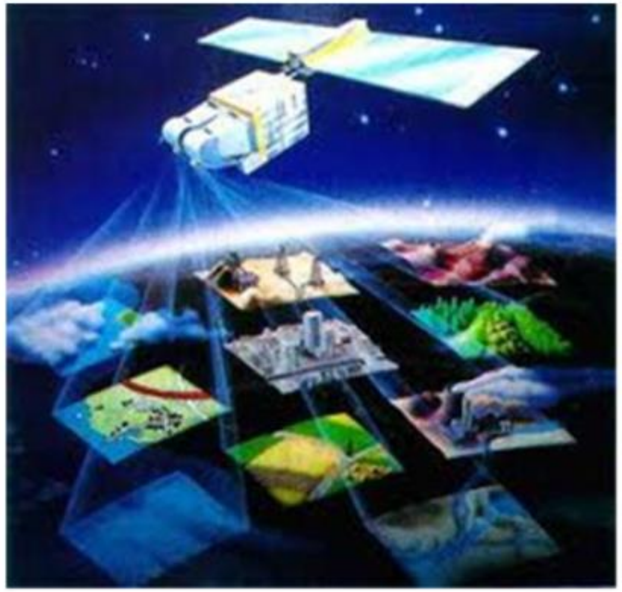
BASIC PROCESSES

- Data acquisition
- Processing
- Analysis (quantitative and qualitative Analysis)
- Accuracy assessment
- Information distribution to users



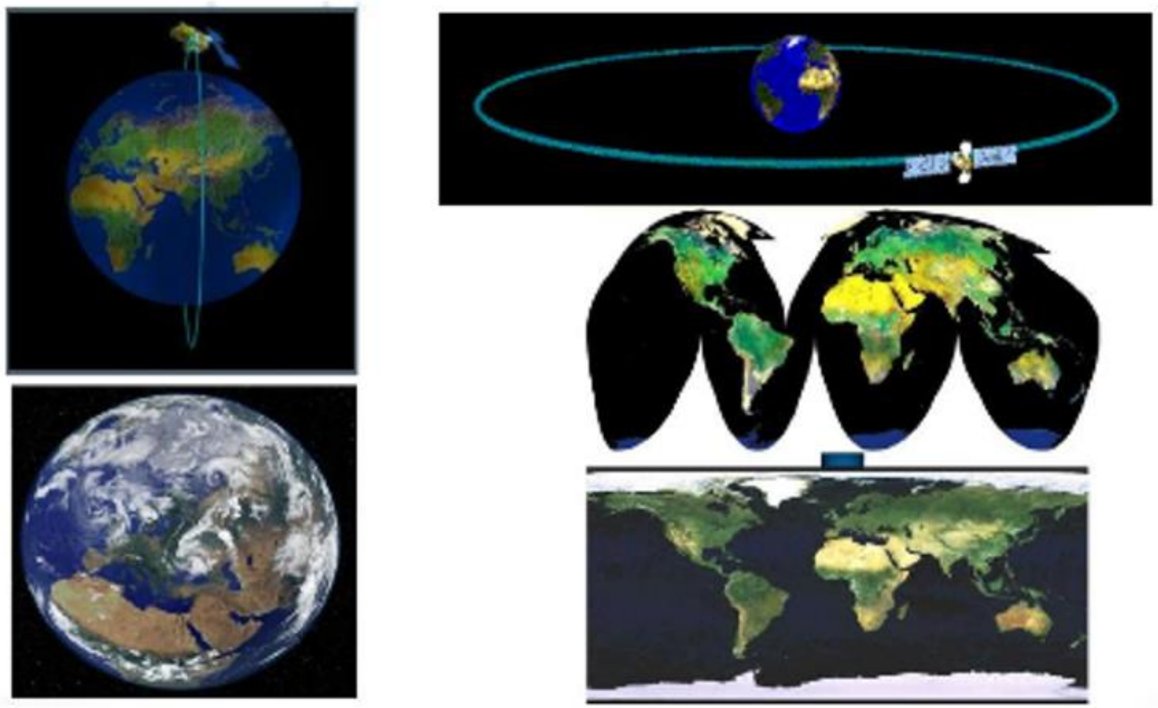
Why Remote Sensing

"Considerably improve our knowledge of our environment, facilitating the interpretation of the multiple processes affecting the planet"



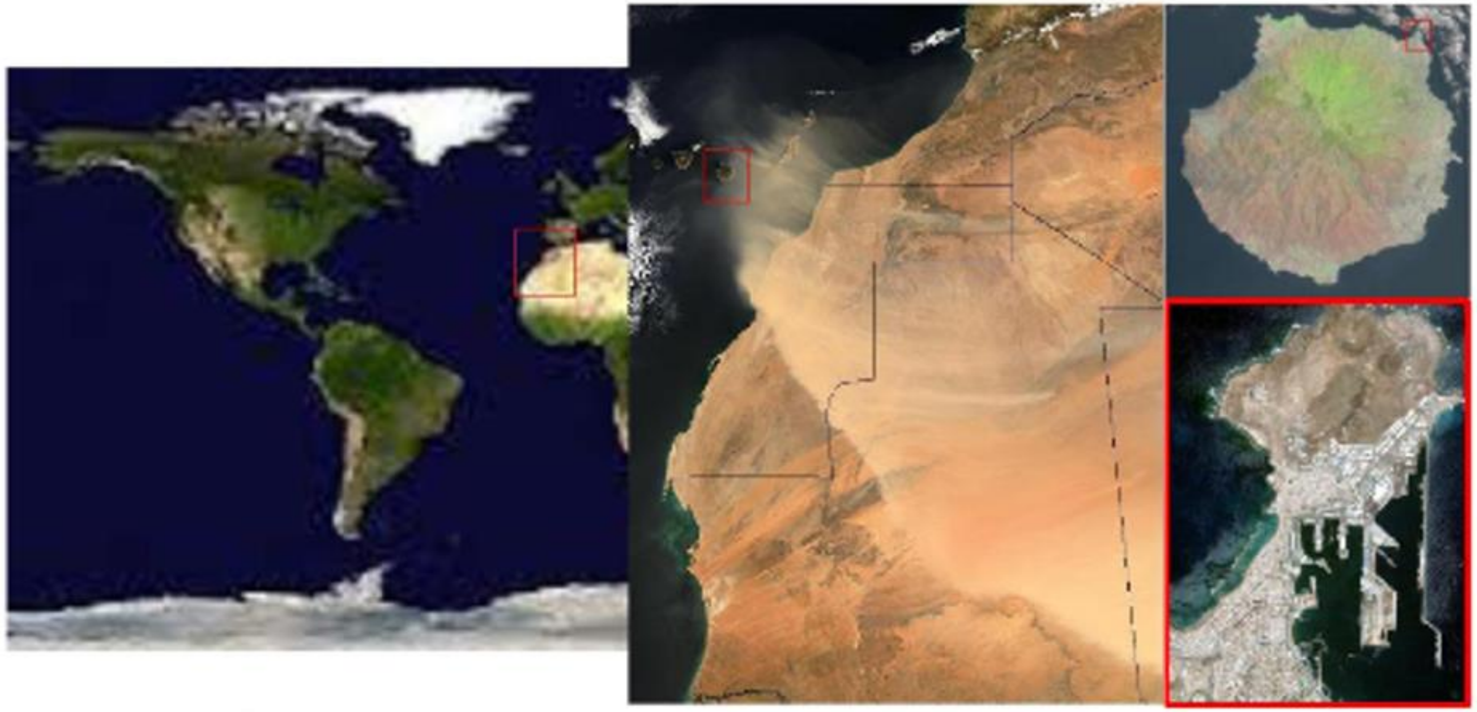
Why Remote Sensing

- Global coverage and regular large areas of the Earth.



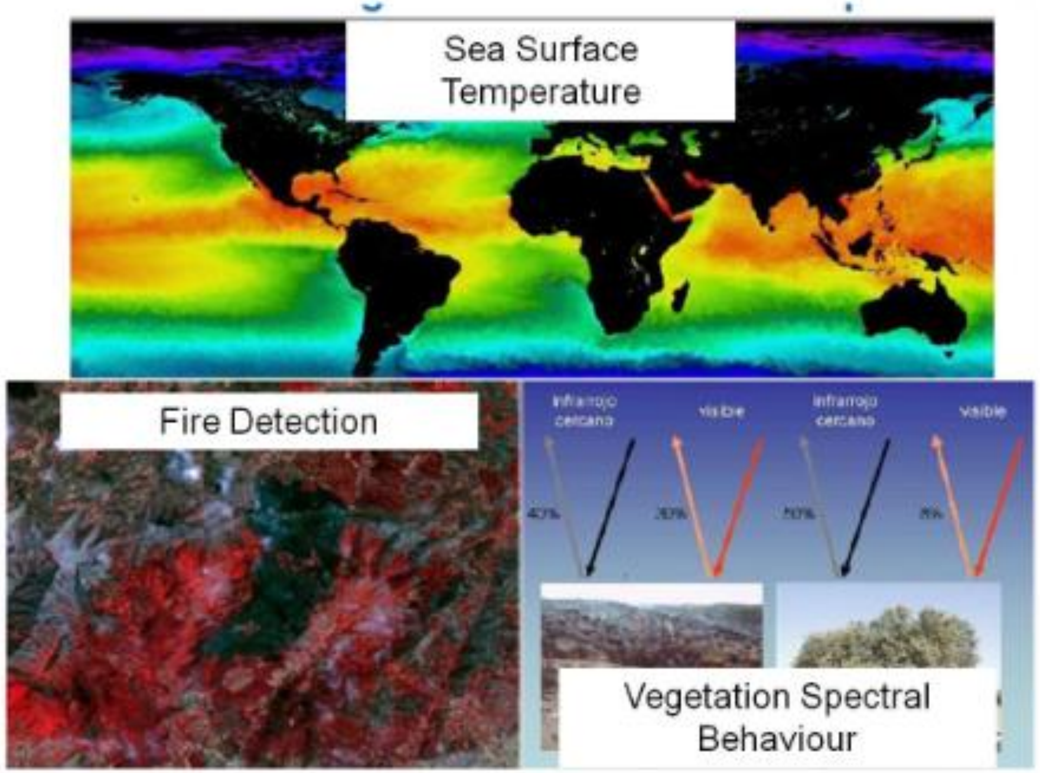
Why Remote Sensing

- Observation multiscale.



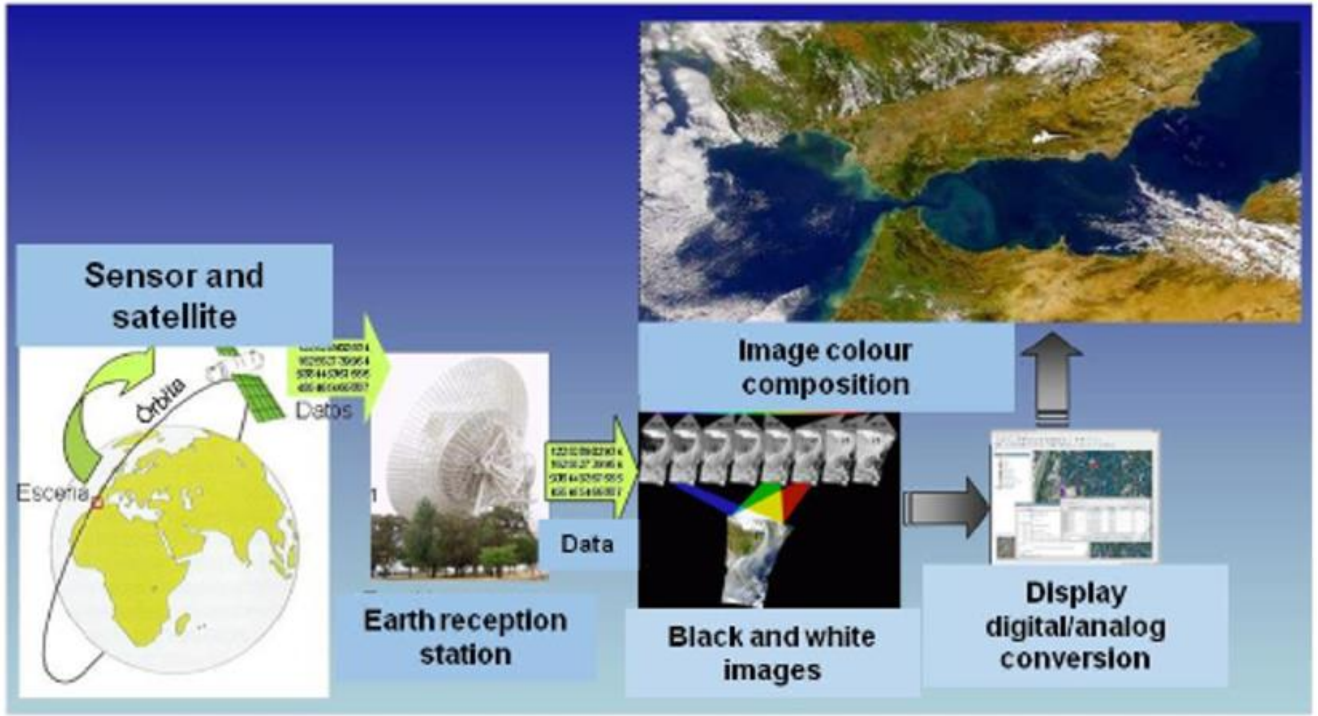
Why Remote Sensing

- Information on non-visible regions of the spectrum.



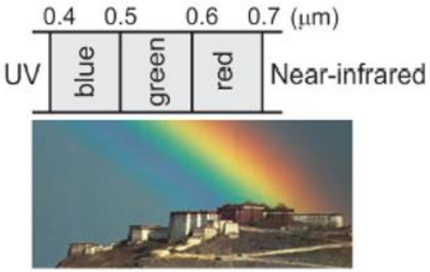
Why Remote Sensing

- Digital processing of the received images.



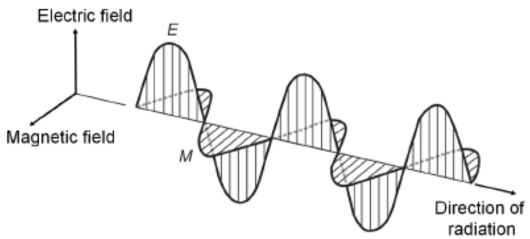
Electromagnetic Waves and Radiation

- Sensing with our eyes (Red, Green, Blue)
- Sun is sources of light, Electromagnetic (EM), which is visible with human eye
- **Emitted** light by sun is **reflected** by an object and **detected** by photosensitive cells in our eyes
- Thermal emission **radiated** by sun (ultraviolet (UV) radiation)
- EM radiation outside the range 0.38 to 0.76 is not visible to human eye

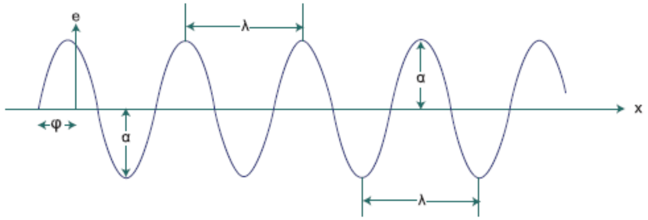


The Spectrum of light

Source: Principles of Remote Sensing, Klaus Tempfli and et al.



Characteristic of a wave:



- We call the amount of time needed by an EM wave to complete one cycle the ***period*** of the wave.
- The reciprocal of the period is called the ***frequency*** of the wave.
- We usually measure the frequency in hertz

(1Hz = 1 cycle per second)

- Light has two oscillating components; electric and magnetic energy
- All EM energy travels at speed of light- 300000 km / s
- It takes 8 minutes before we see sun light

$$e = \alpha sin(\frac{2\pi}{\lambda}x + \varphi).$$

λ is the length of one cycle of the oscillation.

The *phase*, φ, is an important quantity for precise ranging

φ can take any value in the range from 0 to 2π.

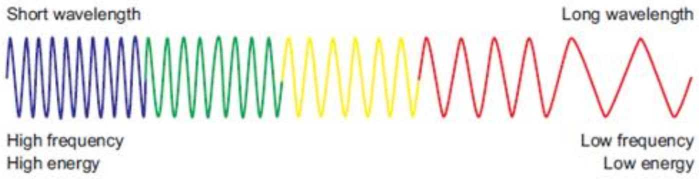
The *amplitude*, α, is the peak value of the wave.

Source: Principles of Remote Sensing, Klaus Tempfli and et al.

Electromagnetic Waves and Radiation

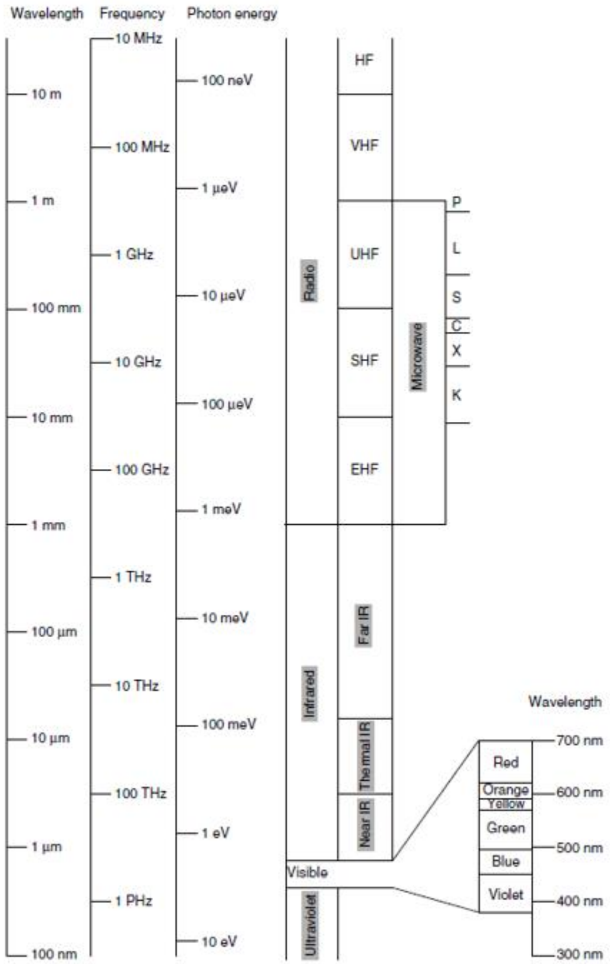
- The relationship between wavelength and frequency

$$c = \lambda \times v. \qquad c = \lambda\, x\, f$$



$$Q = h \times v = h \times \frac{c}{\lambda} \qquad E = hf$$

- ***Q*** or ***E*** is the energy of a photon measured in Joule
- ***h*** is the Plank's constant $(6.6262 \cdot 10^{-34}$ jouleseconds$)$
- ***electronvolt*** $(1\ \mathrm{eV} \approx 1.6 \times 10^{-19}\ \mathrm{J})$

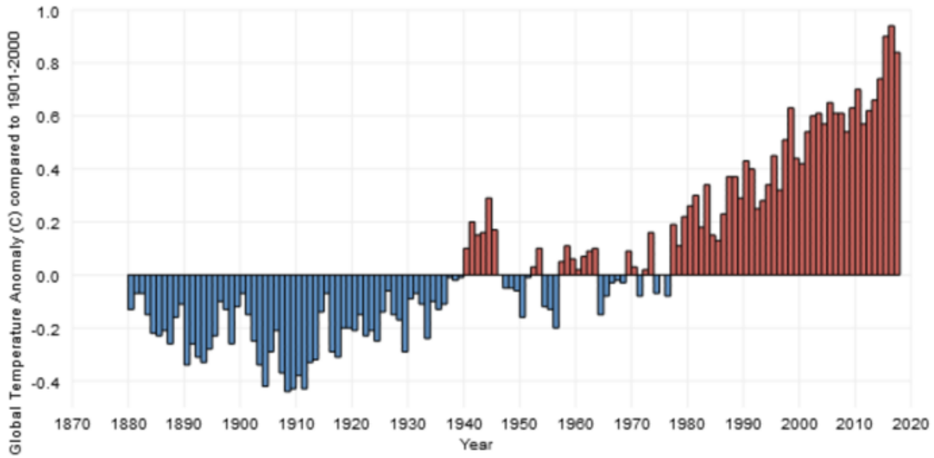


Source: Principles of Remote Sensing, Klaus Tempfli and et al., Physical Principles of Remote Sensing, W.G. Rees

Electromagnetic Waves and Radiation

- Absolute temperature is conventionally measured in Kelvins (K)
- Absolute zero is the lowest possible temperature where nothing could be colder $0K = -273,15\ ^{0}\mathrm{C}$
- The global mean temperature of the Earth's surface is 288 K
- The average temperature on the surface of Earth depends on a number of factors. These include the time of day, the time of year, and where the temperatures measurements are being taken. Given that the Earth experiences a sidereal rotation of approximately 24 hours –which means one side is never always facing towards the Sun – temperatures rise in the day and drop in the evening, sometimes substantially.
- The Sun's temperature is 6000 K

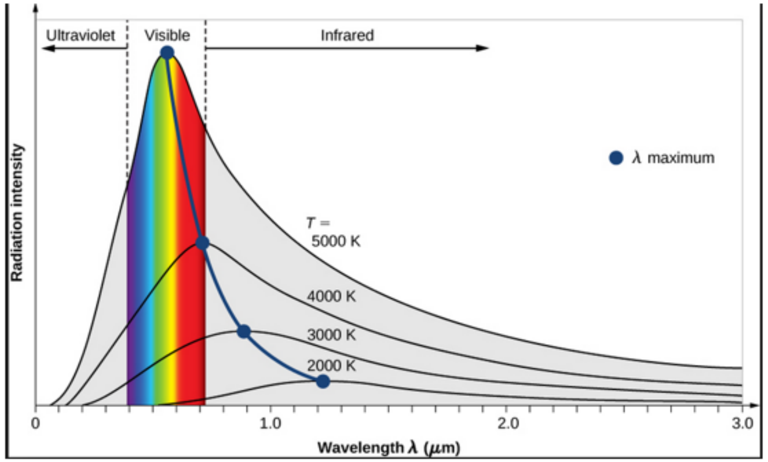
History of global surface temperature since 1880



NOAA , www.climate.gov

Electromagnetic Waves and Radiation

- Sun is (approximately) **BLACK-BODY**
- A black-body absorbs %100 energy of the radiation that hits it
- A black-body re-emits all energy it receives
- A black-body can have different temperatures
- The amount of energy commonly expressed in Joule
- Power (measured in Watts): power is the quantity of energy emitted by an object per unit of time in all directions or received by an object per unit of time from all directions. (1 W = 1 Joule per second)



- **Radiant emittance** is the power emitted from a surface (Wm^{-2})
- **Spectral radiant emittance** characterize emittance per wavelength $Wm^{-2}\mu m^{-1}$
- **Radiance** is the radiometric measure, which describes the amount of energy being emitted or reflected from a particular area per unit solid angle and per unit time $Wm^{-2}sr^{-1}$
- **Irradiance** is the amount of incident energy on a surface per unite area and per unit time Wm^{-2}
- The emitting ability of real material is expressed as dimensionless ratio called **emissivity** (with values between 0 and 1).
- The **emissivity** of a material specifies how well a real body emits energy as compared with a black-body.

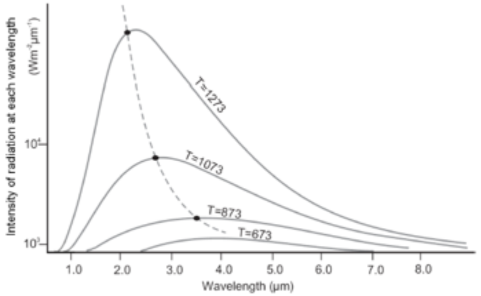
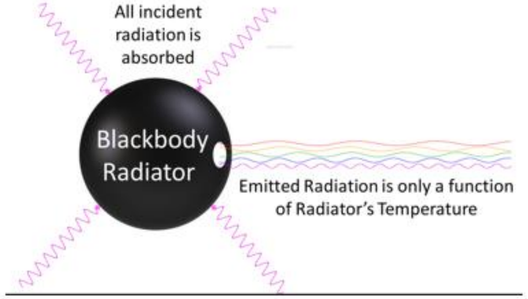


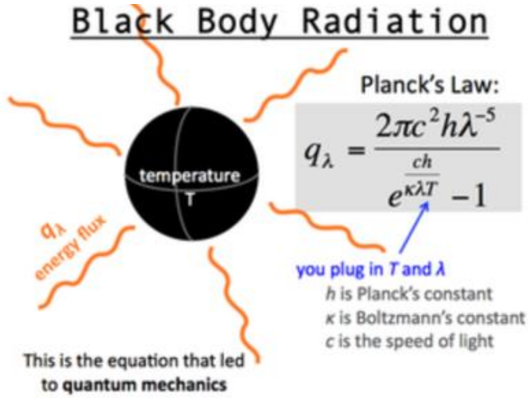
Figure 2.6: Black-body radiation curves (with temperatures, T, in K).

Source: Principles of Remote Sensing, Klaus Tempfli and et al., Physical Principles of Remote Sensing, W.G. Rees

Electromagnetic Waves and Radiation

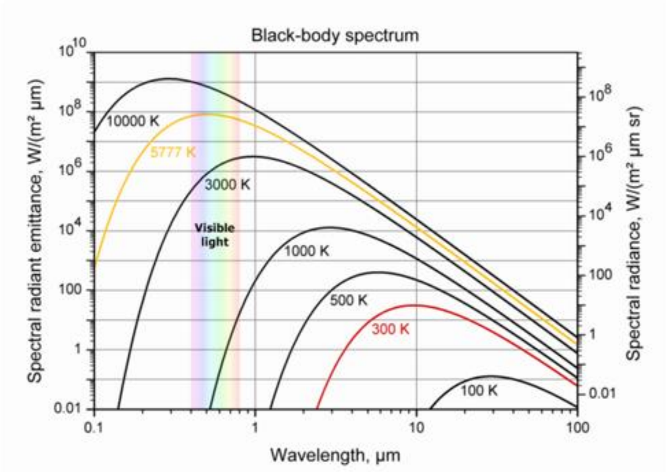
Figure 2.11. Max Planck (1858–1947), the founder of quantum mechanics. He was awarded the Nobel Prize in physics in 1918, the year of this photograph. (Source: Wikipedia. http://en.wikipedia.org/wiki/File:Max_Planck_(Nobel_1918).jpg)





$$q_\lambda = \frac{2\pi c^2 h \lambda^{-5}}{e^{\frac{ch}{\kappa \lambda T}} - 1}$$

h is Planck's constant
κ is Boltzmann's constant
c is the speed of light



Source: Principles of Remote Sensing, Klaus Tempfli and et al., Physical Principles of Remote Sensing, W.G. Rees

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Microwave RS Snow Products: Theory - Part II

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Snow

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Motivation on Snow

- During winter season, snow covers about 40 million km2 in the Northern hemisphere (Huining, 2001).
- Snow is a vital water resource in many regions of the world.
- Climatic changes, Earth's energy balance, water resources are strongly affected by the presence of snow.
- Knowledge of the amount of snow water equivalent from year to year is essential to estimate the effects of snow melt run-off.
- Knowing the snow characteristics helps
  - to improve weather forecasts,
  - to predict water supply for hydropower stations,
  - to anticipate flooding.

Snow Trends

- A non-uniform picture:
  - Snow cover largely decreasing
  - SWE and Depth –
    various trends, including tendencies of increase in NE and decreases over Canada
  - Duration, onset, snow-off – various trends, mostly negative
  - Cold season precipitation –
    largely increasing trends with regional dependence
  - Snow properties, stratigraphy –
    signs of increased bottom layer hardness and moisture
  - Rain on snow, mid-winter thaw – dangerous events

Role of Snow in Climate System

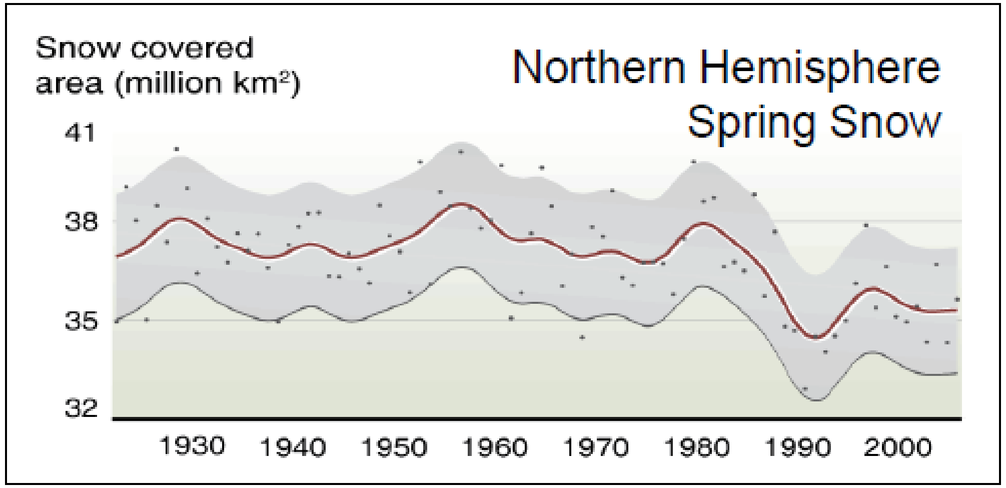
- A very sophisticated picture:
  - Multiple feedbacks and impacts (through albedo, roughness, insulation of surface and at the same time active chemical interaction, permeability for water, impacts on hydrology hence on the Arctic Ocean, vegetation hence on carbon balance, etc.)…

Snow and River Runoff

- Snow Melt -> up to ¾ annual transport in high-latitude rivers
- Arctic:
  - likely changes towards more uniform runoff throughout a year, with a multitude of attendant changes, likely increased (up to 50% runoff to the Arctic ocean)
- Alps:
  - Higher snow line
  - more or less robust conclusion: spring melt, higher peaks on runoff (tendency for flooding) but less annula volume – water shortage (Bavay et al., 2009)

Global Warming and Cryosphere

- United Nations Global Outlook for Ice and Snow : Mean monthly snow cover is decreasing by about 1.3% per decade.

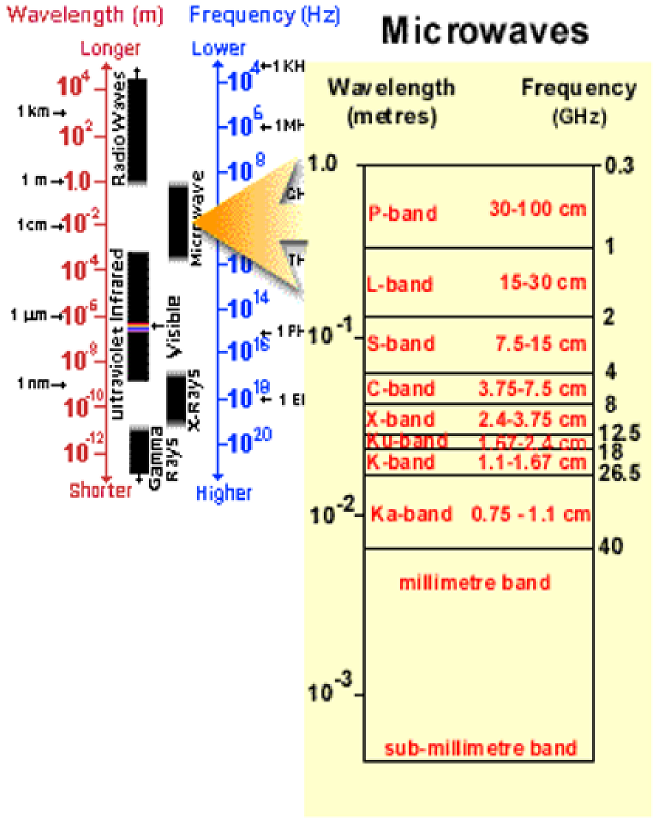


Microwave Remote Sensing

Motivation on Microwave Remote Sensing

- Microwave sensors such as radiometers and radars are often used because of
  - their usability under varying conditions, factors like clouds, rain and lack of light do not affect the measurement,
  - the large penetration depth into the surface with increasing wavelength,
  - sensitive to liquid water.

- Understanding of the relationship between microwave signatures and snow is very important for retrieving desired snowpack parameters such as snow density, snow water equivalent and snow wetness.



Remote Sensing Instruments

Active Instruments

Active remote sensing instruments illuminate their target with their own signal

- **Radar** (imaging microwave sensor)
  - Real aperture radar
  - Synthetic aperture radar
- **Lidar** (Light Detection and Ranging) (optical radar)
- **Scatterometers** (non-imaging radar)

Active sensor = transmitter + receiver

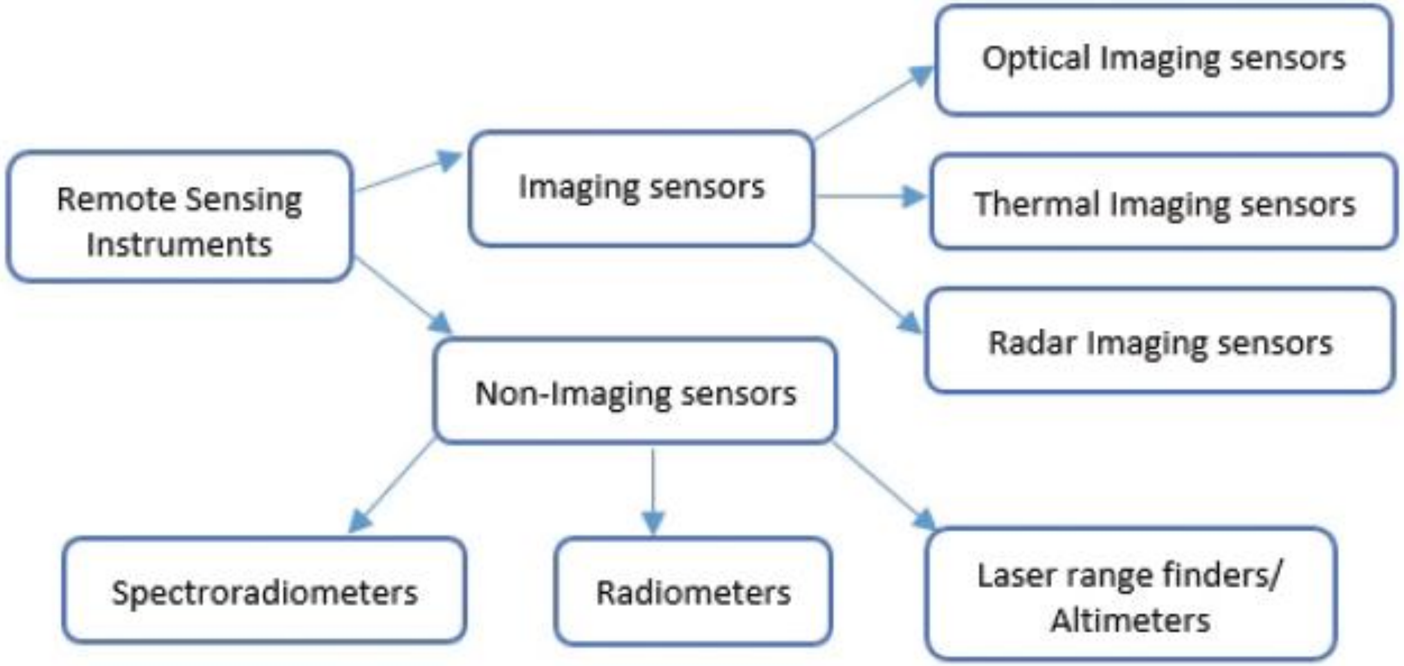
Passive Instruments

Passive remote sensing instruments measure intensity of either emission from target or Sun radiation reflected by target

- Most optical sensors
- Spectrometers (reflection and emission)
- Imaging high resolution cameras (reflection)
- Microwave radiometers (emission)

Passive sensor = receiver

Remote Sensing Instruments



Remote Sensing Instruments

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https://webapps.itc.utwente.nl/sensor/Default.aspx?view=allsensors

Search

Microwave spectrum

From to resolution (m)

35 results

Name	Description	No of Bands	Mission
AMR	Advanced Microwave Radiometer	3	Jason-2
AMR-2	Advanced Microwave Radiometer - 2	3	Jason-3
AMSR	Advanced Microwave Scanning Radiometer	8	ADEOS-II
AMSR-2	Advanced Microwave Scanning Radiometer-2	7	GCOM-W1
AMSR-E	Advanced Microwave Scanning Radiometer for EOS	6	Aqua
MWI	MicroWave Imager	26	Metop-SG B1, Metop-SG B2, Metop-SG B3
MWR	Microwave Radiometer	2	ENVISAT, ERS-1, ERS-2, Sentinel-3A, Sentinel-3B, Sentinel-3C, Sentinel-3D
MWRI	Microwave Radiation Imager		FengYun-3A
SMAP radiometer	Passive Microwave Radiometer	1	SMAP
SMMR	Scanning Multichannel Microwave Radiometer	5	NIMBUS-7, Seasat

Search

SAR-C spectrum

From to resolution (m)

17 results

Name	Description	No of Bands	Mission
ALT	Dual Frequency Radar Altimeter	2	TOPEX/Poseidon
AMI	Active Microwave	1	ERS-1, ERS-2
ASAR	Advanced Synthetic Aperture Radar	1	ENVISAT
ASCAT	Advanced scatterometer		Metop-A, Metop-B, Metop-C
RADARSAT 2	Radar		RADARSAT-2
SAR-C (RCM)	SAR-C on RADARSAT Constellation Mission		RADARSAT Constellation Mission
SAR-C Radarsat1	Synthetic Aperture Radar on RADARSAT-1	1	RADARSAT-1
SAR-C Sentinel1	C-band SAR on Sentinel-1A/Sentinel-1B	1	Sentinel-1A, Sentinel-1B, Sentinel-1C, Sentinel-1D
SCA	Scatterometer		Metop-SG B1, Metop-SG B2, Metop-SG B3
SIR-C	Spaceborne Imaging Radar-C	1	SRTM
SRAL	SAR Radar Altimeter	2	Sentinel-3A, Sentinel-3B, Sentinel-3C, Sentinel-3D

Remote Sensing Instruments

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ADVANCED MICROWAVE SCANNING RADIOMETER FOR EOS

Satellites
Aqua

AMSR-E websites

Information
NASA - Aqua instrument AMSR-E
JAXA - Japan Aerospace Exploration Agency
JAXA EORC - AMSR/AMSR-E

Data ordering
Copernicus - Marine env. & monit. Service
NASA EarthData - Search
JAXA - G-Portal Data providing service
NSIDC DAAC - AMSR-E data
GCOM-W Research Product Distribution Service
NASA Giovanni (data and visualisation)

AMSR-E Bands

Band	Wavelength (µm)	Bandwidth (µm)	Resolution (m)	Swath width (km)	Revisit time (days)
Band 1 (6.925 GHz) (Microwave)			10000	1450	
Band 2 (10.65 GHz) (Microwave)			10000	1450	
Band 3 (18.7 GHz) (Microwave)			10000	1450	

abs-resources/satellite-sensor-database/glossary

MICROWAVE IMAGER

Satellites
Metop-SG B1
Metop-SG B2
Metop-SG B3

MWI websites

Information
Eumetsat - EPS-SG Design/Sensors
ESA eoPortal - Metop-SG Sensors

MWI Bands

Band	Wavelength (µm)	Bandwidth (µm)	Resolution (m)	Swath width (km)	Revisit time (days)
Band 1) 18.7 GHz (Microwave)			10000	1700	
Band 2) 23.8 GHz (Microwave)			10000	1700	

Remote Sensing Instruments

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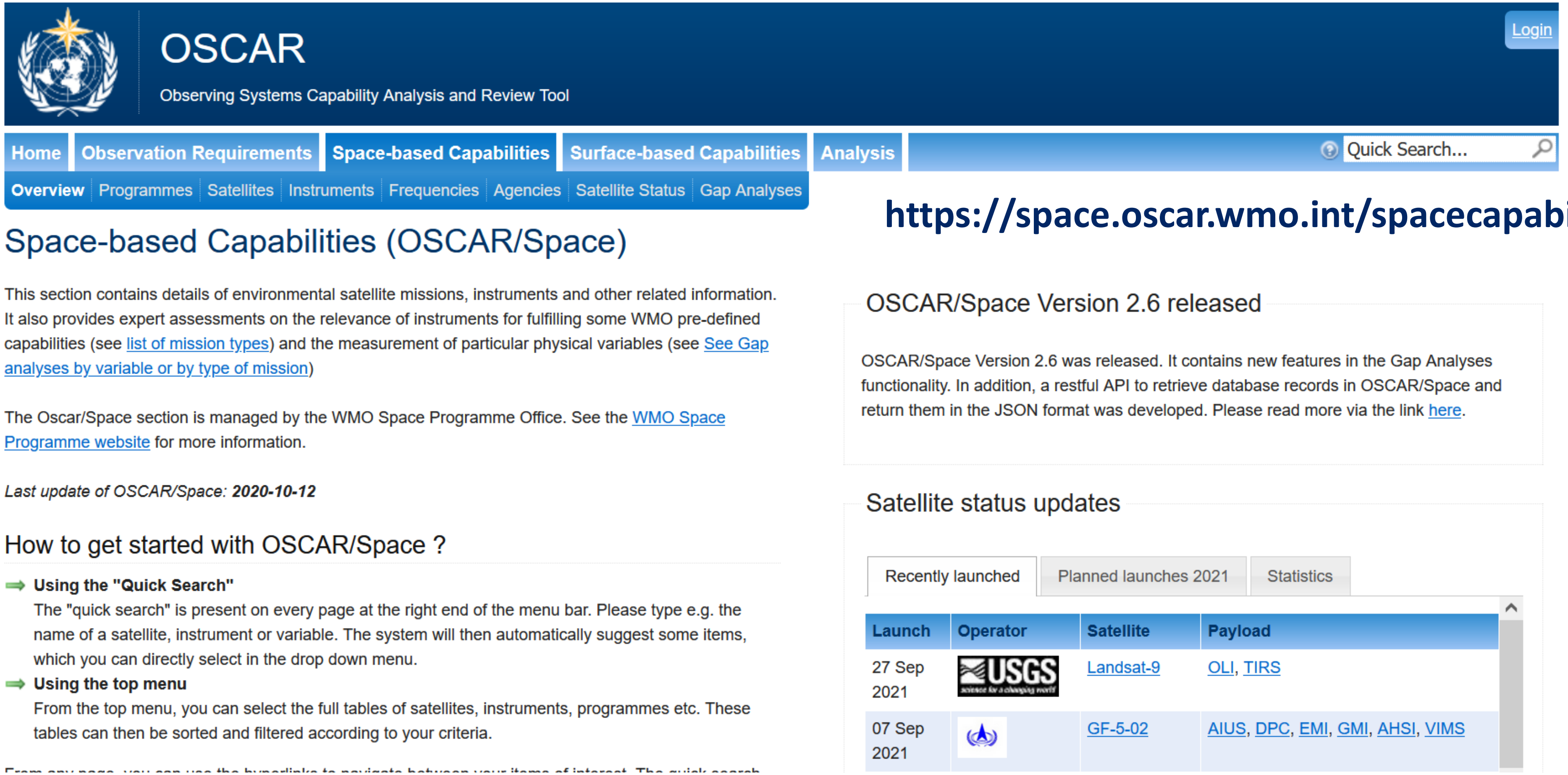

https://space.oscar.wmo.int/spacecapabilities

Remote Sensing Instruments

Radiometer Measurement

- For homogeneous target brightness temperature T_B is obtained from:

$$T_B(\theta) = e(\theta) T_{fys}$$

e(θ) = emissivity, $0 \le e \le 1$
T_{fys} = target physical temperature (K)
Θ = incidence angle off nadir

- Radiometer measures antenna temperature, obtained from:

$$T_A = \frac{\iint_{4\pi} T_B(\theta,\phi) F_n(\theta,\phi) d\Omega}{\iint_{4\pi} F_n(\theta,\phi) d\Omega}$$

F_n = normalized antenna power pattern (value between 0 and 1)

Polarization not denoted in above equations, usually V or H

Radar Measurement

- Radar measures the (differential) backscattering coefficient σ^0, which is obtained from:

$$\sigma^0(\theta) = \frac{(4\pi)^3 R^4 P_r}{P_t G_t(\theta) G_r(\theta) \lambda_0^2 A}$$

R = distance to target
P_r = received power, P_t = transmitted power
G_r = gain of receiving antenna, G_t = gain of transmitting antenna
λ_0 = wavelength in air
A = surface of measured area

Polarization is not shown in the equation:
usually VV, HH, VH, or HV for transmit/receive

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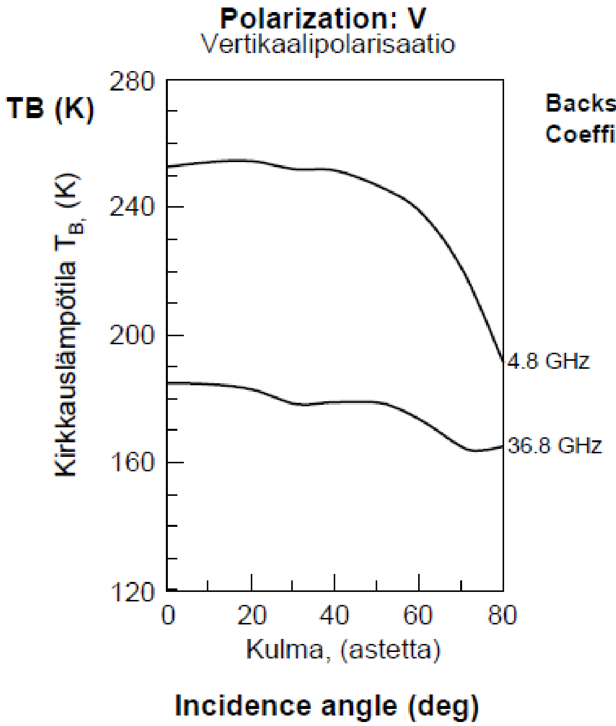
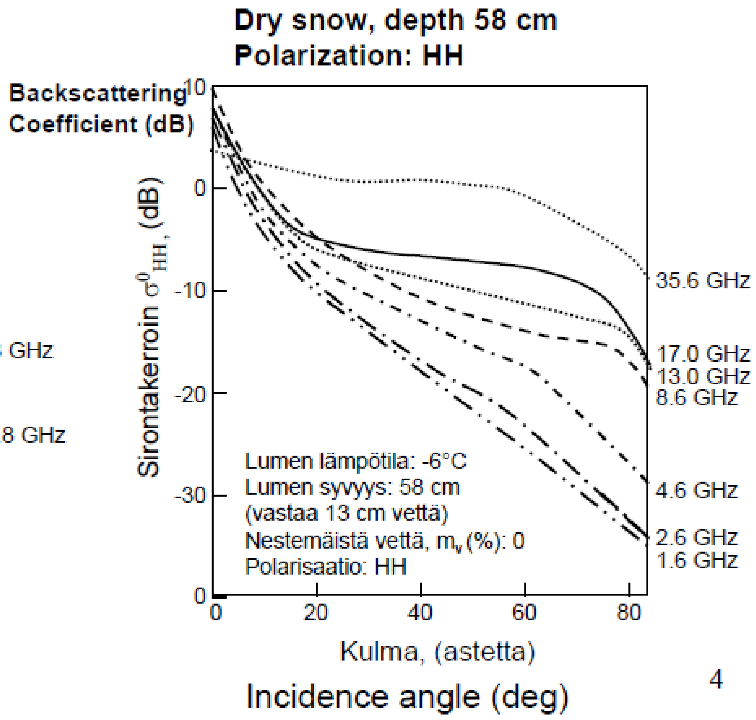
Example of Radiometer and Radar Result

Radiometer



Radar



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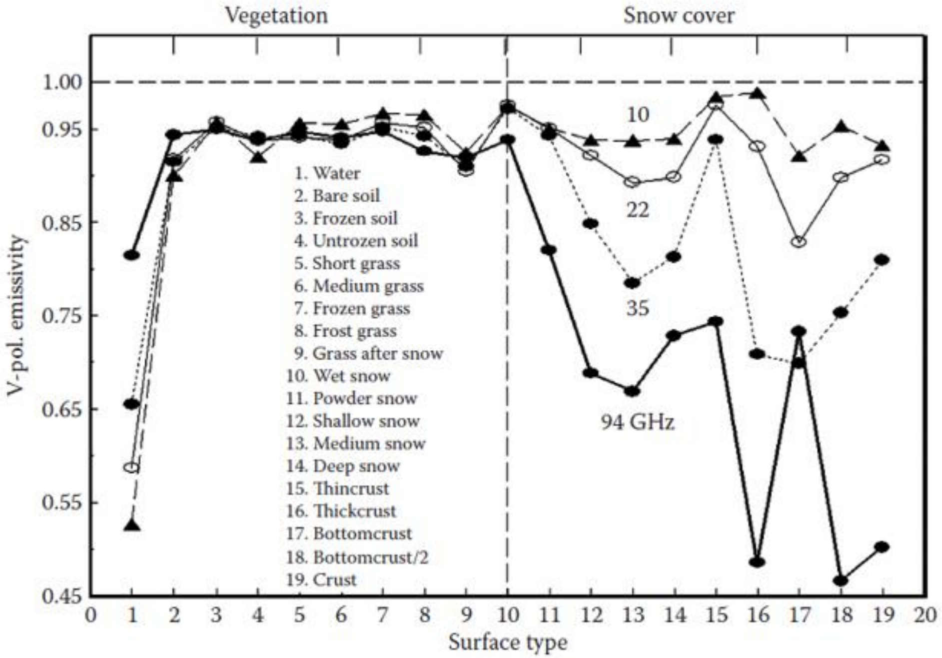

FIGURE 15.3 Spectral emissivity of snow cover and other surfaces at 10, 22, 35, and 94 GHz. (From Mätzler, C., *Meteor. Atmosph. Phys.*, 54(1–4), 241, 1994.)

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Snow Cover Monitoring from Remote-Sensing Satellites: Possibilities for Drought Assessment

Cezar Kongoli
National Oceanic and Atmospheric Administration

Peter Romanov
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Ralph Ferraro
National Oceanic and Atmospheric Administration

shows spectral MW measurements of snow and nonsnow materials made with a MW radiometer at 6, 10, 22, 37, and 94 GHz with a vertical polarization. All the listed snow types display a monotonic decrease in surface emissivity with increasing frequency, except for snow type 17 (bottom crust) at 94 and 37 GHz frequencies. The anomalous spectral response of snow type 17 (higher emissivity at 94 GHz than at 37 GHz) is explained by increased absorption (due to the presence of an ice layer)

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TABLE 15.1
Snow Parameters That Affect Visible, Near-IR, IR, and MW Spectral Response

	Visible Solar Albedo	Near-IR Solar Albedo	Thermal IR Emissivity	MW Emissivity
Grain size	(+)	Yes		Yes
Zenith (or nadir) angle	(+)	Yes	Yes	Yes
Depth	Yes			Yes
Contaminants	Yes			
Liquid water content				Yes
Density				Yes
Temperature				Yes

+ Only if snowpack is thin or impurities are present.

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Of particular importance for the retrieval of snow parameters is the observation that the MW spectral response shows dependence on a larger set of snow parameters than optical imagery (Table 15.1), which complicates the interpretation of MW imagery for snow identification and mapping. Among the snow parameters affecting the MW response, the most important are grain size, SD, SWE, and liquid water content. Dense vegetation can also attenuate MW radiation, particularly at higher frequencies (20 GHz and above), reducing the signal of the snow underneath. All other parameters being equal, an increase in SD or SWE is associated with a steeper emissivity gradient with frequency, because of increased scattering caused by a larger number of snow grains. Also, coarser-grained snow cover produces a steeper emissivity gradient. A small amount of liquid water in snow dramatically increases emission and reduces the scattering response and thus the ability to accurately map SCA, SD, and SWE over melting snow cover.

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Snow property	Sensor band: Gamma rays	Visible/near infra-red	Thermal infra-red	Microwaves
Snow covered area	Low	High	Medium	High
Depth	Medium	If very shallow	Low	Medium
Water equivalent	High	If very shallow	Low	High
Stratigraphy	No	No	No	High
Albedo	No	High	No	No
Liquid water content	No	Low	Low	High
Temperature	No	No	Medium	Low
Snowmelt	No	Low	Low	Medium
Snow-soil interface	Low	No	No	High
Additional factors				
All weather capability	No	No	No	Yes
Current best spatial resolution from space platform	Not possible	10 m	100 m	25 km passive 10 m active

Rango, A. (1993) Snow hydrology processes and remote sensing. *Hydrological Processes*. 7(2), pp. 121-138.

Rango, A. (1983) Application of a simple snowmelt-runoff model to large river basins. *Proc. 51st Western Snow Conf.* Western Snow Conference, pp. 89-99.

Rango, A. (1985) Results of the snowmelt-runoff model in an international test. *Proc. 53rd Western Snow Conf., Boulder, Co.*, Western Snow Conference, pp. 99-106.

Rango, A. (1993) Snow hydrology processes and remote sensing. *Hydrological Processes*. 7(2), pp. 121-138.

Rango, A., Chang, A. T. C. and Foster, J. L. (1979) The utilization of spaceborne microwave radiometers for monitoring snowpack properties. *Nord. Hydrol.* 10, 25-40.

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Rango, A., Martinec, J., Chang, A. T. C, Foster, J. L., and van Katwijk, V. F. (1989) Average areal water equivalent of snow in a mountain basin using microwave and visible satellite data, *IEEE Trans. Geosci. Remote Sens.*, 27, 740-745.

Rango, A., Martinec, J., Foster, J. and Marks, D. (1983) Resolution in operational remote sensing of snow cover. *Hydrological Applications of Remote Sensing and Remote Data Transmission, Proc. Hamburg Symp., August, 1983, IAHS Publ. No.* 145, pp. 371-82.

Rango, A., Salomonson, V. V. and Foster, J. L. (1977) Seasonal streamflow estimation in the Himalayan region employing meteorological satellite snow cover observations. *Water Resour. Res.* 13, 109-12.

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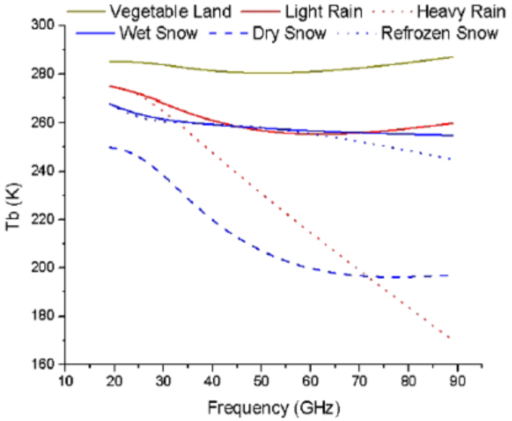

Fig.5. Microwave spectral responses at different frequencies to snow and land parameters

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Synergistic Use of Remote Sensing for Snow Cover and Snow Water Equivalent Estimation

Jonathan Muñoz[1*], Jose Infante[1], Tarendra Lakhankar[1], Reza Khanbilvardi[1], Peter Romanov[1], Nir Krakauer[1] and Al Powell[2]

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Passive microwave sensors detect the weak microwave radiation that is constantly emitted from the surface and atmosphere of the Earth. In the field of microwave radiometry, the microwave radiance is mostly expressed in terms of brightness temperature, Tb at the measured frequency (Fig.5.). In the case of the snow the upwelling microwave radiation is emitted by the sub-snow surface and altered by the snowpack and consequently it carries information on the physical properties of the snowpack. Furthermore, the radiation emitted by the snowpack strongly depends on the physical properties of the snowpack, including liquid water content, snow density, grain size, vertical temperature profile and often, on the state of the ground surface beneath the snowpack [18–20].

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Table 3. Characteristics of commonly used microwave emission models for snowpack property retrieval

Model	Model type	Characteristics	References
Grody	Empirical	Decision tree algorithm for global snow covers mapping from spectral gradients in SSM/I data.	Grody & Basist [4]
HUT	Semi-Empirical	Considers homogeneous snow or multiple layers. Includes the atmosphere, soil and vegetation.	Pulliainen et al.[22]
MEMLS	Semi-Empirical	Considers a layered structure of the snowpack. Classical RT with Empirical scattering and absorption properties.	Wiesmann & Mätzler [23]
DMRT	Theoretical	Based on scattering theory. Considers snowpack as a medium consisting of scattering particles.	Tsang et al.[30] & Tsang & Kong [31]

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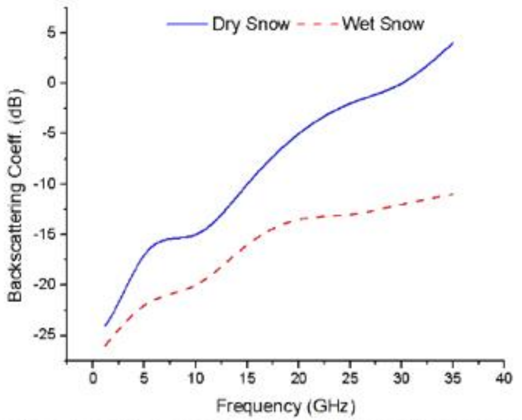

Fig. 7. Response to active microwave sensors by dry and wet snowpack conditions at different frequencies

Instruments such as the QuikSCAT active microwave scatterometer has been used to estimate the timing of snow melt across Greenland [38] and Arctic lands [39] with fairly accurate results. Both studies were based in the backscattering's signature difference (Fig. 7) between the dry snow and wet snow. Furthermore, a product developed by [40] for mapping wet snow in mountainous terrain showed very good correlation with existing snow cover retrievals. This product used comparisons between images from consecutive passes of the Synthetic Aperture Radar (SAR). Then, filtering was performed over the measured backscattering using a high precision Digital Elevation Model (DEM) and a reference image.

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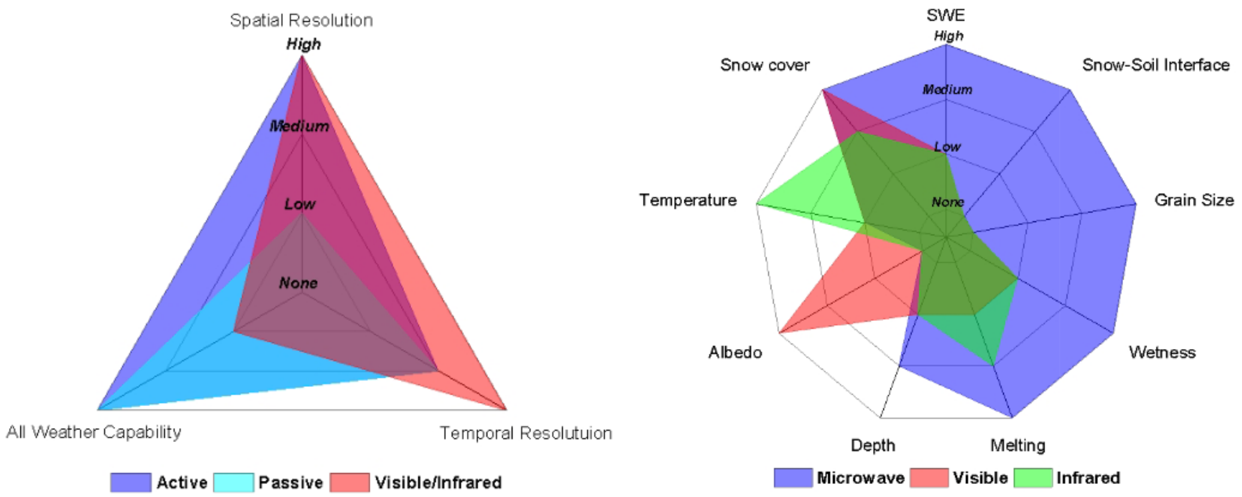

Fig.1. (a) Sensor capabilities in qualitative terms for spatial, temporal resolution and data production and (b) Sensor responses to snowpack properties. Different regions of the electromagnetic spectrum provide useful information about the snow characteristics. Nevertheless, certain regions had better capabilities or responses to measure certain properties. For this reason, the integration of all the available resources could lead to unbiased and better estimations of the snowpack properties

Snow Products

https://globalcryospherewatch.org/reference/snow_inventory.php

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Snow Dataset Inventory

Here is an inventory of satellite-derived, in situ, and analysis/reanalysis snow datasets, compiled by the Snow Watch Team as of 23 February 2015. This inventory of snow cover datasets was compiled following a recommendation of the GCW Snow-Watch meeting in Toronto, January 2013. The workshop highlighted the need for an up-to-date and comprehensive inventory of snow cover datasets in light of the significant increases in sources of snow cover information over the past decade. The inventory is provided in three categories: (1) Satellite-derived snow products and datasets, (2) Analyses, reanalyses and reanalysis-driven snow products and datasets, and (3) In-situ snow products and datasets. A dataset must be freely available online, represent an important source of information, and have supporting English documentation to be included in the inventory. The inventory is meant as a living document with updates and additions incorporated on an ongoing basis. To change, update or add datasets to the inventory please e-mail the required information to Ross Brown (ross.brown at canada.ca).

Type:

- Satellite-derived
- Analysis/Reanalysis
- In situ

You may select more than one dataset type.

Search for keyword(s):

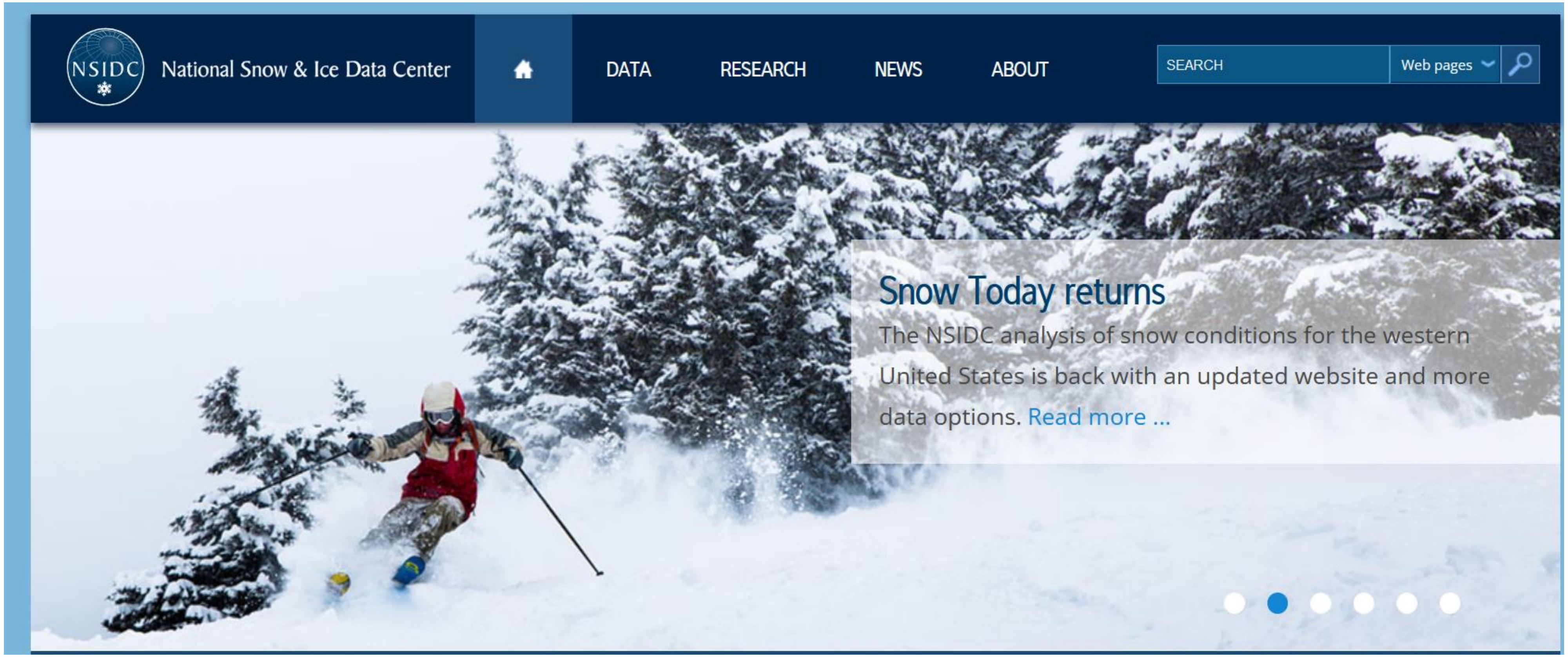
Filter | Reset

Scroll table up-down, left-right (after 1st column)

Product(s)	ency	Data Sources	Comments	References	Dataset Location	Contact

Snow Products

https://nsidc.org/

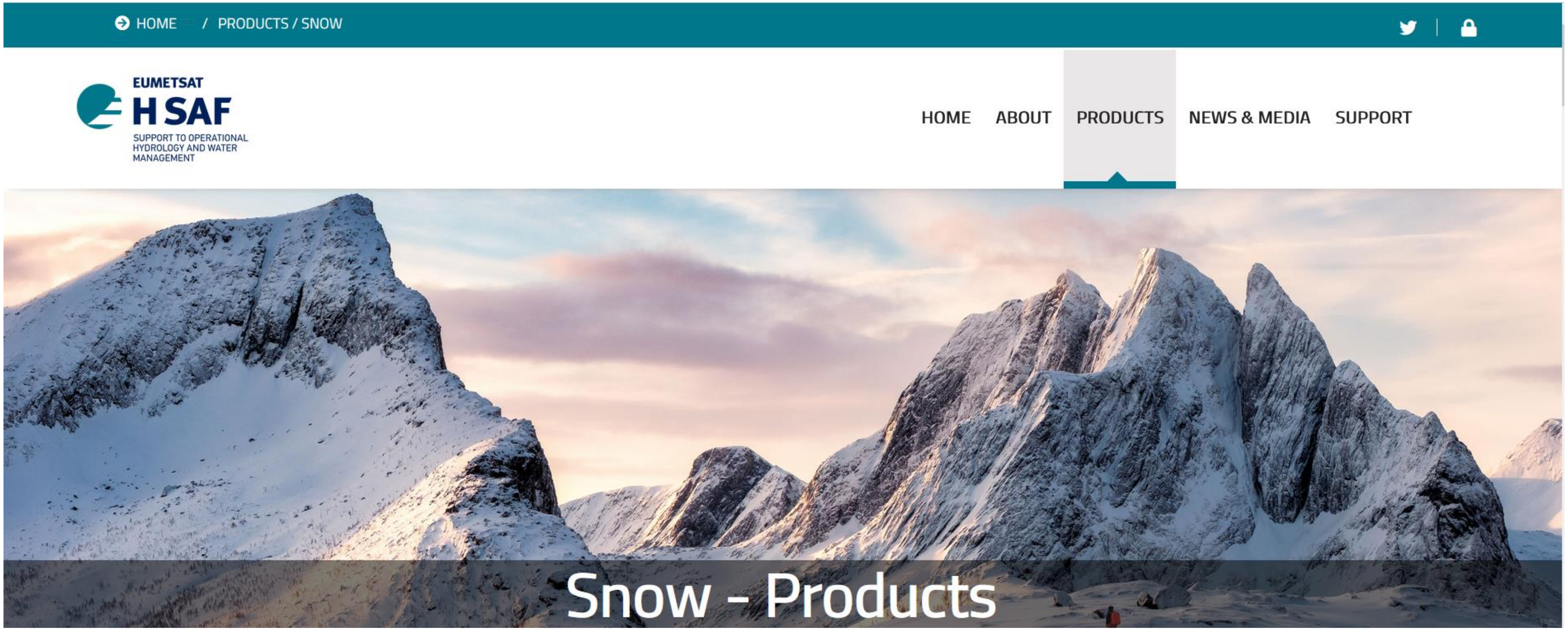


Snow Products

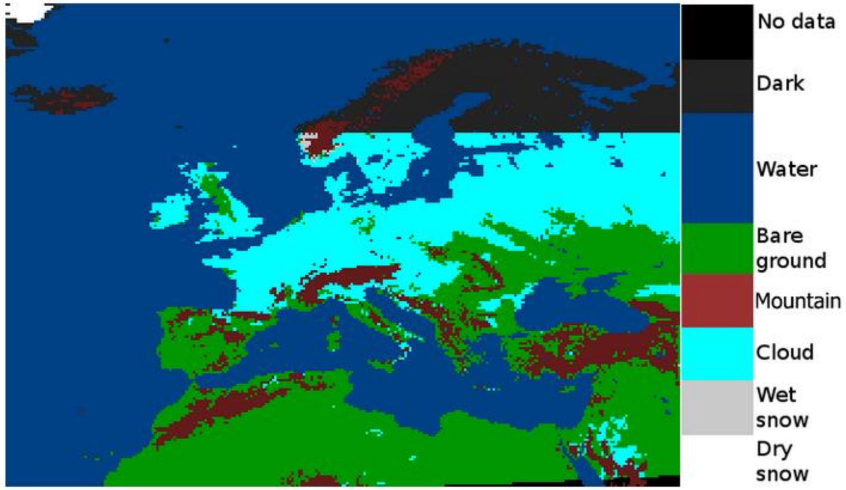
https://land.copernicus.eu/global/themes/cryosphere

Snow Products

https://hsaf.meteoam.it/Products/ProductsList?type=snow



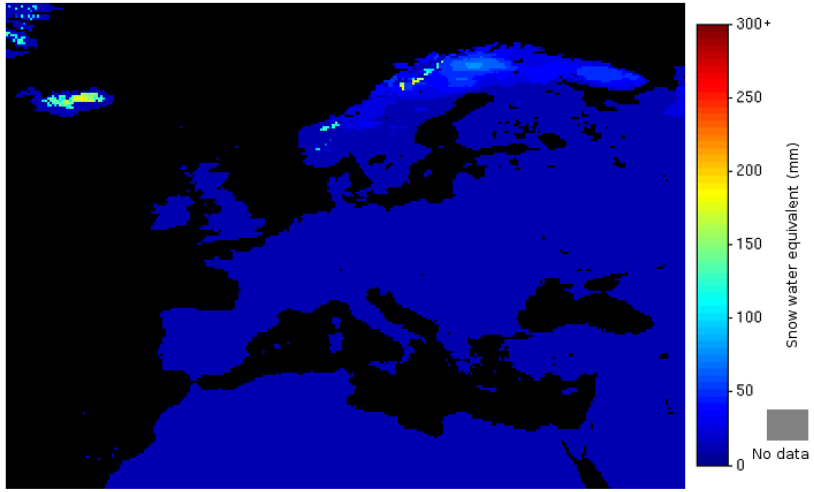
Snow Products-EUMETSAT H SAF



Snow status (dry/wet) by MW radiometry

- **Coverage**: The H-SAF area [25-75°N lat, 25°W-45°E long]
- **Cycle**: Daily
- **Resolution**: 10-30 km (0.25 deg grid), depending on the location (best for northern parts, worst for southern parts of the H-SAF area)
- **Accuracy**: HR 80 %, FAR 10 % - Depending on snow thickness (it must not be too shallow)
- **Timeliness**: Fixed time of the day, product updated to account for data available until 1 h before delivery
- **Dissemination**: By dedicated lines to centres connected by GTS - By EUMETCast to most other users, especially scientific
- **Formats**: Values in fixed grid points in latitude/longitude grid - Also JPEG or similar for quick-look.

Snow Products-EUMETSAT H SAF



Snow water equivalent by MW radiometry

- **Coverage**: The H-SAF area [25-75°N lat, 25°W-45°E long]
- **Cycle**: Daily/weekly
- **Resolution**: 10-30 km (0.25 degrees), depending on the location (best for northern parts, worst for southern parts of the H-SAF area)
- **Accuracy**: To be assessed - Tentative: 20 mm - Depending on geographical situation (flat/forested, mountainous)
- **Timeliness**: Fixed time of the day, product updated to account for data available until 1 h before delivery
- **Dissemination**: By dedicated lines to centres connected by GTS - By EUMETCast to most other users, especially scientific
- **Formats**: Values in fixed latitude/longitude grid, each representing the area covered by the nominal resolution of the used instrument. - Also JPEG or similar for quick-look.