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State of the art for snow extent (SE) monitoring using optical sensors

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Current snow extent services (1)

Name	*Link*	*Sensor*	*Resolution of snow product*	*Repeat Interval*	*Period covered*	*Region*
MODIS (Terra, Aqua) MOD10, MYD10 products	http://modis-snow-ice.gsfc.nasa.gov/intro.html	MODIS (Terra, Aqua)	500 m	Daily, 8 day composite	since 2000	global
Rutgers University Climate Lab: Snow Data Resource Center	http://climate.rutgers.edu/snowcover/	IMS sub-sampled by factor 10	ca. 200-300 km (?)	daily weekly	1970 - 2000	Northern Hemisphere
NOAA Operational Daily Snow Cover Analysis (IMS)	http://www.natice.noaa.gov/ims/	NOAA-15 AVHRR	24km/4km	Daily	1997 (weekly) 1999 (daily)	Northern Hemisphere
State of the Canadian Cryosphere	http://www.socc.ca/examples/socc/snow_images/daily_images.jsp	MODIS	500 m	Daily	since 2000	Canada
Northern Hemisphere EASE-Grid Weekly Snow Cover and Sea Ice Extent Version 3	http://nsidc.org/data/docs/daac/nsidc0046_nh_ease_snow_seaice.gd.html	AVHRR, GOES, other	25 km	weekly	1966-10-03 to 2007-06-24	Northern Hemisphere
NOAA NESDIS	http://www.nesdis.noaa.gov/sat-products.html	GOES, SSM/I	5 km	Daily	Since winter 1998/1999	US

Current snow extent services (2)

NOAA SNODAS	http://www.nsidc.org/data/g02158.html	Several Satellites, airborne, meteostations, models	1 km	Daily	2003-10-01	US
AMSR-E/Aqua L3 Global Snow Water Equivalent EASE-Grids	http://www.nsidc.org/data/docs/daac/ae_swe_ease-grids.gd.html	AMSR-E	25 km	Daily	2002-06-19	Global
Near-real-time SSM/I EASE-Grid Daily Global Ice Concentration and Snow Extent	http://www.nsidc.org/data/nise1.html	SSM/I	25 km	Daily	2002-05-04	Global
Syke Snow Monitoring		MODIS				Finland
Polar View Scandinavian Snow Mapping Service	http://www.ksat.no/Products/SnowMapping.htm	MODIS ASAR	250 m	Daily	Since 2003	Scandinavia

Relevant optical sensors (1)

Satellite	*Sensor*	*Resolution*	*Repeat-cycle / observation*	*Coverage*	*Availability*
TERRA, AQUA	MODIS	0.25 km (bands 1-2) 0.5 km (bands 3-7) 1 km (bands 8-36)	16 day repeat-cycle 1-2 days global coverage	Global swath-width: 2330 km	Systematic data acquisition; since 2000
NOAA POES	AVHRR	1.1 km	12h - daily repeat-cycle	Global swath-width: ca. 2900 km	Systematic data acquisition since 1978/1981, incomplete archives
ERS-2	ATSR-2	1 km x 1 km	35 days repeat cycle At least 2-weekly coverage at mid an high latitudes	Global swath-width: 500 km	Incomplete since 1995
ENVISAT	AATSR	1 km x 1 km	35 days repeat cycle At least weekly coverage	Global swath-width: 500 km	Incomplete since 2002
ENVISAT	MERIS	Ocean: 1040m x 1200 m, Land: 260m x 300m	3 day global coverage	Global swath-width: 1150 km	Incomplete since 2002
SPOT	VEGETATION	1.16 km	Daily coverage	Global swath-width: 2250 km	Since 1998

Relevant optical sensors (2)

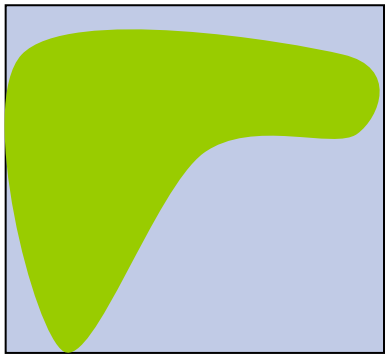
Geostationary Weather Satellites					
Meteosat	MVIRI	5 km (IR) / 2.5 km (VIS) at image centre	30 min	Earth disc lower resolution at mid and high latitudes	Operational 1977-1979 1981-
Meteosat Second Genreration (MSG)	Seviri	3 km / 1 km (HRV - pan) at image centre	15 min	Earth disc lower resolution at mid and high latitudes	Operational since 2006

State-of-the-art SCA algorithms: Terminology

- Snow Cover Area (SCA)
  - Snow (Cover) Extent (SE/SCE)
  - Fractional Snow Cover (FSC)

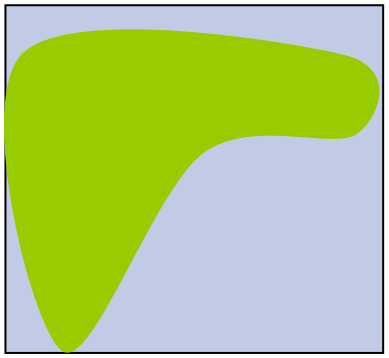
No snow

50 % threshold?



Snow Extent

Snow/no snow (cat)



42 % FSC

Fractional Snow Cover

Percentage of snow (%)

State-of-the-art SCA algorithms: Overview

Physically motivated approaches

- Supervised classification
- Unsupervised classification
- Hybrid classifiers
- Normalised Difference Snow Index (NDSI) (Dozier 1989)
- SNOWMAP (Hall et al. 1995)
- NASA MODIS algorithm (Klein et al. 1997)
- MODIS FSC (Salomonson and Appel 2004)
- Apparent forest transmissivity (Metsämäki et al. 2005)

Spectral unmixing approaches

- Two-class linear spectral unmixing (Østrem et al. 1979, Solberg and Andersen 1994))
- Full linear spectral unmixing (Nolin 1993)
- Unsupervised spectral unmixing (Rosenthal 1996, Painter et al. 2003)
- Forest modelling (Vikhamar and Solberg 2003)

State-of-the-art SCA algorithms: Overview (2)

SE approaches

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- Unsupervised classification
- Hybrid classifiers
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FSC approaches

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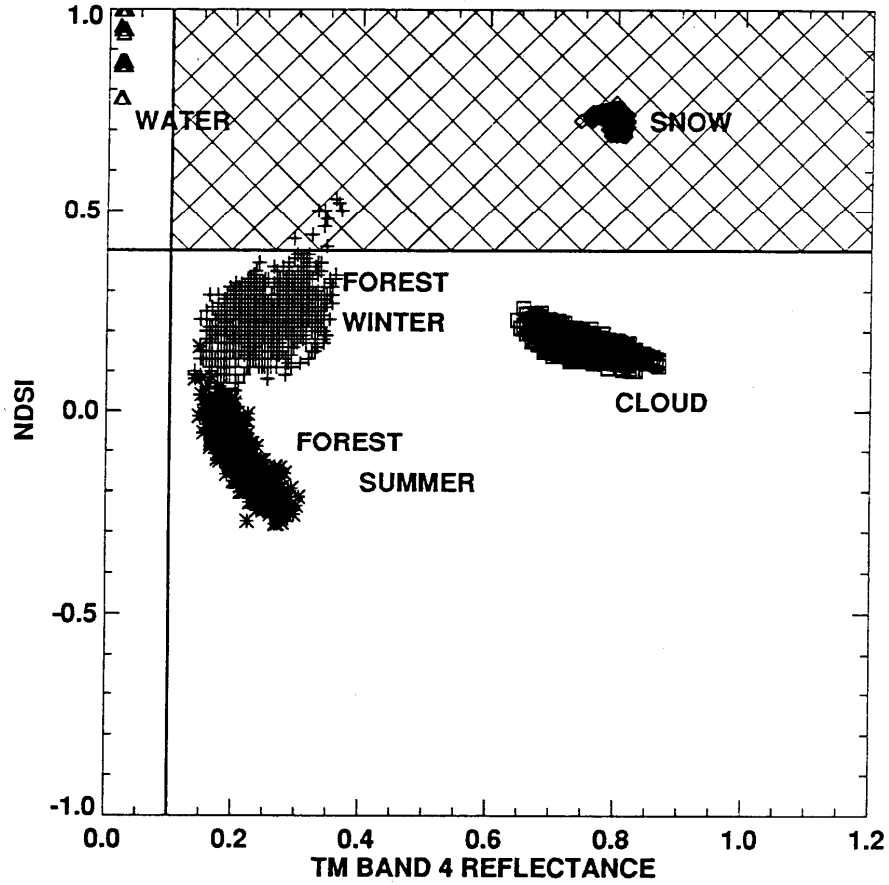
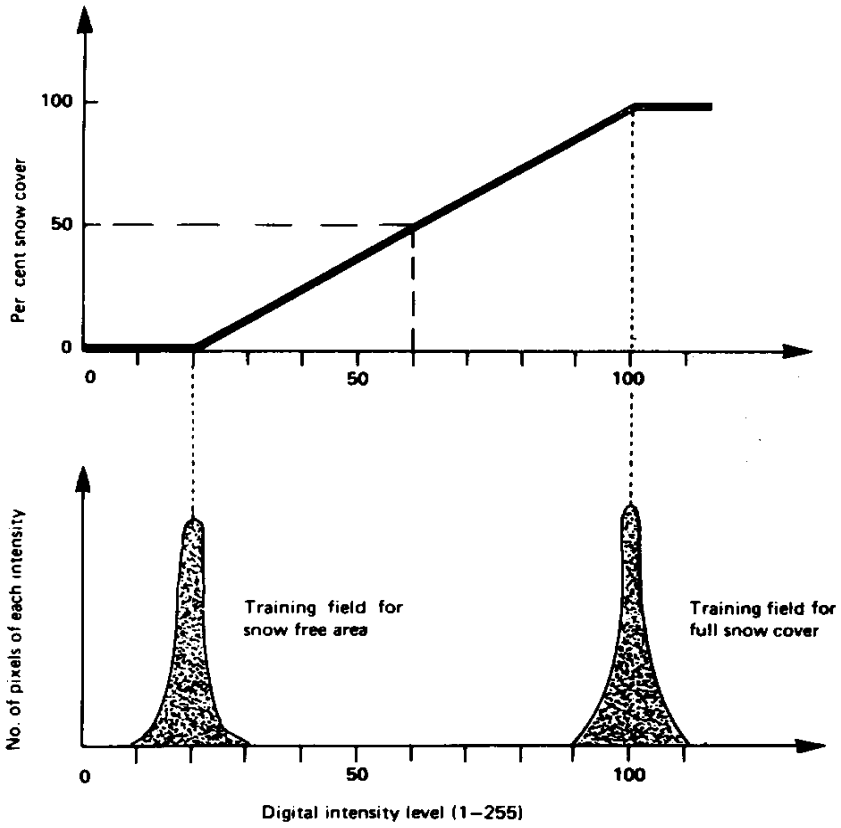
SE: The NASA MODIS algorithm

- Normalised Difference Snow Index (NDSI) proposed by Dozier 1989:
  $(R_{TM4} - R_{TM6})/(R_{TM4} + R_{TM6})$
- SNOWMAP (Hall et al. 1995) utilises NDSI in a box classification approach
- Klein et al. 1997 includes handling of winter forest in the algorithm → NASA MODIS algorithm
- De facto snow/no-snow threshold: ~60 % FSC
- Does not work well for dense forest



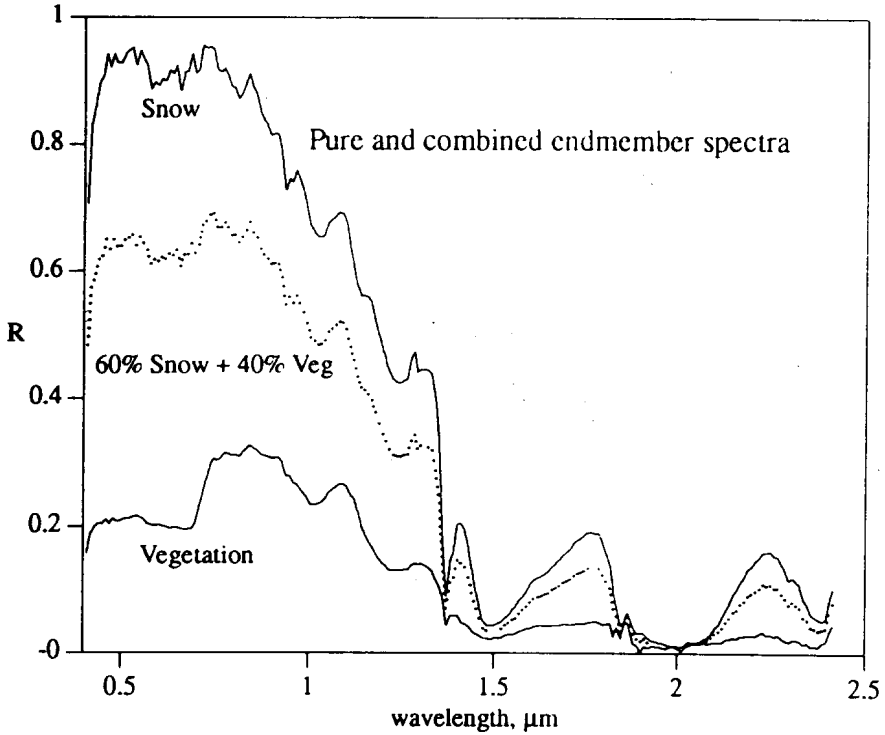
FSC: Two-class linear spectral unmixing

- Two-class linear spectral mixing model applying VIS or NIR channel (Østrem et al. 1979, Solberg and Andersen 1994)
- Regional calibration targets
- Implicit regional atmospheric and snow metamorphosis correction
- Cloud detection using a regionally optimised k-NN classifier
- Topographic correction
- Non-forested areas (for FSC)
- Tested on AVHRR, MODIS and MERIS
- Accuracy: 10-30 % FSC error



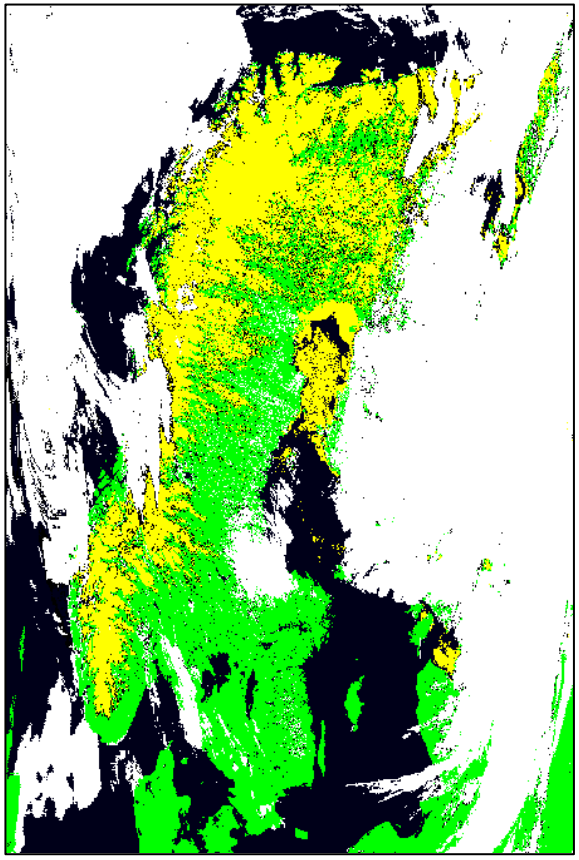
FSC: N-class linear spectral unmixing

- N-class linear spectral mixing model applying VIS & NIR channels (Nolin 1993, Rosenthal 1996, Painter et al. 2003)
- Supervised (manual training or library spectra)
- The method gives a measure of fitness to the model (RMS error)
- Very accurate if training data for all classes can be determined (and preferably a high number of bands)
- Accuracy: 4 % RMS error in AVIRIS experiment
- Never been applied for large-scale snow mapping



Cloud detection

- NASA MODIS cloud algorithm:
  - Decision tree including up to 13 separate spectral thresholds
  - Optimised for global applications
- NR MODIS cloud algorithm:
  - k-NN classifier using 7 MODIS bands
  - Optimised for regional applications
- Comparison in Scandinavia:
  - In general very similar results
  - For cold weather and dry snow: NASA algorithm sometimes gives clouds in cloud-free areas
  - Along snow borders: NASA algorithm sometimes gives clouds, probably due to a spectral mixture problem
  - Snowmelt conditions in general with dry-snow areas included: NR algorithm may give clouds

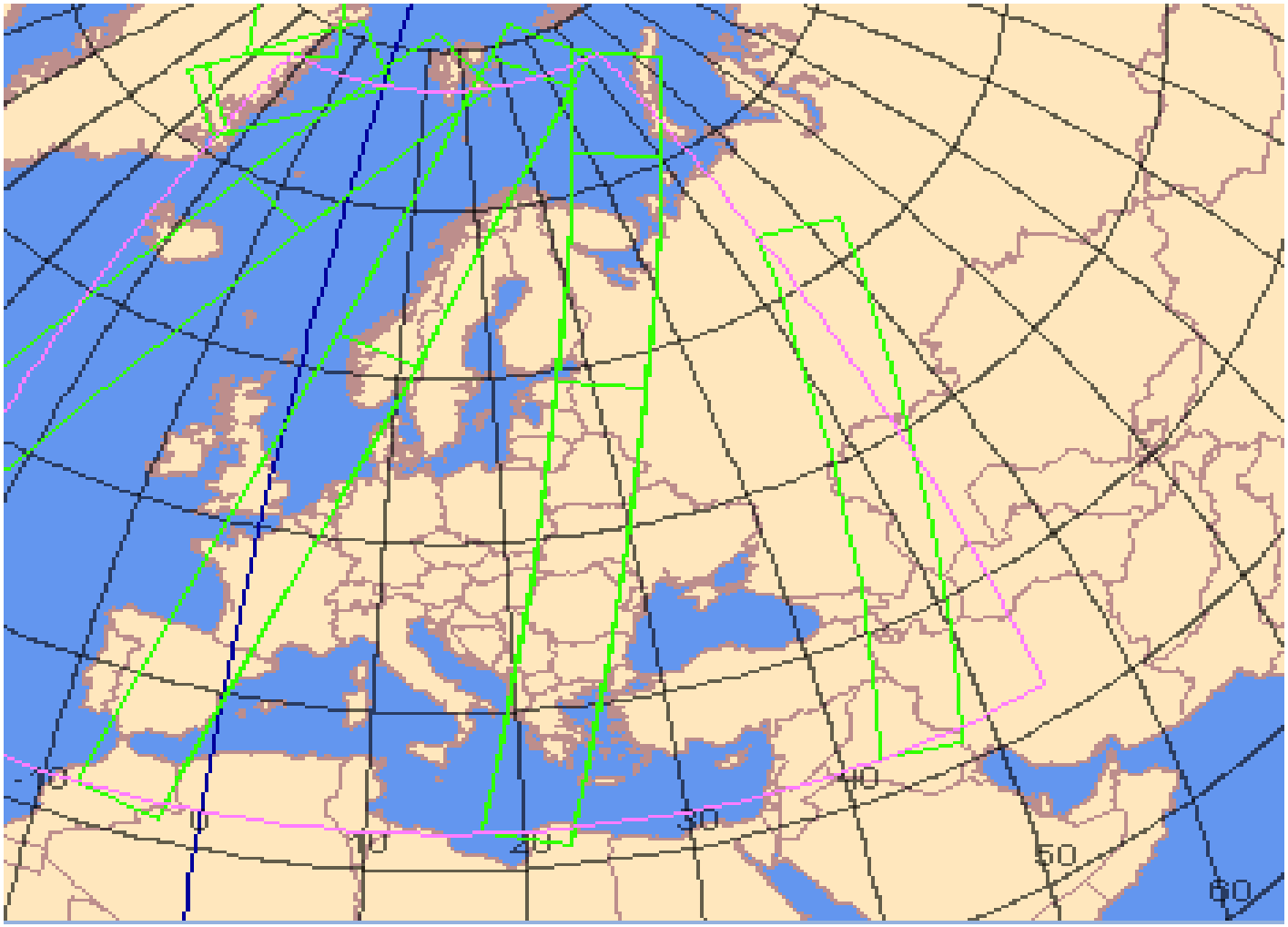


k-NN cloud mask

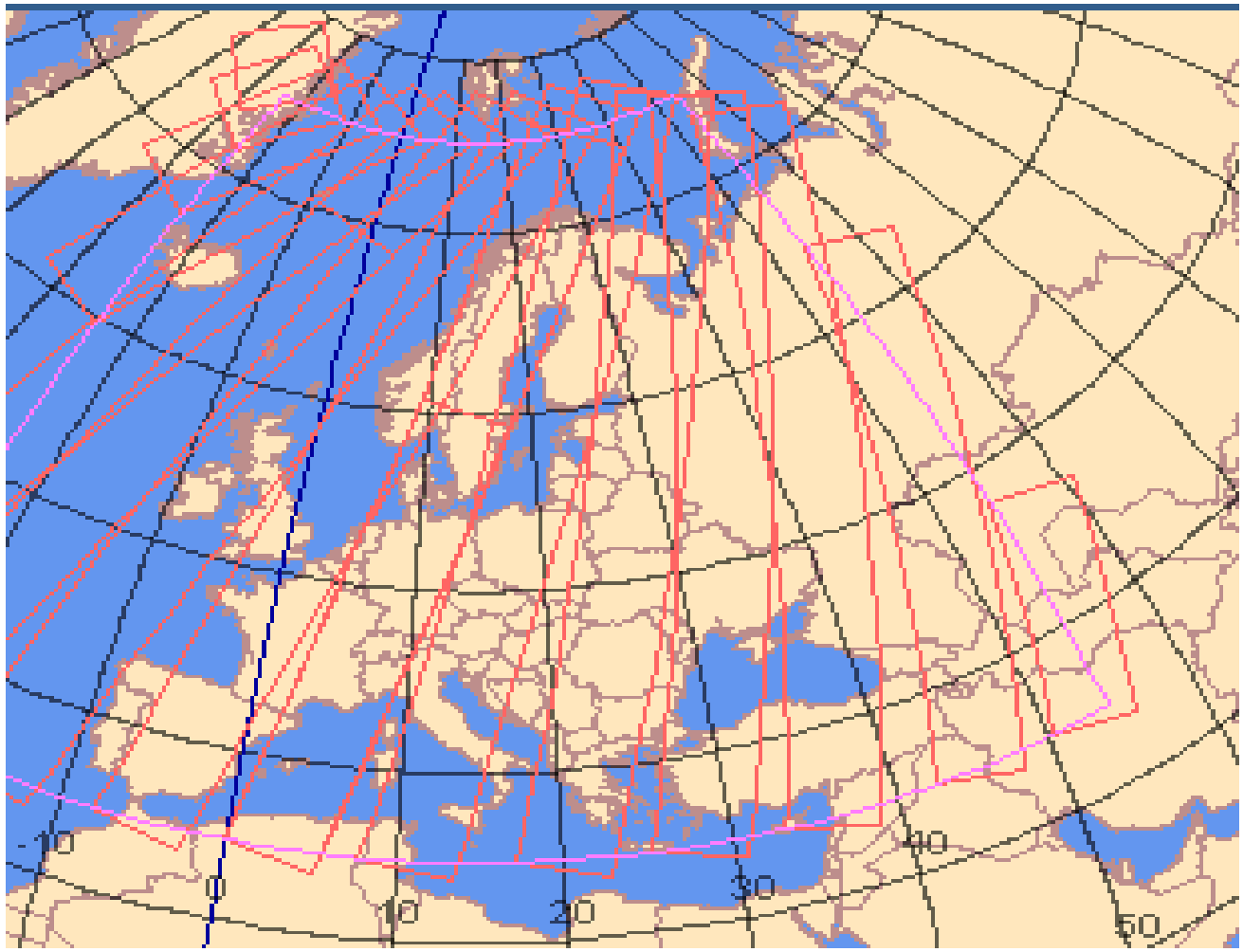
Optical data – the options

- Long time series:
  - NOAA AVHRR (since 1978/1981) – FCDR unavailable currently
  - ERS-2 ATSR-2: (since 1995) – accurate radiometric calibration
- Most spectral information:
  - Terra MODIS (since 2000): 36 channels
- FCDR options:
  - ERS-2 ATSR-2 + Envisat AATSR (since 2002)
  - ERS-2 ATSR-2 + Terra MODIS
  - ERS-2 ATSR-2 + SPOT VEGETATION (since 1998)
- Temporal resolution:
  - Daily products: Only possible with MODIS, AVHRR and VEGETATION
  - Weekly products: Also possible with ATSR-2 and AATSR
- Spatial resolution:
  - Higher than 1 km only possible with MODIS

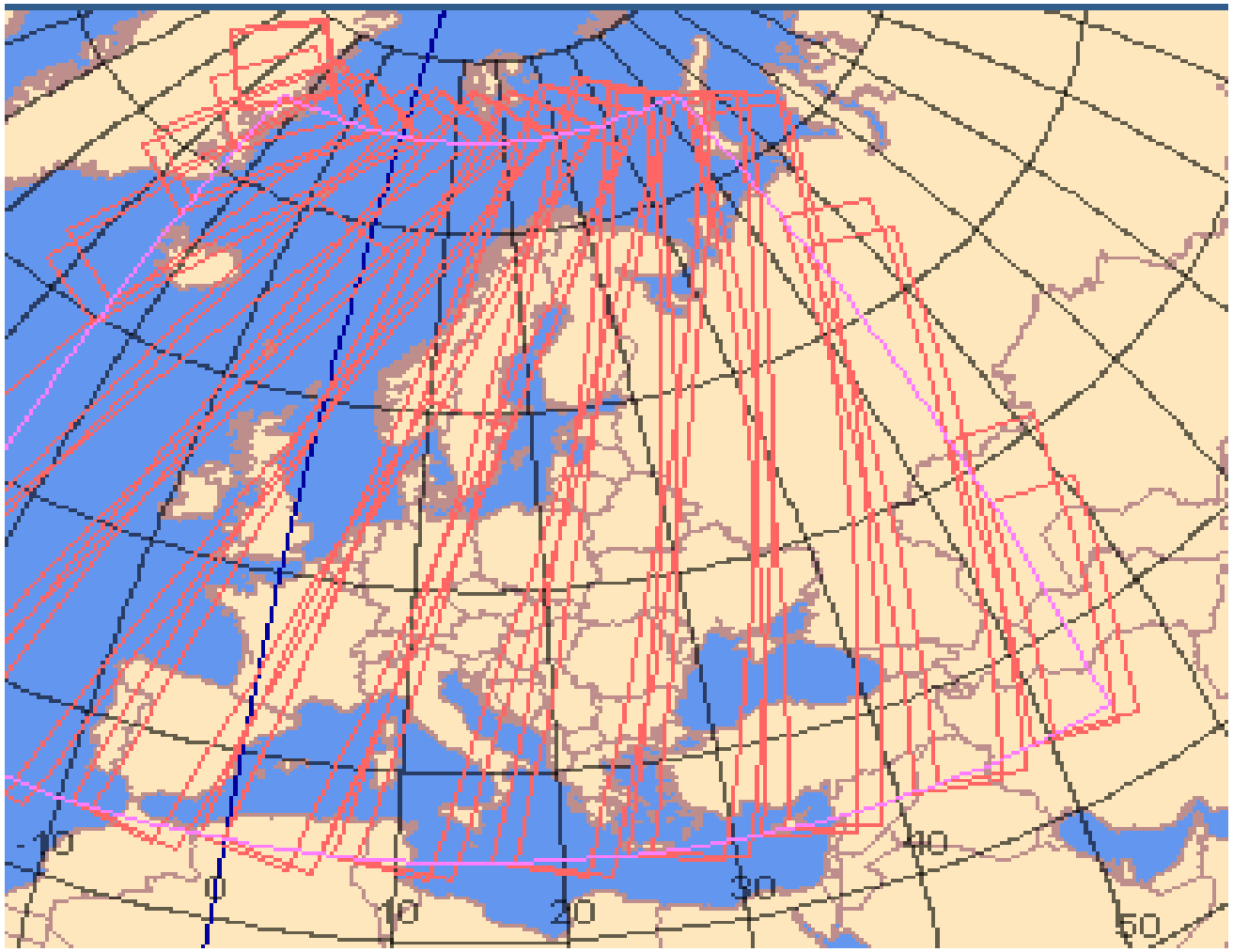
AATSR spatial coverage – 1 day



AATSR spatial coverage – 3 days



AATSR spatial coverage – 6 days



SE optical: Conclusions

- Minimum 15 years time period requires the use of ERS-2 ATSR-2 (from 1995)
- Daily product requires the use of Terra MODIS (from 2000)
- Coverage limited by cloud cover and winter darkness
- Spatial resolution of ~300 m requires Terra MODIS
- Thematic accuracy (≤ 5 %) probably only possible for open non-mountainous terrain
- Handling relevant amounts of data very challenging. Requires machine-interface to data source or delivery of hard disks to the project
- Data availability: MODIS, ATSR-2 and AATSR free
- **The largest of all challenges is the amount of work. GlobSnow is a small project, and the ambitions of the SoW requires processing of the order of hundred of thousands of images of 'unknown land'**

The Snow Extent product…

Criteria	State of the art	Proposed GlobSnow product	User requirements
Coverage	Global	Global (map segments TBD)	
Time period	From 2000	From 1995	
Temporal frequency	Daily	Daily (from 2000), weekly and monthly products, all limited by clouds and winter darkness	
Delivery time	12-48 hours	Target: 24 hours	
Spatial resolution	500 m	1 km (from 1995), 250 or 500 m segments from 2000	
Geometric accuracy	Sub-pixel location accuracy	Sub-pixel location accuracy	
Thematic accuracy	About 60 % FSC threshold snow/no-snow	$\leq$ 5 % (omission and commission) error	
Grid/Projection	TBD	TBD