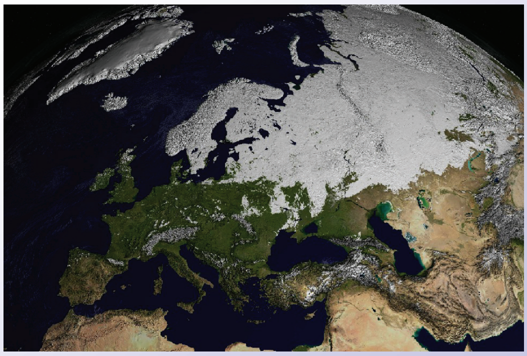
Fjernmåling av snø

Dagrun Vikhamar Schuler

Bidrag fra:
Max Konig, Norsk Polarinstitutt
Rune Engeset, NVE
Rune Solberg, Hans Koren, Jostein Amlien, NR

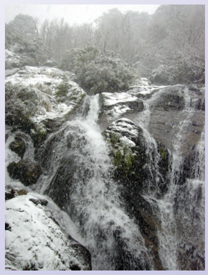
The retrieval of snow properties using remote sensing techniques from the visible to the microwave spectral region.



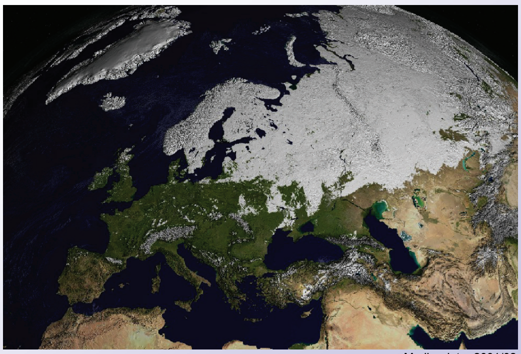
Overview

- Motivation: Why snow monitoring?
- Principles of Remote Sensing
  - EMS, sensors,signatures,...
- Visible and Near Infrared
  - Parameters: Snow-coverage, reflectance/albedo, grain size, wetness
- Thermal Infrared
  - Parameter: Surface temperature
- Microwave (passive/active)
  - Parameter: Depth, wetness,….

Why snow? – Runoff

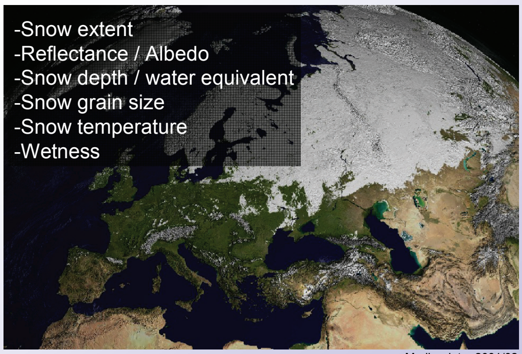


Why Snow? - Albedo

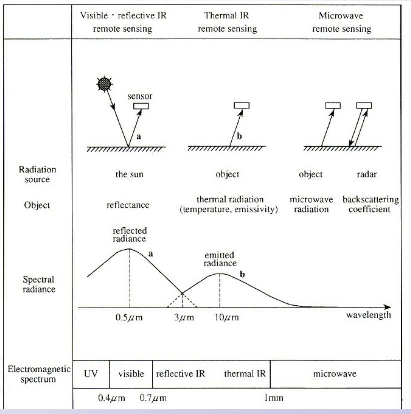


Modis winter 2001/02

Why Snow?

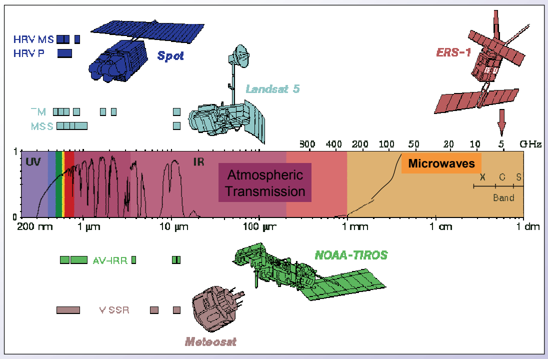


Modis winter 2001/02



Japan Association of Remote Sensing

Elektromagnetisk spektrum og sensorer



http://www.uni-kiel.de/ewf/geographie/forum/unterric/material/einf_fe/index.htm

Which wavelength regions are appropriate for extracting individual snow parameters?

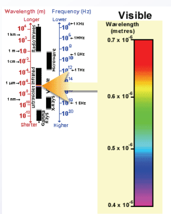
1. Visible and Near Infrared
   – Parameters: Snow-coverage, reflectance/albedo, grain size, wetness

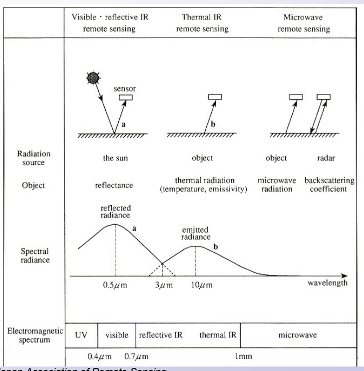
2. Thermal Infrared
   – Parameter: Surface temperature

3. Microwave (passive/active)
   – Parameter: Depth, wetness, when cloudy: snow-coverage….

Visible and Near Infrared

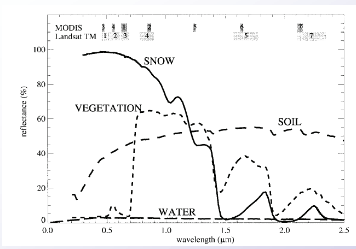
Visible and Near Infrared





Japan Association of Remote Sensing

Parameter: Reflectance and Albedo



from Klein, Hall and Riggs, 1998

- Sensor measures **reflectance** in image band (e.g. TM 1)
- Can be converted to **spectral albedo**
- **Broadband albedo** is integrated over all of the reflective spectrum
- Wavelength not covered by sensor are interpolated, modelled or empirical relation.

MODIS Snow Albedo Prototype

- Albedo is calculated only for areas identified as cloud-free by the MODIS cloud mask and as snow-covered by the MODIS snow algorithm.
- Once a pixel meets these criteria, atmospherically corrected surface reflectances are retrieved from the MODIS/Terra Surface Reflectance Daily L2G Global 500 m ISIN Grid product, available from The Land Processes (LP) DAAC (Klein and Stroeve 2002).

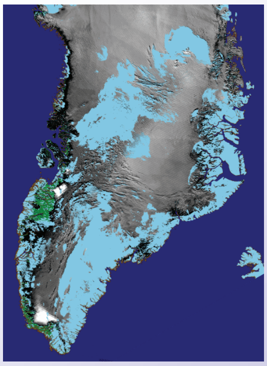
References:

Klein, A.G. and Stroeve, J., 2002. Development and validation of a snow albedo algorithm for the MODIS instrument. Annals of Glaciology, 34: 45-52.

Klein, A.G. in prep. Determination of broadband albedos of partially snow-covered sites for validation of MODIS snow albedo retrievals. 60th Annual Eastern Snow Conference, Sherbrooke, Quebec, June 4-6, 2003

http://geog.tamu.edu/klein/modis_albedo/

MODIS Albedo: Greenland ice sheet

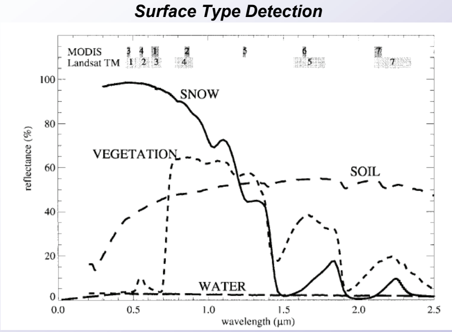


Klein and Stroeve 2002

Parameter: Snow-cover mapping

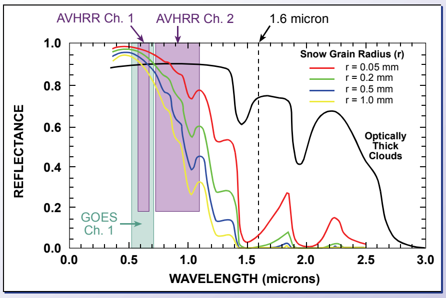
Different surface = different reflectance curve

Surface Type Detection



from Klein, Hall and Riggs, 1998

Snow Mapping - Clouds

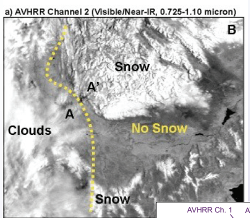


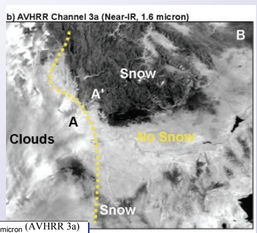
Ambiguities since not whole reflectance curve is measured.

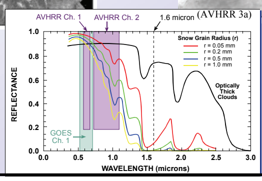
Example: Clouds look like snow in the visible

Snow Cover Mapping - Clouds

Snake River Valley, Idaho

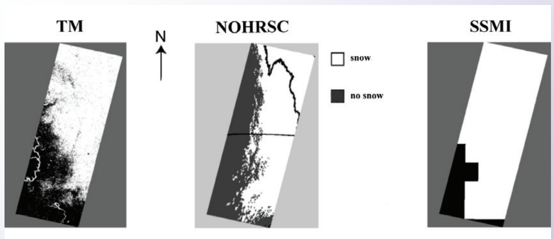






http://www.nohrsc.nws.gov/technology/avhrr3a/avhrr3a.htm

Snow map at different scales



Landsat with SNOWMAP 30m resolution

AVHRR weekly Product – 1.1km resolution

SSMI - 25km resolution

After *Hall et al. 2000*

Operational snow-cover products

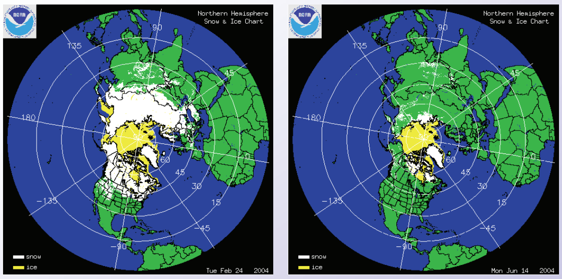
Algorithm	Snow maps	Sensor
NLR	Norway	AVHRR/MODIS
Finnish	Finland	AVHRR
NOHRSC	North America	GOES/AVHRR
NOAA	Northern hemisphere	GOES
NASA	Global maps	MODIS

We will now look closer to some of these products

National Operational Hydrologic Remote Sensing Center (NOHRSC)

- Snow maps over U.S. and Alaska
- Provide daily maps of snow cover
  - derived from NOAA's GOES and AVHRR satellites
- Estimates of snow water equivalent
  - based on ground and airborne observations combined with snow cover information from the satellite maps.

Snow Cover Mapping



Daily snow map from NOAA/NESDIS

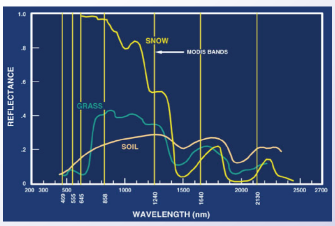
http://www.ssd.noaa.gov

Operational snow-cover products

Algorithm	Snow maps	Sensor
NLR	Norway	AVHRR/MODIS
Finnish	Finland	AVHRR
NOHRSC	North America	GOES/AVHRR
NOAA	Northern hemisphere	GOES
NASA	Global maps	MODIS

We will now look closer to some of these products

MODIS snow-cover product



<u>36 spectral bands:</u>
2 bands: 250 m
7 bands 500 m
Rest: 1000 m

Spatial Resolution: 250 m (bands 1-2)
500 m (bands 3-7)
1000 m (bands 8-36)

MODIS snow-cover algorithm

- Analysis for snow in a MODIS swath is constrained to pixels that:

1. have nominal Level 1B radiance data
2. are on land or inland water
3. are in daylight
4. are unobstructed by clouds (two separate criteria are applied)
5. have an estimated surface temperature less than 283K

Table 2. MODIS data product inputs to the MODIS snow algorithm.

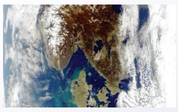
ESDT	Long Name	Data Used
MOD02HKM	MODIS Level 1B Calibrated and Geolocated Radiances	Reflectances for MODIS bands: 1 (0.645 µm) 2 (0.865 µm) 4 (0.555 µm) 6 (1.640 µm)
MOD021KM		31 (11.28 µm) 32 (12.27 µm)
MOD03	MODIS Geolocation	Land/Water Mask Solar Zenith Angles Sensor Zenith Angles Latitude Longitude
MOD35_L2	MODIS Cloud Mask	Cloud Mask Flag Unobstructed Field of View Flag Various cloud test results Day/Night Flag

MODIS snow-cover algorithm

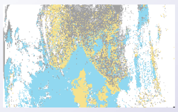
Pixel classified as snow covered:

- a normalized snow difference index (NDSI), ((band 4-band 6) / (band 4 + band 6)) greater than 0.4
- and near-infrared reflectance (band 2) greater than 0.11
- and band 4 reflectance greater than 0.10.

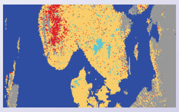
MODIS snow-cover algorithm



Level-1B (MOD02)
- calibrated radiances



cloud mask



Snow mask (MOD10)
Institutional product sample.
Contains snow mask
at 500m resolution.

MODIS snow-cover algorithm

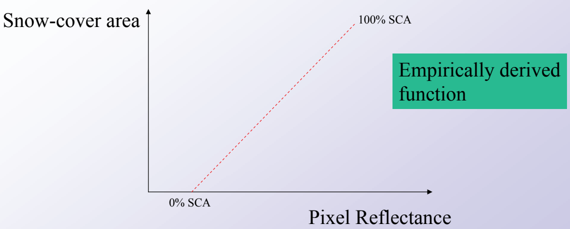
- Kartene kan foreløpig fritt lastes ned fra internett

Operational snow-cover products

Algorithm	Snow maps	Sensor
NLR	Norway	AVHRR/MODIS
Finnish	Finland	AVHRR
NOHRSC	North America	GOES/AVHRR
NOAA	Northern hemisphere	GOES
NASA	Global maps	MODIS

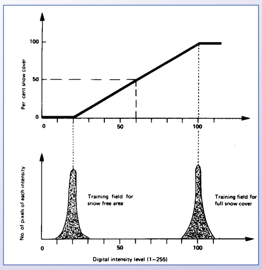
We will now look closer to some of these products

NLR: Norwegian Linear reflectance to snow-cover algorithm



Sub-pixel classification algorithm.
Output: 0-100% SCA per pixel

NLR: Norwegian Linear reflectance to snow-cover algorithm



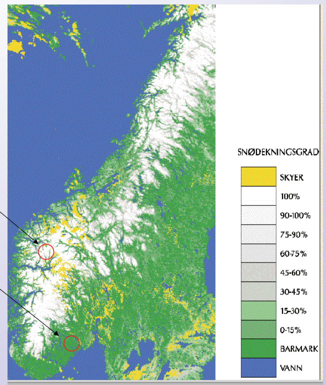
Snow covered area derived from NOAA AVHRR images or MODIS

2 calibration values:

1. Areas with 100% SCA are identified from glaciers

2. Areas with 0% SCA are identified

Snow cover map is made as a linear function of the reflectance in each gridcell compared to the reflectances in the 100% and 0% SCA areas



NLR: Norwegian Linear reflectance to snow-cover algorithm

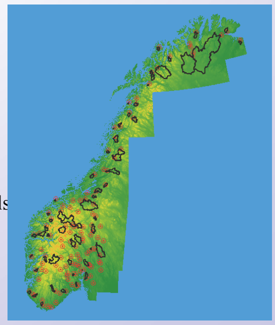
- Anvendes hos NVE
  - Flomvarsling
- Anvendes hos Statkraft
  - Kraftproduksjon
- Felles: Man vil forbedre estimatet av snødekning i fjellet, for prediksjon av avrenning (runoff models)
- Algoritme utviklet av flere:
  - Andersen (1970-årene)
  - Videreutviklet av Norsk Regnesentral, NVE m.fl. (Solberg & Andersen, 1994)

Hans-Christian Udnæs, Rune V. Engeset and Liss M. Andreassen NVE

NVE Objective:

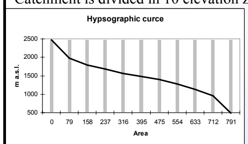
To test if updating of snow cover area (SCA) in the HBV model improves runoff simulations in NVEs operational flood warning

- 180 automatic discharge stations
- 63 operative HBV models

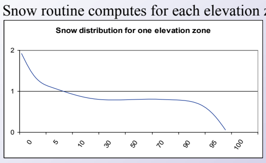


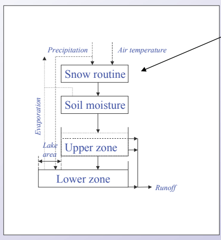
THE HBV MODEL

Catchment is divided in 10 elevation zones :



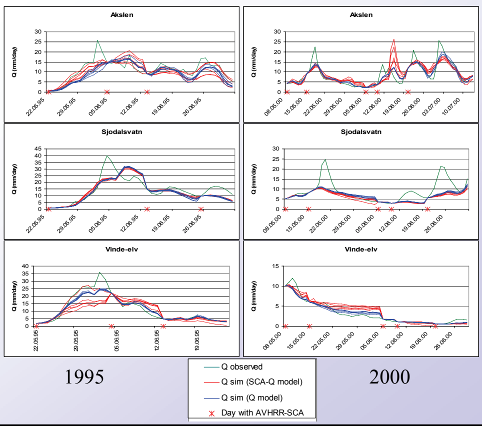
Snow routine computes for each elevation zone





Snow melt from each elevation zone is aggregated as input to the sub-surface models:

HBV simulations



Conclusions

- By calibration of HBV models against runoff, simulated SCA will be clearly overestimated compared to AVHRR-derived SCA.

- HBV models can be calibrated to simulate SCA more consistent with AVHRR-derived SCA without major reduction in the precision of the runoff simulations.

- Models calibrated against SCA and runoff do not improve runoff simulations by updating of AVHRR-derived SCA and runoff

- Updating of SCA in the operative models will probably be of interest when there are obvious large errors in the SCA simulation

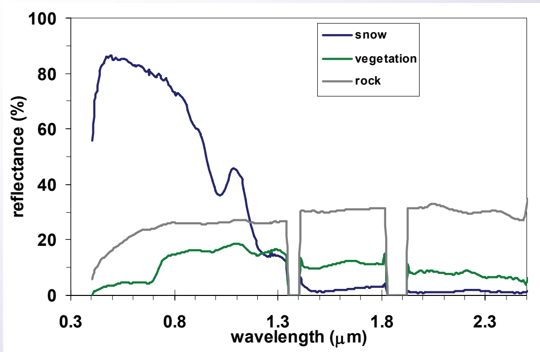
NLR: Norwegian Linear reflectance to snow-cover algorithm

- Vis simulering laget vha. MODIS: VIDEO
- Snøsmelte scenario over Sør-Norge i 250 m oppløsning.

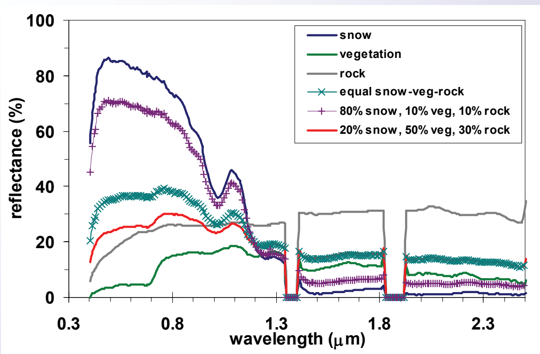
Snow-cover mapping: - spectral unmixing

-subpixel klassifikasjon

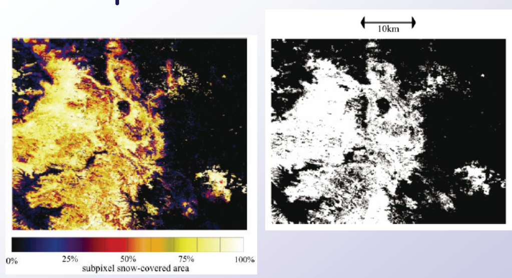
Mixed pixels – spectral unmixing



Mixed pixels – spectral unmixing



Subpixel Snow Cover Fraction

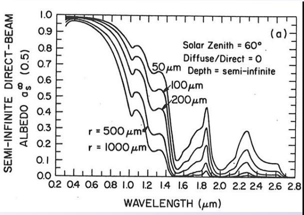


Snow mapping with spectral mixing algorithm (*left*) and MODIS standard algorithm (*right*) for NASA's Cold Land Processes field experiment area in the Rocky Mountains. In the standard algorithm, each pixel is mapped as entirely snow or entirely snow-free.

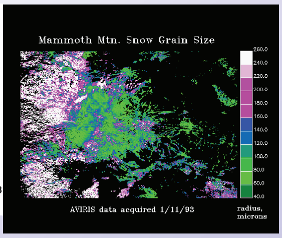
(Dozier and Painter, 2004)

Parameter: Grain Size

Different surface property – different reflectance curve
Grain size determination

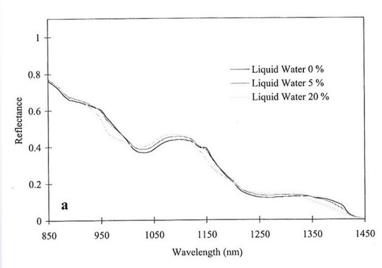


Wiscombe and Warren 1980



Analyse egnet for hyperspektrale data

Parameter: Liquid Water Content



-Snow wetness observed during melting conditions.
-With precise spectral information from hyperspectral sensors (e.g. AVIRIS), even liquid water content (at surface) can be detected.
- Due to small penetration depth in visible range, only surface wetness is determined.

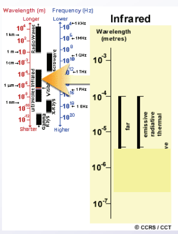
Analyse egnet for hyperspektrale data

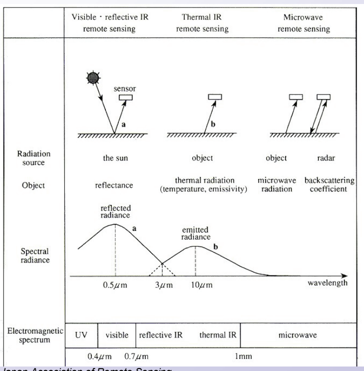
Summary Visible/Near Infrared

- Reflectance curve characterizes surface and its properties (snow/no-snow ; grain size, wetness)
- Several operational algorithms for snow mapping
- Snow maps can be improved through spectral unmixing for snowfraction within pixel
- Disadvantage in Vis/Near IR: no direct measure of snow volume
- Problems in Visible: Cloud cover may obscure area for most of the time

Thermal infrared

Thermal Infrared





Japan Association of Remote Sensing

Surface Temperature

- In thermal infrared the surface is source of radiation, which depends on the surface temperature
- Relate thermal band to temperature

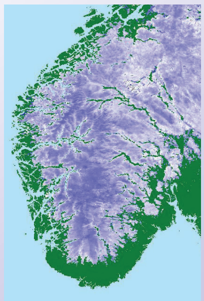
Snøtemperaturprodukt (STS)

Jostein Amlien, Rune Solberg

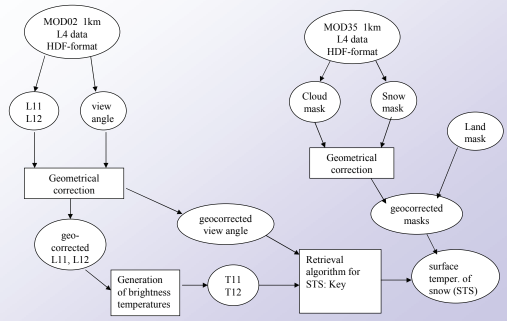
Norsk Regnesentral

Snøtemperatur

- Basert på Keys algoritme for ekstraksjon av overflatetemperatur
- Må kjenne emissiviteten til overflatematerialet for å kunne regne om fra strålingstemperatur til overflatetemperatur. Begrenses dermed til snø
- Korreksjon for atmosfæreeffekter: Benytter seg av at atmosfæren påvirker ulike observasjonsvinkler forskjellig
- Kan brukes for både AVHRR og MODIS

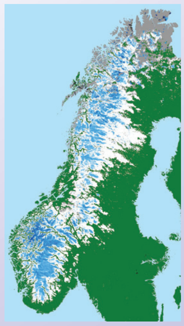


STS-produksjonslinje



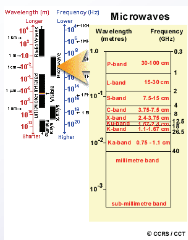
Konklusjoner

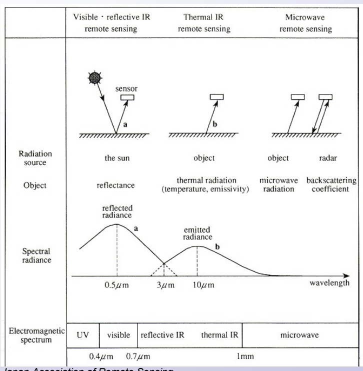
- Sammenlikning med bakkesannhet viser gode resultater
- For 0°C fant vi en nøyaktighet på ca. 0,5°C på Valdresflya
- Kartene begrenser seg kun til områder med 100% SCA



Passive microwaves

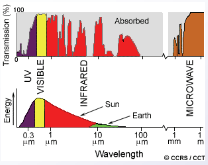
Microwave





Japan Association of Remote Sensing

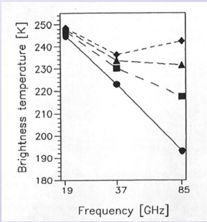
Advantages of Microwave



- Not influenced by clouds
- Not influenced by (polar) night
- Penetrate surfaces

-In visible we measure reflectance, in microwave we measure brightness temperature (passive) or backscatter (active)

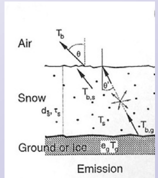
-Ideally a sensor measures various wavelengths, microwave satellites generally only one frequency



Rott and Nagler 1994

Mapping Snow Water Equivalent (SWE)

- Objects emit microwave radiation
  - For dry snow, radiation from ground dominates, but is weakened by snow cover.



Rott, Karthaus 2000

Mapping SWE

- Brightnesstemperature
  - decreases with increasing SWE-> mapping depth
- Wet snow has high brightness temperature and absorbs all radiation from ground → wet snow mapping, but hard to distinguish from bare ground

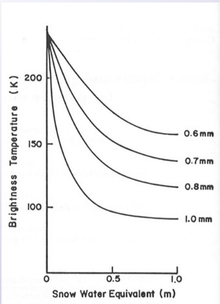
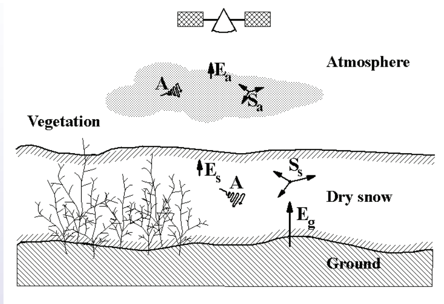


Fig. 1. Calculated relationship between 37 GHz brightness temperature (vertical polarization) and snow water equivalent (m) as a function of snow grain diameter (mm) (from Chang and others, 1981).

Armstrong et al 1993

Chang *et al.* (1987): $SWE = c(T_{b,18H} - T_{b,37H})$

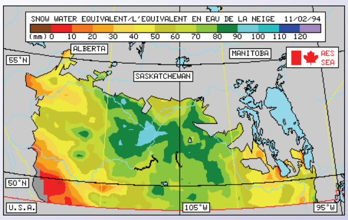
Grody and Basist (1996) $SCAT = T_{b,19V} - T_{b,37V}$



Engeset & Osmo, 1997

Snow Water Equivalent

- Surface emits TB, attenueated by snow – Low resolution

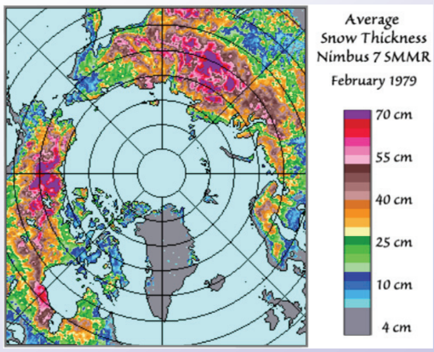


SSM/I

Figure 2: Snow water equivalent derived from SSM/I satellite data for the Canadian Prairies, February 11, 1994.

http://www.socc.ca/nsisw/intro.cfm

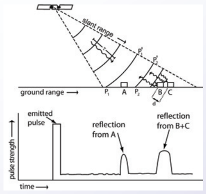
Snow depth

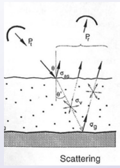


http://www.ngdc.noaa.gov/seg/cdroms/ged_iib/datasets/b08/cs.htm

Active Microwave Sensing

Active Microwave Sensing

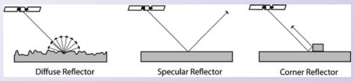




Synthetic aperture radar
-Emits microwave pulse and measures return (backscatter)

- Surface scattering and volume scattering.

- Dependent on dielectric properties of surface.



Snow depth, SWE

- Dry snow on land basically invisible (penetration depth), but snowcover dampens backscatter from ground.
- SWE/depth relation in C-band (5.3GHz); grain size relation in L-band (1.25GHz) (Shi and Dozier, 2000)
- Depth relation between vertically and horizontally polarized SAR signal (Shi 1990)

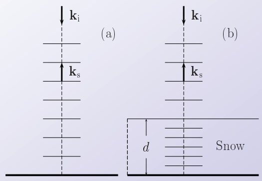
ERS-2 SAR

Snow depth

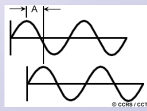
- Dry snow invisible: Backscatter mainly from snow-ground interface.

- In snowpack different wavespeed, therefore different wavelength (but same frequency)

- Phase shift due to propagation in snow related to SWE (Rott, Nagler, Scheiber 2003)



Engen, Guneriussen, Overrein, 2003



Phase shift "A"

Snow Type

Dry snow on ground invisible

On glaciers, deep penetration depth no problem.

-**Dry snow** dark: no reflection

-**Firn bright**: crystals, ice lenses reflect

-**wet snow** dark: absorption, surface scattering

Greenland ice sheet

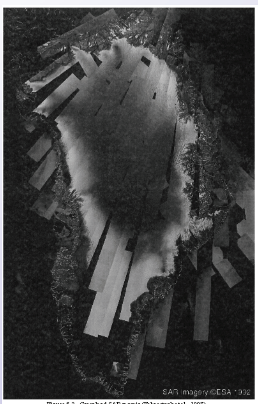
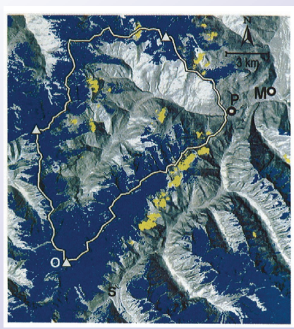


Figure 5-3. Greenland SAR mosaic (Fahnestock et al., 1993).

Wet Snow mapping

- Dry snow is invisible for SAR
- Small amount of water reduces penetration depth to cm or less (dielectric constant)
- Wet snow is visible to SAR
- Using ratio between wet snow and dry snow image;
If $\sigma_{wet}/\sigma_{dry}$ < *threshold* then snow
- relative values eliminate backscatter variations due to incidence angle in mountaineous areas.



ERS 19 Mai 1997

Nagler and Rott 2000

Summary Microwave

- Microwaves unaffected by atmosphere, nighttime or clouds
- Microwaves penetrate with surface → snow depth
- Problems: Dry snow basically invisible for microwave→ wet snow is visible and can be mapped
- Problem: Large pixel size in passive microwave due to low energy→ active microwave sensing better resolution

Summary

- Visible:
  - Advantage: Comparably easy image interpretation, longer experience.
  - Disadvantage: Clouds cause problems
  - Snow maps, reflectance as operational products
- Passive Microwave:
  - Advantage: Unhindered by clouds and night; surface penetration for snow pack properties
  - Disadvantage: Large pixel size (~25km)
  - Large scale snow maps (extent and depth) as operational products
- Active Microwave:
  - Advantages: Same as passive microwave plus good resolution (~12m)
  - Disadvantage: Dry snow almost invisible
  - Wet snow mapping, snow depth (interferometry) in development
- Future:
  - Increased computing power and new sensors (multispectral; multifrequency) will give much more possibilities

Further Reading

- Review Papers
  - Dozier and Painter 2004. Multispectral and Hyperspectral Remote Sensing of Alpine Snow Properties. Annu. Rev. Earth Planet Sc. 32:465-94
  - König, Winther and Isaksson. 2001. Measuring Snow and Glacier Ice Properties from Satellite. Reviews of Geophysics 39(1), 1-27.