Optical RS Snow Products: Theory - Part I

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Remote Sensing

- Remote sensing uses measurements of the electromagnetic spectrum to characterize the landscape, or infer properties of it, or in some cases, actually measure hydrologic state variables.

- Different sensors can provide unique information about properties of the surface or shallow layers of the Earth.

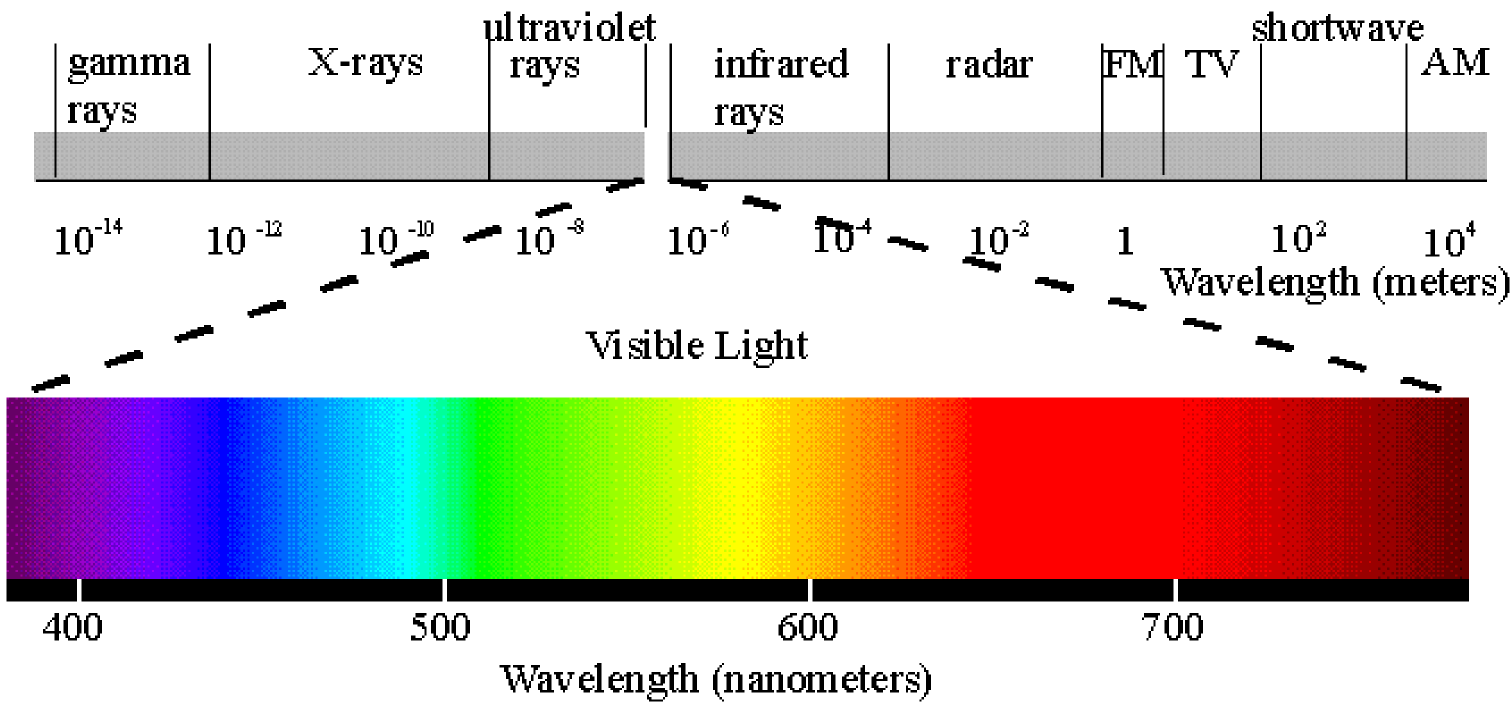
Measurements of the reflected solar radiation give information on **albedo**,

thermal sensors measure surface temperature, and **microwave sensors** measure the dielectric properties and hence, the moisture content, of surface soil or of snow .

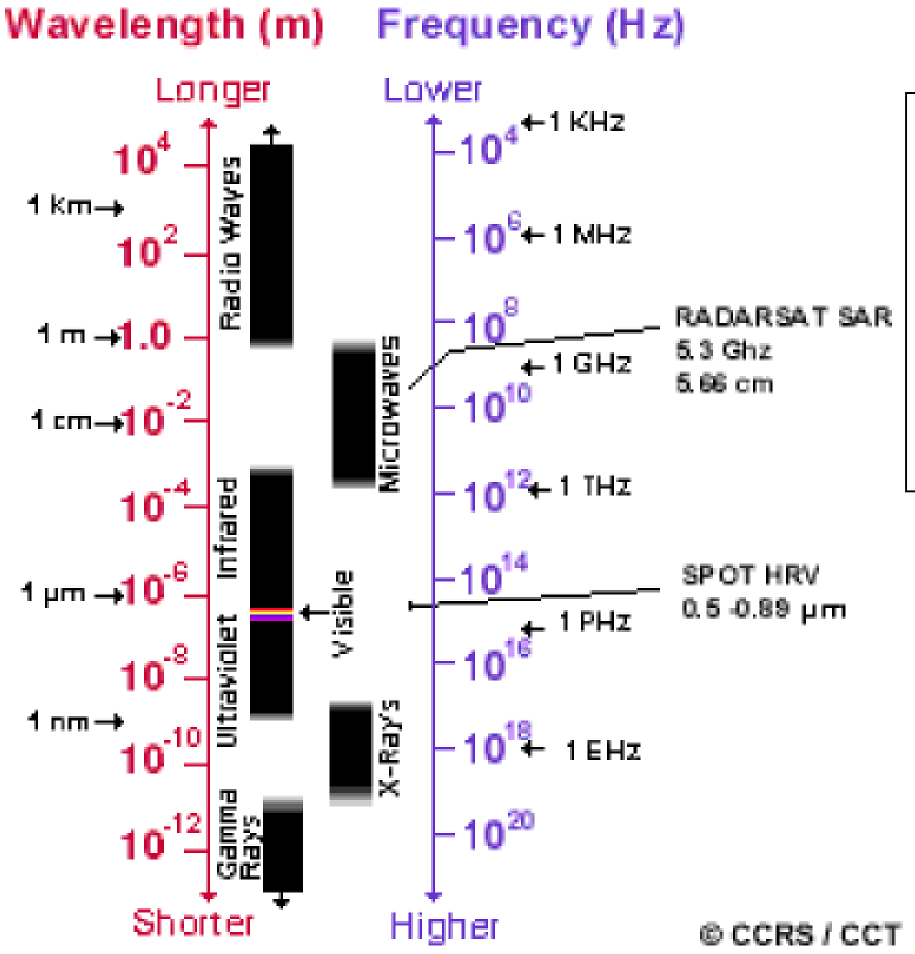
Remote Sensing

- **Optical remote sensing**
  (visible and near-IR)
  – Examine abilities of objects to reflect solar radiation

- **Emissive remote sensing**
  (mid-IR and microwave)
  – Examine abilities of objects to absorb shortwave visible and near-IR radiation and then to emit this energy at longer wavelengths



Electromagnetic Radiation



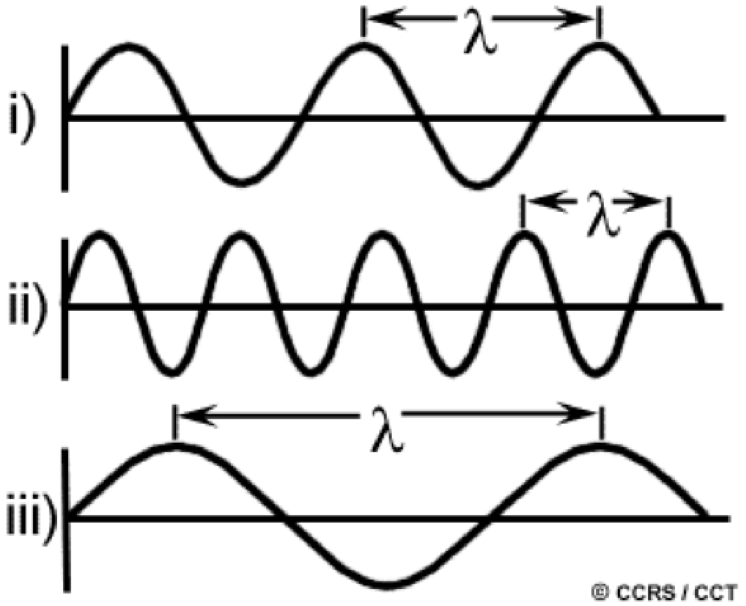
$c = \lambda \nu$

where:

λ = wavelength (m)

ν = frequency (cycles per second, Hz)

c = speed of light (3×10^{8} m/s)



Radiation

- A body radiates energy when electrons in its atoms receive or generate so much energy that they release a small packet of energy (photon)
- If the atoms are receiving or generating a lot of energy (i.e. they are hot) they emit photons in large numbers. Thus, both the intensity (energy per unit time) and the frequency of emission are high.
- Since energy (*E*) travels through a vacuum at a constant speed
- Planck's law: At a given temperature a body emits a spectrum of wavelengths and the intensity of radiation varies with the wavelength

$$\nu = c/\lambda$$

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

E= Energy or total radiant exitance, W m^{-2}

h = Planck's constant (6.63×10^{-34} Js)

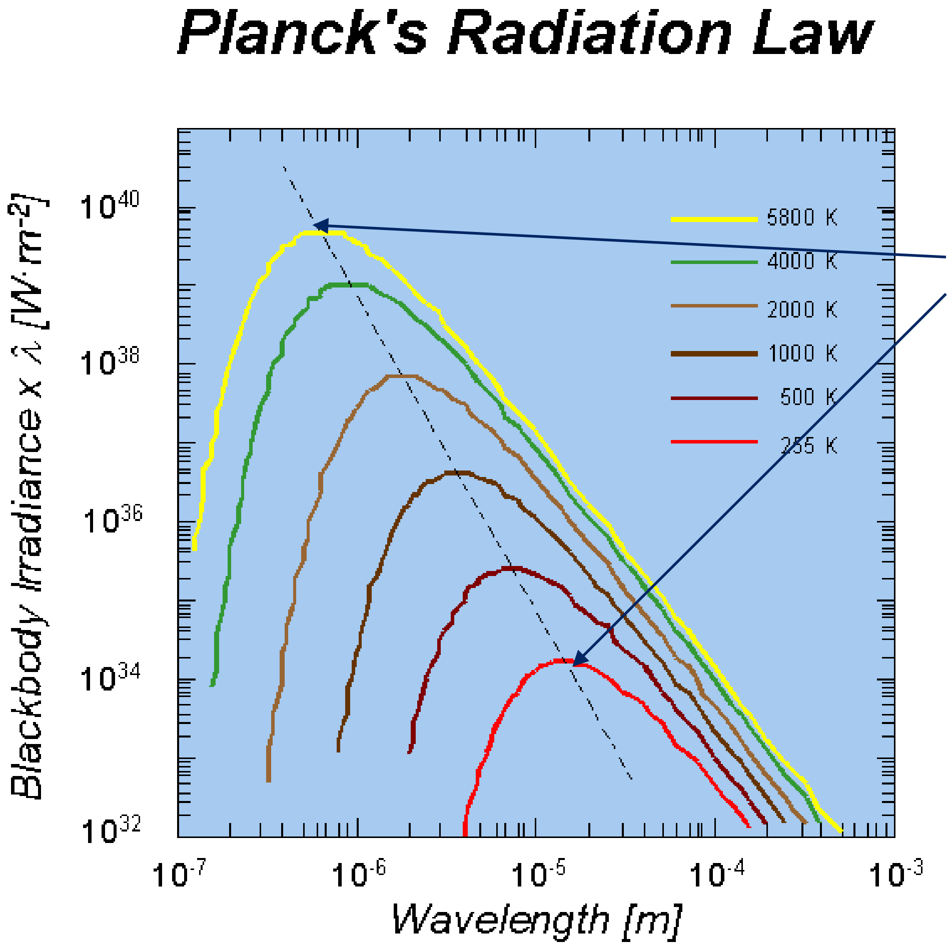
k = Boltzmann constant 1.38×10^{-23} JK^{-1}

c = speed of light (3.0×10^{8} ms^{-1})

T = temperature (in K)

λ = Wavelength

Radiation



Notice that the peak of the Blackbody curve shifts to shorter wavelengths as temperature increases

This peak represents the wavelength of maximum emittance (λ_{max})

Total radiation emitted (W/m^2) = σT^4, where T is in degrees K and σ is the "Stefan-Boltzmann" constant, $5.67\times10^{-8}\ K^{-4}Wm^{-2}$

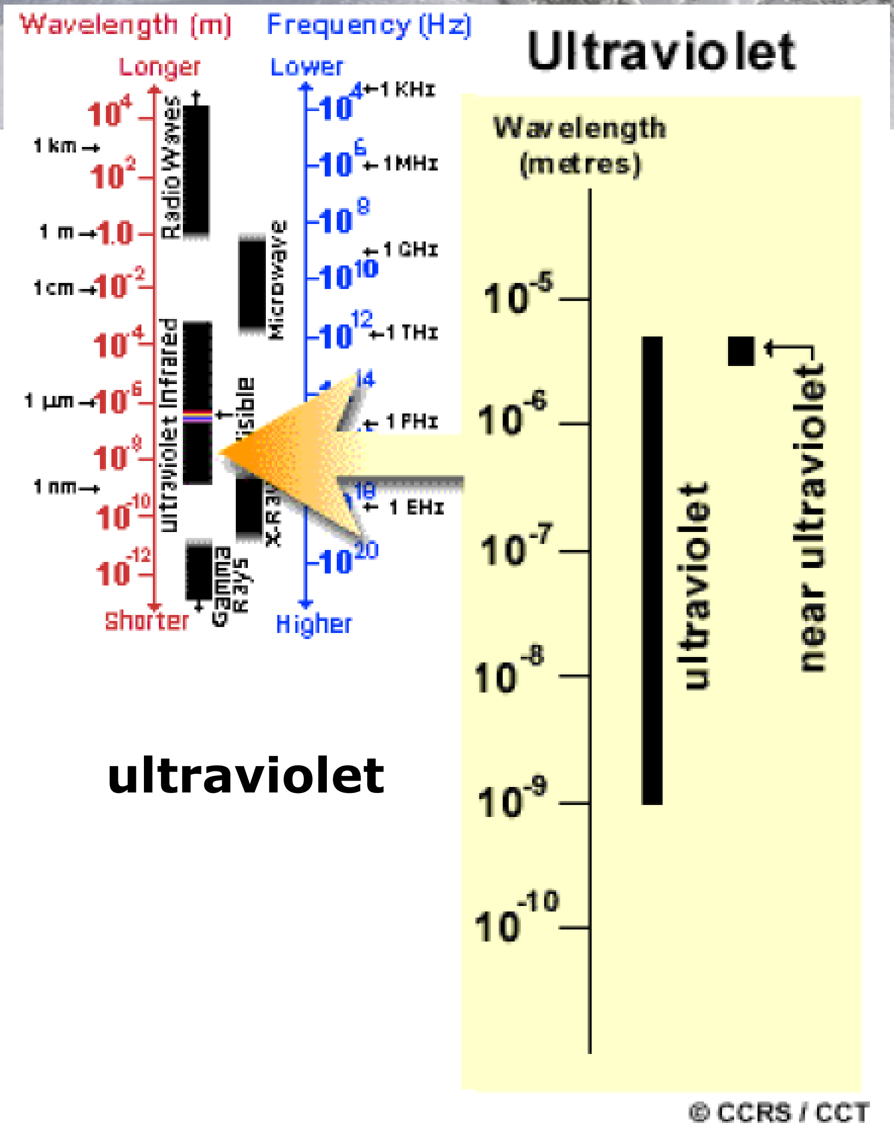
Wavelength λ_{max} of peak radiation, in µm = 2897/T

Peak of Sun's radiation = 2897/5800 = 0.5 µm

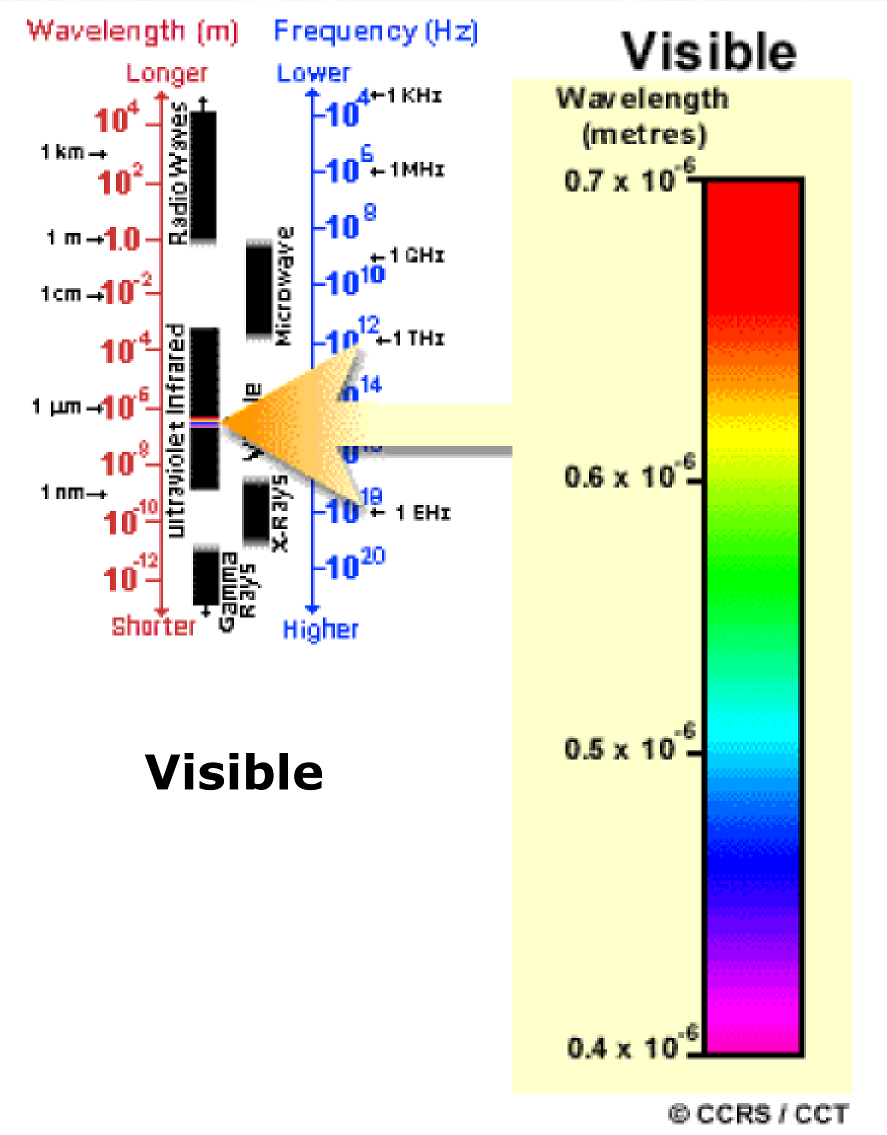
Peak of Earth's radiation = 2897/288 = 10 µm

An object at 288 K emits 390 Wm^{-2}

Radiation

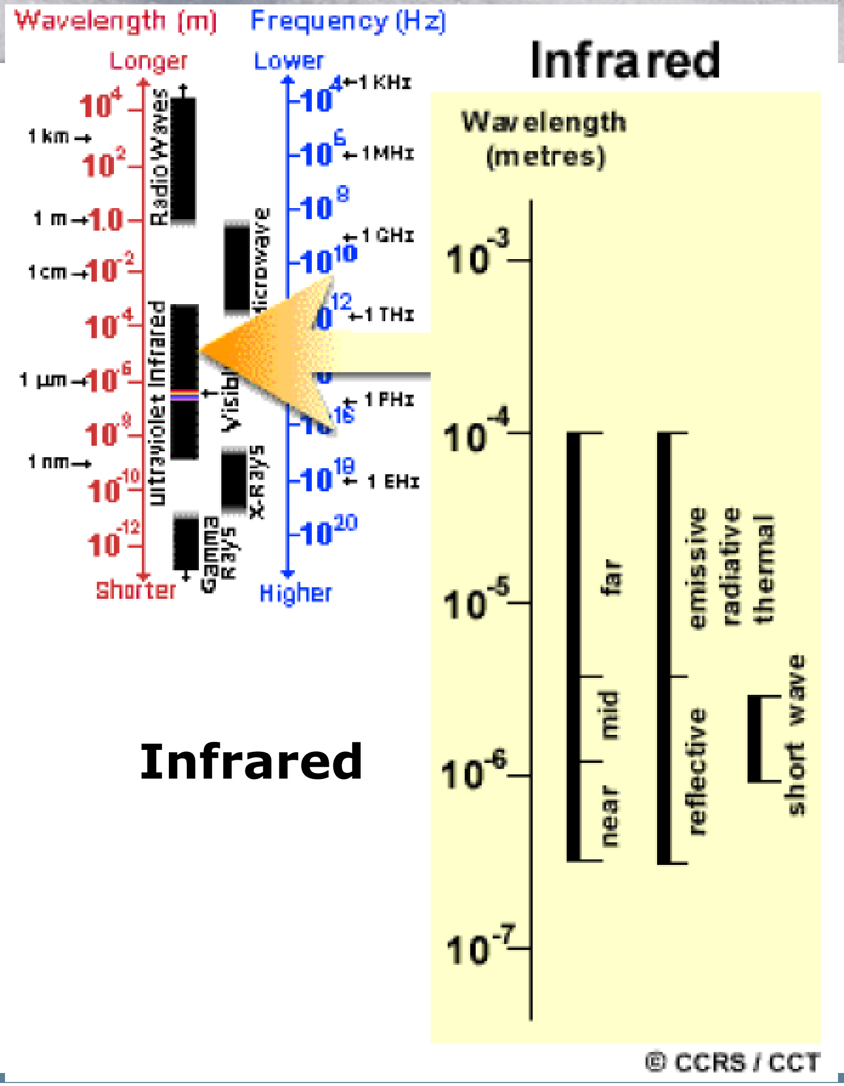


ultraviolet

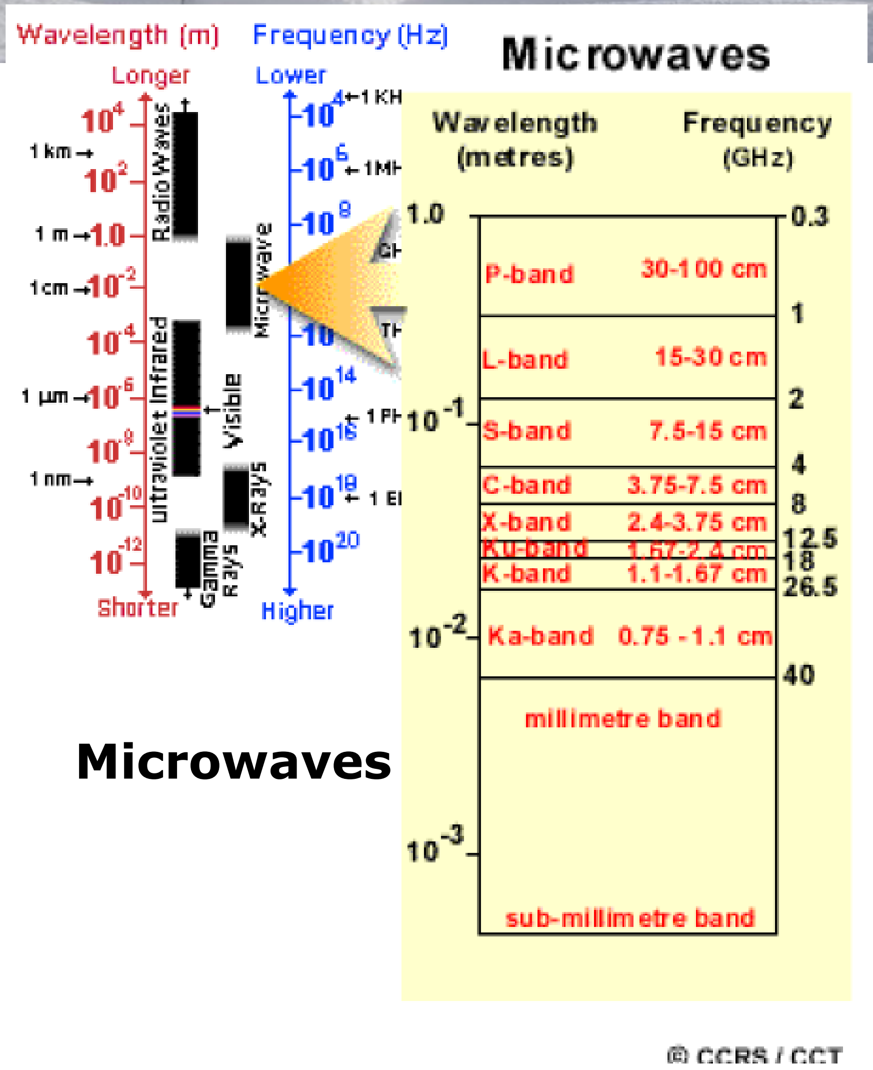


Visible

Radiation



Infrared



Microwaves

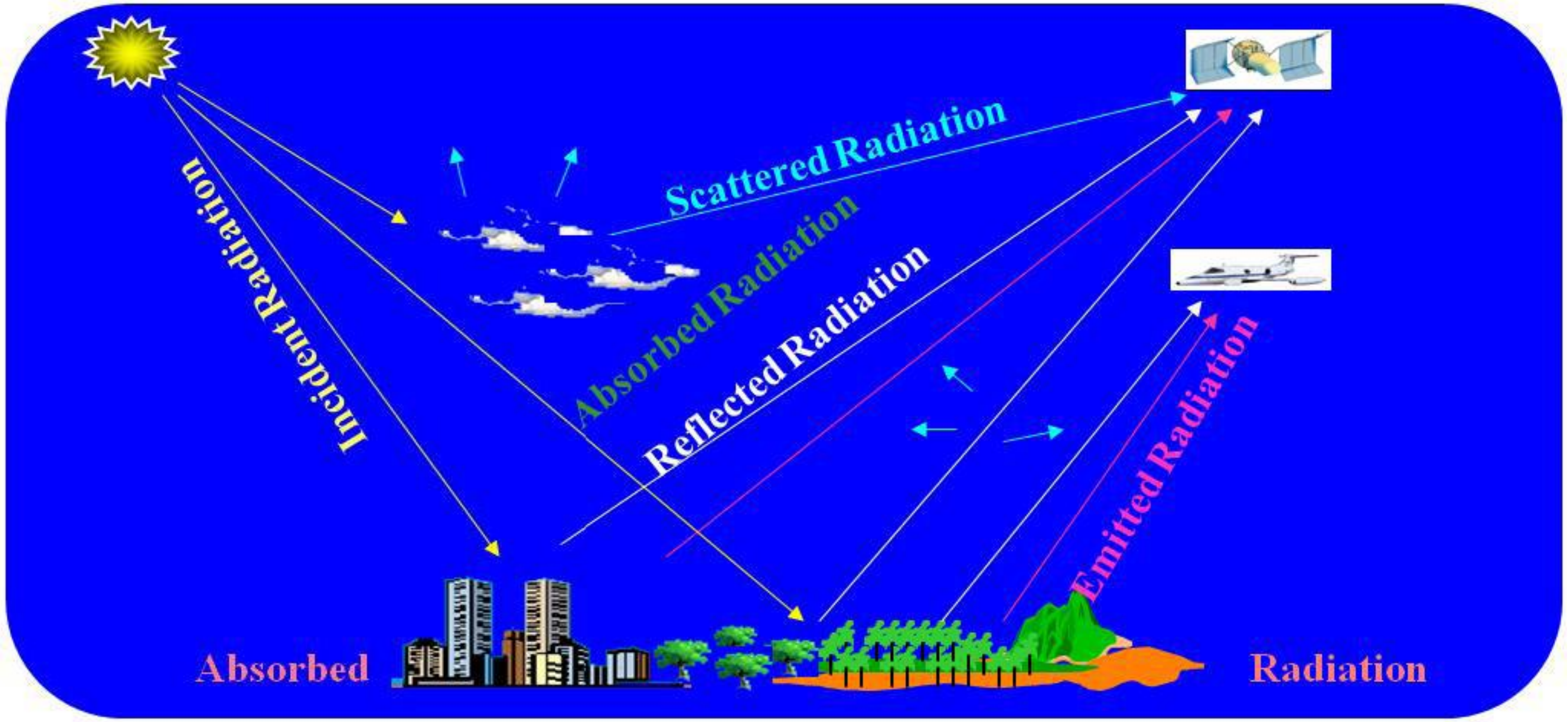
Thermal IR Remote Sensing

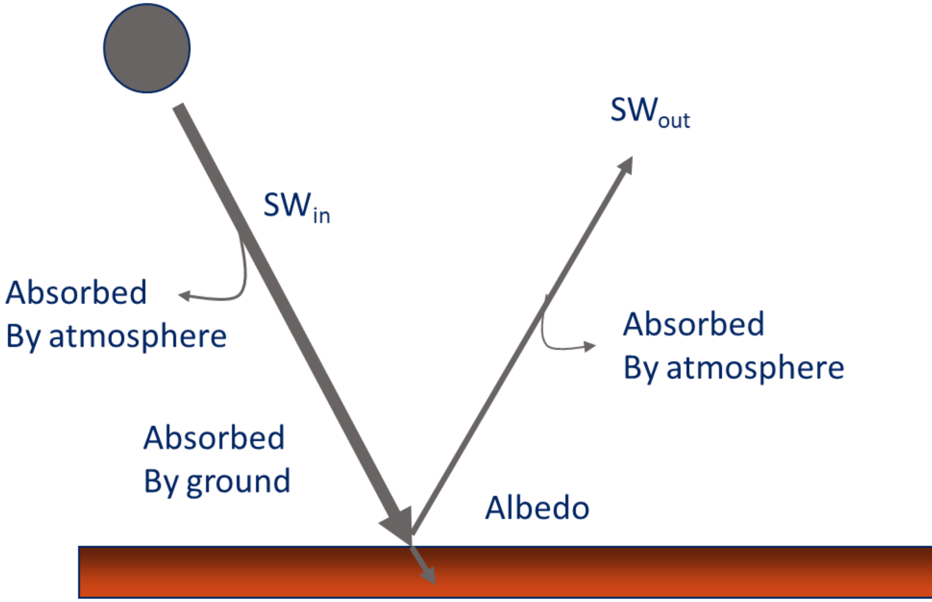
- Thermal infrared radiation refers to electromagnetic waves with a wavelength of between 3 and 20 micrometers.

- Most remote sensing applications make use of the 3 to 5 and 8 to 14 micrometer range (due to absorption bands).

- The main difference between thermal infrared and near infrared is that thermal infrared is emitted energy, whereas the near infrared is reflected energy, similar to visible light.

Atmospheric absorption and scattering

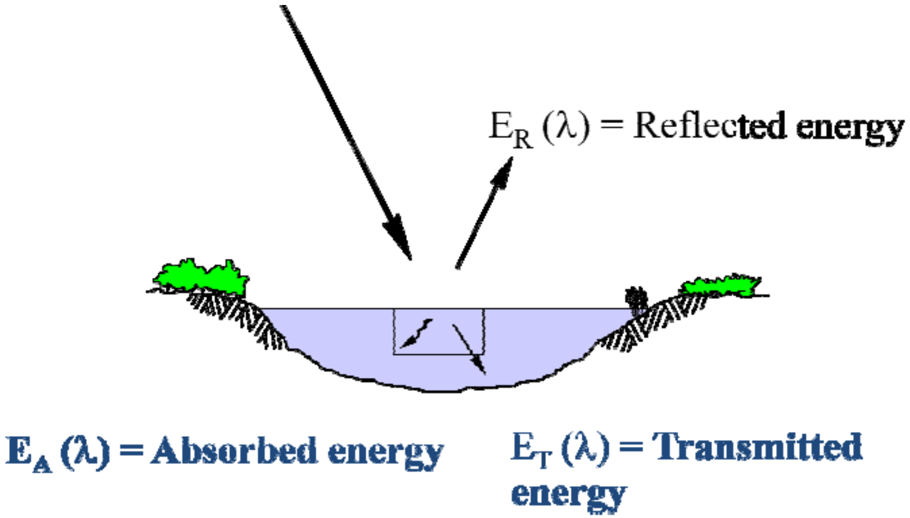


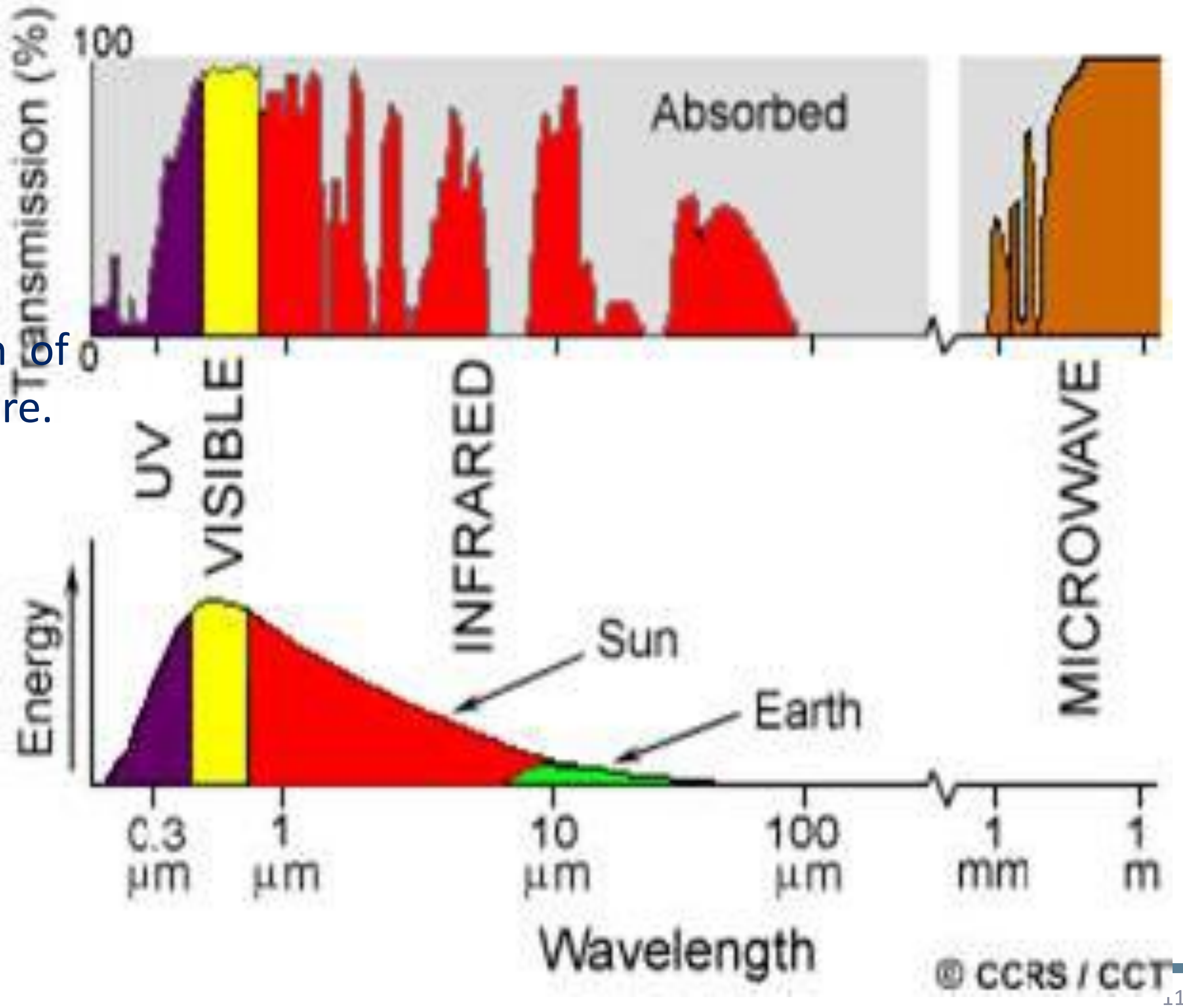


Atmospheric absorption and scattering

Absorbtion causes molecules in the atmosphere to absorb energy at various wavelengths. Ozone, carbon dioxide and water vapor are the three main atmospheric constitutes which absorb radiation.

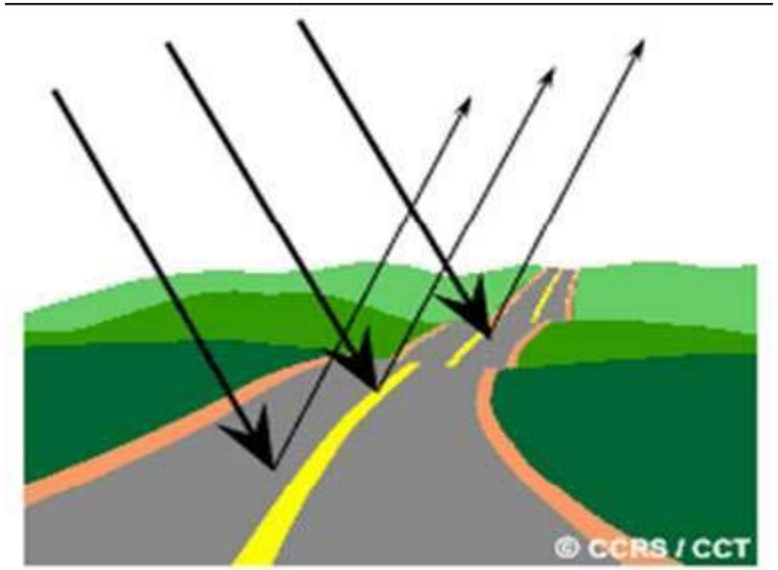
The proportions of each will depend on the wavelength of the energy and the material and condition of the feature.

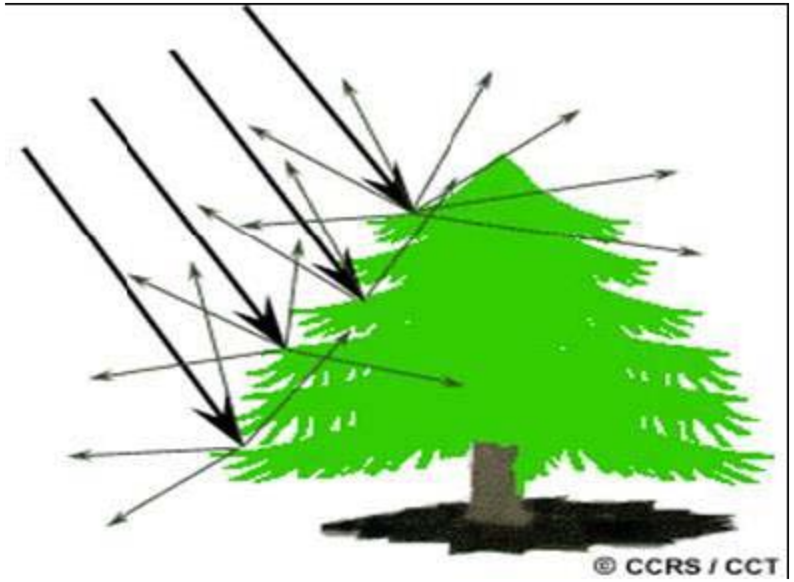




Reflectance

depends on the surface roughness of the feature in comparison of the wavelength of the incoming radiation.





A *Lambertian* surface is one where the *BRDF* does not vary with angle (i.e. the bidirectional reflectance is the same in all directions)
A *specular* surface is one where the *BRDF* is entirely concentrated in the forward direction at the same angle as the incident irradiance

Resolutions:

79m

79m

Spatial Resolution:
1pixel = 79x79 m

Radiometric Resolution:
8-bit (0-255)

Spectral Resolution:
0.52-0.60 mm

Day 1

Day 17

Day 31

Temporal Resolution:
Same area viewed
every 16 days

Landsat TM –Band 2 (Four Types of Resolution)

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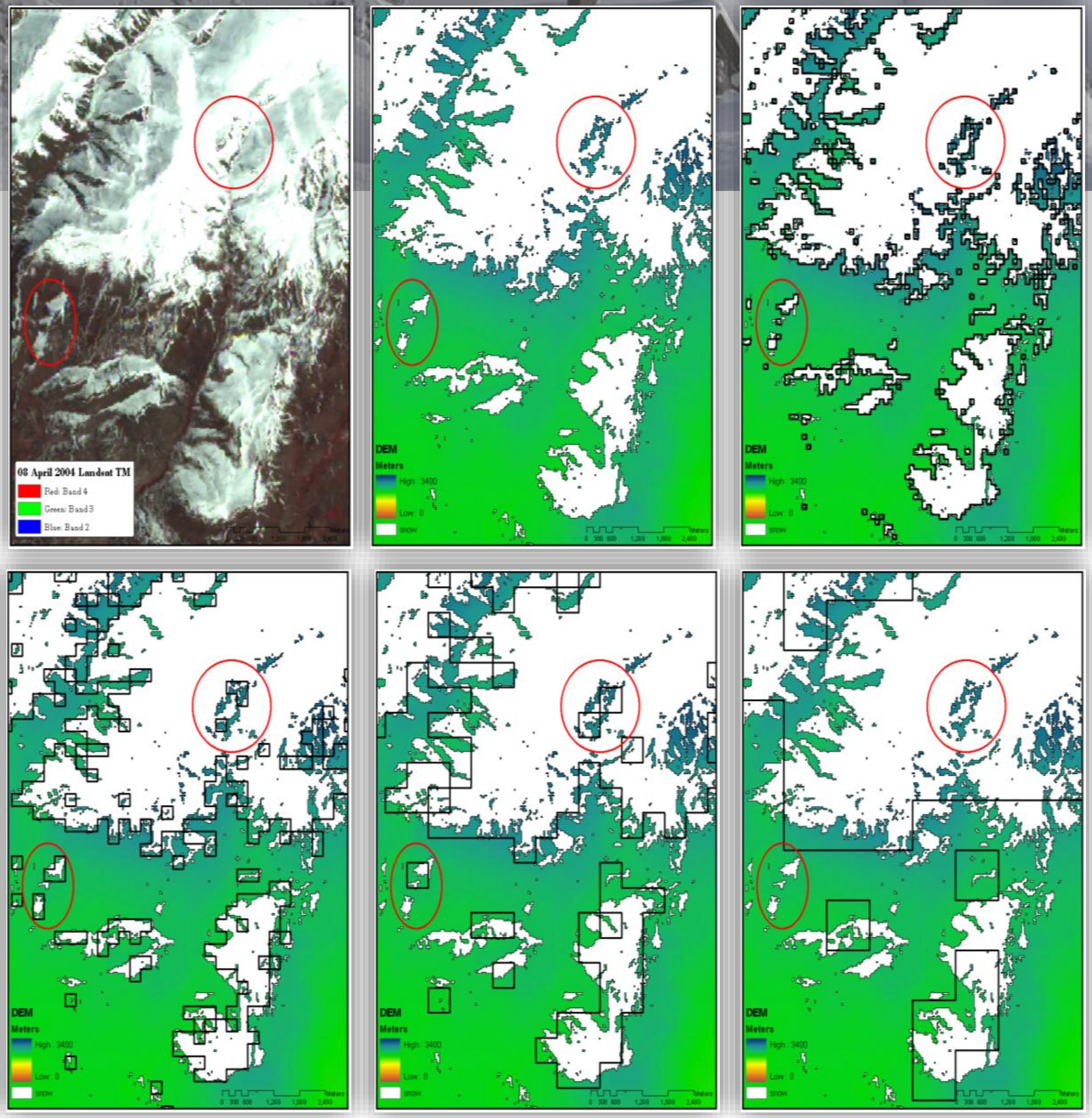
University

Resolutions

Spatial Resolution

Seasonal snowlines extracted from a Landsat TM image at different spatial resolutions. (a) Area of interest shown with blue rectangle on Figure 5. (b) 30m resolution snowline used as reference extracted from the binary snow classification of Landsat TM image (ground truth); (c), (d), (e), (f) show the snowlines extracted after aggregation of the Landsat TM binary snow map at 100m, 250m, 500m, 1km spatial resolution, respectively.



Resolutions

Spectral Resolution

Rdiometric Resolution

8 bit (0~255)

11 bit (0~2047)

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Optical Remote Sensing

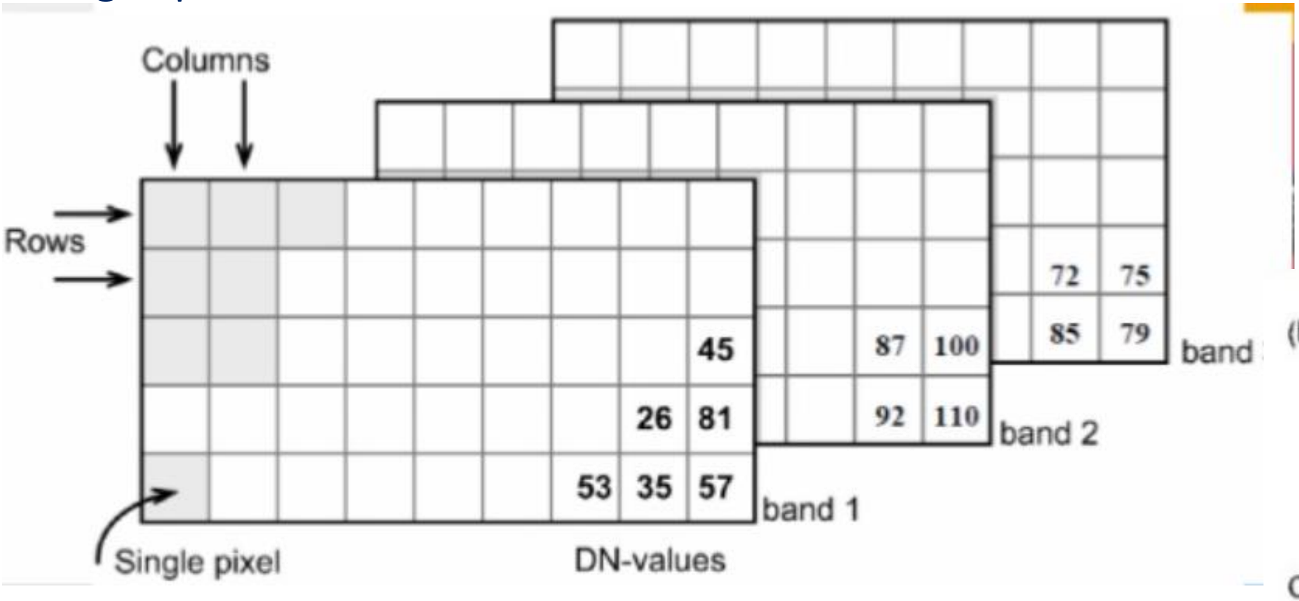
Table 1. Specifications of the Landsat TM, SPOT VGT, MODIS and AVHRR/3 sensors.

Spectral range	TM	VGT	MODIS	AVHRR/3 (NOAA-15,16, M)
Blue	0.45–0.52 μm (b1)	0.43–0.47 μm (b0)	0.46–0.48 μm (b3)	
Green	0.52–0.60 μm (b2)		0.55–0.57 μm (b4)	
Red	0.63–0.69 μm (b3)	0.61–0.68 μm (b2)	0.62–0.67 μm (b1)	0.58–0.68 μm (ch1)
Near-infrared	0.76–0.90 μm (b4)	0.78–0.89 μm (b3)	0.84–0.88 μm (b2)	0.73–1.00 μm (ch2)
Mid-infrared	1.55–1.90 μm (b5)	1.58–1.75 μm (SWIR)	1.63–1.65 μm (b6)	1.58–1.64 μm (ch3A)
Spatial resolution	30 m	1 km	250 m (b1–2) 500 m (b3–6)	1.1 km
Revisit time	16 days	daily*	daily	twice each day

*At latitudes higher than 35° N and S.

Image Processing

Image Space



Spectral scatter plot

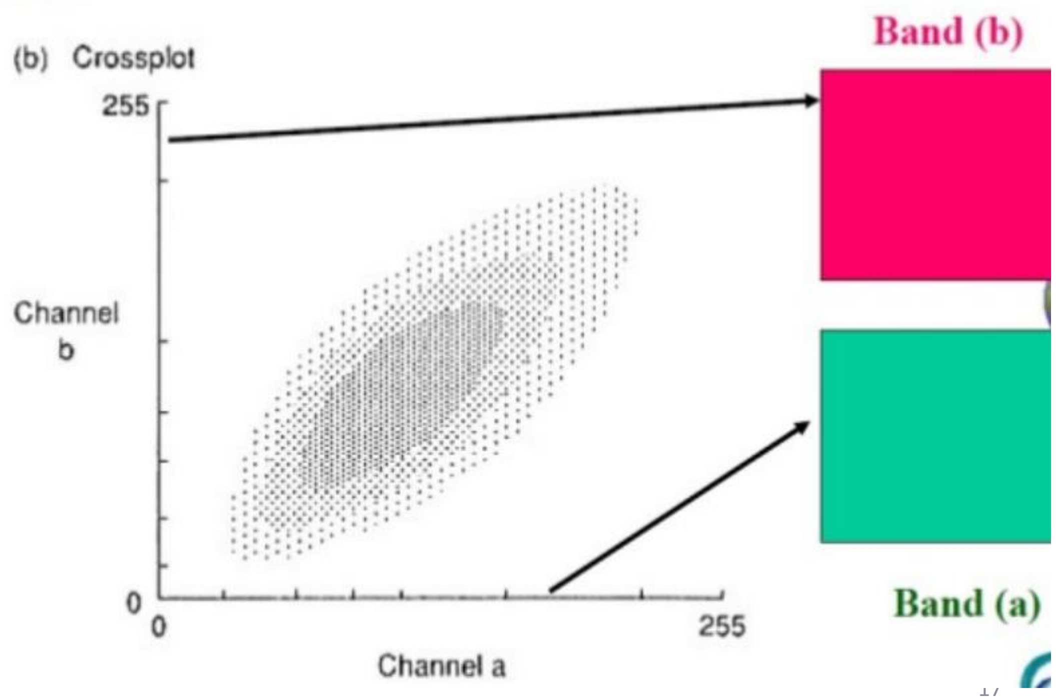
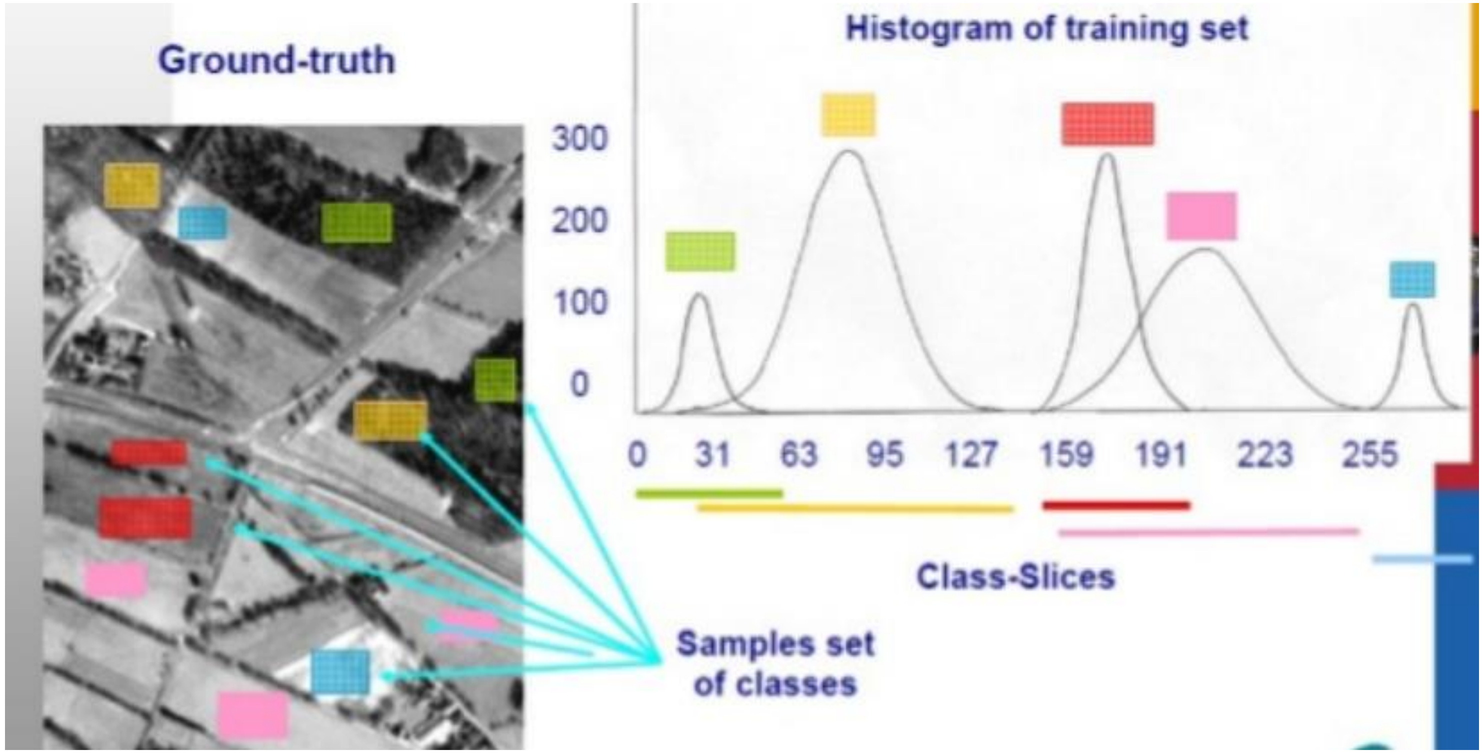
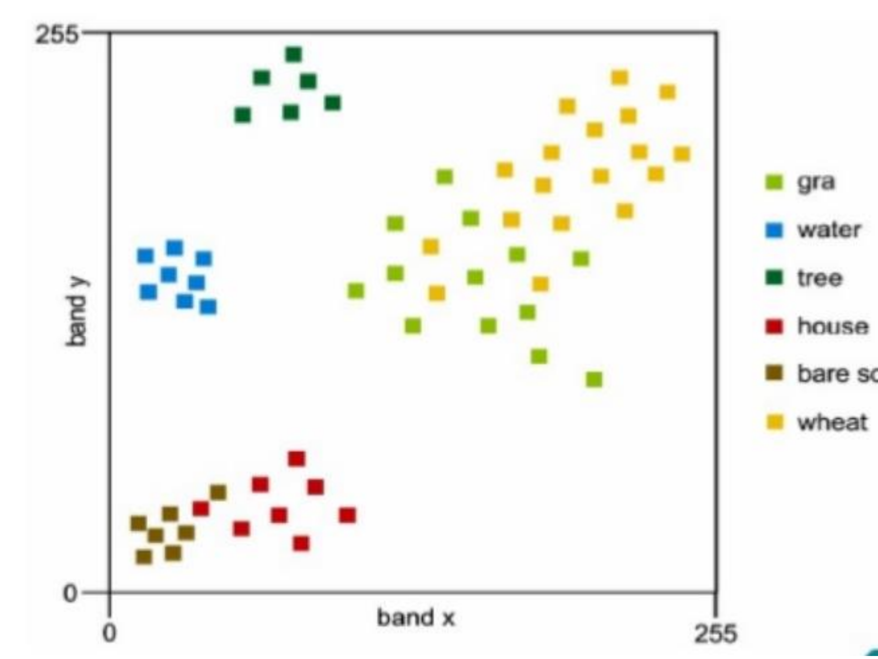
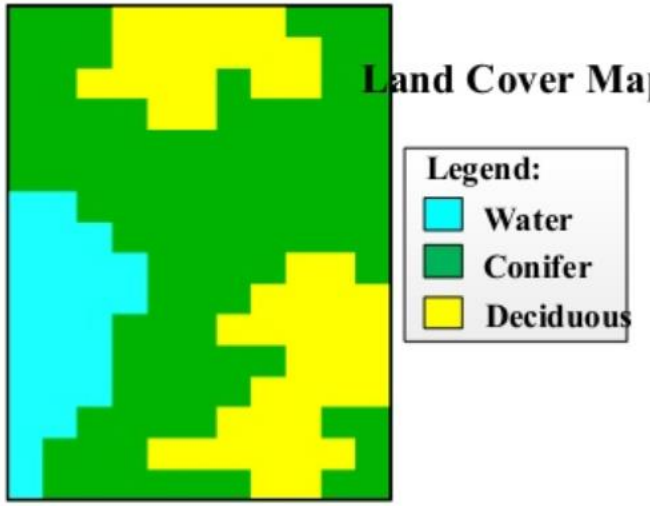


Image Processing







-Supervised Classification
-Unsupervised Classification

Optical RS Snow Products: Theory - Part II

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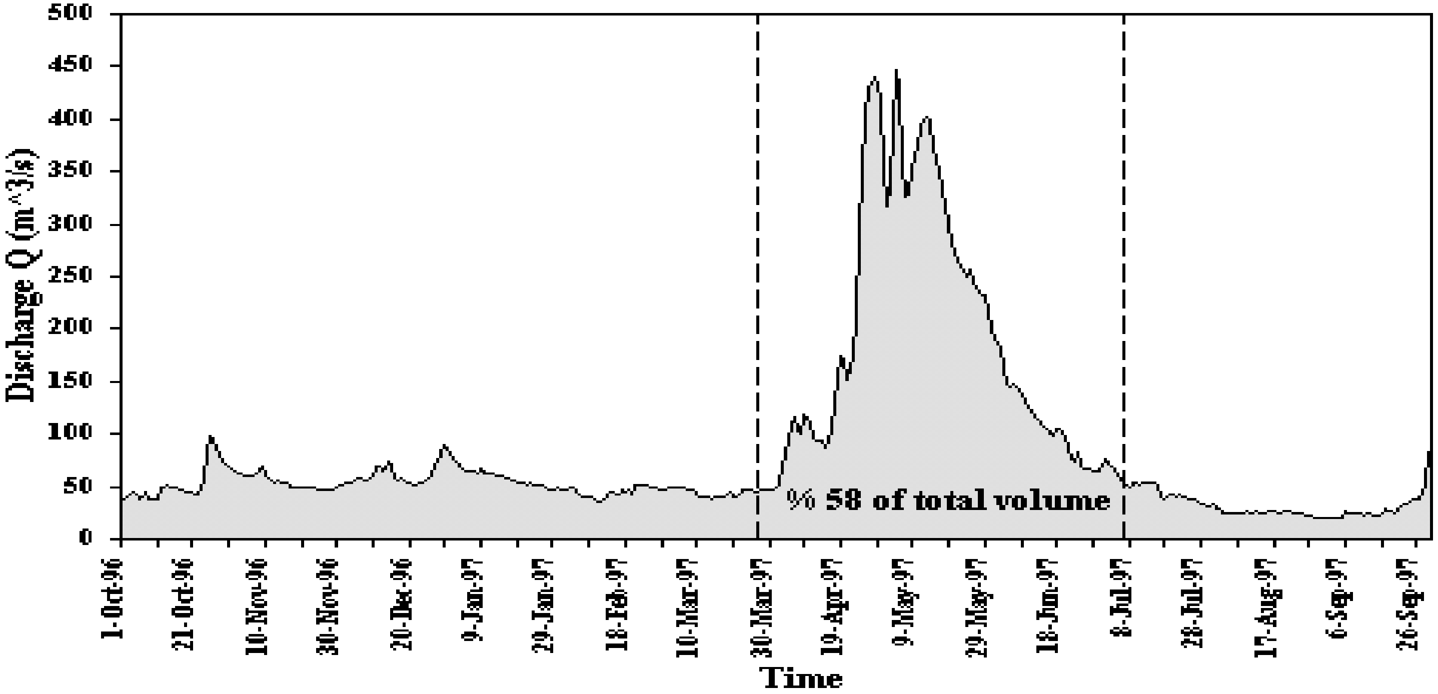
Snow Hydrology

- Snow is a form of precipitation,
- Important for water resources,
- Temporal storage, highly variable: daily to seasonal
- Spatially variable
- Nearly all regions of the electromagnetic spectrum provide useful information about the snow pack.



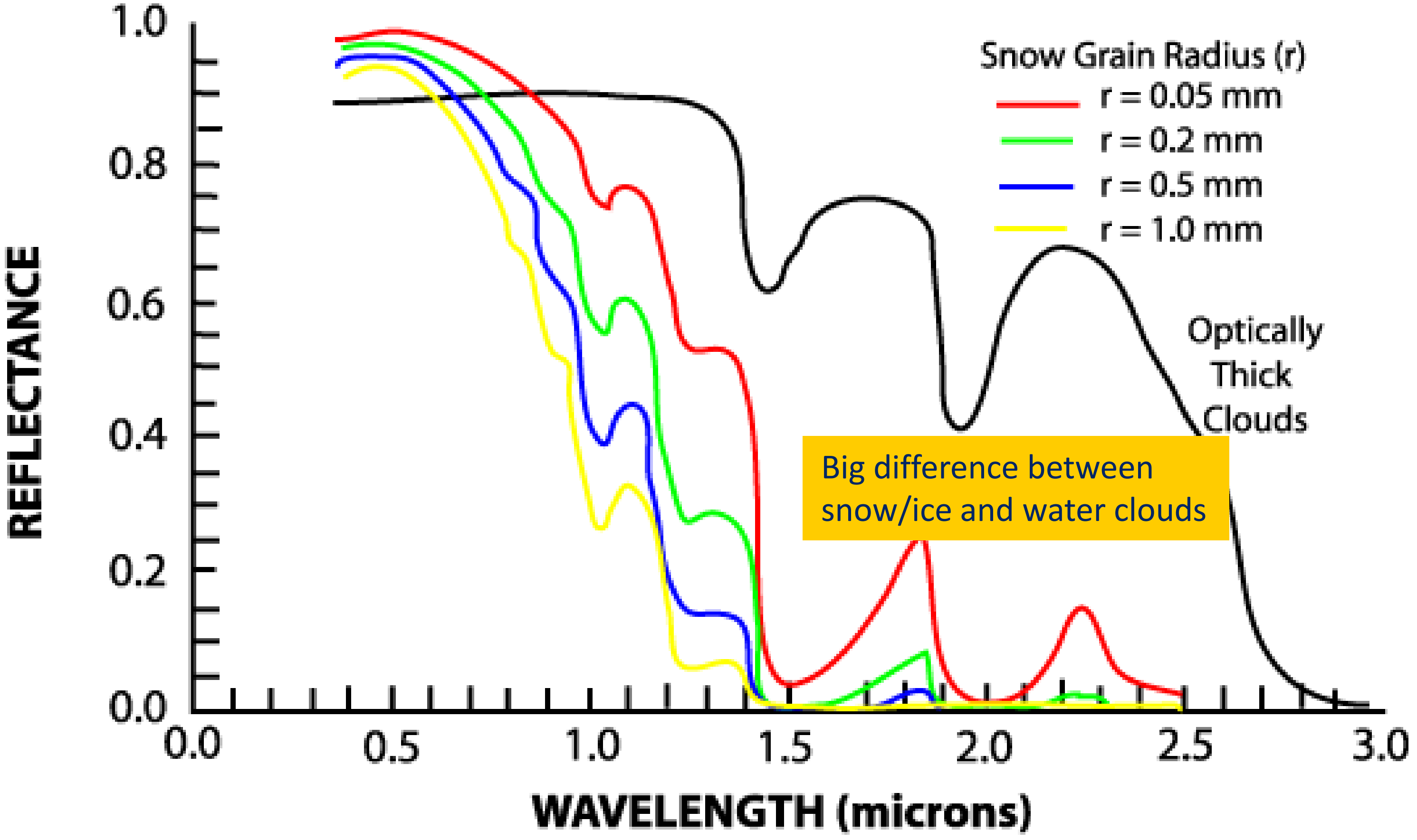
Optical Remote Sensing of snow

- High albedo in visible and near-infrared wavelengths easily recognisable
- Discrimination between snow and clouds (mi infrared around 1.6mm)

$$NSDI = \frac{(Visible-SWIR)}{(Visible+SWIR)}$$

SI = NIR1.6/VIS0.6

No difference between snow/ice and water clouds



Big difference between snow/ice and water clouds

Remote Sensing of Snow

- Optical sensors:snow extent
  - Snow can readily be identified and mapped with the visible bands of satellite imagery because of its high reflectance in comparison to non-snow areas.

- Microwave sensors: snow depth and snow water equivalance
  - Active microwave remote sensing also has the potential to provide important information about the snow pack and at very high resolution with Synthetic Aperture Radar (SAR), [*Stiles et al,* 1981, and *Rott,* 1986].

- Other techniques: Gama Radiation, Cosmic Ray, lidar
  - The water equivalent of snow can be measured from low elevation aircraft carrying sensitive gamma radiation detectors *[Carroll and Vadnais, 1980]*

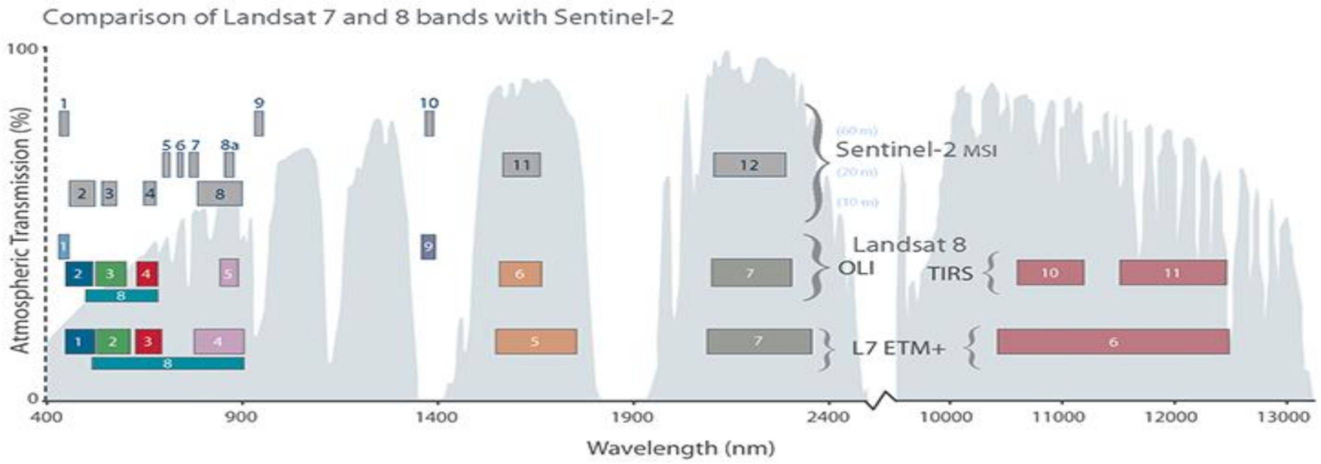
Snow cover mapping

- Snow is determined if: NDSI ≥ 0.4, and the reflectance in Band 2 (near-IR) ≥ 0.11, and Band 4 (green) ≥ 0.10, to eliminate water and other dark surfaces from being classified as snow. A Normalized Difference Vegetation Index (NDVI) is computed from MODIS Band 1 (Red) and Band 2, and the NDSI and NDVI are used together to map snow in dense forests. (*Hall et al., 2006; Hall and Riggs, 2007*)

- Snow cover maps using MSG-SEVIRI data have been produced for each 15 minutes cycle between 8:00-15:45 GMT that makes 32 individual images in a day. Snow index (SI= NIR1.6 / VIS0.6) values lower than a fixed threshold value 0.6 can be used to map snow (*Dozier, 1989; Surer and Akyurek, 2012*).

- NDSI > n1;red band > r1;SWIR band < s1.
  Senticor snow mapping (*Richiardi et al., 2021*).

- Nonparametric regression and classification techniques have gained popularity in snow mapping (*Dobreva and Klein, 2011); Moosavi et al. ,2014; Czyzowska-Wisniewski et al., 2015; Kuter and Akyurek, 2018, Kuter S., 2020*)



https://landsat.gsfc.nasa.gov/wp-content/uploads/2015/06/Landsat.v.Sentinel-2.png

Snow cover mapping

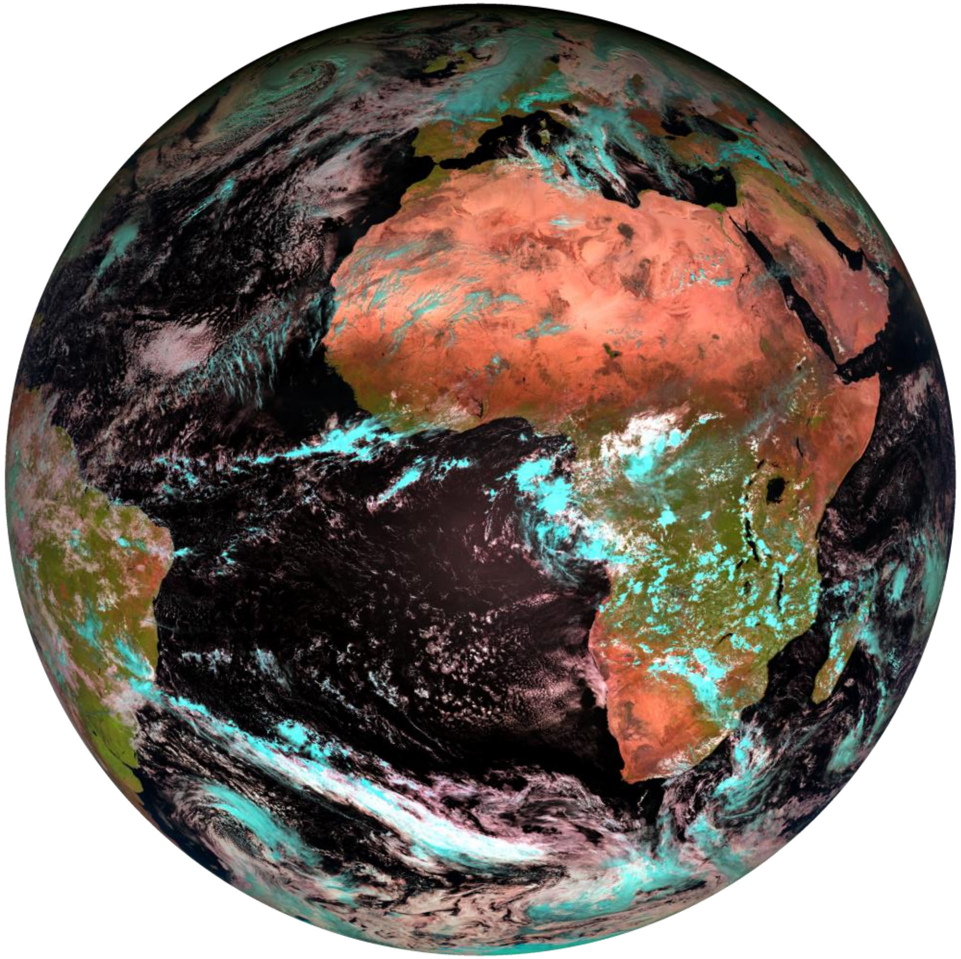
Some operational snow products that are available currently, with published accuracy estimates (disk 5 Geostationary satellite detection disk, NH 5 Northern Hemisphere).

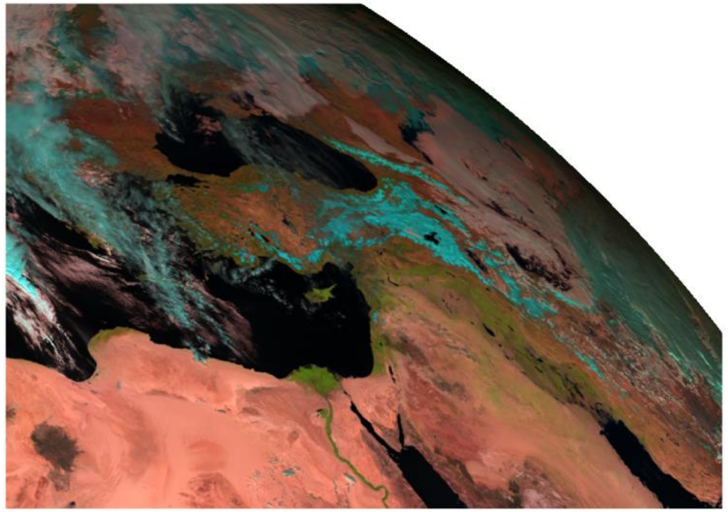
Challenges and limitations:
- -Operational products
- -Spatial Resolution
- -Temporal resolution
- -Cloud/snow discrimination
- -Wet snow mapping

Product	Data source	Start year	Resolution	Time res.	Coverage	Reference/accuracy
VIIRS snow products	*Suomi NPP*; *NOAA-20*	2012	375 m/0.05°	Daily	Global	Comparable to MODIS, but VIIRS has the potential to map snow-cover area more accurately (Riggs et al. 2017; Thapa et al. 2019)
MODIS snow products	*Terra* (MODIS); *Aqua* (MODIS)	2000	500 m/0.05°	Daily; 8-day; monthly	Global	The PC against in situ snow observations in Collection 5 is about ~93%, but lower accuracy is found in forested areas and complex terrain and when snow is thin and ephemeral; very high PC, up to 99%, may be found in croplands and agricultural areas (Hall and Riggs 2007); note that Collection 6 has been published (Riggs et al. 2017)
NOAA/NESDIS IMS	Multisource	1998	4 km	Daily; 8-day	NH	Described in Helfrich et al. (2007) and Ramsay (1998); the PC against in situ snow observations is 80%–90%, *H* ≈ 95%, and *F* 0%–20% during the NH winter, but values vary with season (Brubaker et al. 2005; Chen et al. 2012)

H SAF optical snow products H31, H32, H34,H35 since 2008

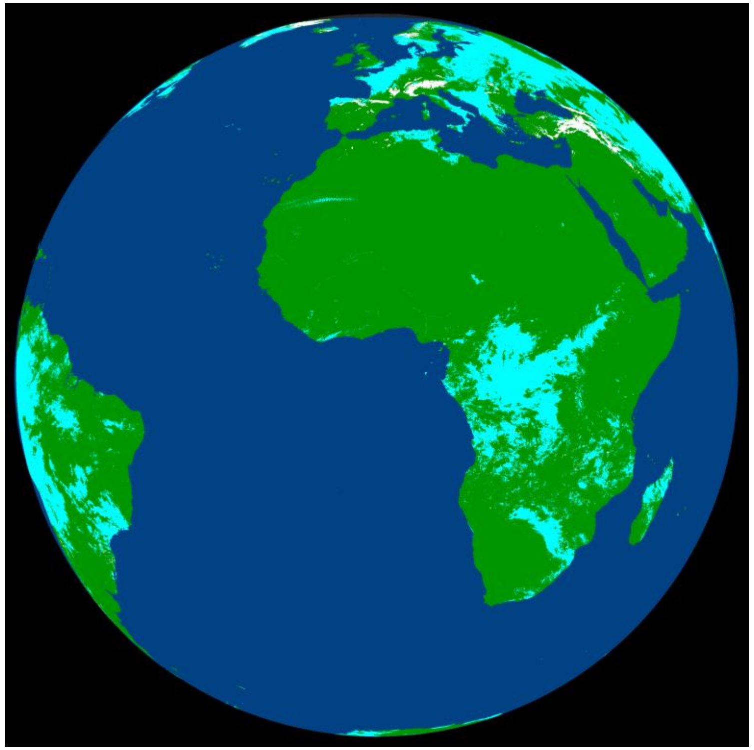
Snow cover mapping



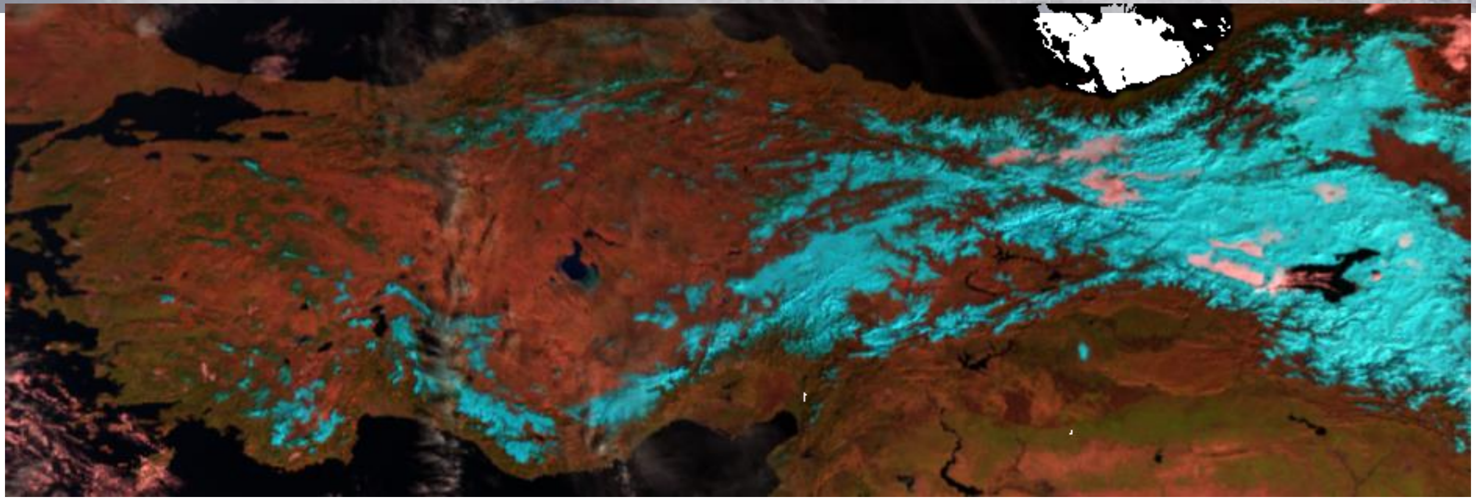


MSG SEVIRI
RGB 321
4 Feb 2019

H34 4 Feb 2019

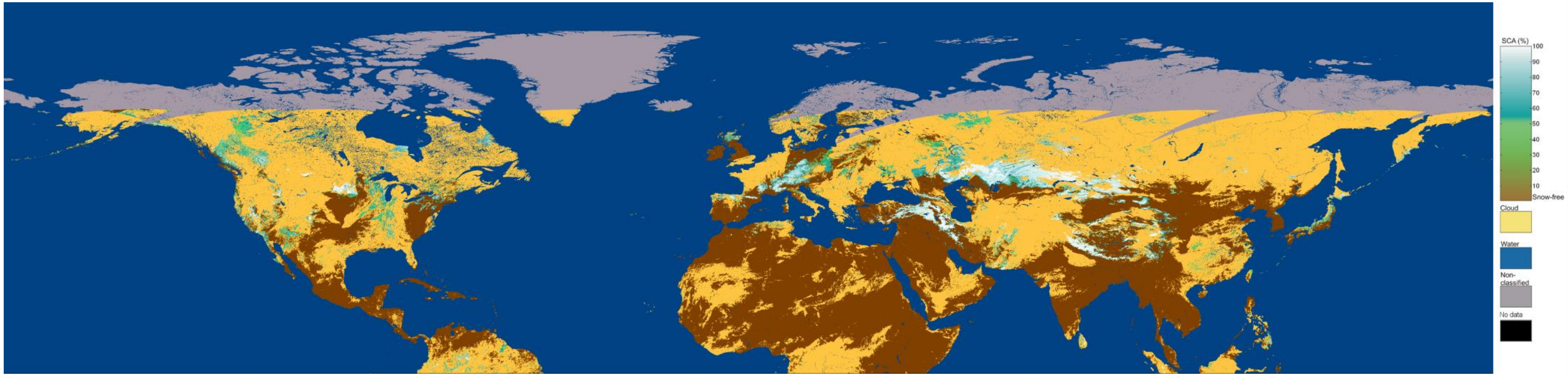


Snow cover mapping

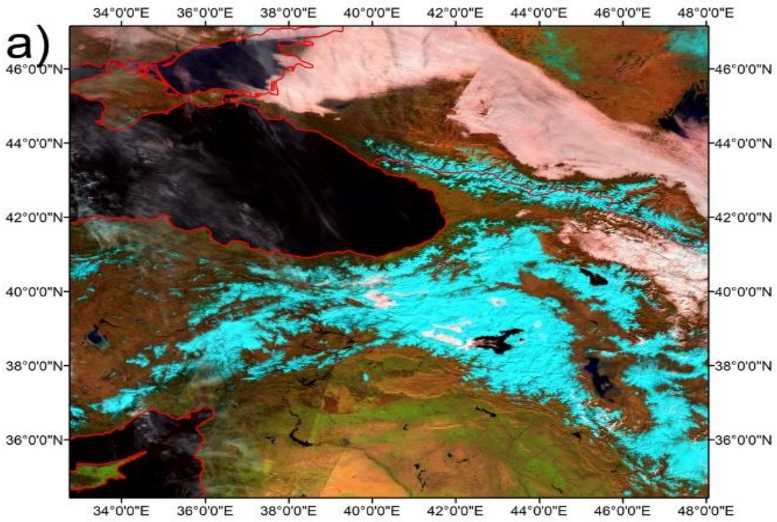


METOP AVHRR
RGB 3A21
4 Feb 2019

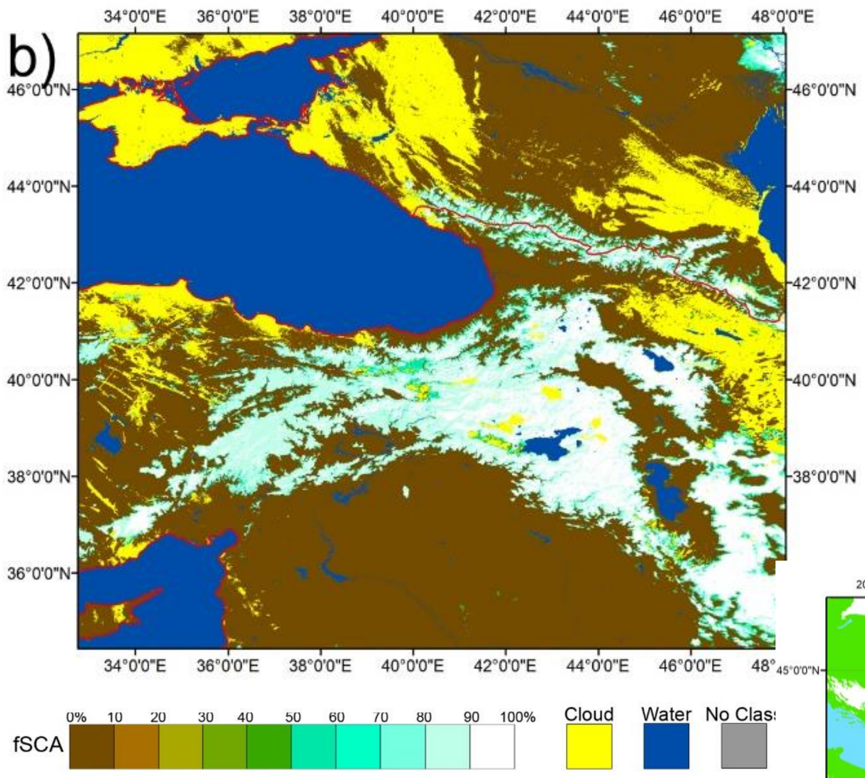
H35 snow product
4 Feb 2019



Snow cover mapping

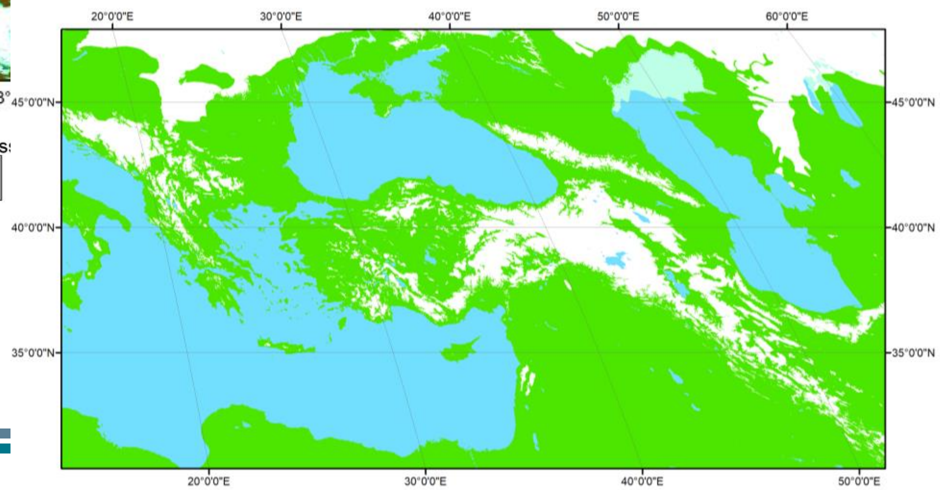


MODIS RGB 653
4 Feb 2019



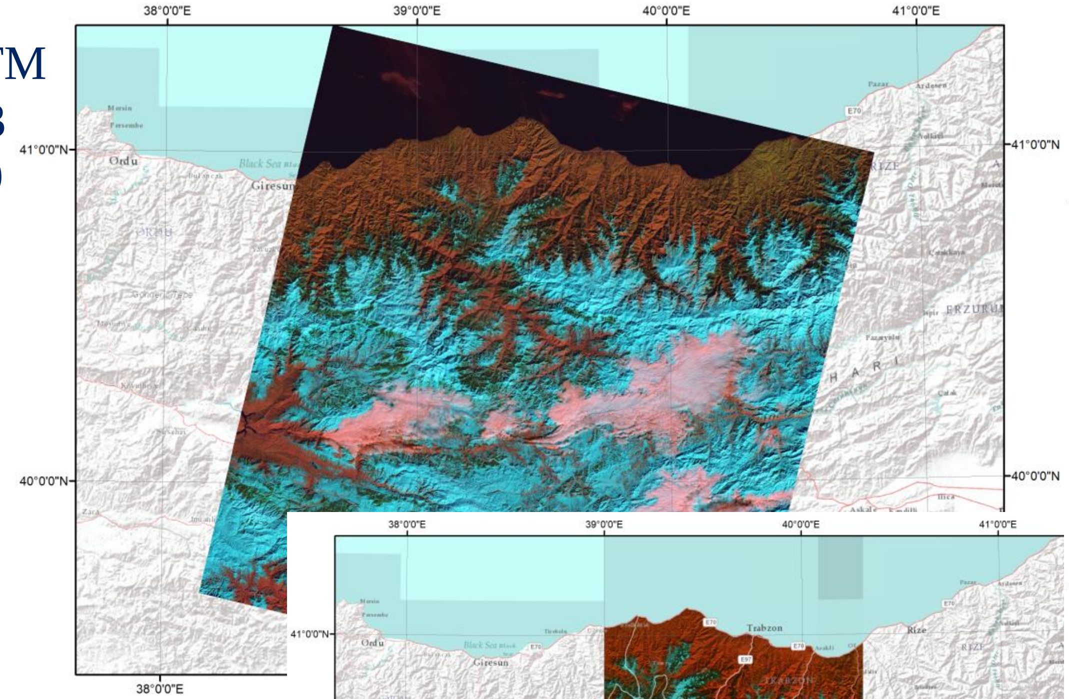
MOD10A1 snow product 4 Feb 2019

IMS snow product 4 Feb 2019

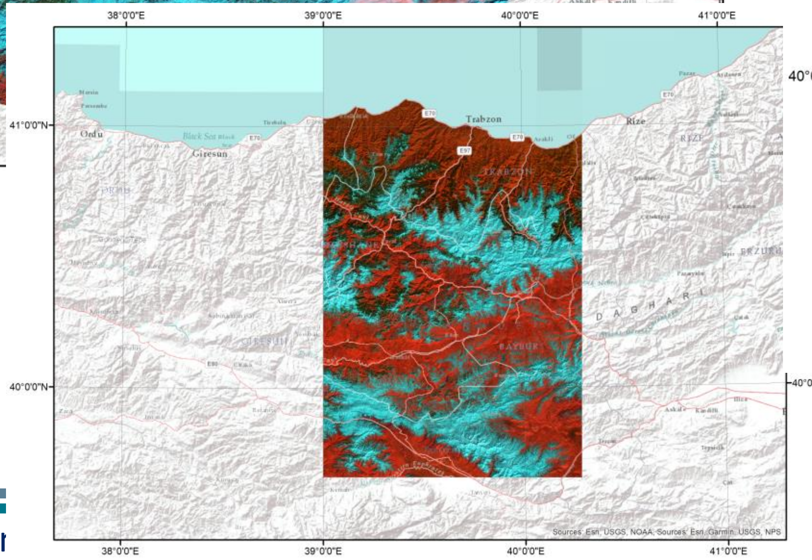


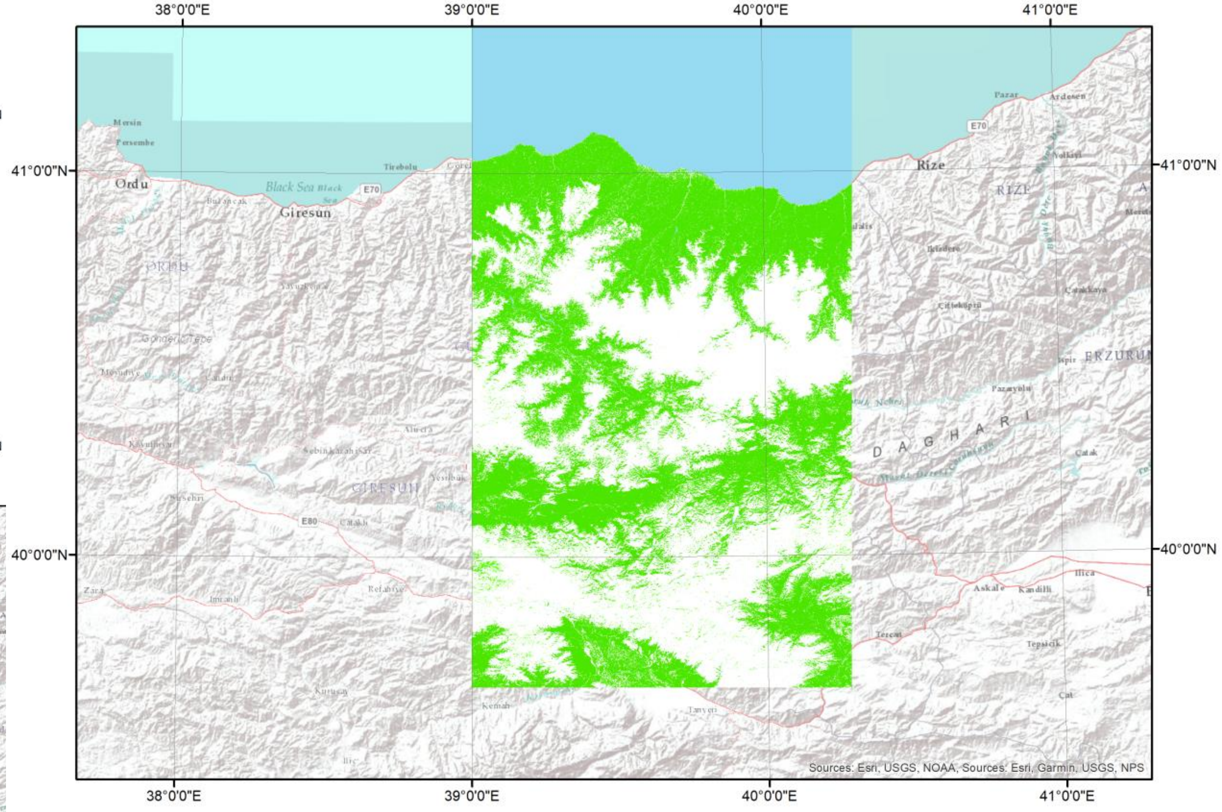
Snow cover mapping

Landsat 8 TM
RGB653
4 Feb 2019



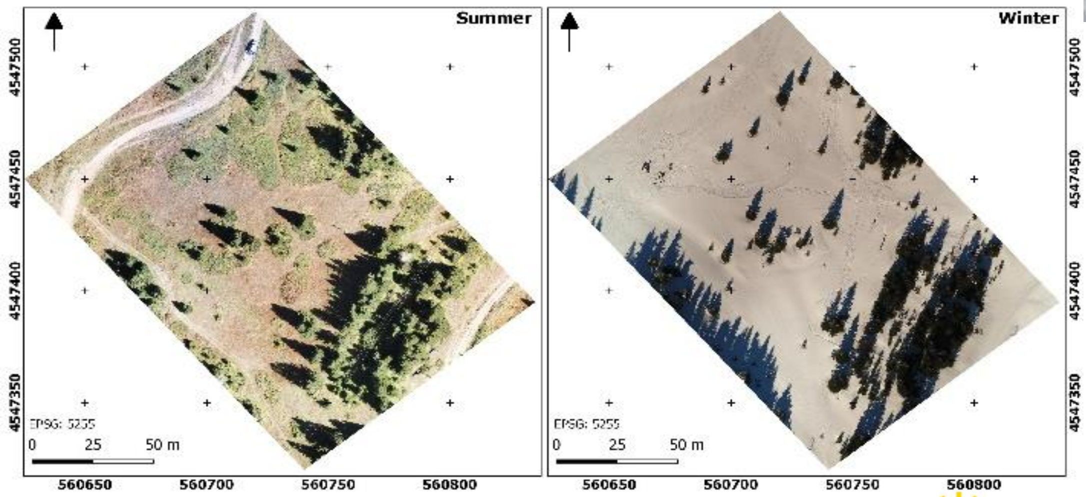
Sentinel 2
RGB 118A3
4 Feb 2019

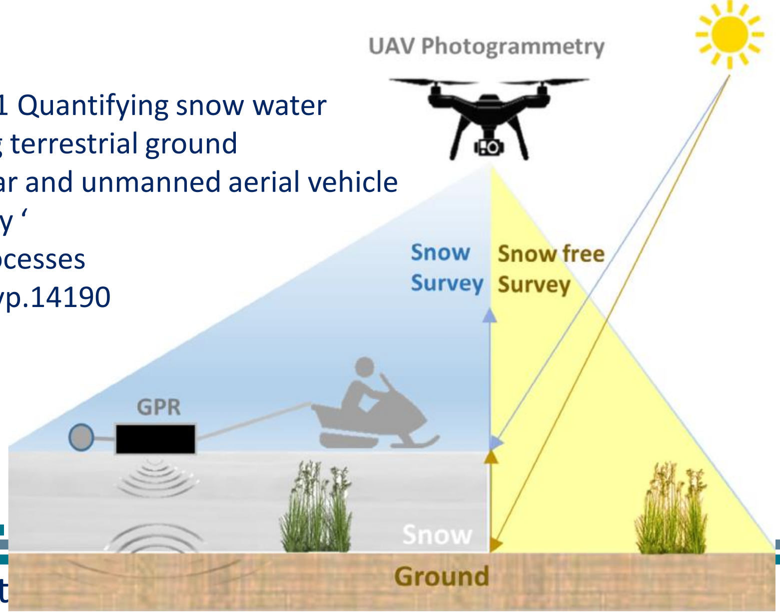




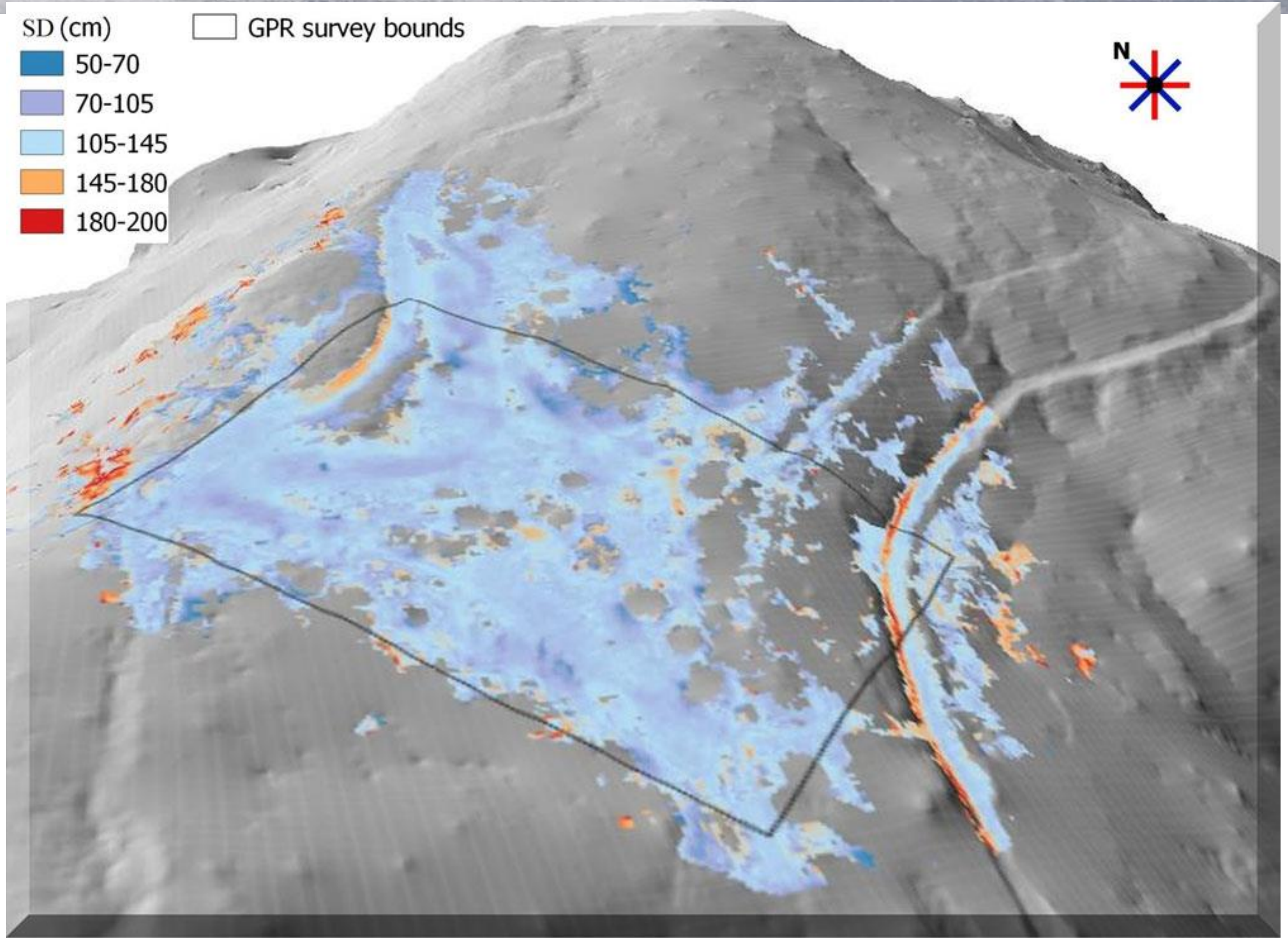
Sentinel snow map 4 Feb 2019

Snow cover mapping





Yildiz et al., 2021 Quantifying snow water equivalent using terrestrial ground penetrating radar and unmanned aerial vehicle photogrammetry ‘
Hydrological Processes
DOI: 10.1002/hyp.14190



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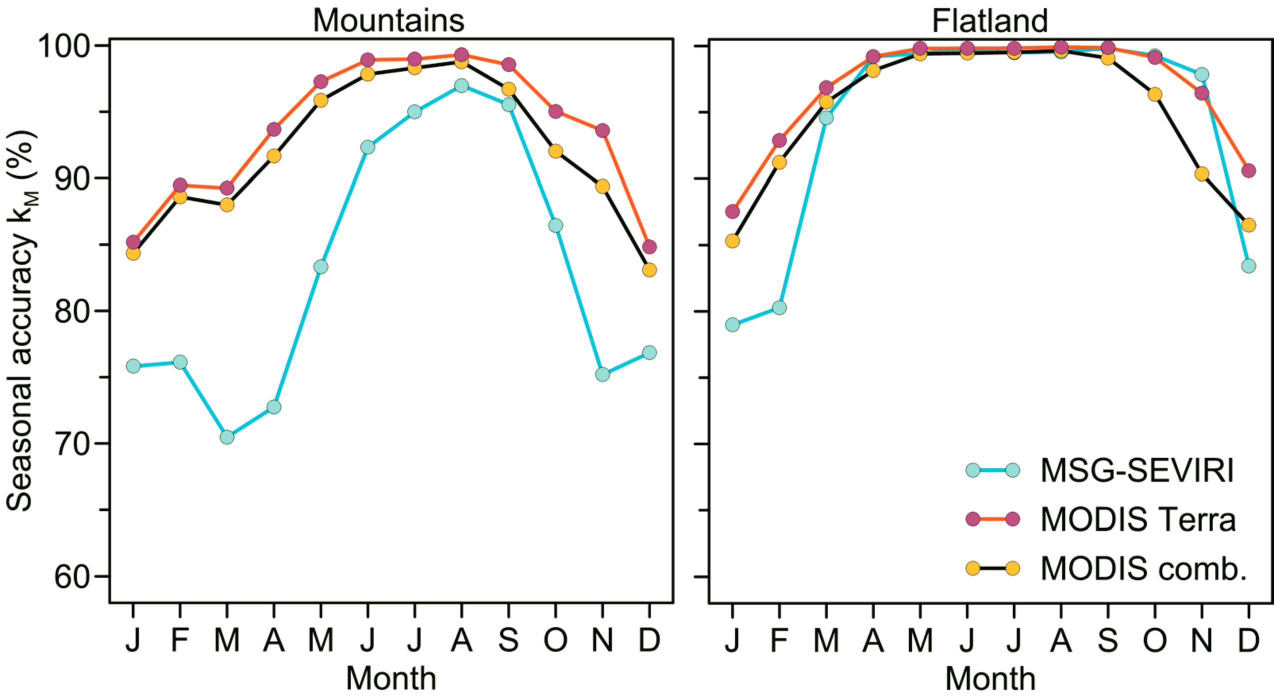
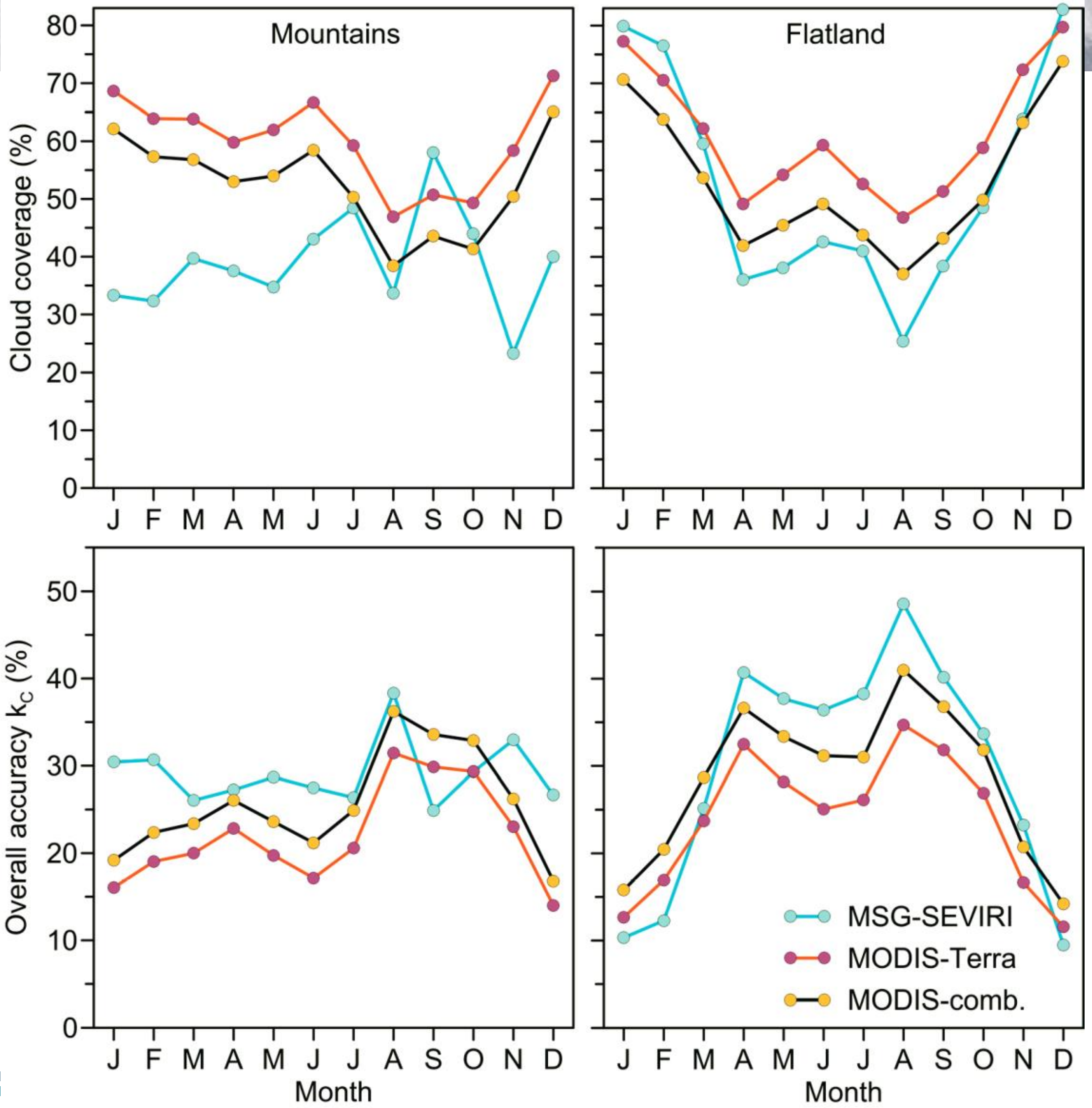
Snow cover mapping





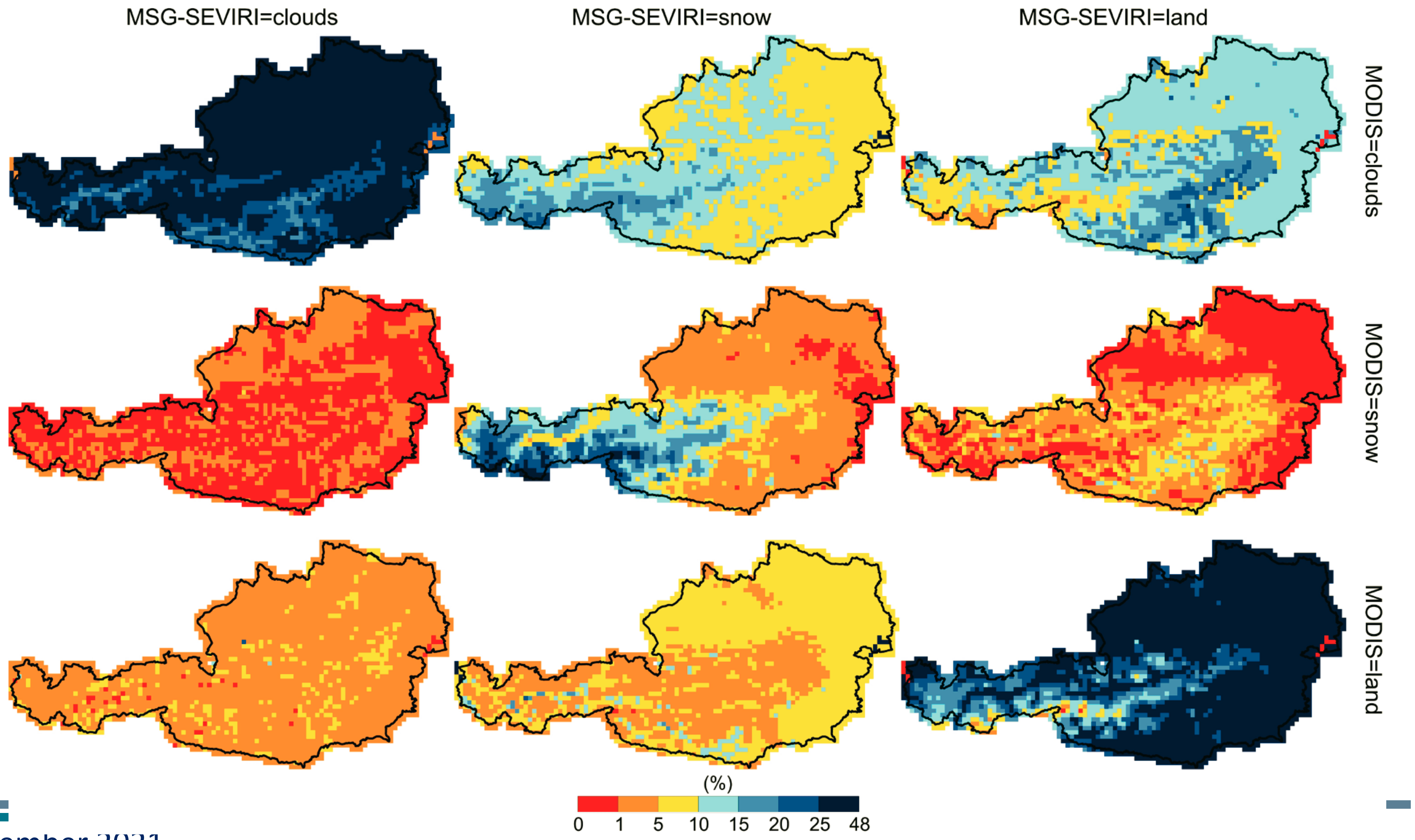
Surer , Parajka and Akyurek, 2014

Validation of the operational MSG-SEVIRI snow cover product over Austria

Hydrology Earth System Science Journal, (in print), 2014.

Snow cover mapping

Relative frequency of days with agreement and disagreement between the MSG-SEVIRI (H10) and MODIS-combined snow cover products in the period April 2008 - June 2012.



What is next?

Using Snow products H31, H32, H34 and H35 from juypiter notebook........