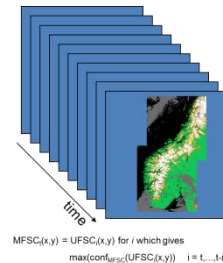
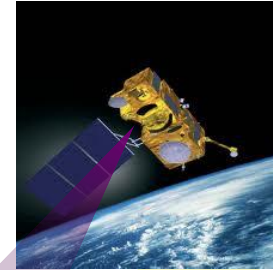
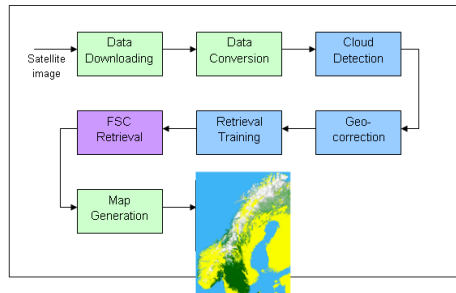


Scandinavian Snow Products

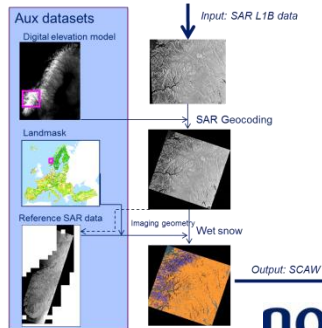


Rune Solberg (NR) and Eirik Malnes (Norut)
Hans Eilif Larsen (KSAT)
Øivind Due Trier (NR)
Heidi Hindberg (Norut)

“Scandinavian snow product and service development concept”



$$MFSC(x,y) = UFSC(x,y) \text{ for } i \text{ which gives } \max(\text{conf}_{MFSC}(UFSC(x,y))) \quad i = 1, \dots, t-n$$



R & D

Operational

User



KONGSBERG
Kongsberg Satellite Services



KONGSBERG
Kongsberg Satellite Services



Operational level / product maturity

Scandinavian snow products



Variable	Developed by	Provider	Resolution	Sensor type	Status
FSC	NR & Norut	KSAT	$0.0025^{\circ} \times 0.0025^{\circ}$	Multi-sensor/temporal [Sentinel-1+3]	Operational (MODIS or VIIRS & RS-2)
SCAW	Norut	KSAT	$0.0005^{\circ} \times 0.0005^{\circ}$	SAR [Sentinel-1]	Operational (Radarsat-2)
SSW	NR	NR	$0.01^{\circ} \times 0.01^{\circ}$	Optical [Sentinel-3]	Pre-operational (MODIS or VIIRS)
SST	NR	NR	$0.01^{\circ} \times 0.01^{\circ}$	Optical [Sentinel-3]	Pre-operational (MODIS or VIIRS)

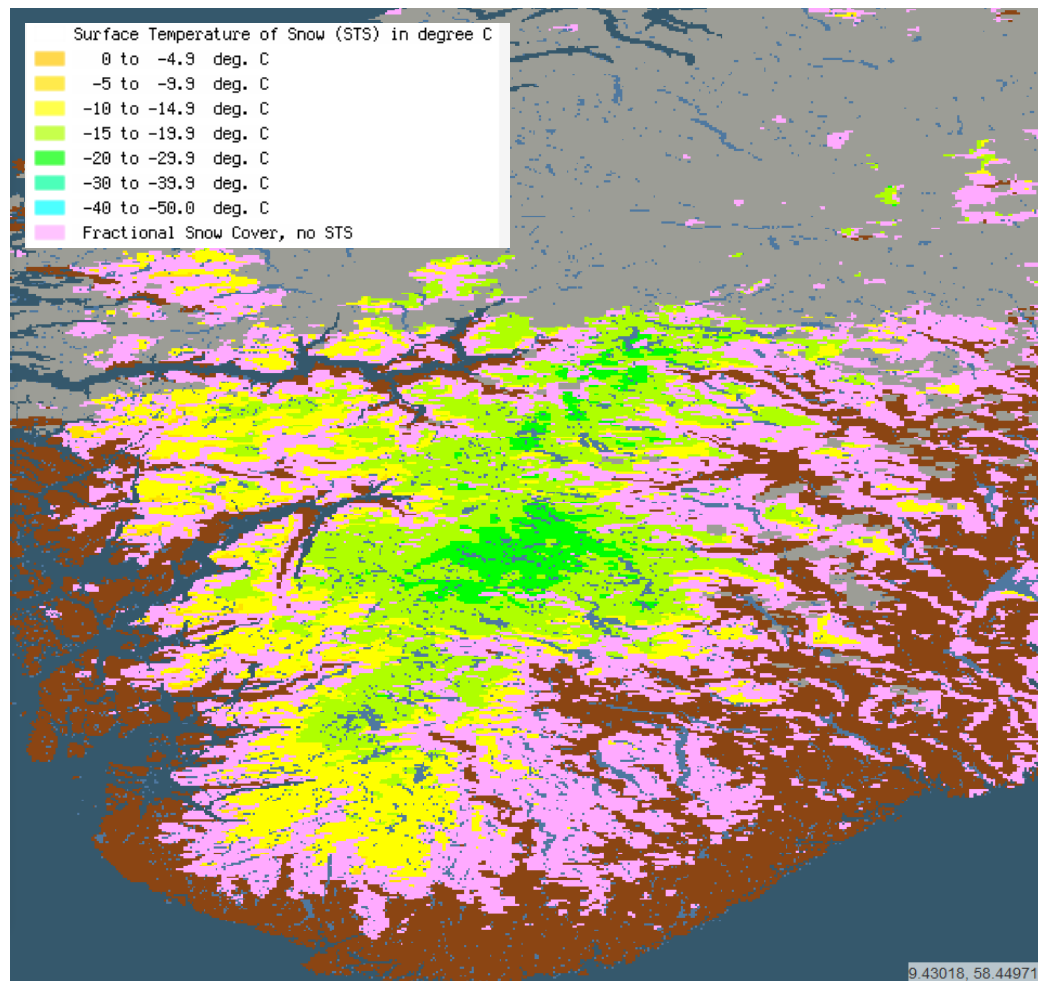


Pre-operational snow surface temperature



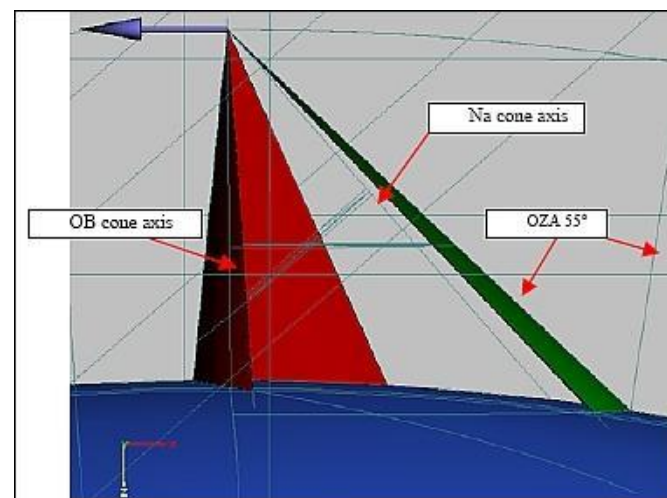
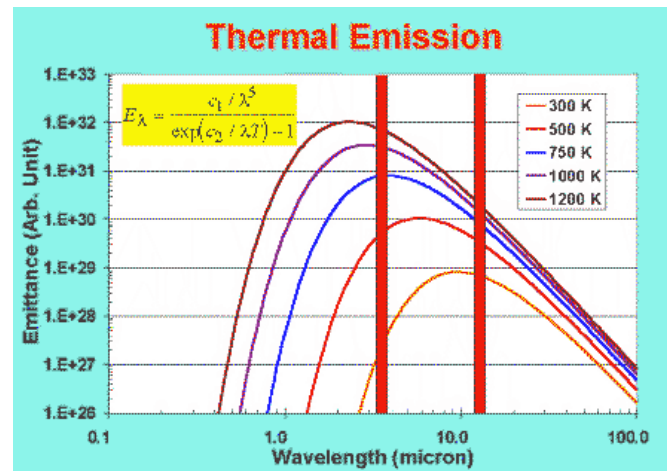
- Thematic information:
 - Skin surface temperature for fully snow-covered surfaces
- Pre-operational service provision:
 - Tested by processing MODIS data for three spring seasons (2012 – 2014)
- Overall results:
 - Stable processing following bug fixing after first large-scale tests
 - Thematic contents generally confirmed when comparing with synoptic data
 - More detailed validation ongoing

Parameter	Description
Thematic variable	Surface Temperature of Snow
Spatial coverage	Local (demonstrated for South Norway)
Delivery time period	Snowmelt season (March-June)
Temporal frequency	Daily
Spatial resolution	0.01° × 0.01°
Sensor	MODIS
Service start	1 March
Service status	Pre-operational (at least 2015)
Service provider	NR (KSAT)



STS for South Norway on 11 March 2013

- Based on Key's algorithm (split window + view angle correction)
- The retrieval algorithm requires that the emissivity of the surface is known. Therefore, we restrict the use to snow-covered surfaces
- Atmospheric correction: Done by measuring the atmospheric effect at two wavelengths and then correcting according to atmospheric path length
- At 0°C we found an accuracy of about 0.5°C in our test site
- Can be applied on NOAA AVHRR, Terra/Aqua MODIS, ENVISAT AATSR and Sentinel-3 SLSTR



Snow

Pan-European

Regional

- ☐ ■ daily_SSW_SouthNorway_Optical ○
- ☒ ■ daily_STS_SouthNorway_Optical ○
- ☐ ■ multitemp_FSC_Scandinavia_Optical_Radar ○
- ☐ ■ daily_FSC_Alps_Optical ○
- ☐ ■ daily_SCAW_Scandinavia_Radar ○
- ☐ ■ multitemp_FSC_Scandinavia_Optical ○
- ☐ ■ daily_FSC_Baltic_Optical ○

In-situ

Lake / River Ice

Glacier

External Services

Overlays

Base Layers

111

5.68933, 62.81128



2

2014-03-15

2014-03-18

2014-03-21

2014-03-24

2014-03-27

2014-03-2014-03-31

2014-04-03



daily_FSC_PanEuropean_Optical

daily_SCAW_Scandinavia_Radar

daily_FSC_Alps_Optical

daily_LIE_Baltic_Optical

RIE_SE_FI_Torne_River_2013_Radar

View_10day_FSC_PanEuropean_Cloudfree

View_10day_LIE_Baltic_Cloudfree

multitemp_FSC_Scandinavia_Optical_Radar

daily_STS_SouthNorway_Optical

Surface Temperature of Snow (STS) in degree C

- 0 to -4.9 deg. C
- 5 to -9.9 deg. C
- 10 to -14.9 deg. C
- 15 to -19.9 deg. C
- 20 to -23.9 deg. C
- 24 to -28.9 deg. C
- 29 to -33.9 deg. C
- 34 to -38.9 deg. C
- 39 to -43.9 deg. C
- 44 to -48.9 deg. C

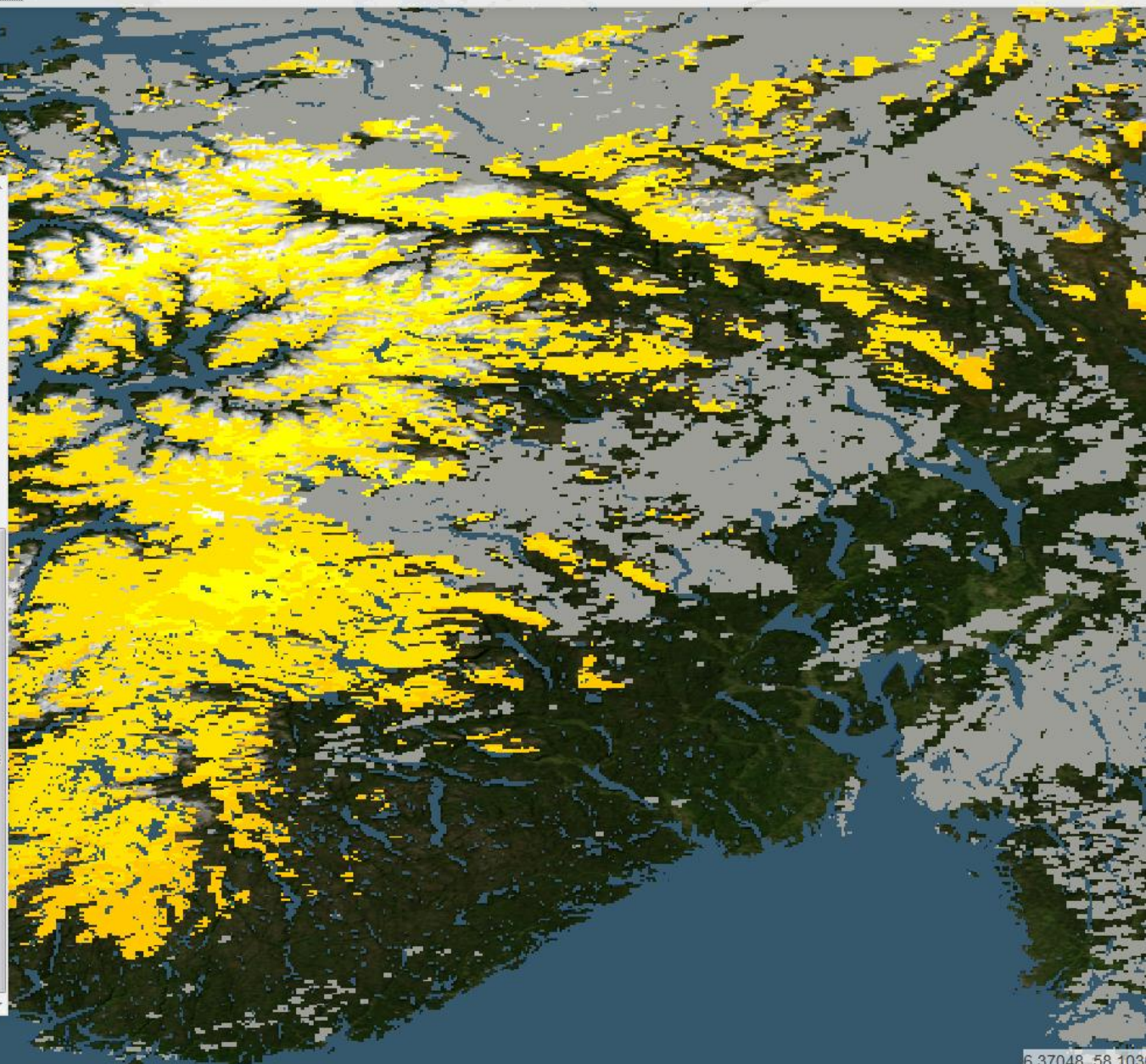
Fractional Snow Cover, no STS

daily_SSW_SouthNorway_Optical

daily_FSC_PanEuropean_Optical_Uncertainty

avg_10day_SSPI_PanEuropean_Microwave

avg_30day_SSPI_PanEuropean_Microwave



6.37048, 58.103



2

2014-03-15

2014-03-18

2014-03-21

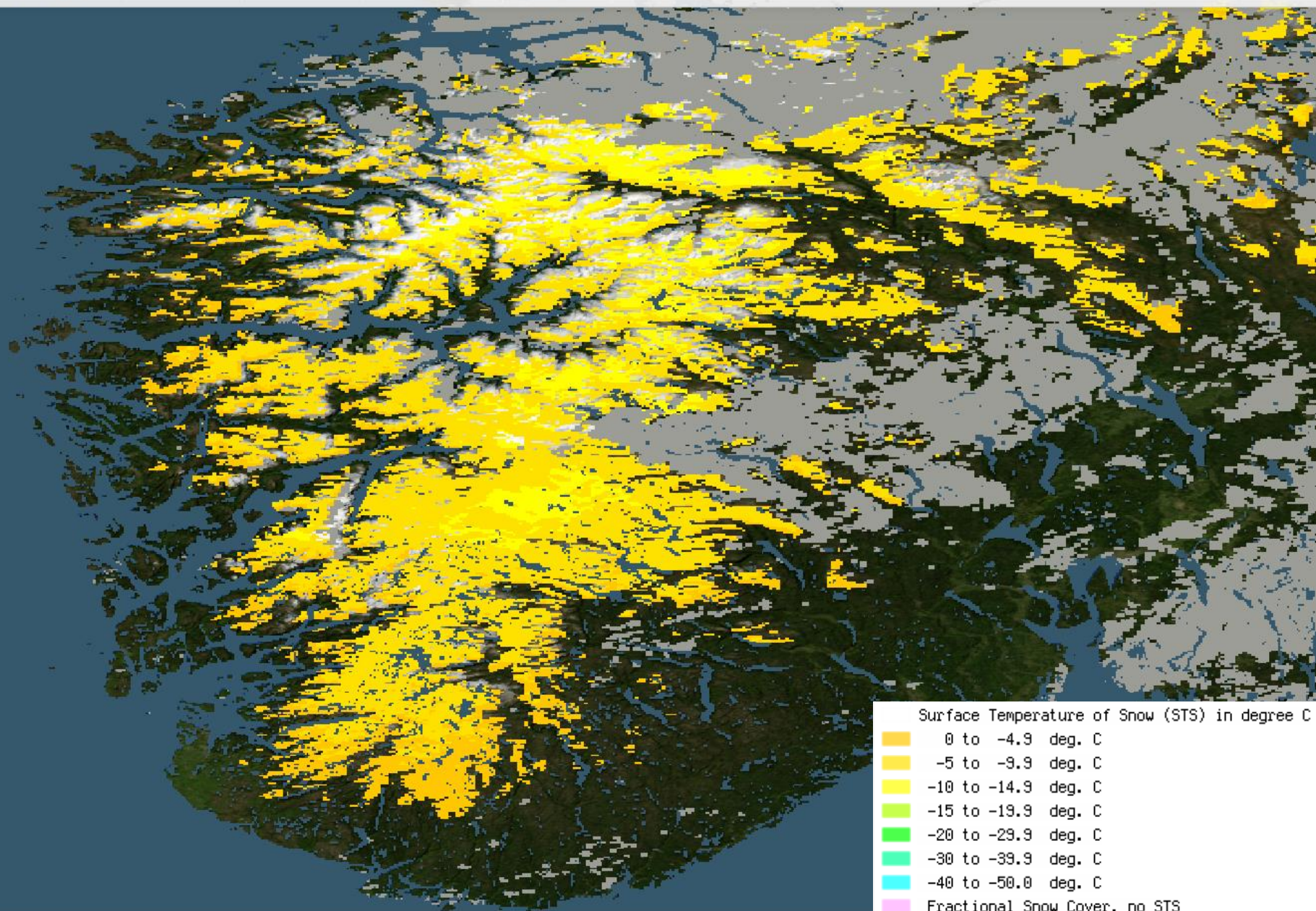
2014-03-24

2014-03-27

2014-03-2014-03-31

2014-04-03





2

2014-03-15

2014-03-18

2014-03-21

2014-03-24

2014-03-27

2014-03-2014-03-31

2014-04-03

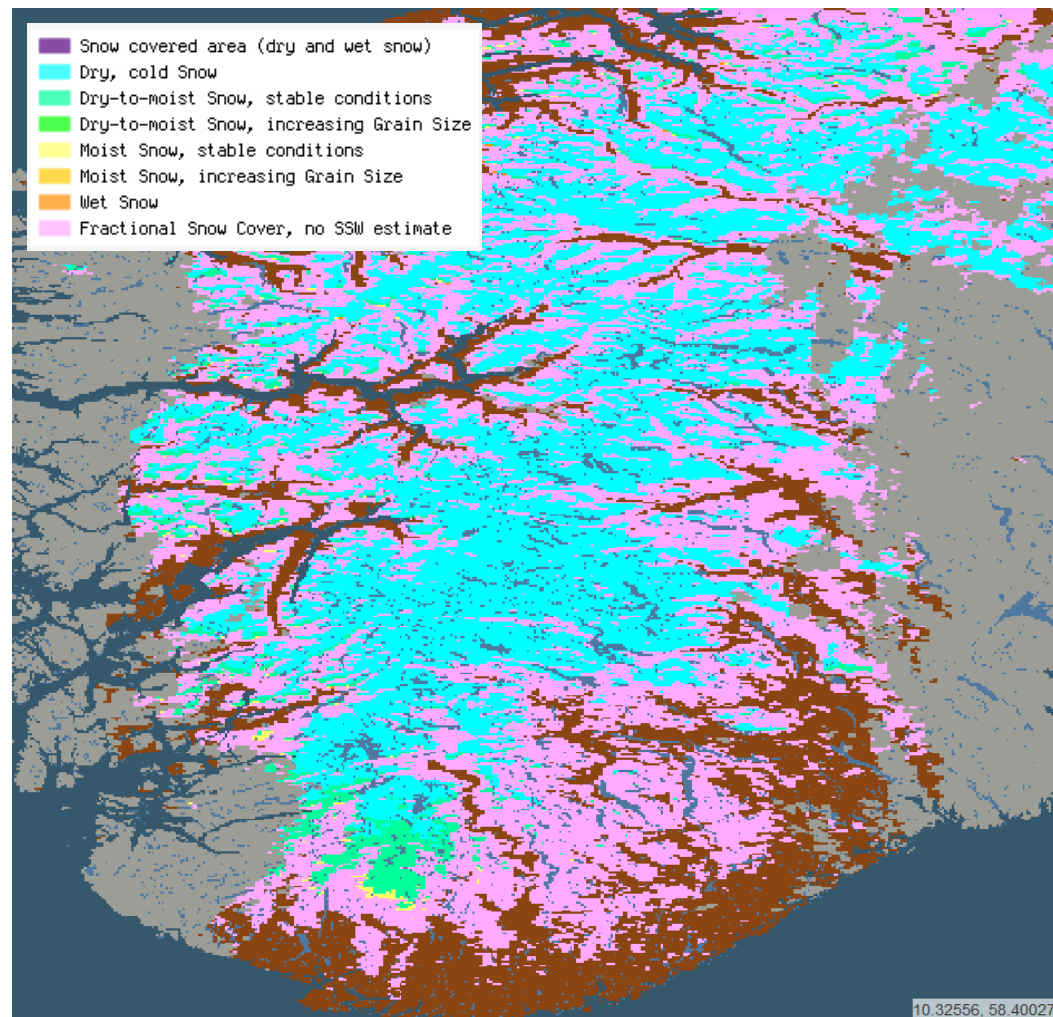


Pre-operational snow surface wetness



- Thematic information:
 - Snow wetness categories for fully snow-covered surfaces
- Testing/verification done:
 - Tested by processing MODIS data for three spring seasons (2012 – 2014)
- Overall results:
 - Stable processing following bug fixing after first large-scale tests
 - Thematic contents generally confirmed when comparing with synoptic data
 - More detailed validation ongoing

Parameter	Description
Thematic variable	Snow Surface Wetness
Spatial coverage	Local (demonstrated for South Norway)
Delivery time period	Snowmelt season (March-June)
Temporal frequency	Daily
Spatial resolution	0.01° × 0.01°
Sensor	MODIS
Service start	1 March
Service status	Pre-operational (at least 2015)
Service provider	NR (KSAT)

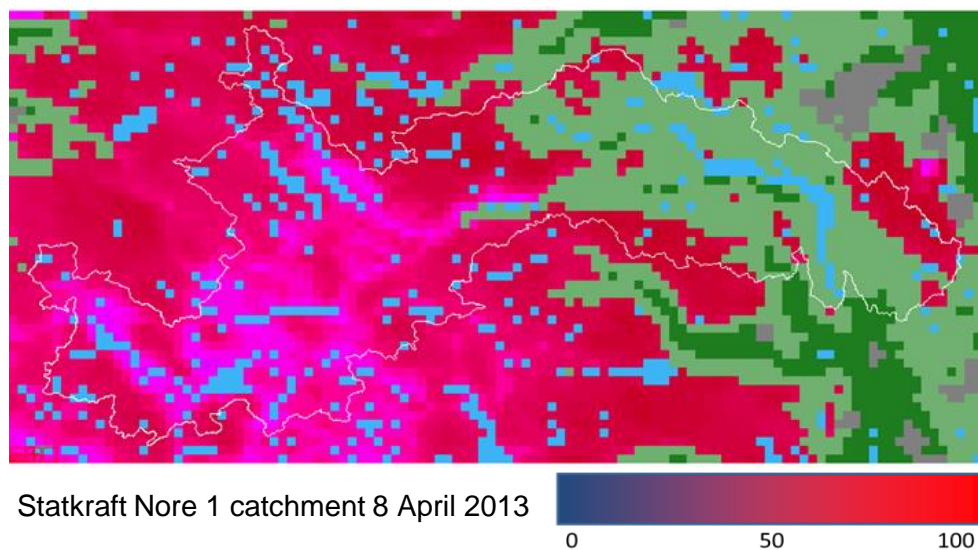
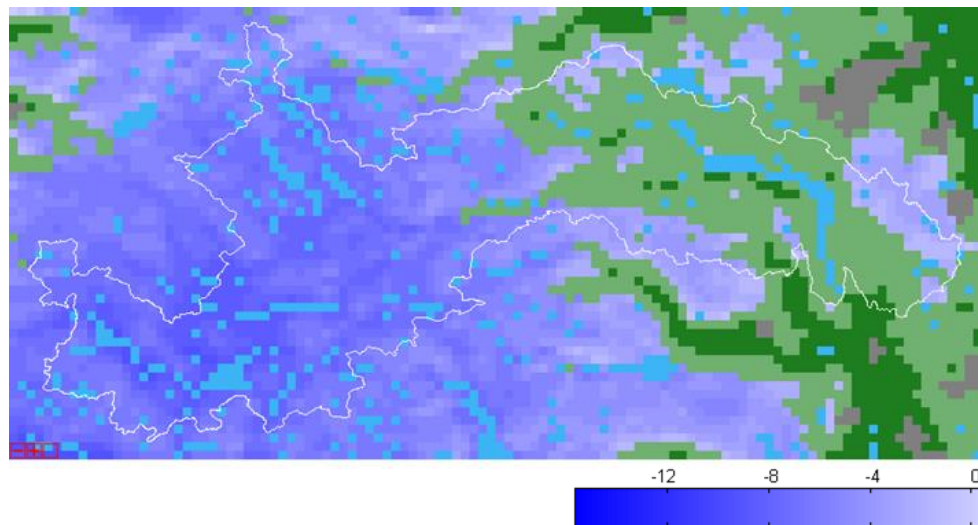


First evidence of snowmelt start in South Norway as seen in the SSW product on 13 April 2013

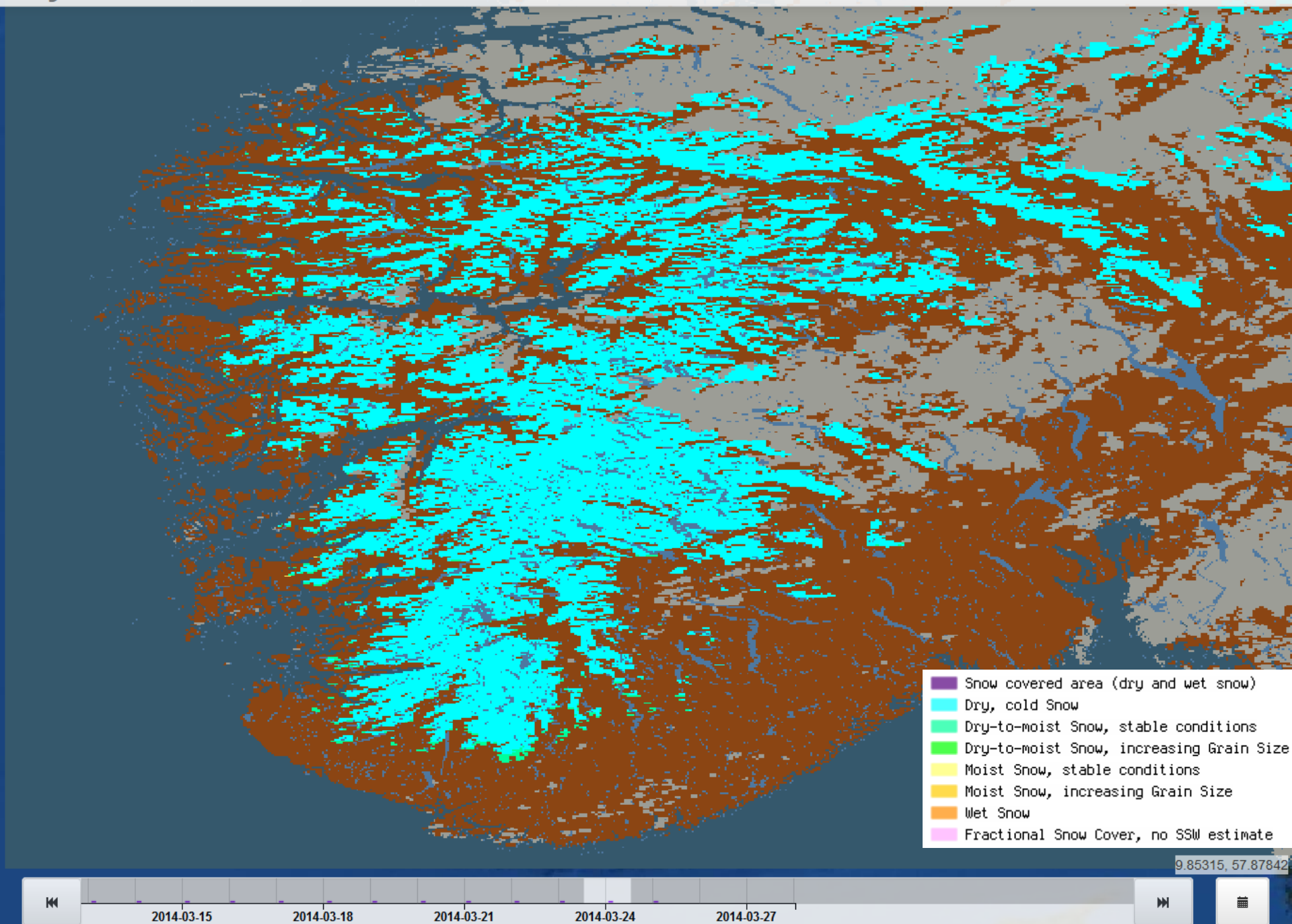
Principle

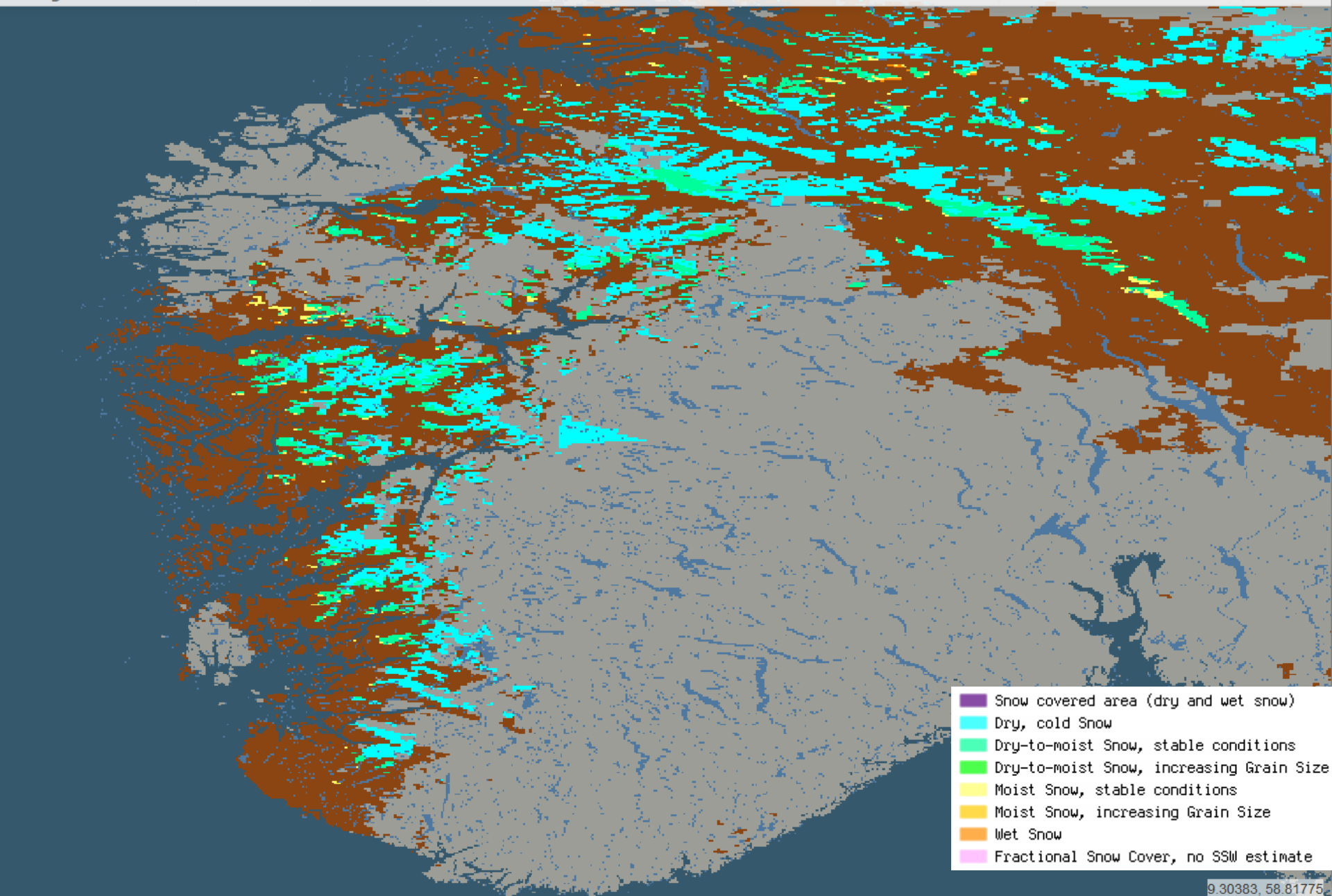


- Infer wet snow from a combination of measurements STS and SGS in a time series of observations
- Temperature gives a good indication of where wet snow may be present
- Rapid increase in the effective grain size simultaneously is a strong indication of a wet snow surface
- A temporal algorithm combining SGS and STS is applied to infer categorical SSW
- Can be applied on NOAA AVHRR, Terra/Aqua MODIS, ENVISAT AATSR and Sentinel-3 SLSTR



Statkraft Nore 1 catchment 8 April 2013





- Snow covered area (dry and wet snow)
- Dry, cold Snow
- Dry-to-moist Snow, stable conditions
- Dry-to-moist Snow, increasing Grain Size
- Moist Snow, stable conditions
- Moist Snow, increasing Grain Size
- Wet Snow
- Fractional Snow Cover, no SSW estimate

9.30383, 58.81775



2014-03-18

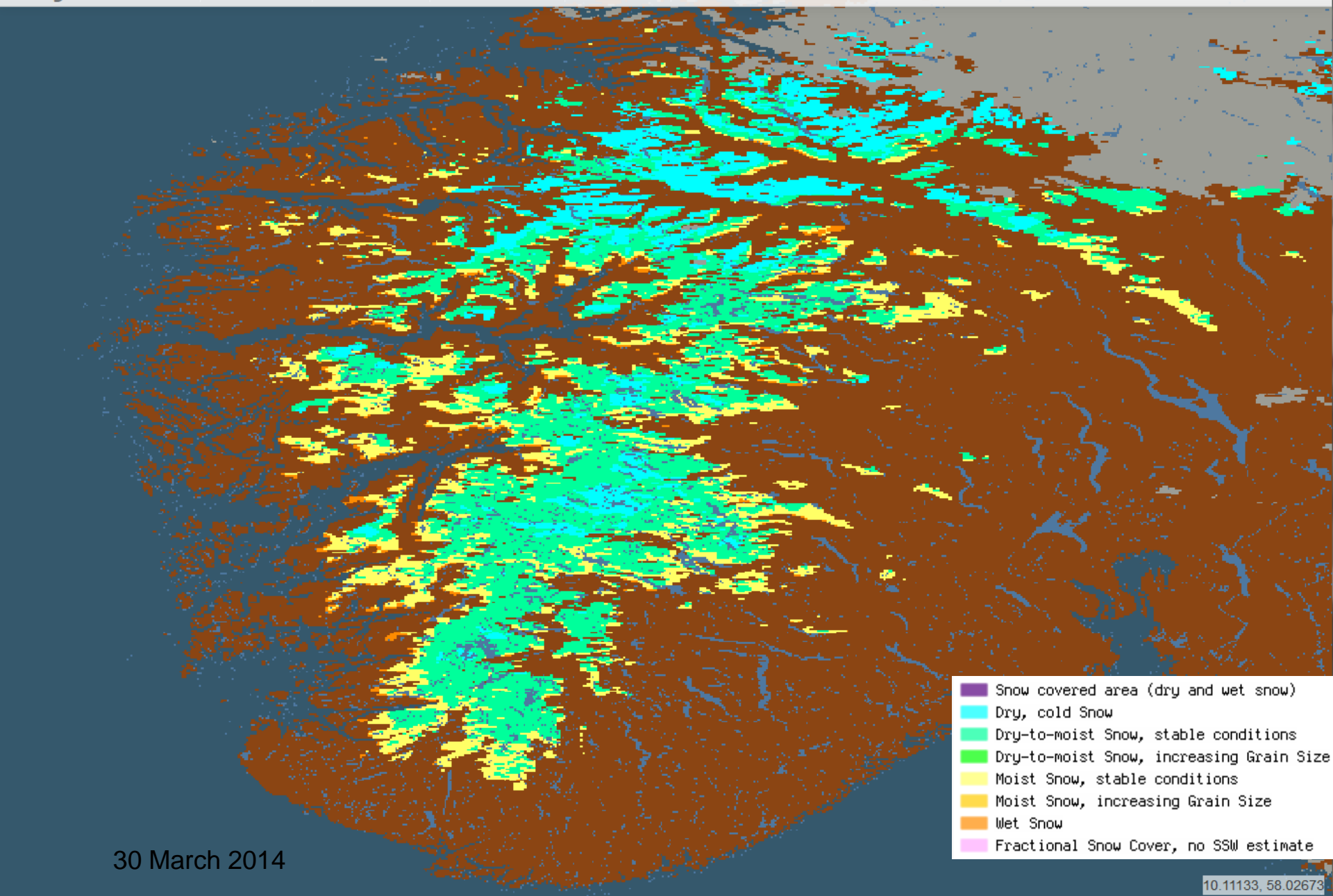
2014-03-21

2014-03-24

2014-03-27

2014-03-2014-03-31





2014-03-21

2014-03-24

2014-03-27

2014-03-2014-03-31

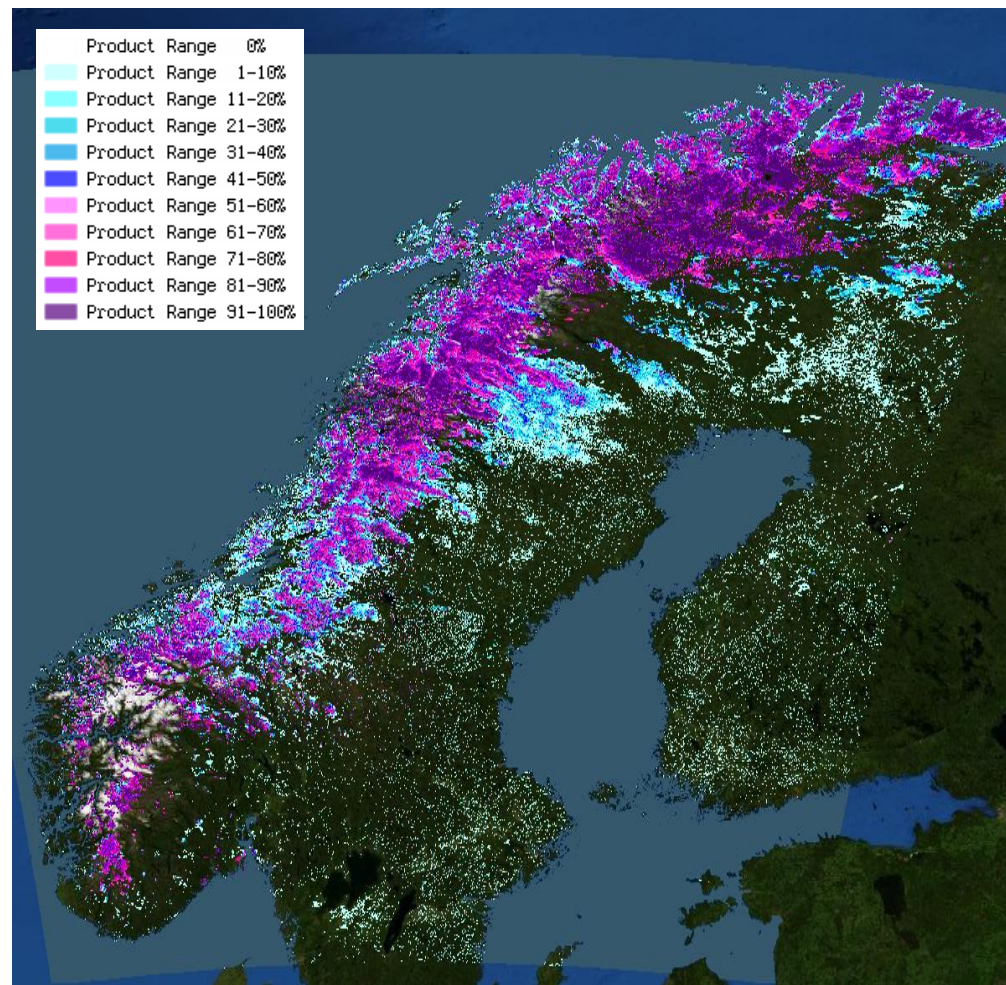


Operational fractional snow cover



- Fractional Snow Cover (FSC)
- Multi-sensor / multi-temporal Radarsat-2 & MODIS
- Manual inspection indicate overall good results
- Testing/verification for 2012/13
- Runs operationally at KSAT

Parameter	Description
Thematic variable	Fractional Snow Cover (FSC)
Spatial coverage	Scandinavia
Delivery time period	15 March – 1 August
Temporal frequency	Daily
Spatial resolution	0.0025° × 0.0025°
Sensor	Terra MODIS, Radarsat-2
Service start	15 March
Service status	Operational (at least 2015)
Service provider	KSAT

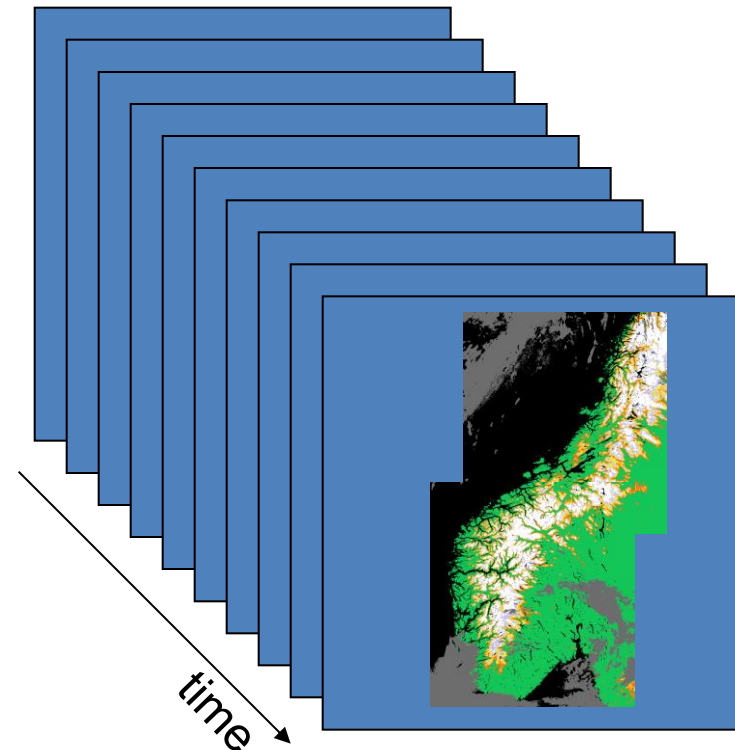


Regional fractional snow cover map from MODIS and Radarsat-2 of 16 May 2013

Multi-sensor multi-temporal principle



- Let each pixel in each optical and SAR image have a confidence value (based on sensor models)
- Let the confidence of a product decrease with time (e.g. linearly)
- Compute the most likely FSC for each pixel based on the above

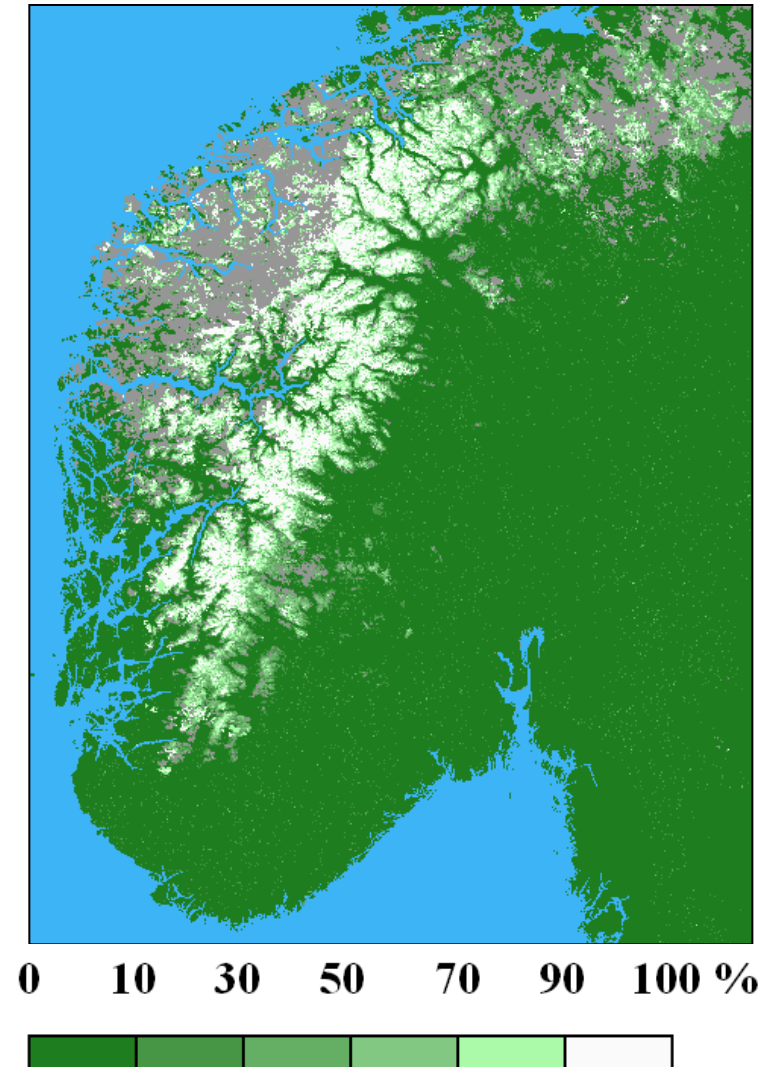


$$\text{MFSC}_t(x,y) = \text{UFSC}_i(x,y) \text{ for } i \text{ which gives} \\ \max(\text{conf}_{\text{MFSC}}(\text{UFSC}_i(x,y))) \quad i = t, \dots, t-n$$

Optical fractional snow cover principle



- Two-class linear spectral mixing model applying the visible part of the spectrum
- Regional training 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, MERIS and AATSR
- Accuracy: 5-20% FSC error
- Can be applied on NOAA AVHRR, Terra/Aqua MODIS, ENVISAT MERIS/AATSR and Sentinel-3 OLCI/SLSTR



Improvement using SAR

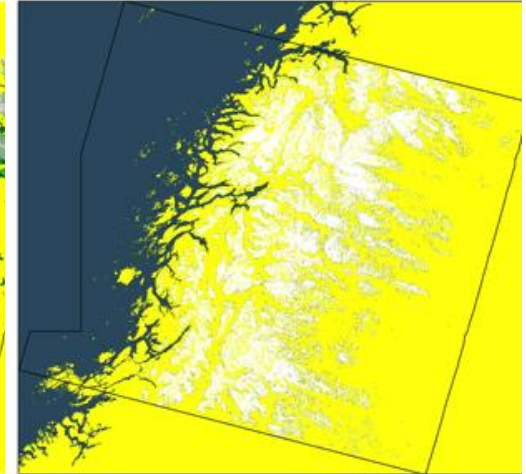
May 30th 2012

- Cloud cover can be significantly reduced when taking SAR into account
- Works best in the spring/summer when there is a lot of wet snow in the mountains
- Can also have an impact early in the season and for the first snow fall in the autumn
- Limited capabilities during the polar darkness period since MODIS data is lacking

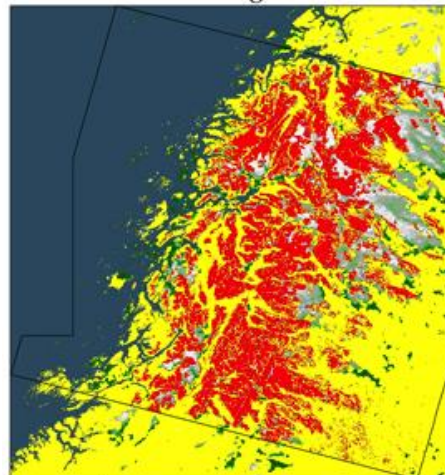
Modis SCF, 85% clouds.



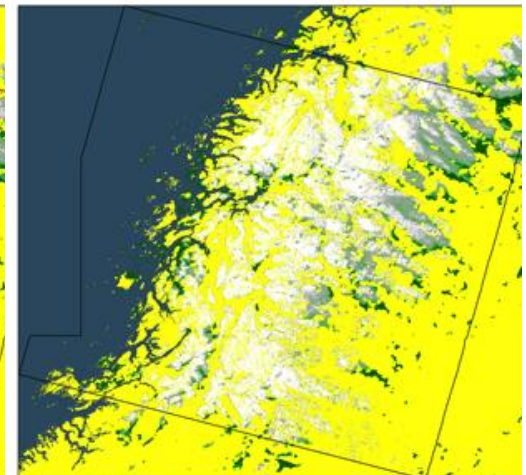
SCAW



Change indicator



MODIS + SCAW SCF, 65% clouds.

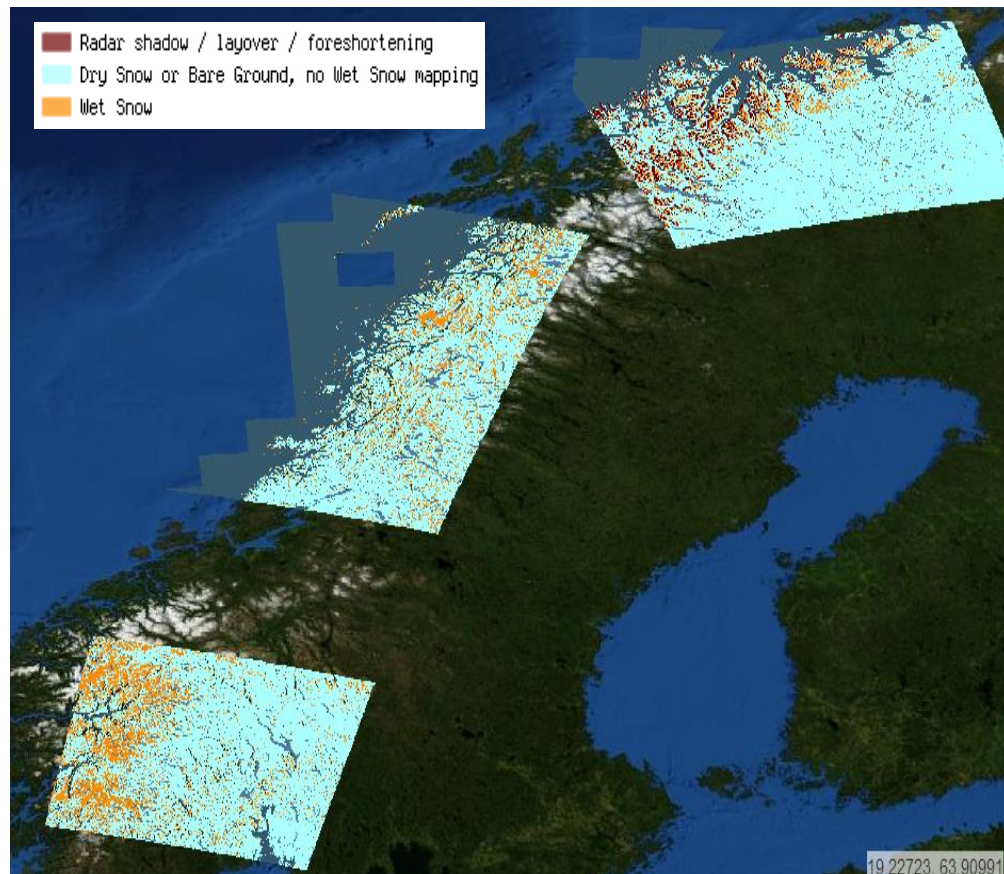


Operational snow covered area wet



- Radarsat-2 algorithm implemented at KSAT
- Testing in 2012, validation versus high-resolution optical data from 2013
- Ran automatically since January 2013
- Processing ready for Sentinel-1 launch, first snow map late 2014/early 2015

Parameter	Description
Thematic variable	Snow covered area wet (SCAW)
Spatial coverage	Scandinavia
Delivery time period	All year
Temporal frequency	Daily
Spatial resolution	$0.0005^{\circ} \times 0.0005^{\circ}$
Sensor	Radarsat-2
Service start	January 2013
Service status	Operational
Service provider	KSAT

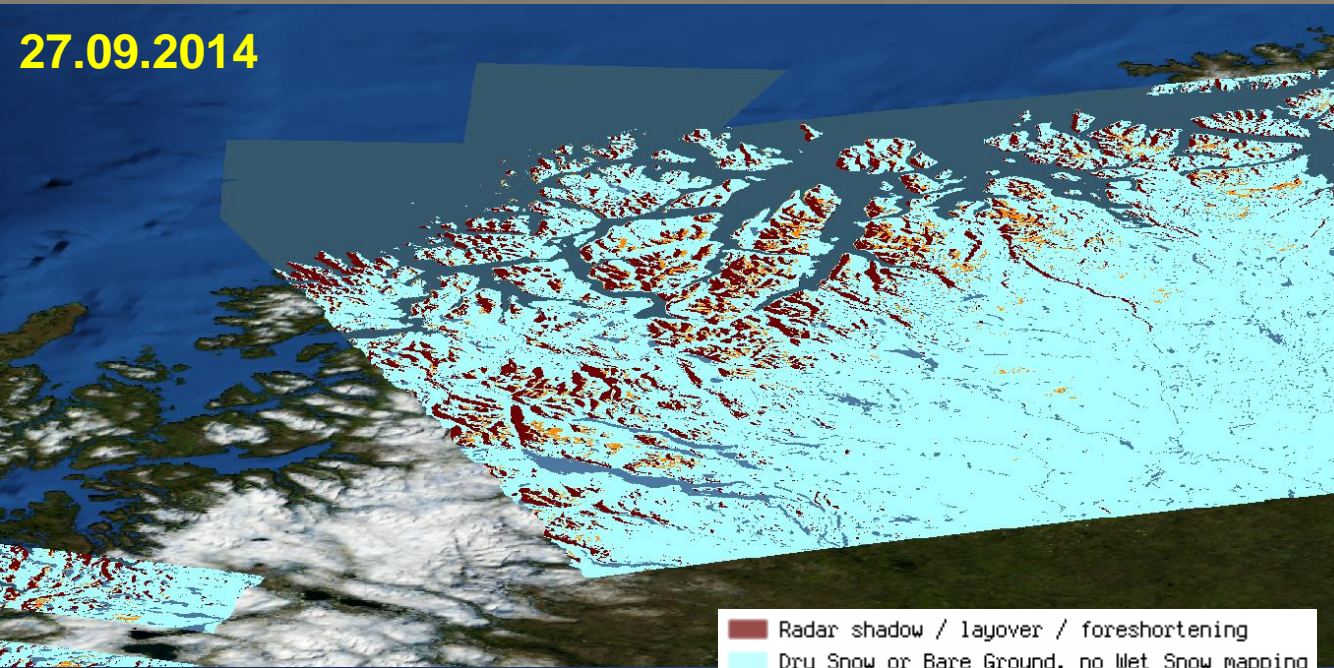


SCAW from Radarsat-2 over Scandinavia at 4 June 2013

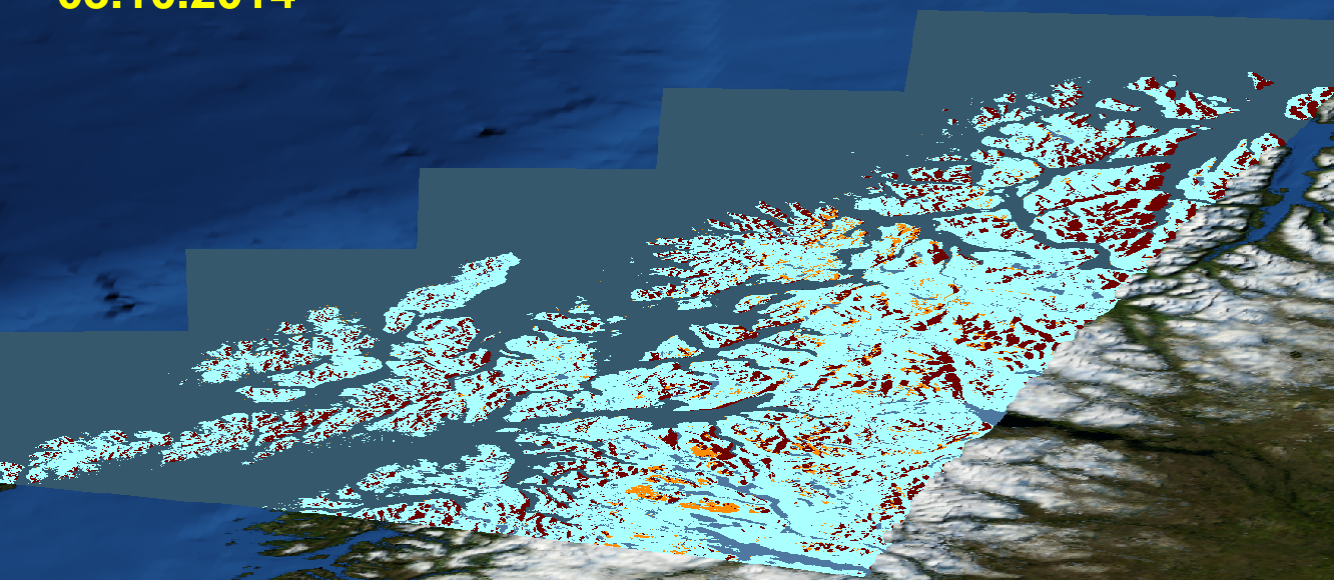
Early snowfall Sept 2014



27.09.2014



03.10.2014



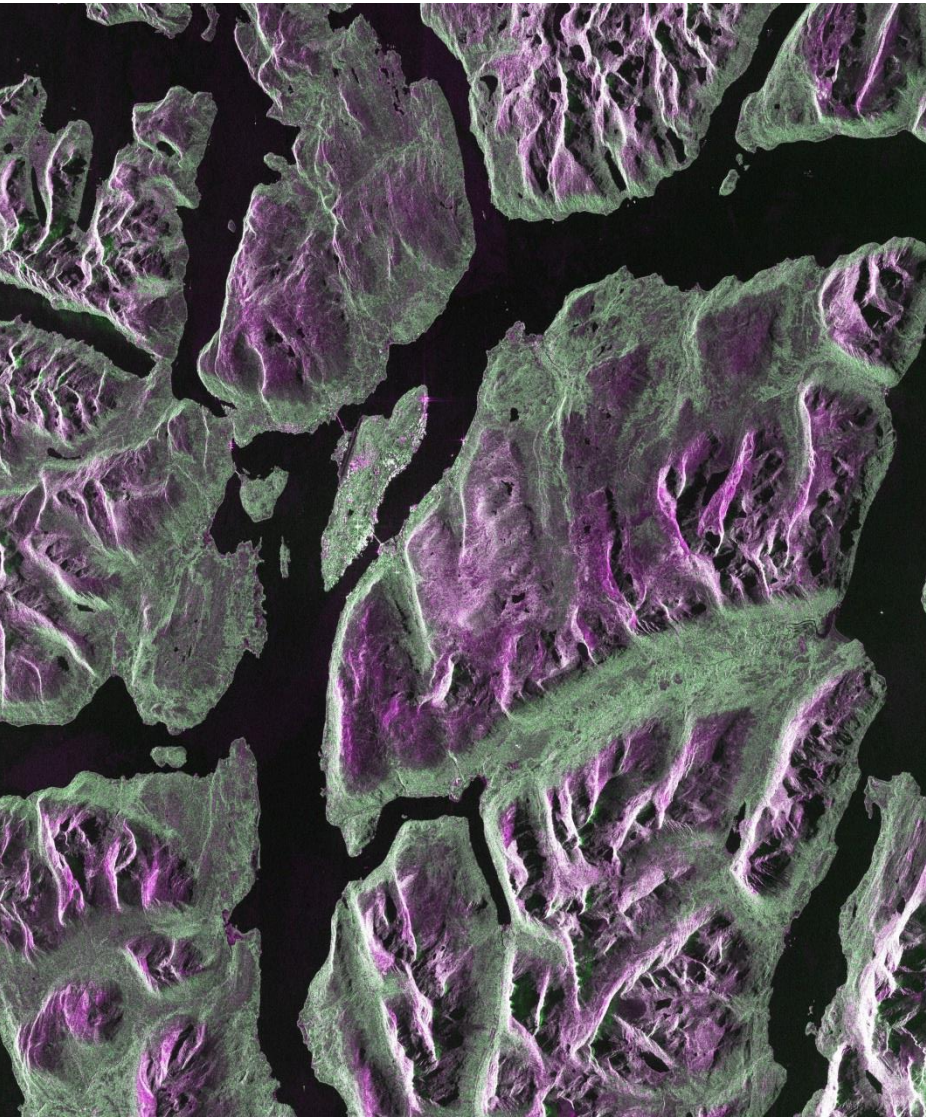
■ Radar shadow / layover / foreshortening
■ Dry Snow or Bare Ground, no Wet Snow mapping
■ Wet Snow

First Sentinel1A images

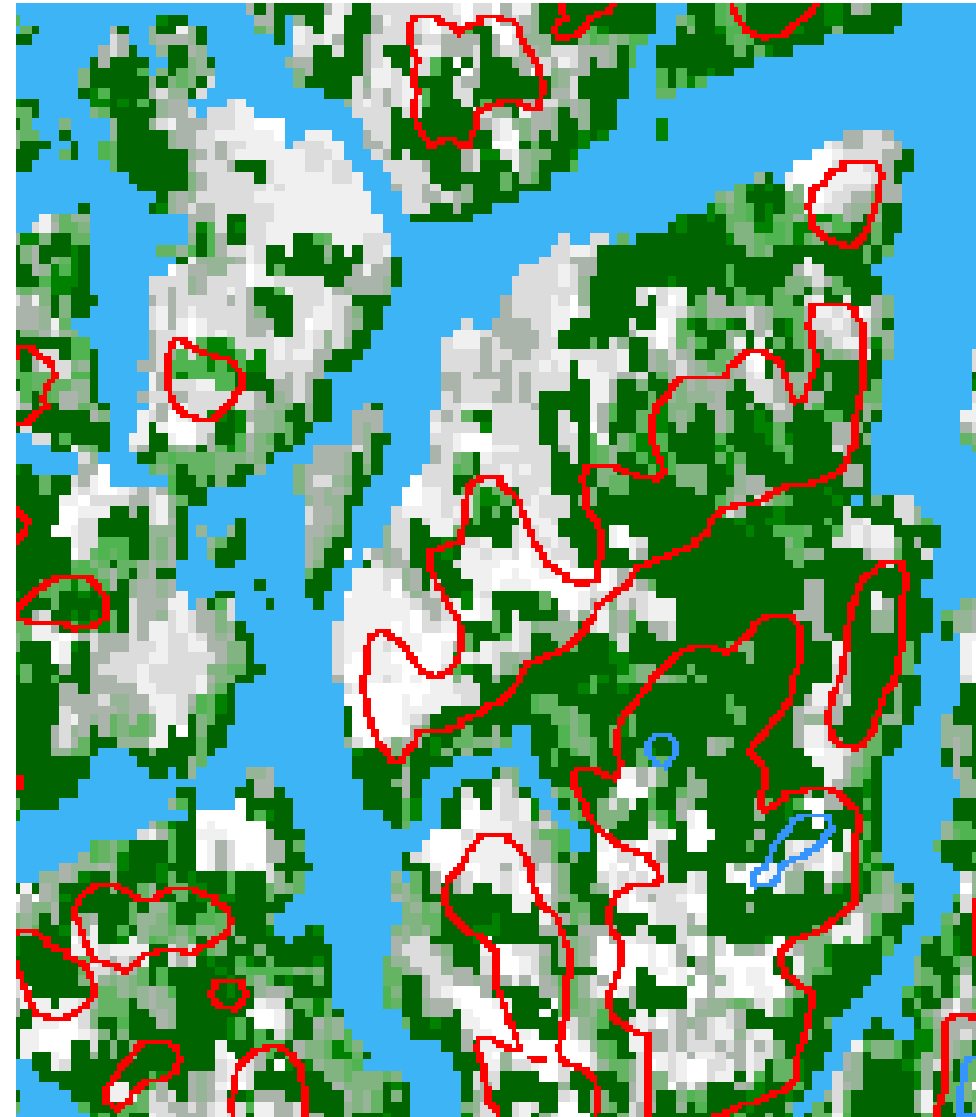
-SCAW products not available yet



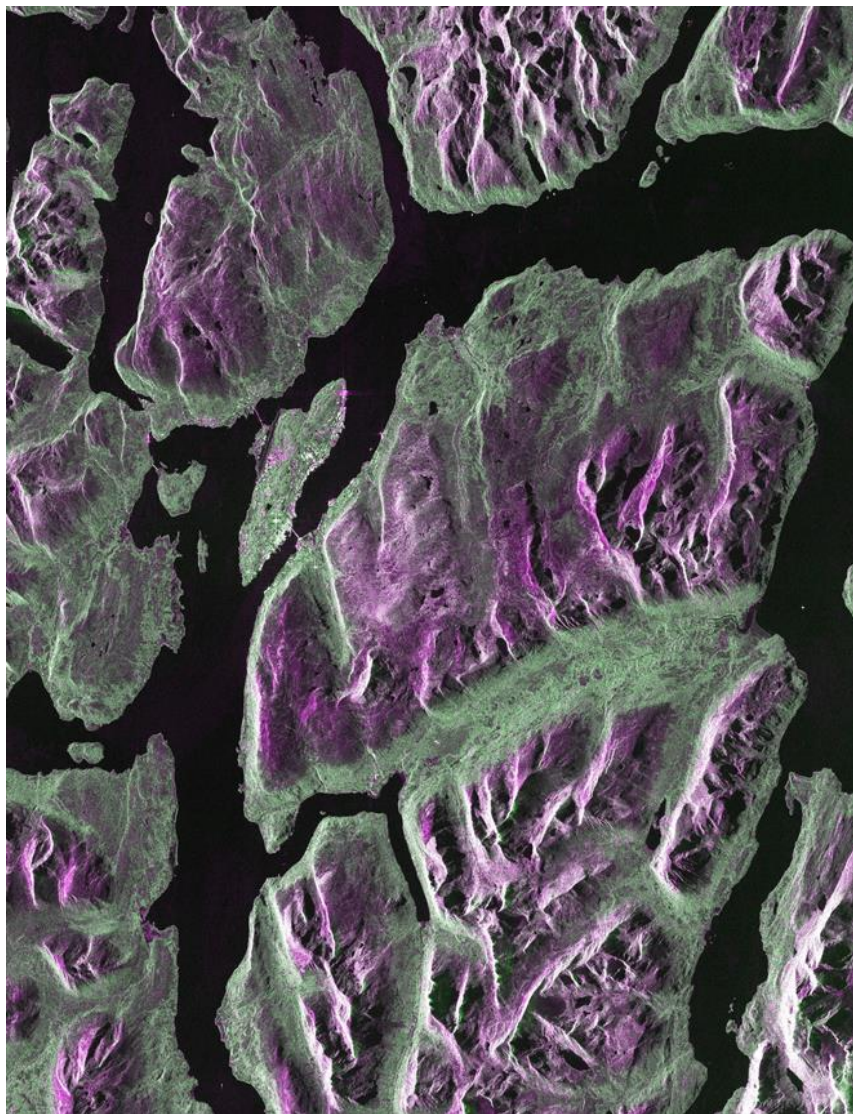
S1 IW 2014.09.20 16:16



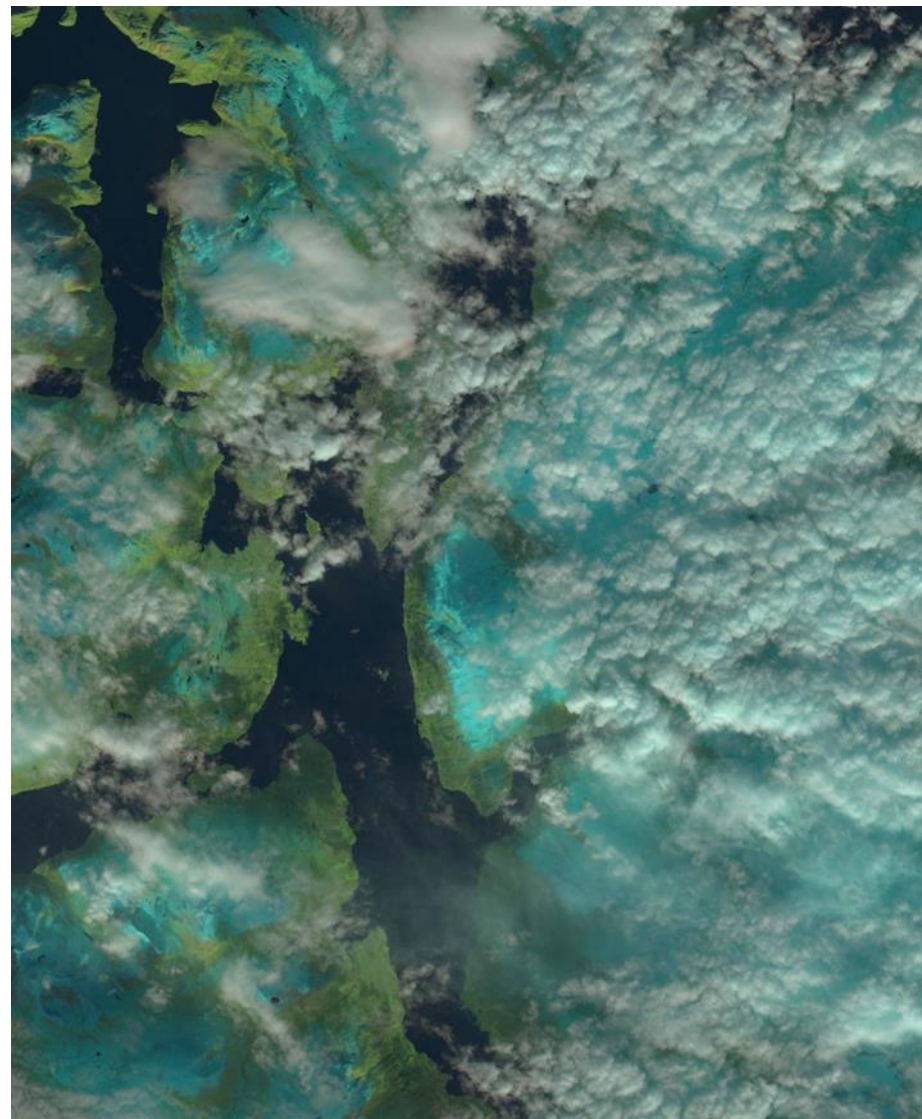
MODIS 2014.09.23 12:00
(interpolated temporaly)



S1 IW 2014.09.20 16:16 (R,G,B)=(VV,VH,VV)



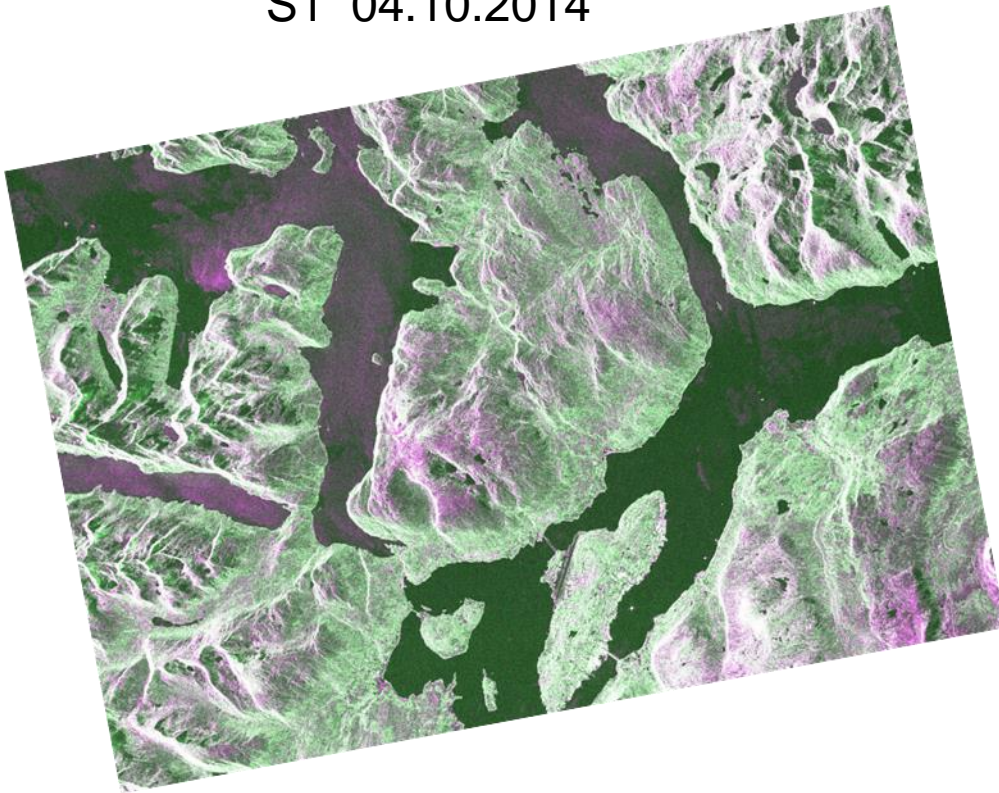
LS-8 2014.09.23 12:00



Sentinel-1A vs Landsat-8



S1 04.10.2014



LS 03.10.2014

