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Empirical Approach in Satellite Snow Detection

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EUMeTrain 10.2.2021

How can you develop satellite snow products

or

What did I do for my PhD thesis?

Why?

UK weather: Hundreds of schools shut and drivers warned of chaos as cold snap set to hit -15C

Hundreds of schools closed across country as

Met Offi warning as Storm Beast from th

d in apped n

vel ntry - BBC

eads to power

Malvern Gazette

News Jobs Sport E-editions What's On Announcements Buy & Sell WW1 Education

News

SNOW 2017: Disruption this Monday as snow chaos continues in Worcestershire

Last updated: 11th December 2017

Travel disruption and schools off as the working week begins.
The big freeze will be hitting the county this evening will temperatures set to plummet to -8C.
Continued coverage throughout the day here on the Worcester News website.

Most read

1

You co couple home raffle

News Devon News

Devon co Office

Snow and ic as thousand happened

Snow and ic thousands

causing UK's worst we

Snow chaos causes deaths, disrupts travel and closes schools and hospitals across the UK as Met Office issues red alert

n Emma, years

What is snow?
Challenges
Satellites
Snow Products
Validation
Future
Conclusions

Snow?

Reality

Chaos!

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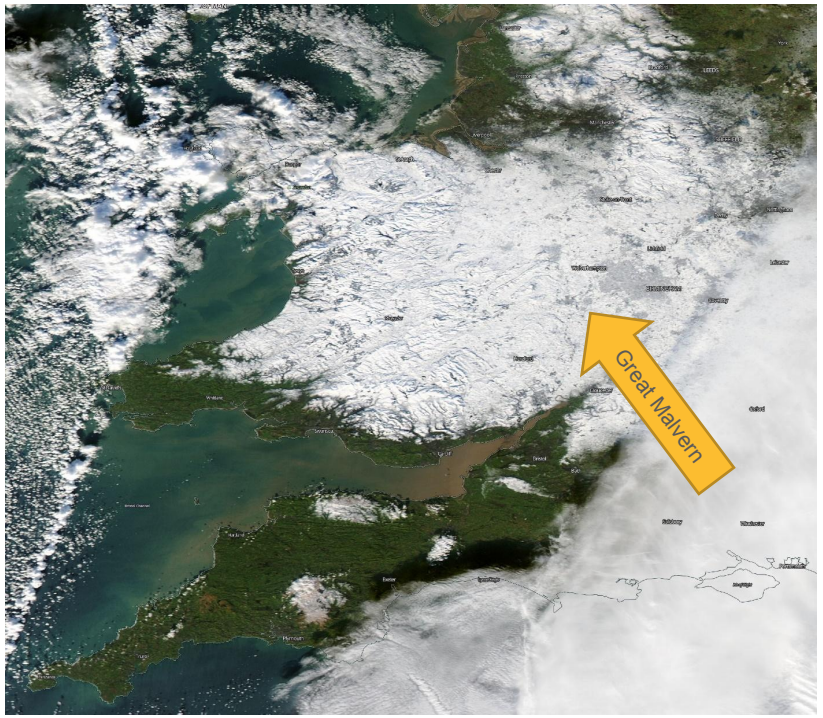
Challenges

- Variability
  - Snow types and structures
  - Temporal variability (new snow, melting snow)
  - Spatial variability
    - Vegetation
    - Forests (tree density, tree species)
    - Small lakes and rivers
    - Solar angles, viewing angles
    - Shadows
- Darkness
- Clouds

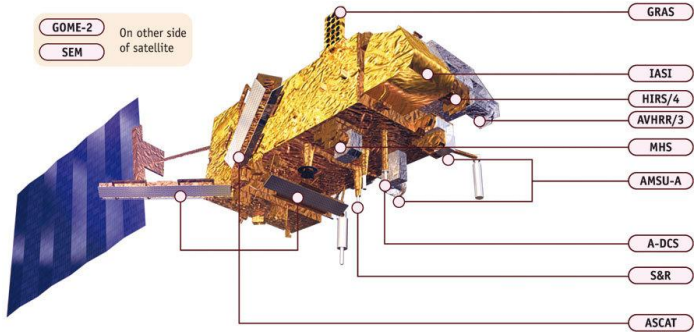
December 12, 2017

Severn Valley from The Beacon, Malvern Hills, UK



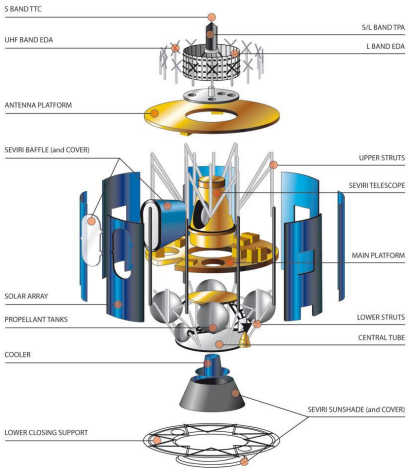
MODIS image: NASA Worldview

Two types of satellites



Geostationary orbit

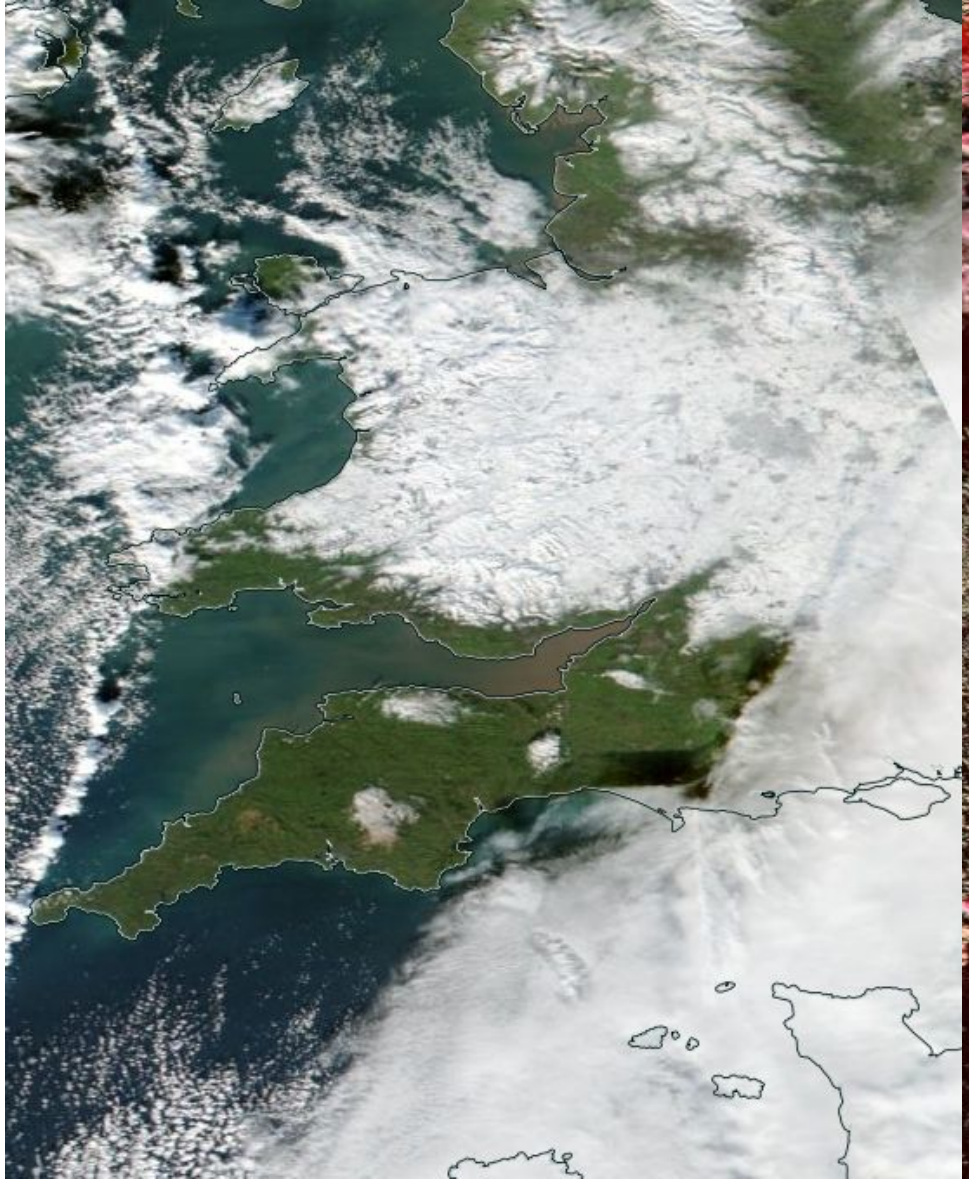
- Detection disk
- High temporal resolution
- Low spatial resolution near the edge of the disk
- Constant viewing angles
- Changing solar angles
- Example: MSG/SEVIRI radiometer, 12 channels



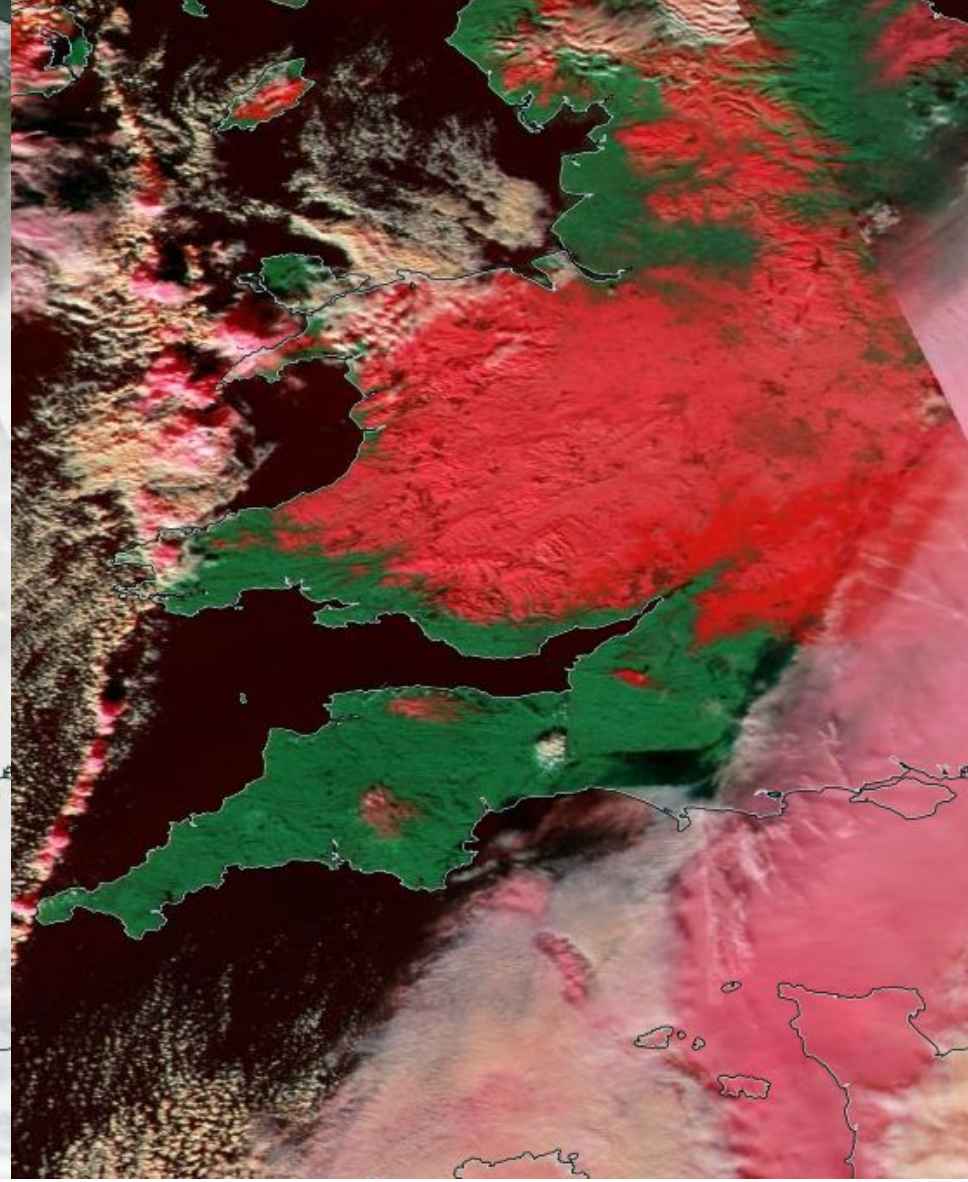
Polar orbit

- Global coverage
- Low temporal resolution
- High spatial resolution
- Changing viewing angles
- Changing solar angles
- Example: Metop/AVHRR radiometer, 6 channels

MODIS RGB, different channels



MODIS, true color corrected reflectance



MODIS, M3-I3-M11 corrected reflectance

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MODIS images: NASA Worldview

Product development preferences

- Planned users: e.g. NWP and meteorological applications
- What these users need? What preferences there are?
  - Ask!

➡️ NWP preferences:

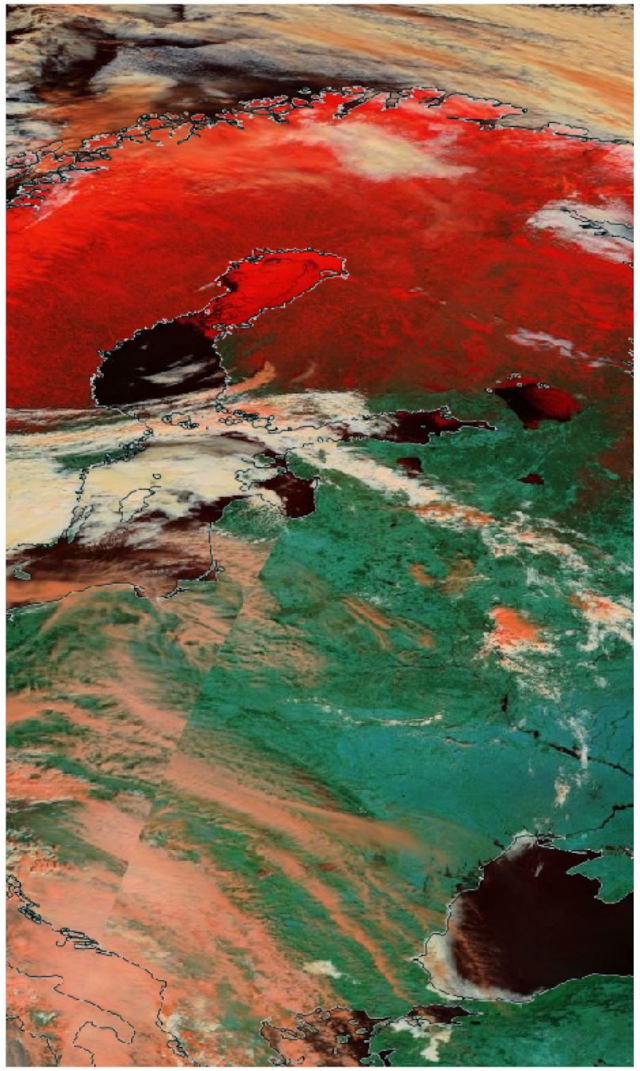
  - Accuracy over coverage (do not force classification, avoid misclassifications)
  - Single-source data (satellite data only, do not smuggle in other data)
  - Directness: Avoid redundant steps (such as cloud masking)
  - Availability: Operational products

MODIS and AVHRR RGB

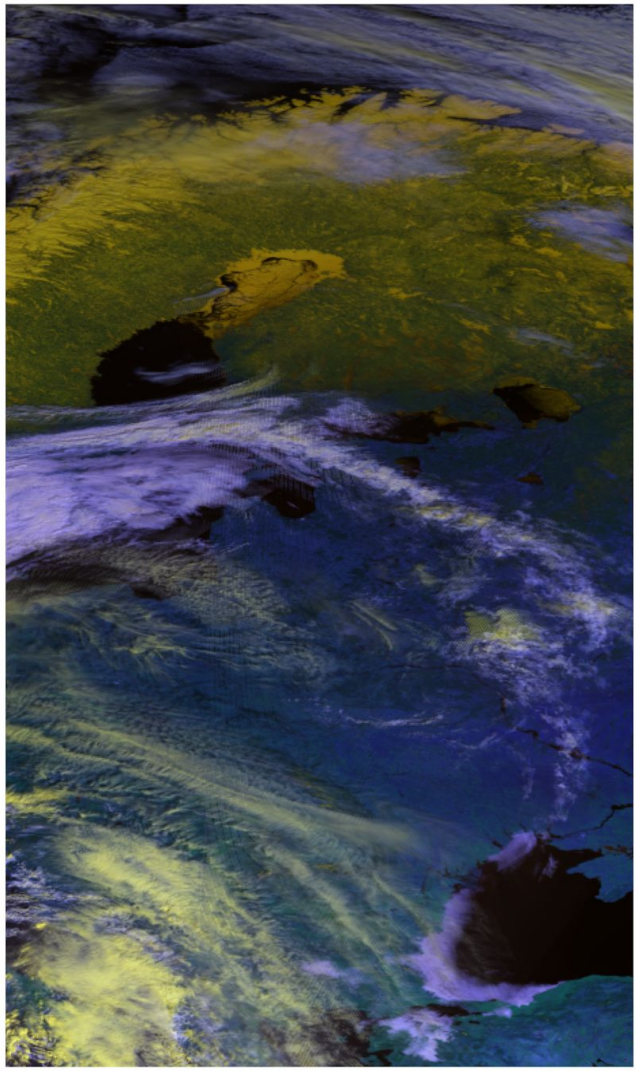
vs

H SAF H32 Metop/AVHRR Snow Extent

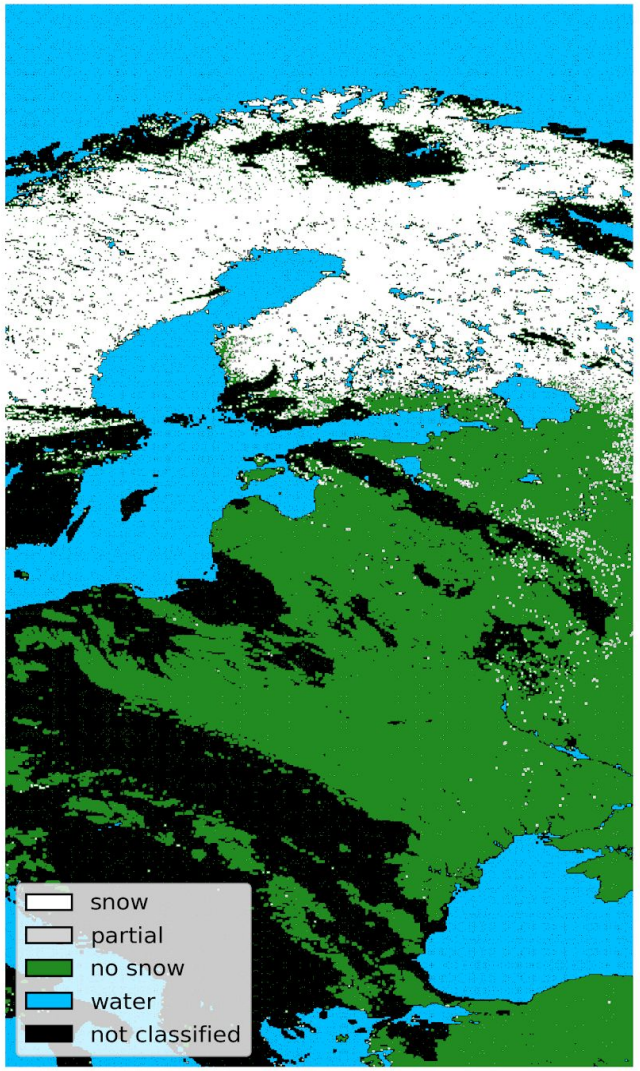
MODIS 20180415



AVHRR 20180415



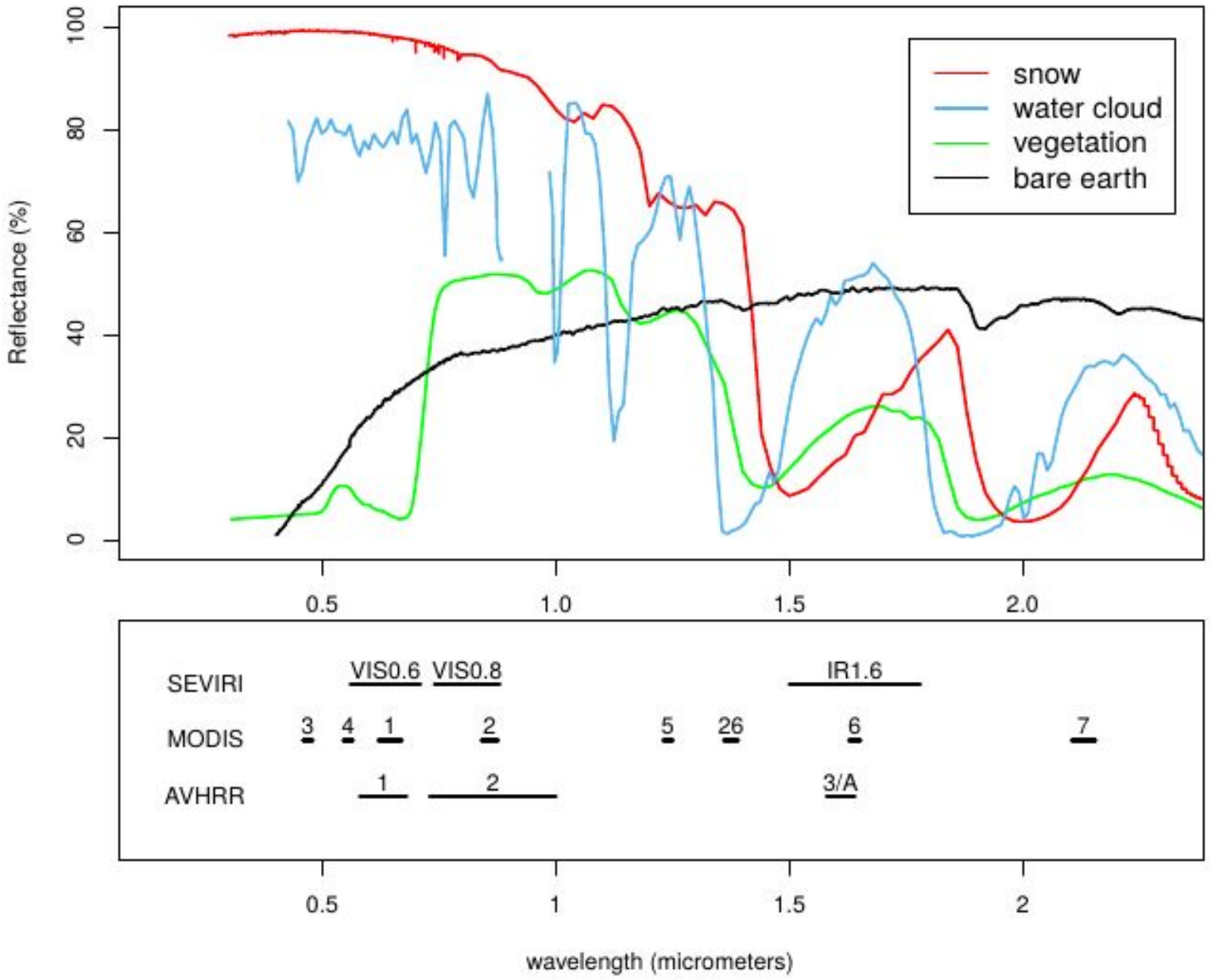
H32 20180415



MODIS image: NASA Worldview

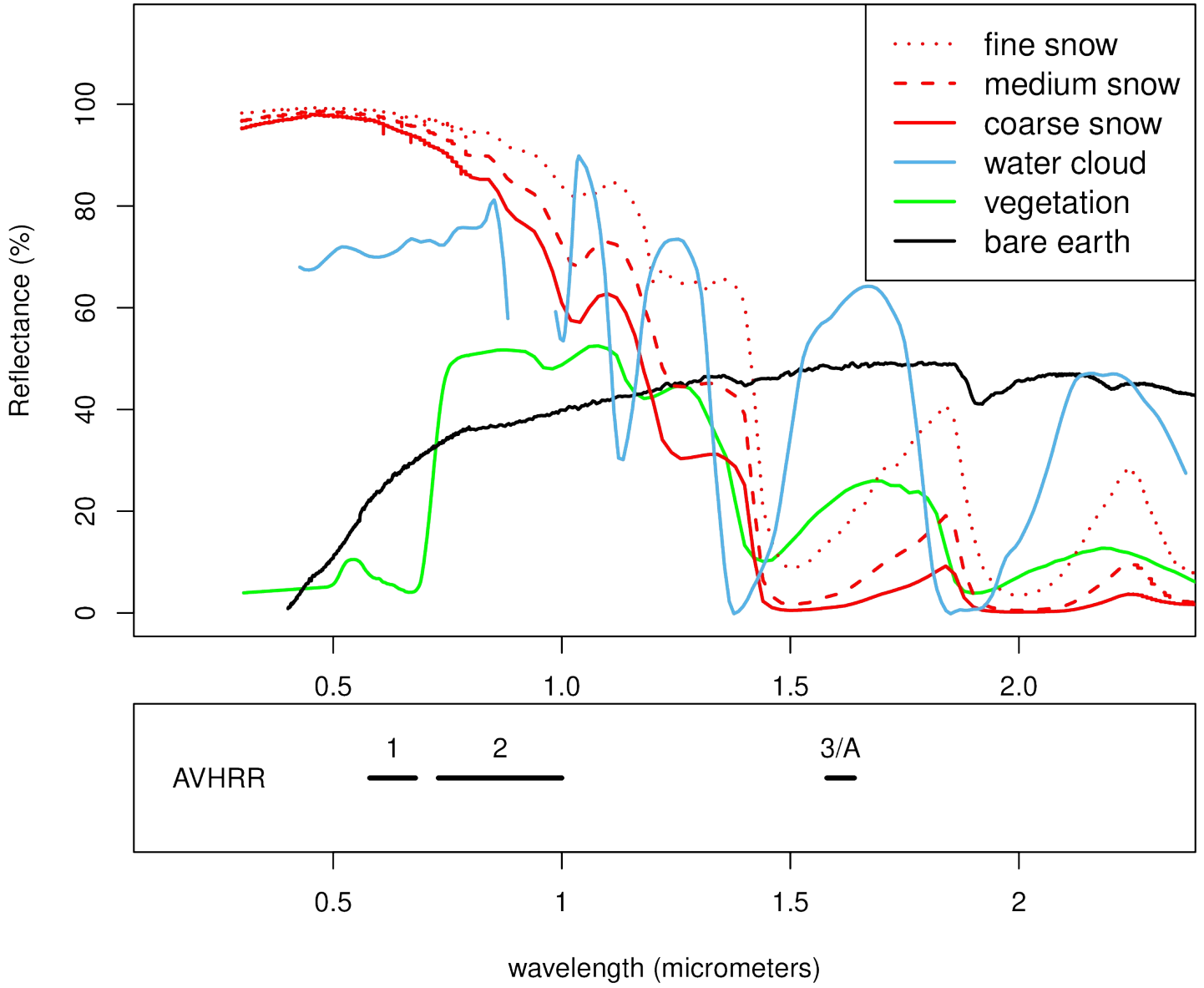
Different methods

- Normalized Difference Snow Index (NDSI)
  - Optical channels
  - “measure of the relative magnitude of the reflectance difference between visible (green) and shortwave infrared (SWIR).”
- Satellite + surface obs
- Microwaves
  - Radiometers
  - Radars
- Multi-source: e.g. IMS



Different methods

- NDSI fine in ideal conditions
- Needs improvement
- Natural variability
  - Snow
  - Vegetation (forests!)
  - Small lakes and rivers
  - Melting snow
  - Buildings
  - Light
  - Shadows



Different methods

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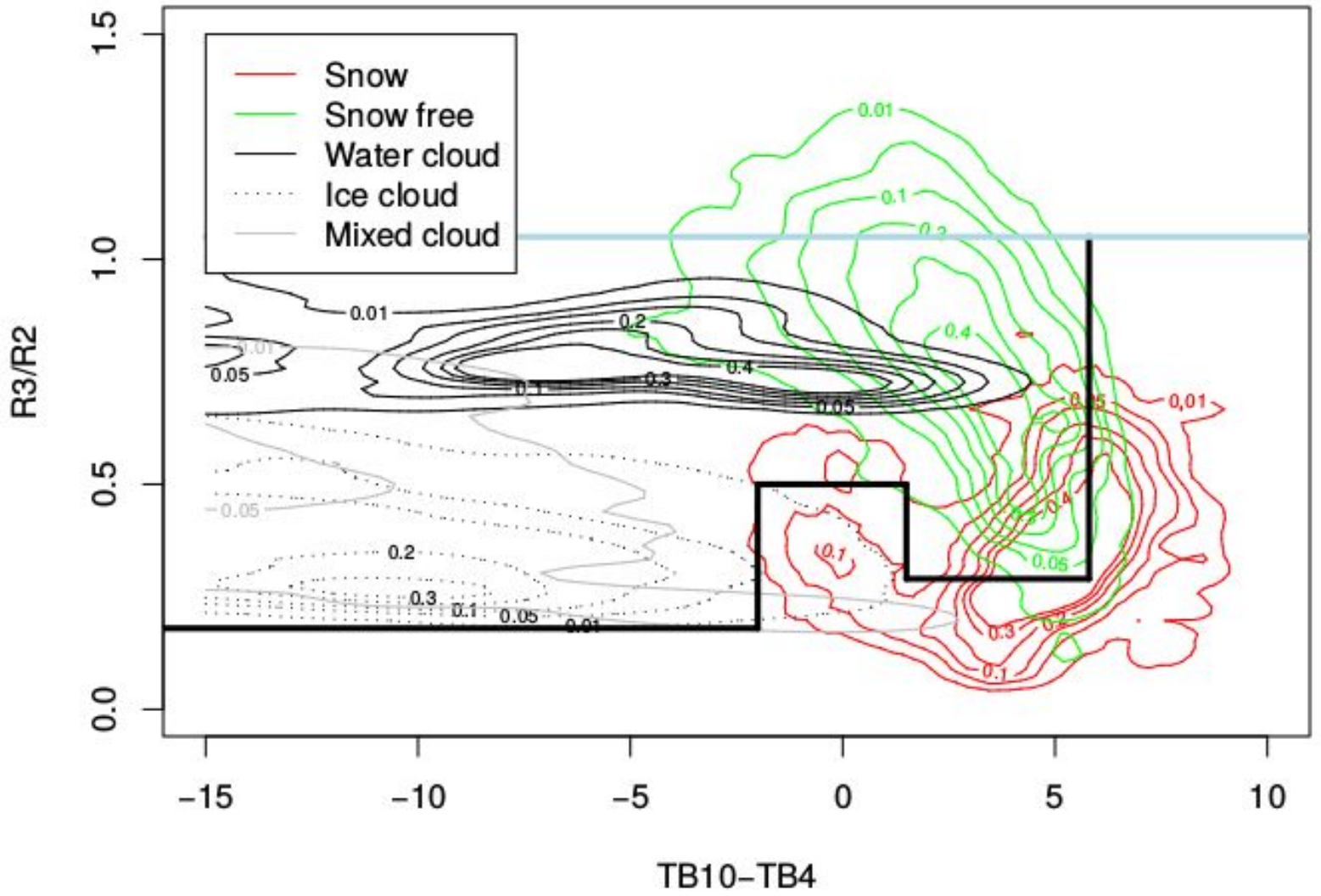
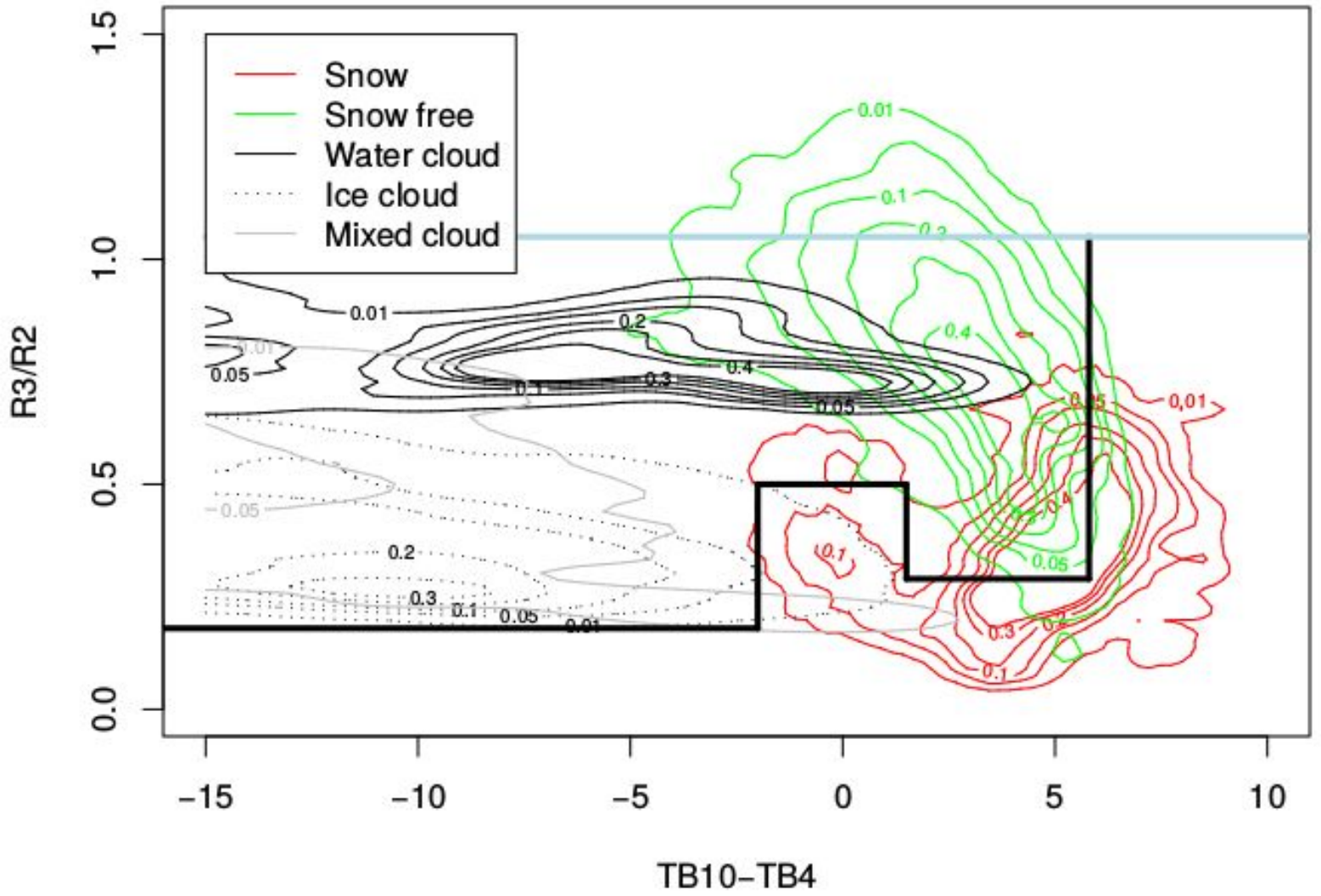
➡️ **Empirical Approach!**



Probability density of the scatterplots based on the development dataset for MSG/SEVIRI. The thick black and blue lines represent some of the rules in the MSG/SEVIRI SC1 algorithm.

Empirical approach

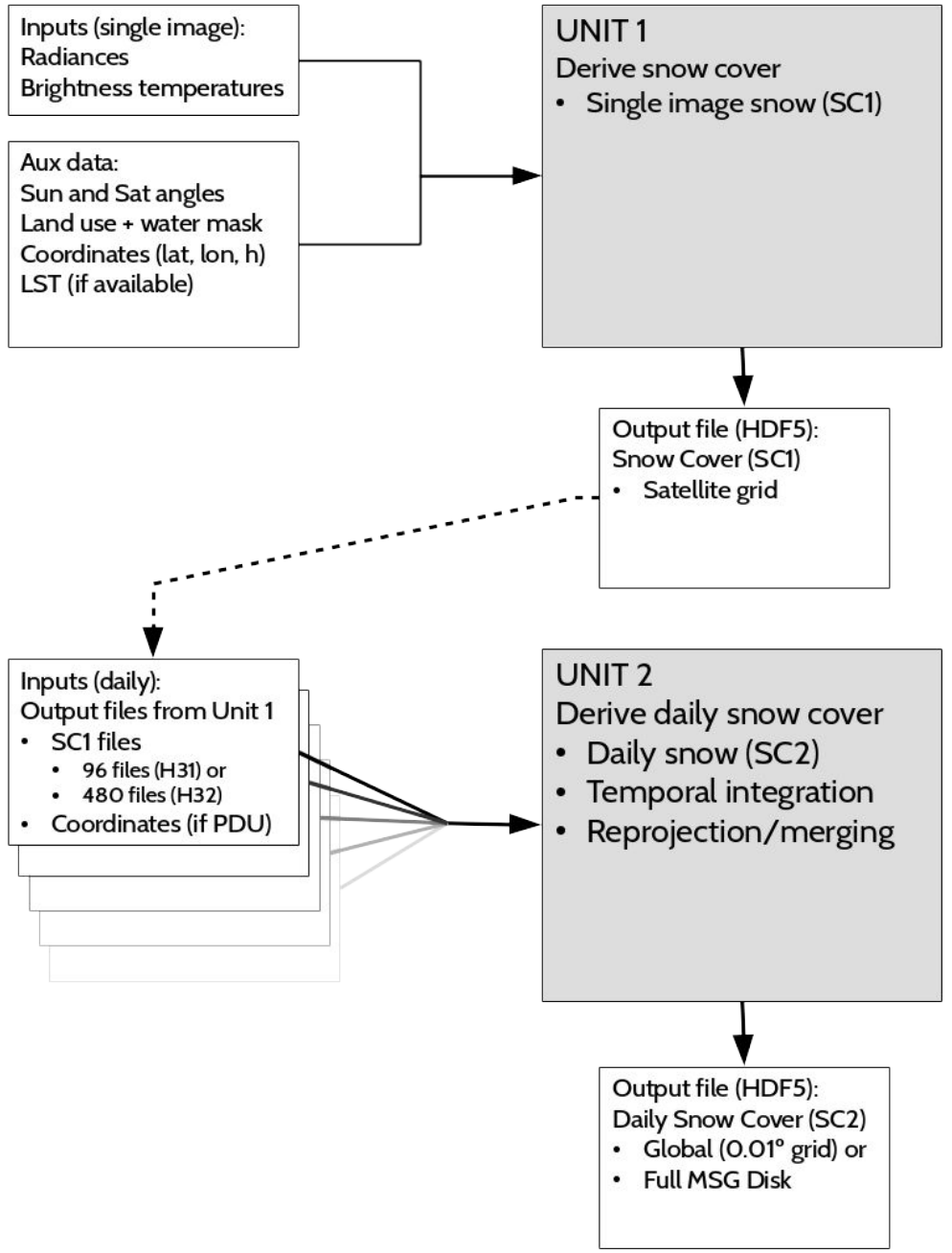
- Development dataset
  - Manual classification of actual satellite data
  - Several classes
- MSG/SEVIRI
  - 509000 pixels
- Metop/AVHRR
  - 609000 pixels
- Development of classification rules
- Check and improve



Probability density of the scatterplots based on the development dataset for MSG/SEVIRI. The thick black and blue lines represent some of the rules in the MSG/SEVIRI SC1 algorithm.

Flow chart of the snow extent algorithms

- Two phases
- Phase 1: Single image product (SC1):
  - Satellite grid
- Phase 2: Daily product (SC2):
  - Merge SC1 products (e.g. one day)
  - Satellite grid (MSG/SEVIRI)
  - Lan-lon grid (Metop/AVHRR)
  - Slight smoothing
- Deliver + archive daily SC2



Metop/AVHRR SC1 algorithm

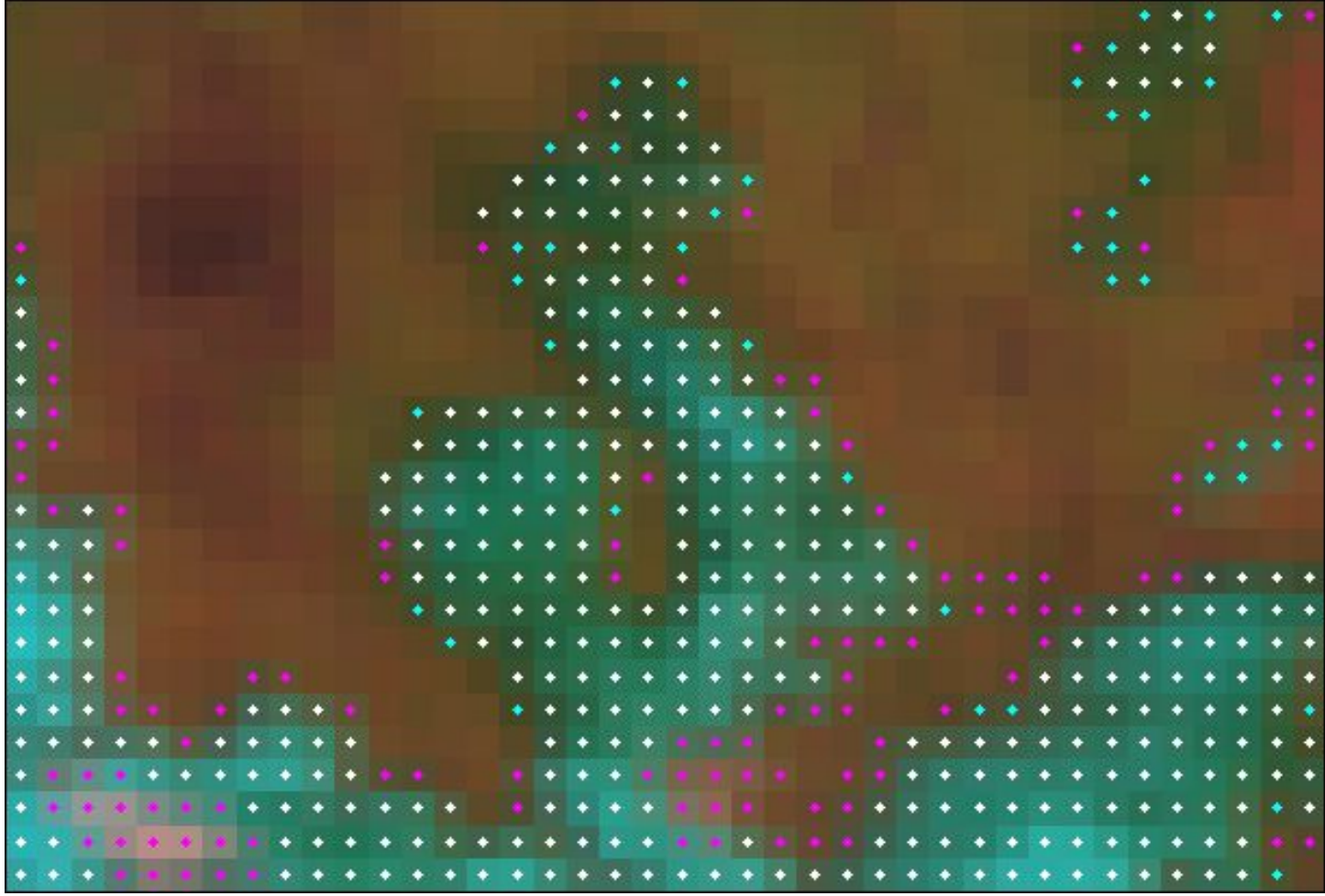
- 6 classes
  - Not processed
  - Unclassified
  - Snow
  - No snow
  - Partial snow
  - Water
- Chain of ifs (Rules)
- In each pixel, apply all rules in order
- The value in effect after the last rule

TABLE 4. List of classification rules in the SC1 algorithm. If the condition is true, the snow cover status is set to Value (SN = snow, NS = no snow, PS = partial snow, WA = water, UC = unclassified). These rules are applied sequentially from the top in the order presented and the final snow cover classification is the value in effect after last rule. For definitions see Tables 1 and 3. Logical AND is marked by $\wedge$ and logical OR by $\vee$.

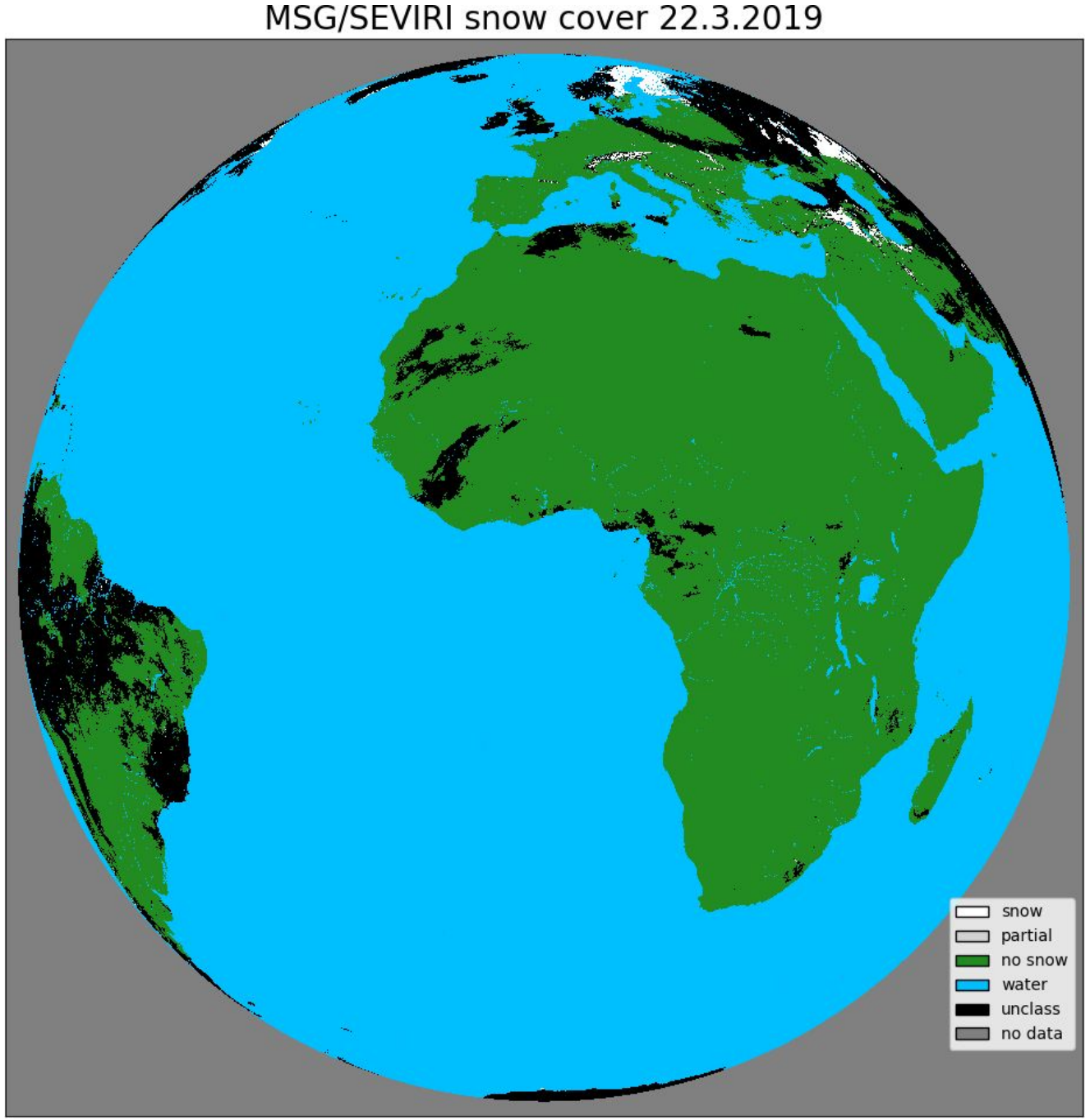
Rule condition	Value	Rule	Notes
set default value	UC		
nonfor $\wedge$ $R_2/R_1 < (-0.2T_{B5}+57) \wedge R_3/R_1 < 0.002T_{B5}-0.45 \wedge$ $T_{B5} < 272.6 \wedge R_2/R_1 > -0.05T_{B5}+15.5$	PS	R1	Cold surface, relatively bright
$T_{B4} > 290$	NS	R2	Too warm for snow
nonfor $\wedge$ $R_3/R_1 > 0.134$	NS	R3	Open, NIR vs VIS too high for snow
creg $\wedge$ nonfor $\wedge$ $R_2/R_3 > (-2T_{B4}+585) \wedge T_{B4} < 277)$	SN	R4	Cold, snow possible, R_2/R_3 indicate snow
Scold $\wedge$ nonfor $\wedge$ $R_2/R_3 > (-2T_{B4}+574) \wedge T_{B4} > 256.5 \wedge T_{B4} < 269.7$	SN	R5	Amends R4 in problem cases
Scold $\wedge$ for $\wedge$ $R_2/R_1 > (-0.1T_{B5}+29.5) \wedge R_2/R_1 < 2.86 \wedge T_{B5} < 280$	PS	R6	Cold forest, 'red edge' less distinct for snow-free
$R_3/R_1 < 0.045 \wedge T_{B4} > 280$	NS	R7	Warm, reflectance indicate snow, set no snow
creg4 $\wedge$ $(R_3-R_2)/(R_3+R_2) < -0.975 \wedge T_{B4} < 279 \wedge T_{B4} > 240$	SN	R8	Low R_3/R_2 with cold surf. No coldest clouds
for $\wedge$ $R_3/R_1 > 0.135$	NS	R9	Forest, distinct 'red edge', snow highly unlikely
creg $\wedge$ $R_2/R_3 > 120 \wedge T_{B4} < 276$	SN	R10	Similar to R8
creg $\wedge$ for $\wedge$ $R_2/R_3 > 72 \wedge T_{B4} > 253$	SN	R11	North Forest, no 'red edge', warm for ice clouds
Scold $\wedge$ for $\wedge$ $R_2/R_3 > 45 \wedge T_{B4} > 263$	SN	R12	North Forest, no 'red edge', warm for ice clouds
Scold $\wedge$ $((R_2/R_3 > 120 \wedge T_{B4} < 254) \vee (R_2/R_3 > 220 \wedge T_{B4} < 280) \vee$ $(R_2/R_3 > 50 \wedge T_{B4} > 267 \wedge T_{B4} < 276 \wedge \Delta T_B < 1.5))$	SN	R13	Snow, filter out clouds
$(T_{B5} > 280 \wedge R_2/R_1 > 2)$	NS	R14	Clear 'red edge', warm. Snow very unlikely
$T_{B4} < 242 \wedge R_2/R_3 < 68.8$	UC	R15	Very cold surface with an indistinct R_2/R_3
$\Delta T_B > 4 \wedge R_3/R_1 > 0.09 \wedge R_3/R_1 < 0.11$	UC	R16	Remove misclassifications
VZA > 60	UC	R17	Viewing geometry is too challenging
SZA > 80	UC	R18	Illumination geometry is too challenging
tropic $\wedge$ slc $\wedge$ (SN $\vee$ PS)	UC	R19	No snow near-equatorial lowlands
moderate $\wedge$ $(T_{B4}+T_{B5})/2 < 253 \wedge$ (SN $\vee$ PS)	UC	R20	Unreliable cold snow surface
LST >= 293.15 $\wedge$ (SN $\vee$ PS)	NS	R21	Trust LST over snow retrieval
(SN $\vee$ PS) $\wedge$ $R_1 < 1.2/\cos^2(\mathrm{SZA}) \wedge R_2 < 1.2/\cos^2(\mathrm{SZA}) \wedge R_3 < 0.02/\cos^2(\mathrm{SZA})$	UC	R22	Unclassify too dark snow pixels
If water pixel in water mask	WA	R23	No retrieval over water

Classification example: Southern France, 29th Jan 2009

- Background: MSG/SEVIRI 1000 UTC RGB 3-2-1
- SC2 (Daily snow cover)
  - White = Snow
  - Blue = Partial snow
  - Magenta = unclassified
  - No dots = no snow



H SAF H31
MSG/SEVIRI



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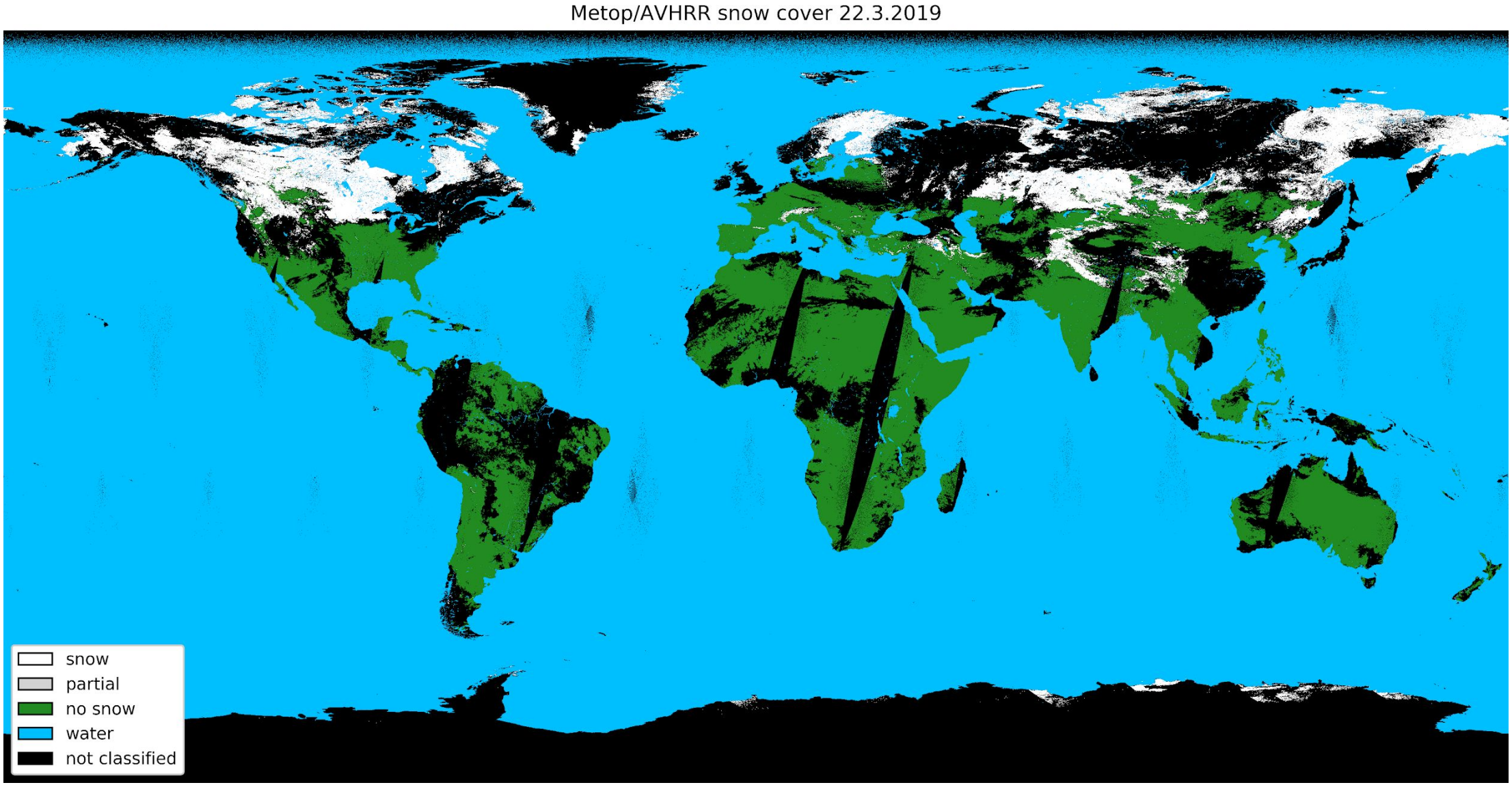
H SAF H32 Metop/AVHRR

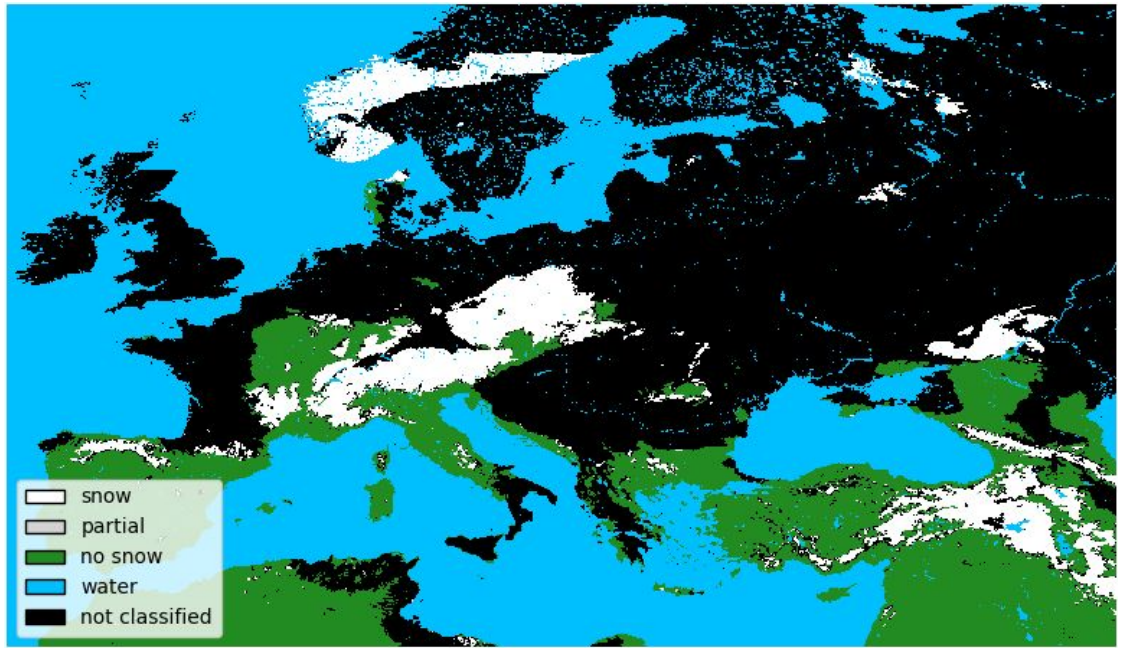


Example: Europe Feb 5, 2019

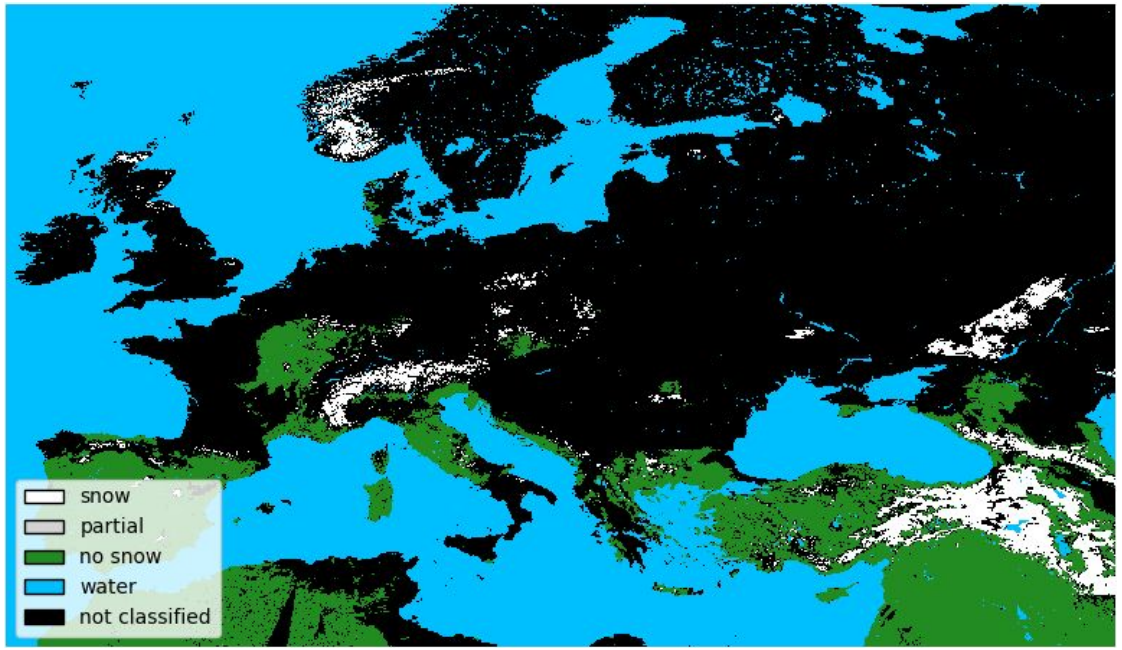
MODIS RGB

© NASA Worldview

MSG/SEVIRI (H31), geostationary orbit

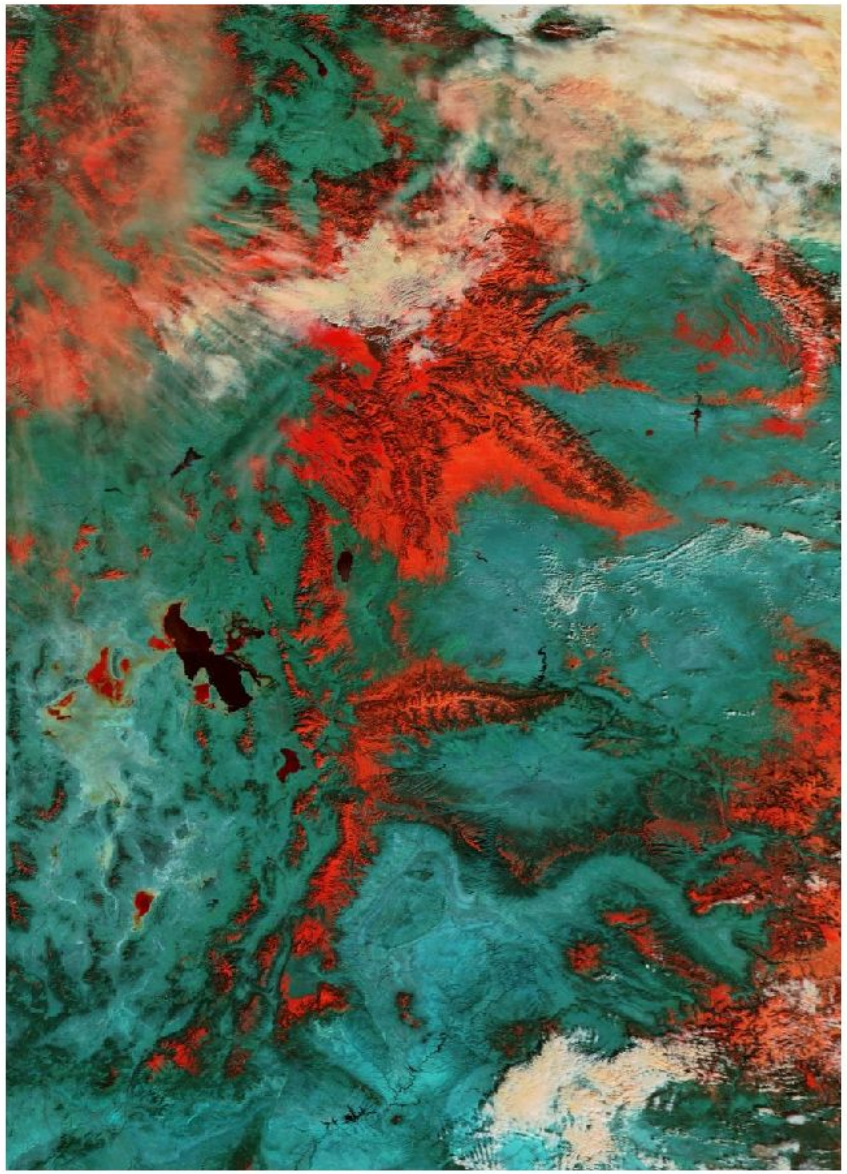


Metop/AVHRR (H32), polar orbit



Example: North America, Nov 20, 2018

MODIS RGB



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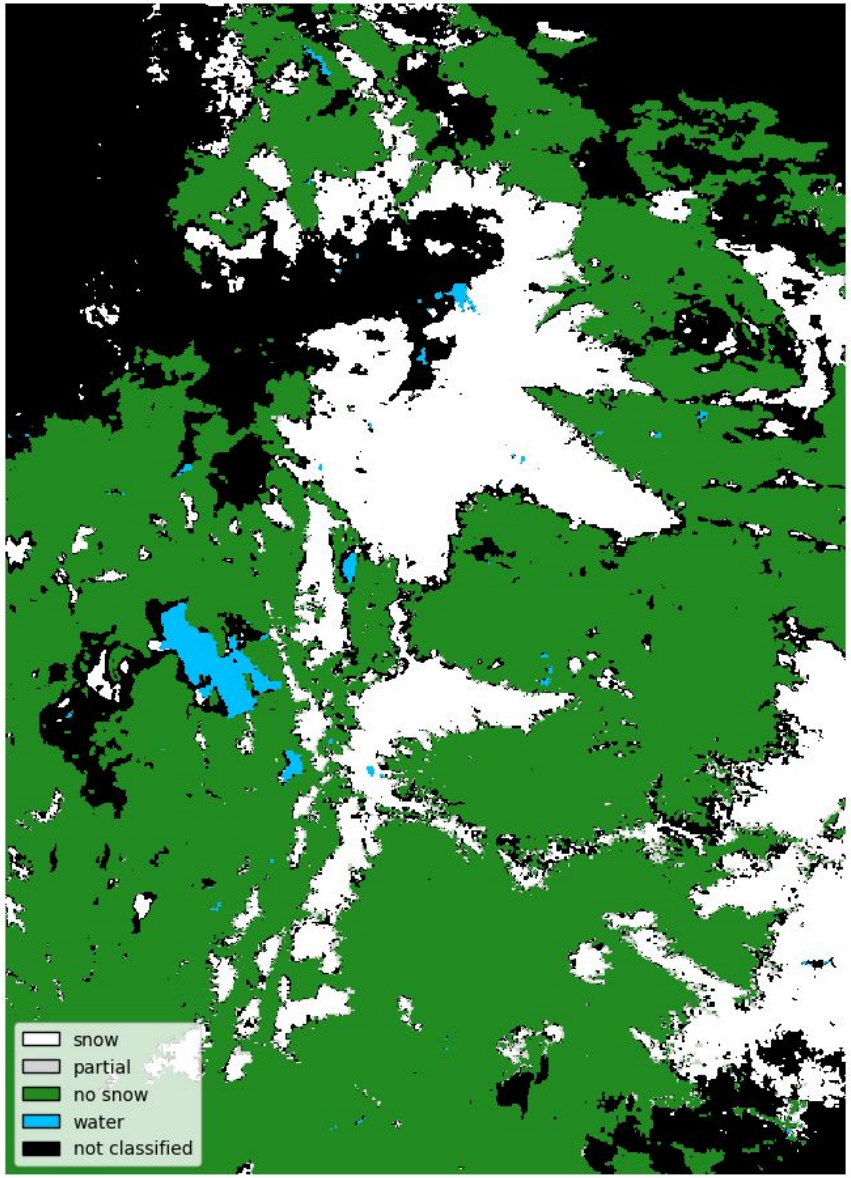
Metop/AVHRR (H32)



Products are worthless without validation!

Validation

- Compare satellite product and surface observations
- Operational snow coverage observations not available
- What we have?
  - Weather station snow depths
  - Weather station state of the ground observations
- Not perfect, but still the best option for global validation

Surface observations

- Snow depth:
  - Measured when snow present
  - Snow free surface usually not reported
  - Missing observations not reported
  - ➡️ No reliable observations of snow free surface
  - Automatic stations:
    - Calibration not possible when snow present
    - Thin (< 1-2 cm) snow layer observations may be unreliable
- State of the ground
  - 20 values, rough estimate of snow coverage
  - Not available from automatic stations at the moment

State of the ground

code	meaning
0	SURFACE OR GROUND DRY (WITHOUT CRACKS AND NO APPRECIABLE AMOUNT OF DUST OR LOOSE SAND), WITHOUT SNOW OR MEASURABLE ICE COVER
1	SURFACE OF GROUND MOIST, WITHOUT SNOW OR MEASURABLE ICE COVER
2	SURFACE OF GROUND WET (STANDING WATER IN SMALL OR LARGE POOLS ON SURFACE, WITHOUT SNOW OR MEASURABLE ICE COVER
3	FLOODED, WITHOUT SNOW OR MEASURABLE ICE COVER
4	SURFACE OF GROUND FROZEN, WITHOUT SNOW OR MEASURABLE ICE COVER
5	GLAZE ON GROUND, WITHOUT SNOW OR MEASURABLE ICE COVER
6	LOOSE DRY DUST OR SAND NOT COVERING GROUND COMPLETELY, WITHOUT SNOW OR MEASURABLE ICE COVER
7	THIN COVER OF LOOSE DRY DUST OR SAND COVERING GROUND COMPLETELY, WITHOUT SNOW OR MEASURABLE ICE COVER
8	MODERATE OR THICK COVER OF LOOSE DRY DUST OR SAND COVERING GROUND COMPLETELY, WITHOUT SNOW OR MEASURABLE ICE COVER
9	EXTREMELY DRY WITH CRACKS, WITHOUT SNOW OR MEASURABLE ICE COVER
10	GROUND PREDOMINANTLY COVERED BY ICE, WITH SNOW OR MEASURABLE ICE COVER
11	COMPACT OR WET SNOW (WITH OR WITHOUT ICE) COVERING LESS THAN ONE-HALF OF THE GROUND, WITH SNOW OR MEASURABLE ICE COVER
12	COMPACT OR WET SNOW (WITH OR WITHOUT ICE) COVERING AT LEAST ONE-HALF OF THE GROUND BUT GROUND NOT COMPLETELY COVERED, WITH SNOW OR MEASURABLE ICE COVER
13	EVEN LAYER OF COMPACT OR WET SNOW COVERING GROUND COMPLETELY, WITH SNOW OR MEASURABLE ICE COVER
14	UNEVEN LAYER OF COMPACT OR WET SNOW COVERING GROUND COMPLETELY, WITH SNOW OR MEASURABLE ICE COVER
15	LOOSE DRY SNOW COVERING LESS THAN ONE HALF OF THE GROUND, WITH SNOW OR MEASURABLE ICE COVER
16	LOOSE DRY SNOW COVERING AT LEAST ONE-HALF OF THE GROUND BUT GROUND NOT COMPLETELY COVERED, WITH SNOW OR MEASURABLE ICE COVER
17	EVEN LAYER OF LOOSE DRY SNOW COVERING GROUND COMPLETELY, WITH SNOW OR MEASURABLE ICE COVER
18	UNEVEN LAYER OF LOOSE DRY SNOW COVERING GROUND COMPLETELY, WITH SNOW OR MEASURABLE ICE COVER
19	SNOW COVERING GROUND COMPLETELY; DEEP DRIFTS, WITH SNOW OR MEASURABLE ICE COVER
31	MISSING VALUE

Validation process

- Surface observation from SYNOP stations
- Nearest pixel from the satellite product
- Convert both to binary snow/no snow format
  - How to handle partial snow cover: snow/no snow/off?
- Calculate validation measures

Validation measures

- Based on contingency table
  - Proportion Correct (PC)
  - Hit Rate (*H*)
  - False Alarm Rate (*F*)
  - Critical Success Index (CSI)
  - Heidke Skill Score (HSS)
  - False Alarm Ratio (FAR)
  - BIAS
  - Symmetric Extremal Dependence Index (SEDI)

	Surface observation	
Satellite observation	**Snow**	**No snow**
Snow	***a* (Hit)**	***b* (False alarm)**
No snow	***c* (Miss)**	***d* (Correct rejection)**

Challenging validation

- Most validation measures degenerate when one group (*a, b, c* or *d*) dominates
- Correct snow free pixels (*d*) dominate during the northern summers

➡️ Results vary a lot from day to day during summers

- Symmetric Extremal Dependence Index (SEDI) does not degenerate

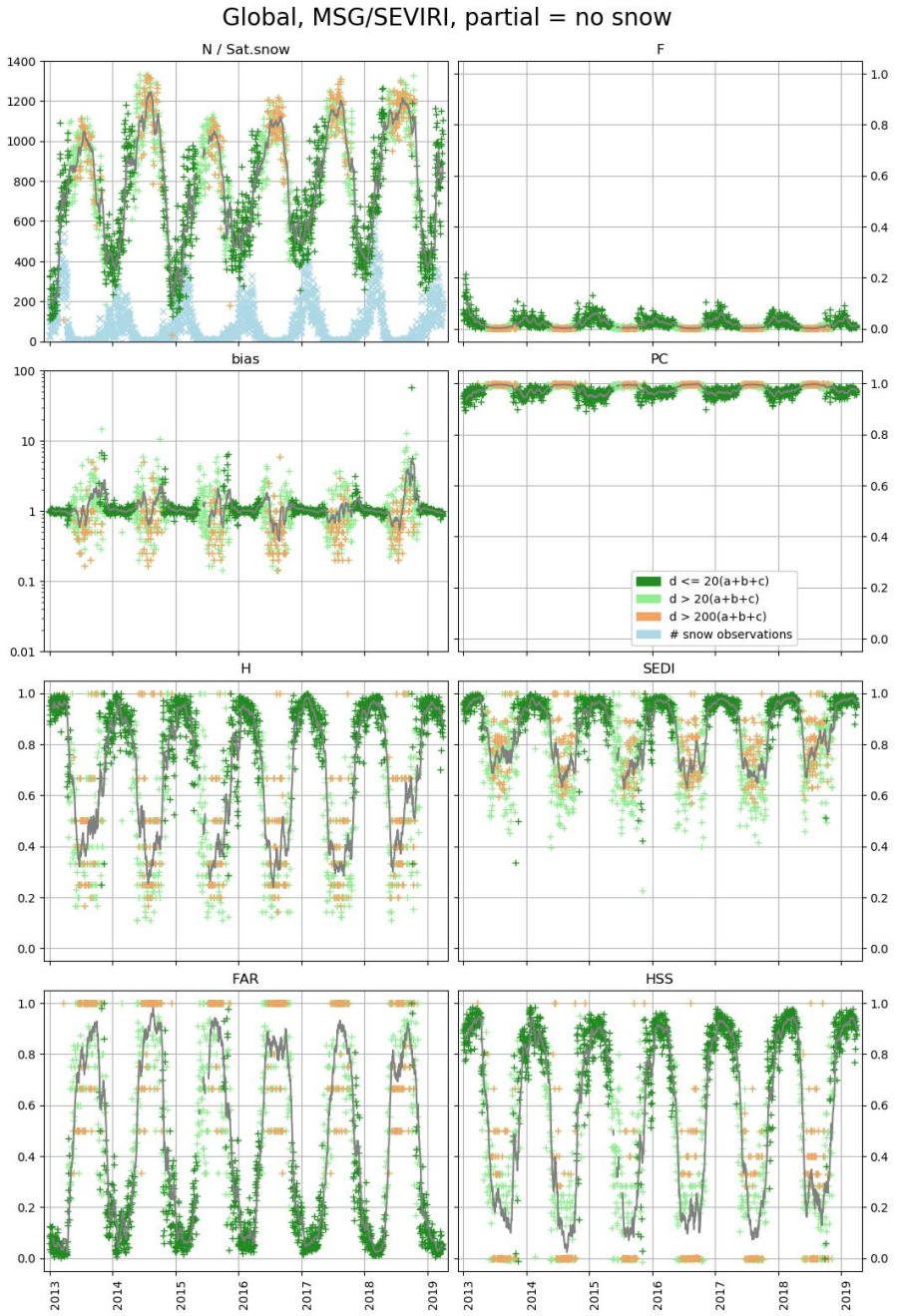
$$\mathrm{SEDI} = \frac{\ln F - \ln H + \ln(1-H) - \ln(1-F)}{\ln F + \ln H + \ln(1-H) + \ln(1-F)}$$

Hit Rate $H = \frac{a}{a+c}$, False Alarm Rate $F = \frac{b}{b+d}$

Results: MSG/SEVIRI SC

Partial snow

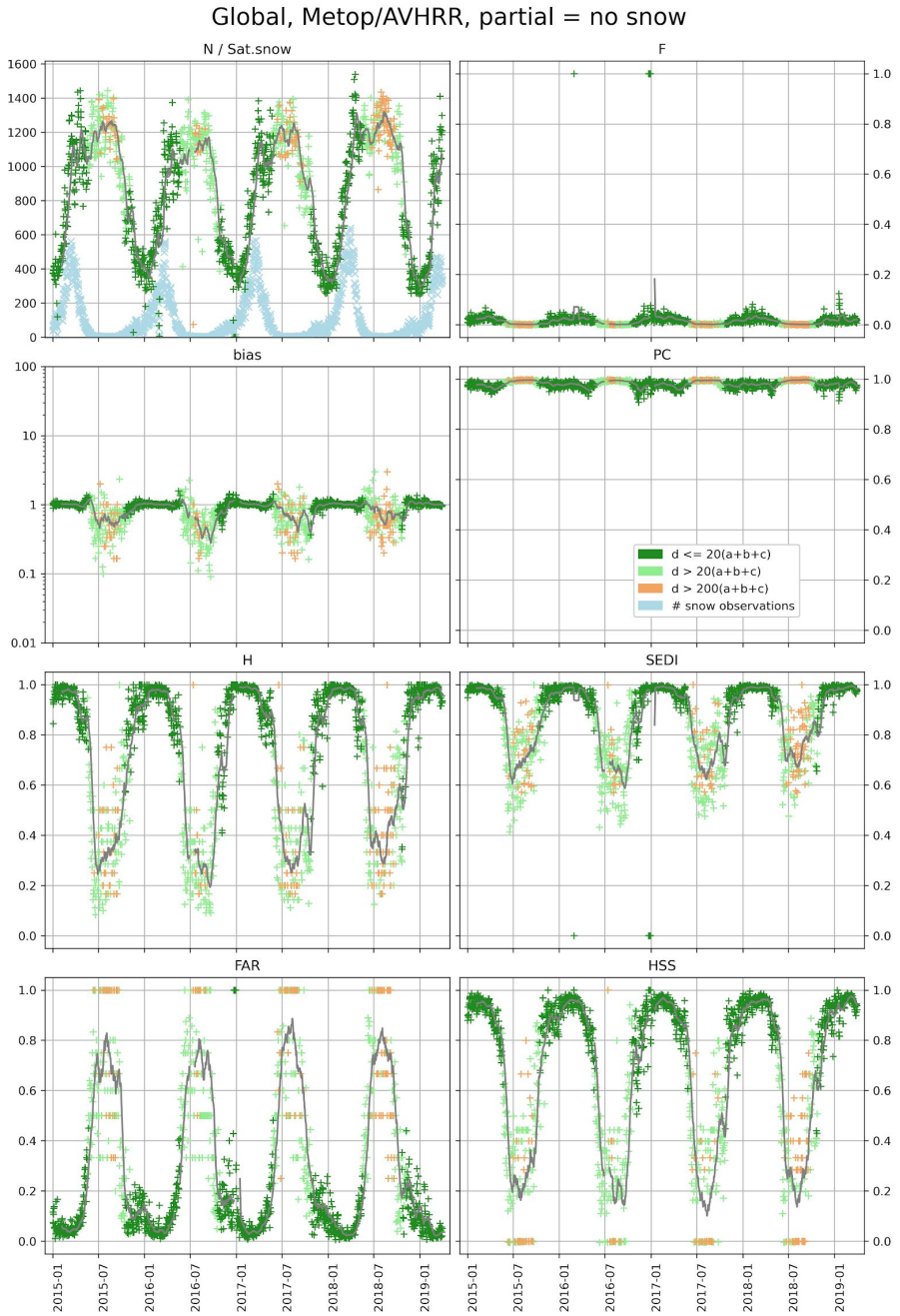
	No snow	Snow	Off
N	2029277	2040930	2019307
Bias	1.000	0.935	0.962
H	0.903	0.854	0.894
F	0.011	0.011	0.008
FAR	0.097	0.086	0.071
PC	0.980	0.973	0.981
CSI	0.823	0.790	0.837
HSS	0.892	0.868	0.901
SEDI	0.967	0.950	0.966



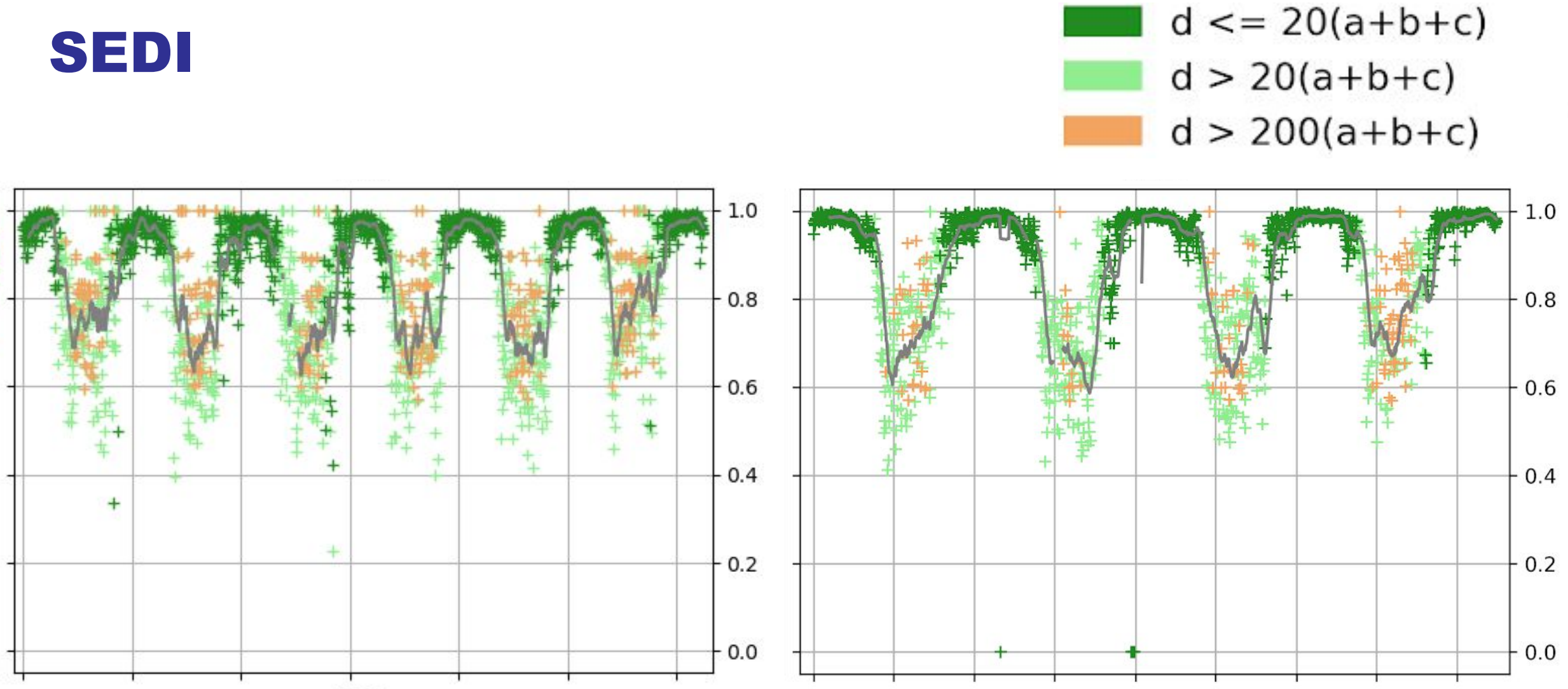
Results: Metop/AVHRR SC

Partial snow

	No snow	Snow	Off
N	1327910	1337570	1328561
Bias	0.989	0.929	0.964
H	0.928	0.884	0.920
F	0.009	0.008	0.007
FAR	0.062	0.049	0.045
PC	0.983	0.977	0.983
CSI	0.875	0.845	0.882
HSS	0.924	0.903	0.928
SEDI	0.978	0.963	0.976



SEDI



MSG/SEVIRI SC

Metop/AVHRR SC

Based on surface observations, both products provide high-quality snow extent data

References

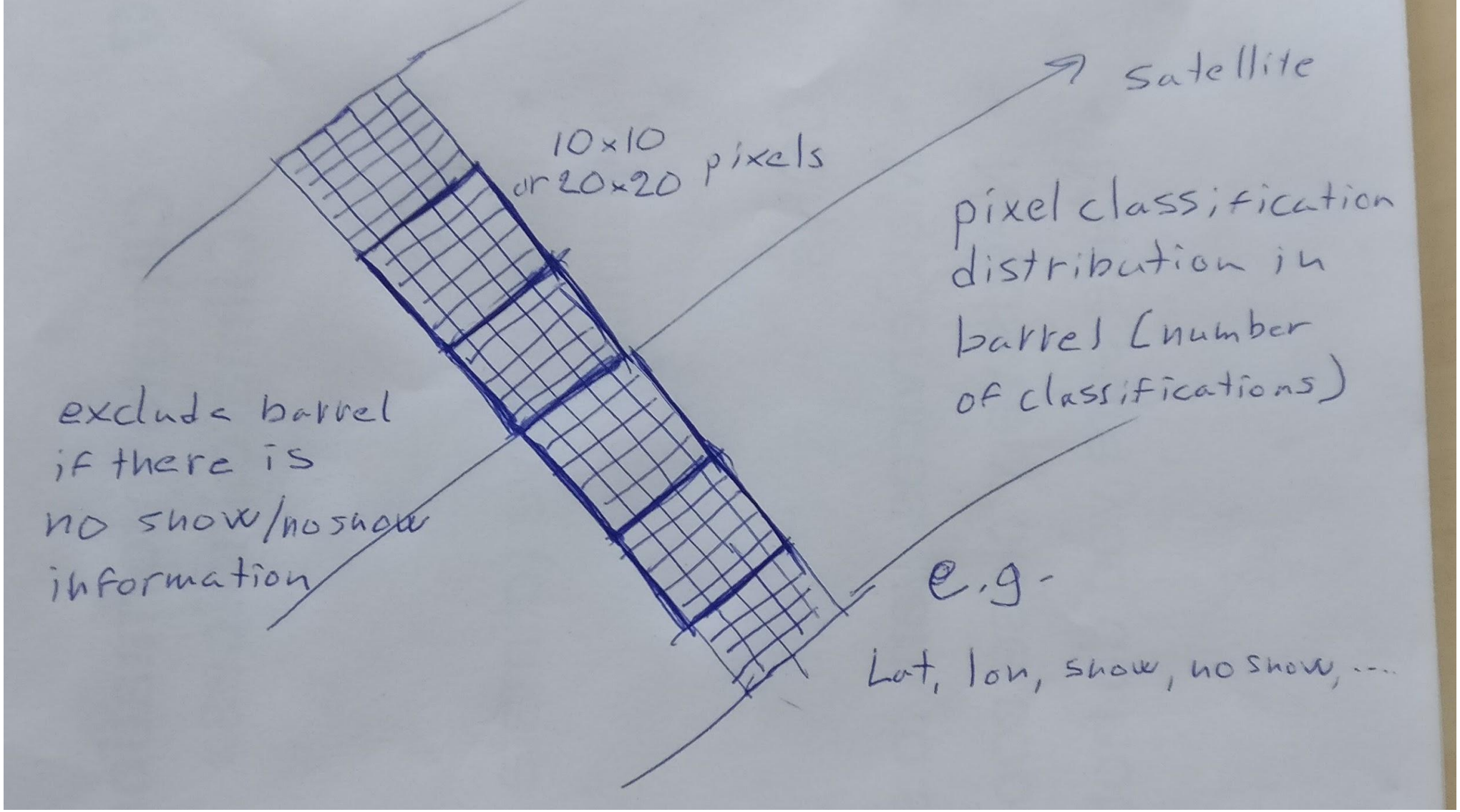
- Siljamo, Niilo, and Otto Hyvärinen. "New Geostationary Satellite–Based Snow-Cover Algorithm", Journal of Applied Meteorology and Climatology 50, 6 (2011): 1275-1290, https://doi.org/10.1175/2010JAMC2568.1
- Siljamo, Niilo, Otto Hyvärinen, Aku Riihelä, and Markku Suomalainen. "MetOp/AVHRR Snow Detection Method for Meteorological Applications", Journal of Applied Meteorology and Climatology 59, 12 (2020): 2001-2019, https://doi.org/10.1175/JAMC-D-20-0032.1
- Siljamo, Niilo. “Empirical Approach to Satellite Snow Detection”, Finnish Meteorological Institute Contributions 171, (2020), PhD Thesis, https://doi.org/10.35614/isbn.9789523361201
- H SAF product documentation

Conclusions, so far

- Empirical approach employed, two satellite snow products developed
  - Geostationary H SAF H31 (MSG/SEVIRI) snow extent
  - Polar H SAF H32 (Metop/AVHRR) snow extent
- Good or very good validation results
- Both products operational
- Currently, the these products are available from the LSA SAF website: https://landsaf.ipma.pt/
- Other H SAF products from: http://hsaf.meteoam.it/

What next?

- H31 MSG/SEVIRI Snow Extent in UK Met Office weather model: operational assimilation started in late 2020
  - User experience will benefit further development
- Develop similar products for new satellites and instruments
  - E.g. MTG/FCI and Metop-SG/METimage
- AI, machine learning as development tools
- Develop new ways to present and deliver products



New idea I got in a (boring?) routine meeting

Snow Barrels

- Snow classification distribution in predefined area, e.g. 10x10 pixels in satellite grid
- Best for polar orbiters?
- NWP trials at FMI ongoing

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