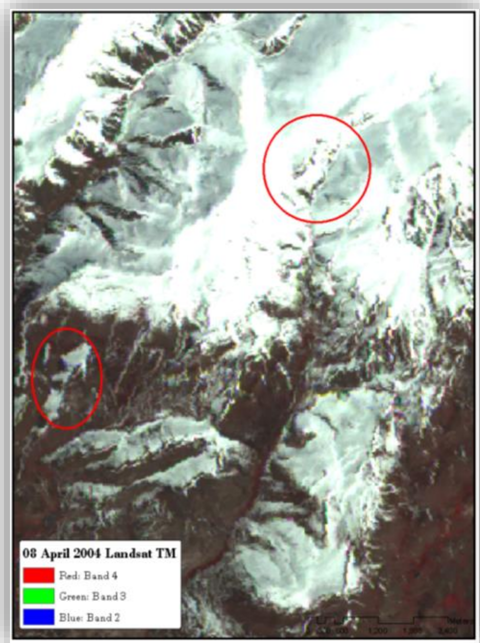
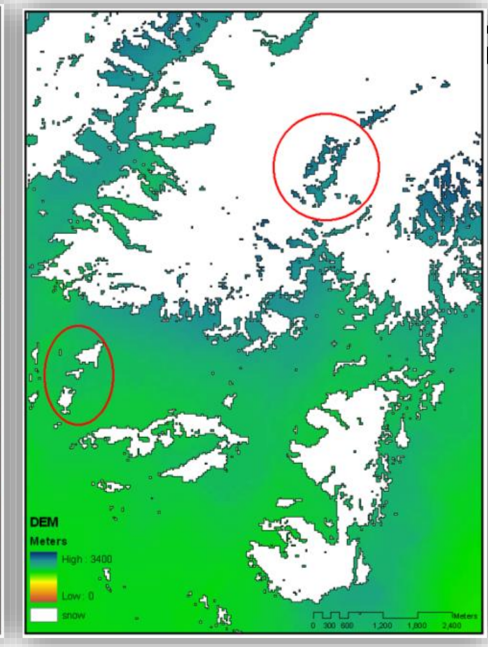
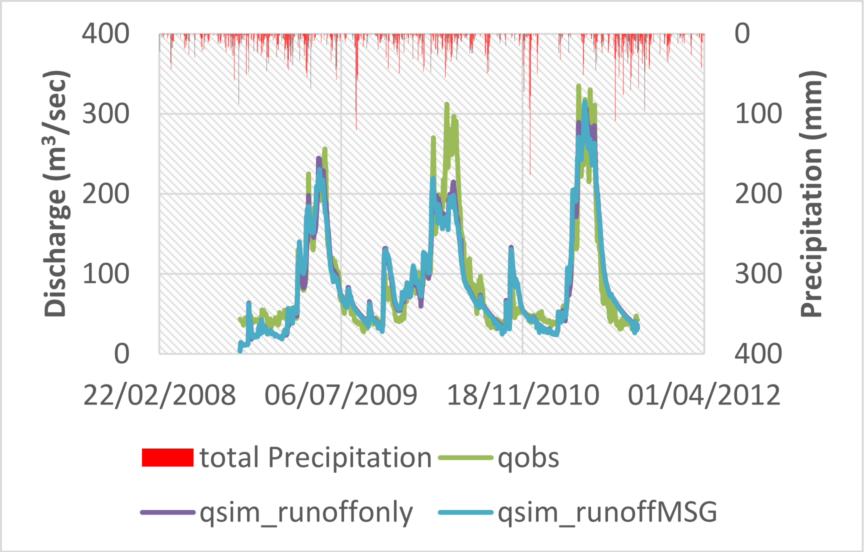
The use of H-SAF snow products on mountainous areas







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H-SAF and HEPEX workshops on coupled hydrology 3-7 November 2014, Reading-UK

Summary

-Ice and Snow Strongly Affect Climate:

During Northern Hemisphere winter, they
(a) blanket up to 15% of the Earth's surface and
(b) reflect up to 80% of the Sun's radiant energy back to space.

During the Southern Hemisphere winter, they cover about half this area. But their influence is far larger than their areal coverage would indicate.

-For mid latitudes snow on the mountainous areas is important from water resources management.

* Snow is one of the main water resources, therefore monitoring and estimating the snow water equivalent play important role in predicting discharges during melting seasons.

* Snow covered area, snow water equivalent are either inputs for hydrological models or internal variables that can be assimilated during modeling.

Summary

Trends in Northern Hemisphere Snow Cover

•Northern Hemisphere (NH) snow-cover extent has decreased ~10%, or >0.2% per year, since 1966 when the satellite snow-cover record began

•Decreases in snow-cover extent have occurred mainly in spring and summer months; snow is melting earlier in the NH, mainly due to increasing air temperatures

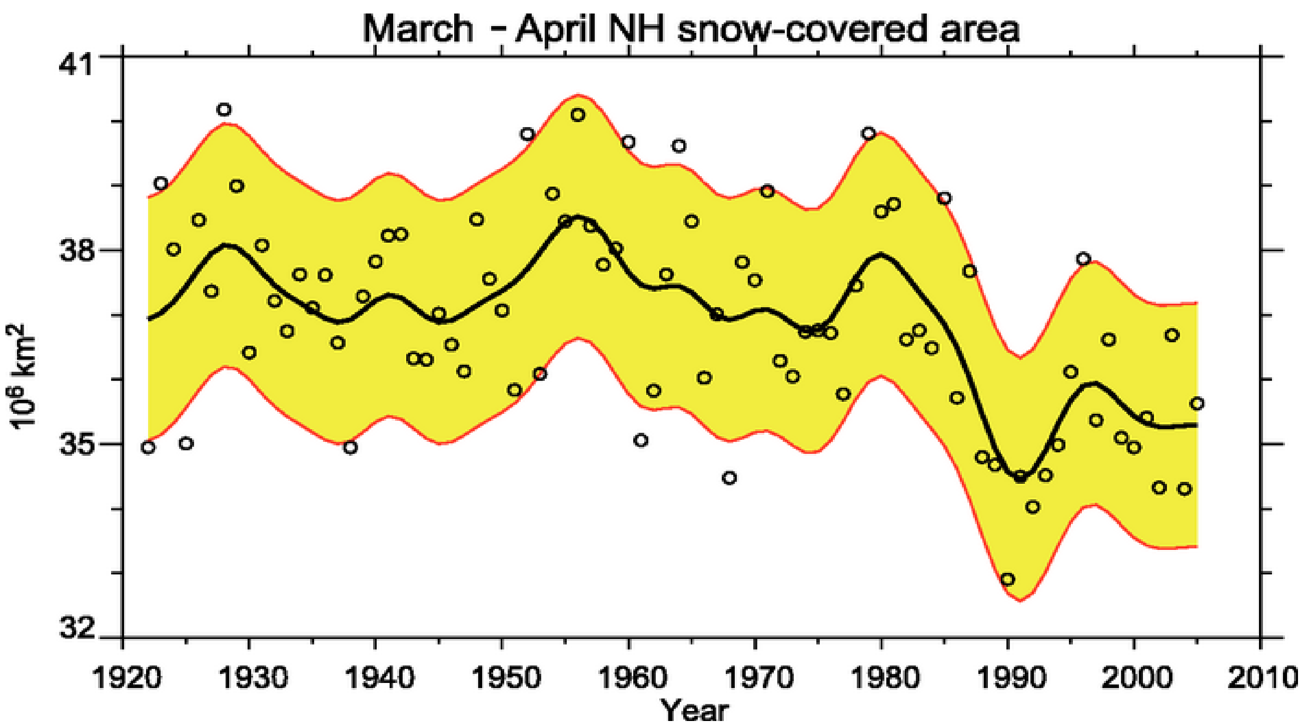
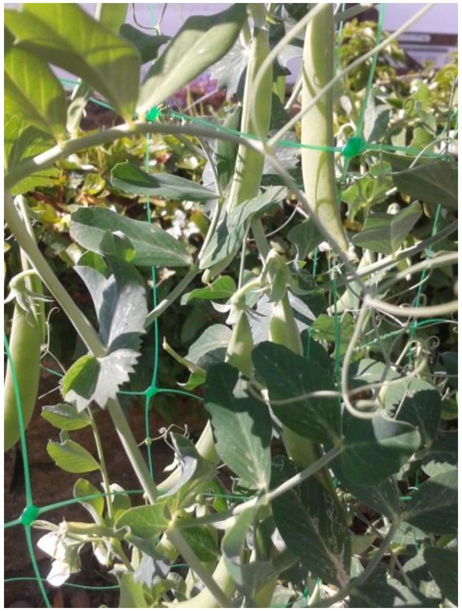
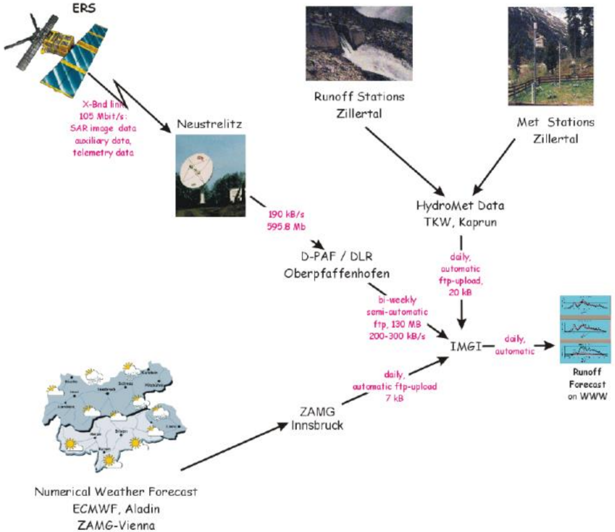


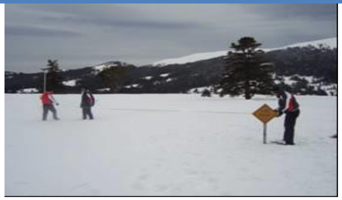
Figure 4.2. Update of NH March-April average snow-covered area (SCA) from Brown (2000). Values of SCA before 1972 are based on the station-derived snow cover index of Brown (2000); values beginning in 1972 are from the NOAA satellite data set. The smooth curve shows decadal variations (see Appendix 3.A), and the shaded area shows the 5 to 95% range of the data estimated after first subtracting the smooth curve.

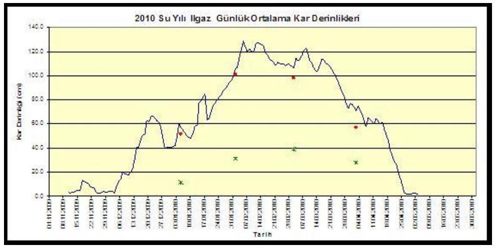
Why Snowmelt Modelling?

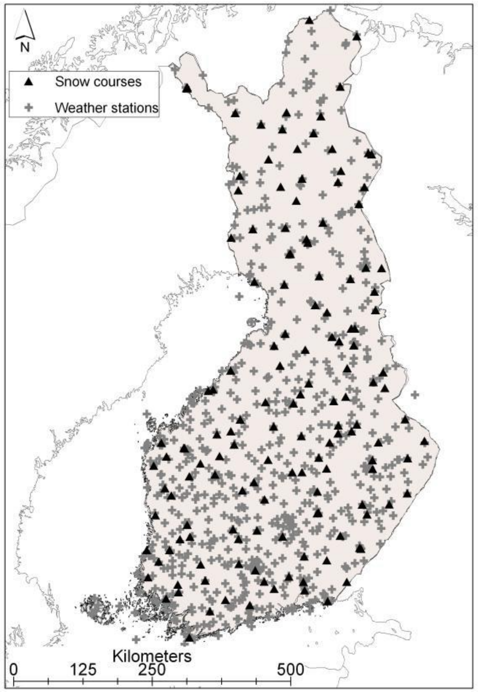


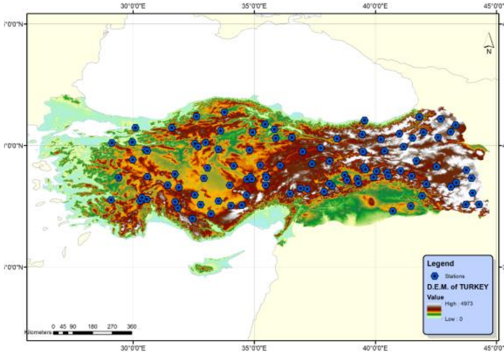


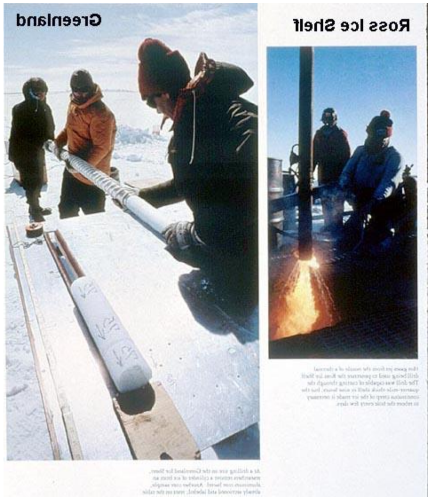
Measurement of Snow







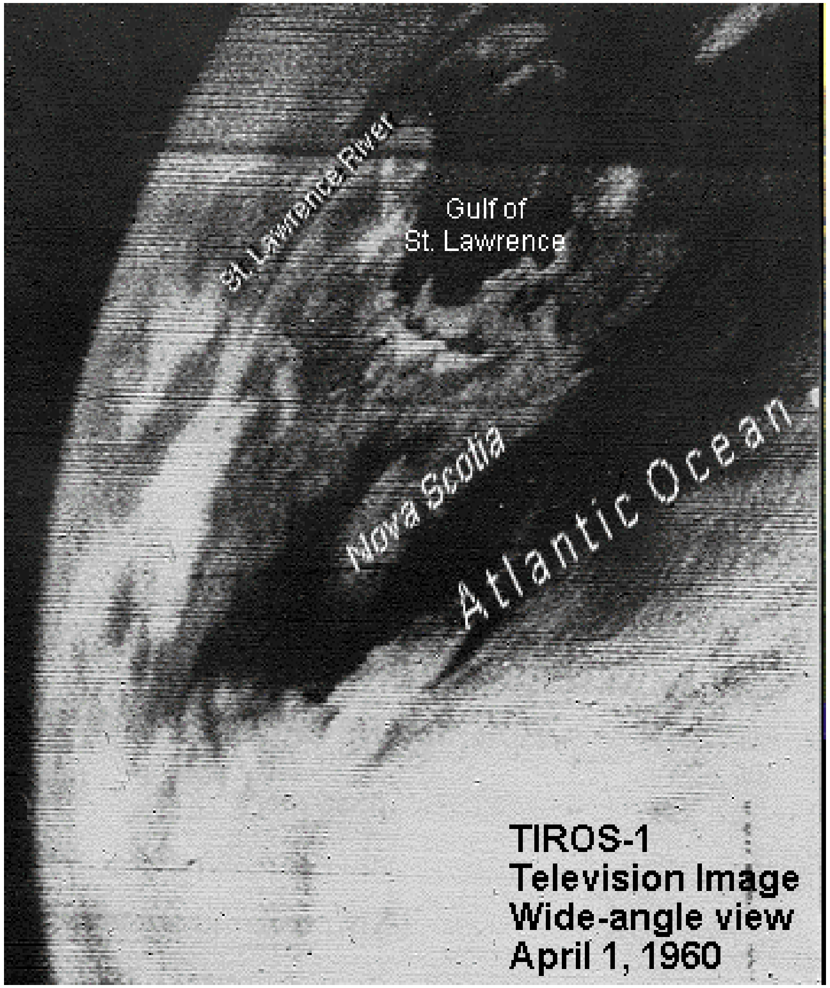


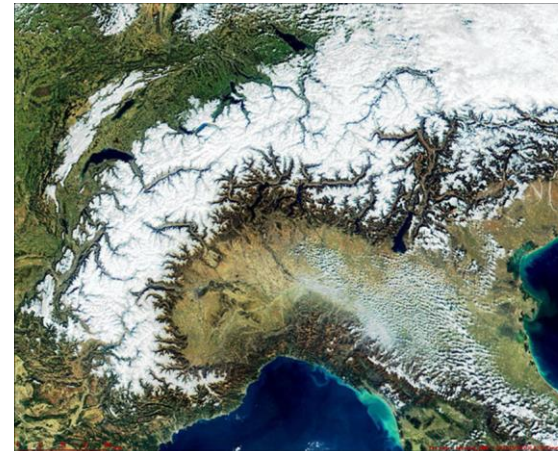


Mountainous areas

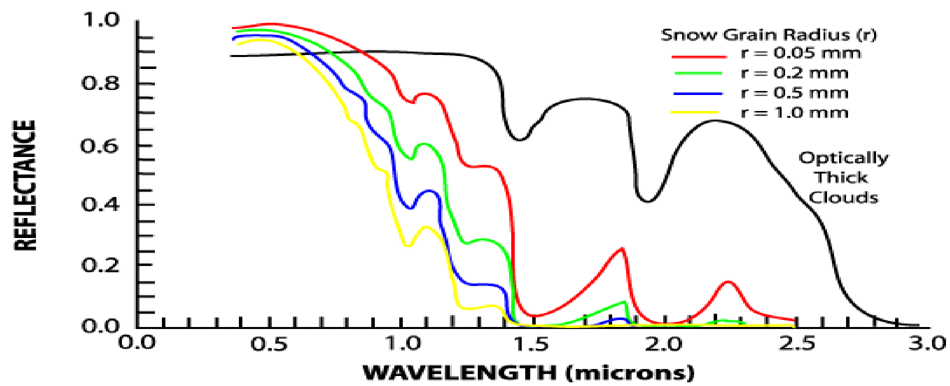
Remote Sensing of Snow

History of Snow Mapping – Satellite Era





Jan 24, 2007 MODIS images



Snow was observed on the first image obtained from the Television Infrared Operational Satellite-1 (TIROS-1) meteorological satellite on April 1, 1960

Remote Sensing of Snow

In the mid- to late-1960s, satellite sensors provided snow-cover images that permitted operational snow-cover mapping

Table 1. Summary of some existing operational satellite snow cover products.

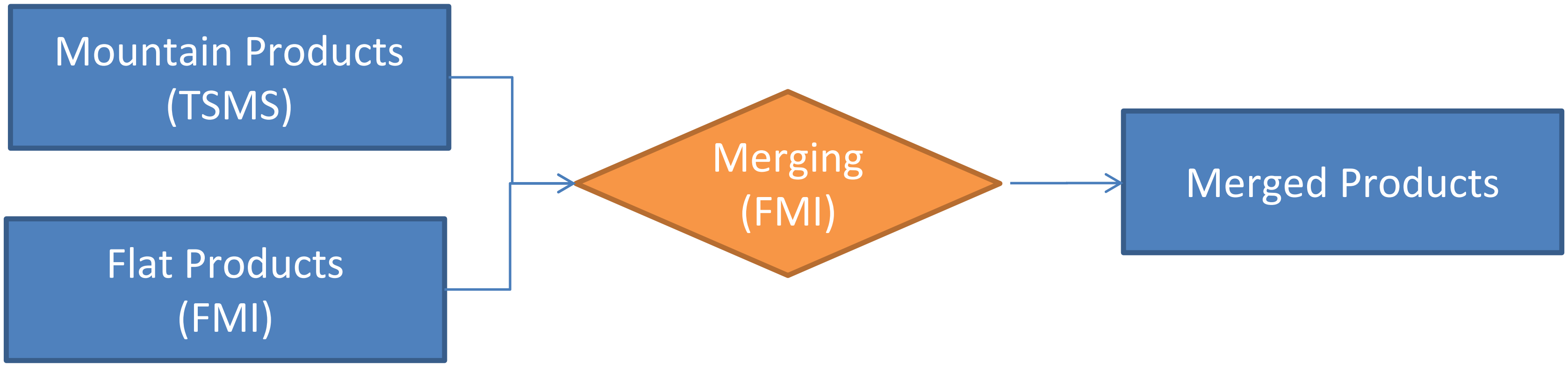
Snow cover product	Sensor	Available since	Spatial resolution	Temporal resolution	Mapping accuracy
NOHRSC/ +GOES	NOAA/AVHRR	1986	1 km	Daily	76 % (Klein and Barnett, 2003)
NOAA/NESDIS (IMS)	GOES+SSM/I	1998	4 km	Daily, weekly	85 % (Romanov et al., 2000); < 20 % (October), ~ 60 % (November), ~ 95 % (December), ~ 70 % (March) (Brubaker et al., 2005)
MOD10A1, MYD10A1, MOD10A2, MYD10A2, MOD10C1, MYD10C1, MOD10CM, MYD10CM	MODIS-Terra/Aqua	2000/2002	500 m –0.05°	Daily, 8-day, monthly	~ 94 % summary in Parajka and Riggs, 2007 or (see e.g., Hall and Blöschl, 2012)
HSAF (EUMETSAT)	MSG-SEVIRI	2008	5 km	Daily	80 % compared to IMS (Siljamo and Hyvärinen, 2011); 69–81 % in winter months (Surer and Akyurek, 2012)

Surer et al., 2014;Hydrol. Earth Syst. Sci., 18, 763–774
doi:10.5194/hess-18-763-2014

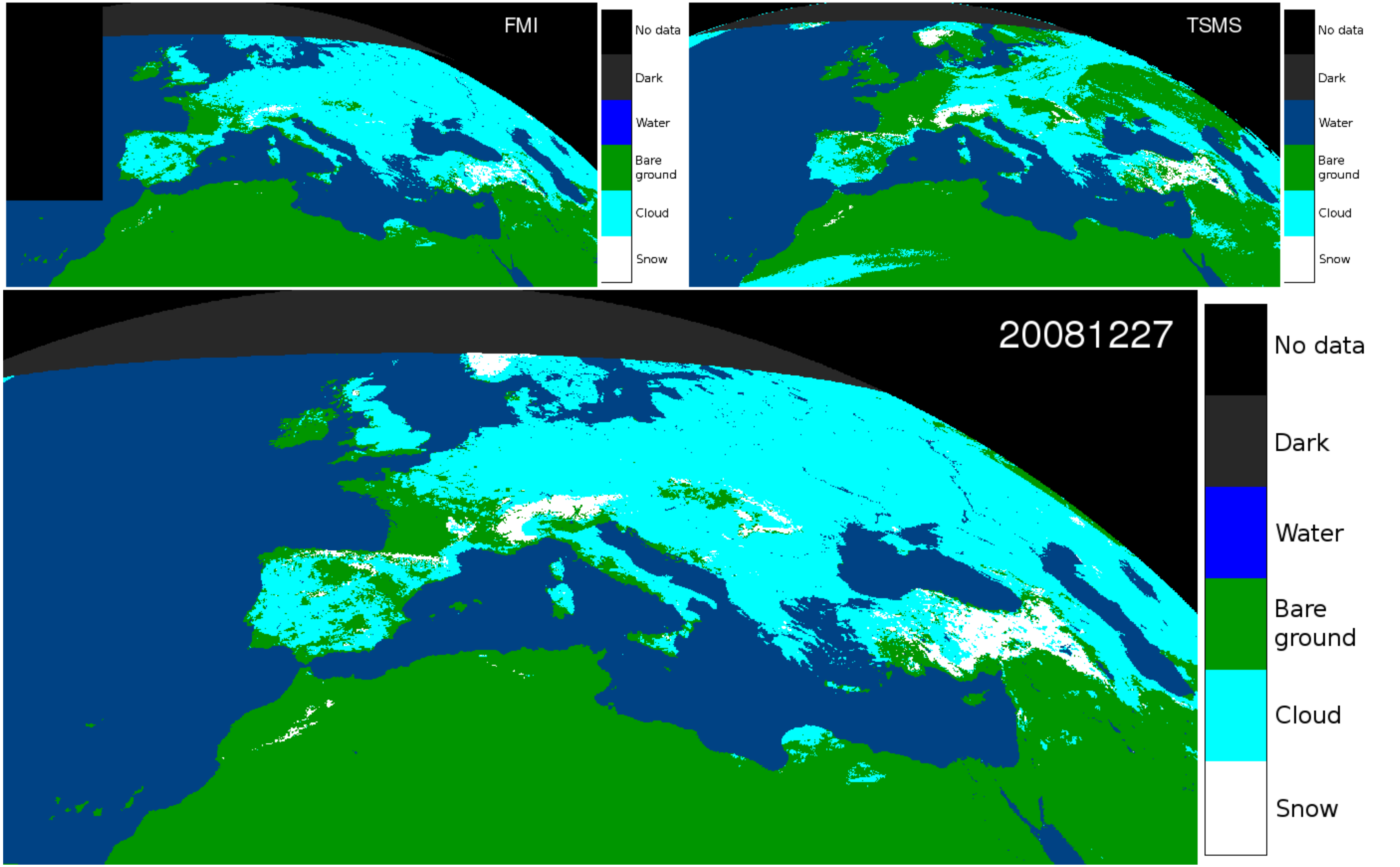
EUMETSAF-HSAF SNOW PRODUCTS

9

- Snow Recognition Product (H10)
- Snow Status Product (H11)
- Fractional Snow Cover Product (H12)
- Snow Water Equivalent Product (H13)

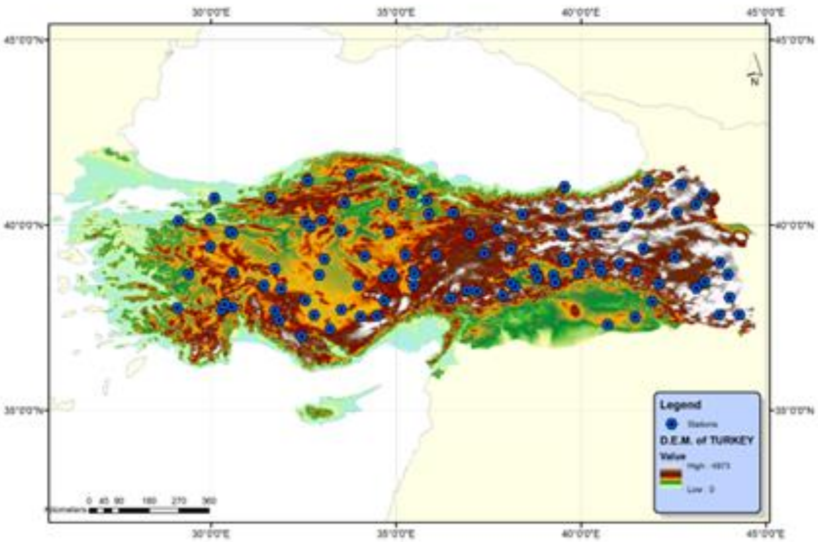


H10 Snow Recognition Product



H10 Snow Recognition Validation Results

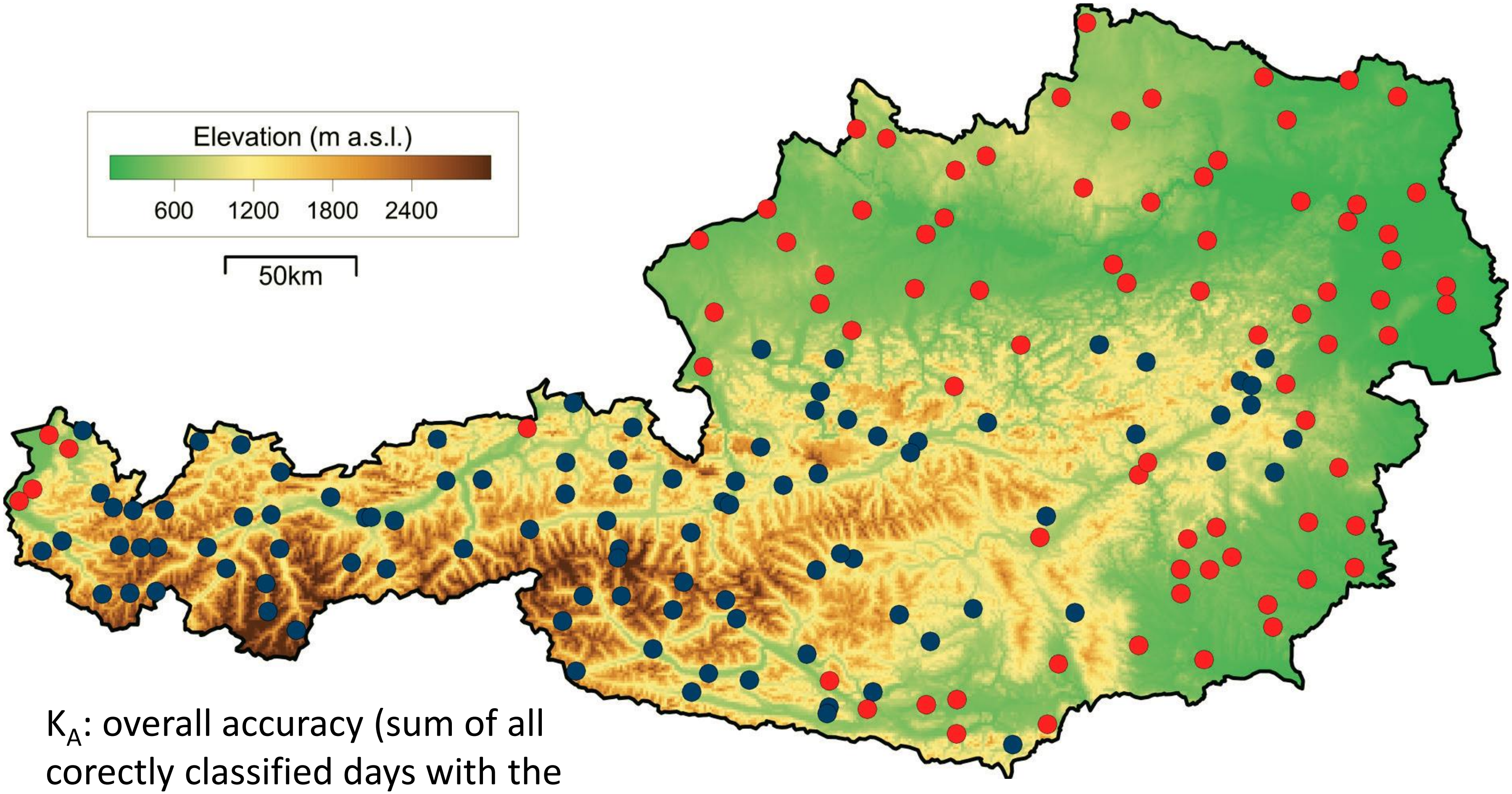
- Water year 2010 (01.10.2009 – 30.09.2010)
  POD= 0.73   FAR= 0.28
- Water year 2011 (01.10.2010 – 30.09.2011)
  POD= 0.85   FAR= 0.15
- Water year 2012 (01.10.2010 – 30.09.2012)
  POD= 0.85   FAR= 0.15
- Water year 2013 (01.10.2012 – 30.09.2013)
  POD= 0.89   FAR= 0.14



		Ground Observation	
Snow Cover Product		Snow Presence	None
	Snow Presence	a	b
	None	c	d

POD	FAR	HR	SMR
$\frac{a}{(a+c)}$	$\frac{b}{(a+b)}$	$\frac{(a+d)}{(a+b+c+d)}$	$\frac{c}{(a+b+c+d)}$

H10 Snow Recognition Validation Results

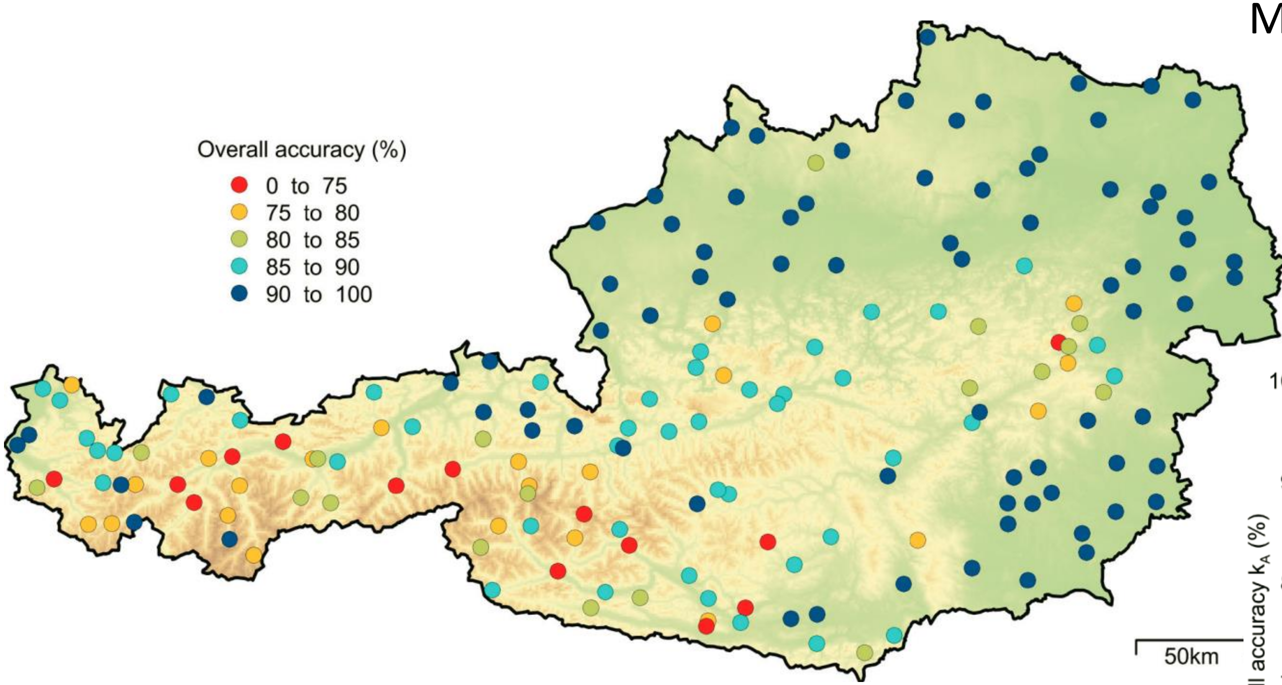


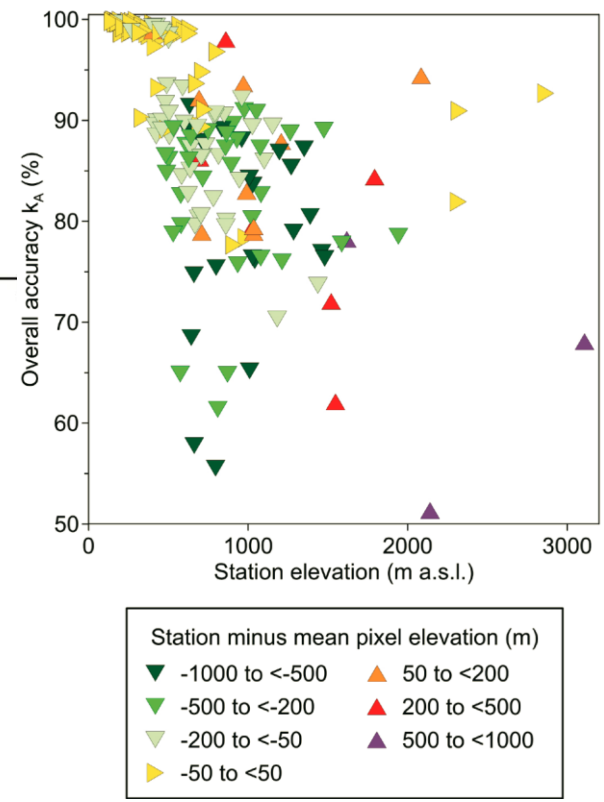
K_A: overall accuracy (sum of all corectly classified days with the presence of snow and no snow to the number of all cloud-free days at met stations.)
K_M: accuracy for the particular month
K_C: alldays accuracy

April 2008 - June 2012.
Red and blue colors represent meteorological stations located in the flatland and (81 stations) and mountain (97 stations)

H10 Snow Recognition Validation Results

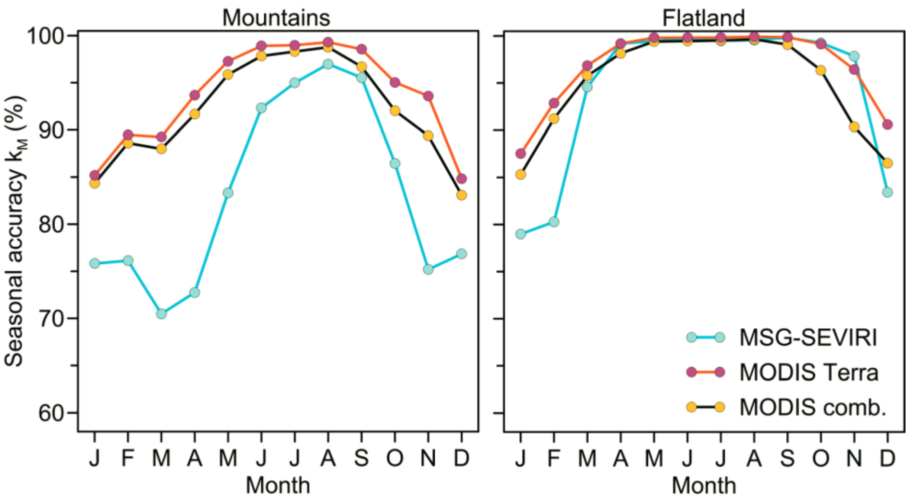
Median k_A for flatland:98.8%
for mountain regions:84.3%

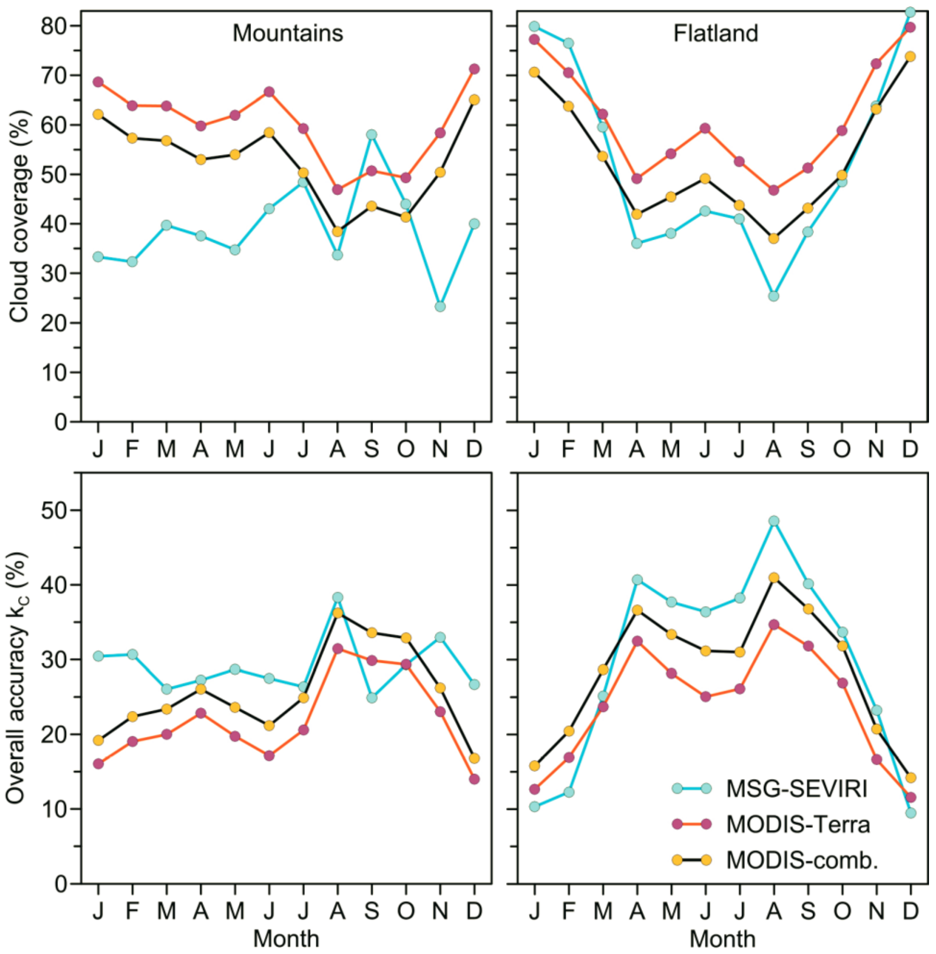




Statistics	All stations	Stations in mountains	Stations in flatland
Count	178	97	81
Minimum k_A	51.3	51.3	78.9
25% percentile k_A	82.6	78.2	93.9
50% percentile k_A	89.3	84.3	98.8
75% percentile k_A	98.7	88.4	99.4
Maximum k_A	99.9	94.4	99.9

H10 Snow Recognition Validation Results over Austria





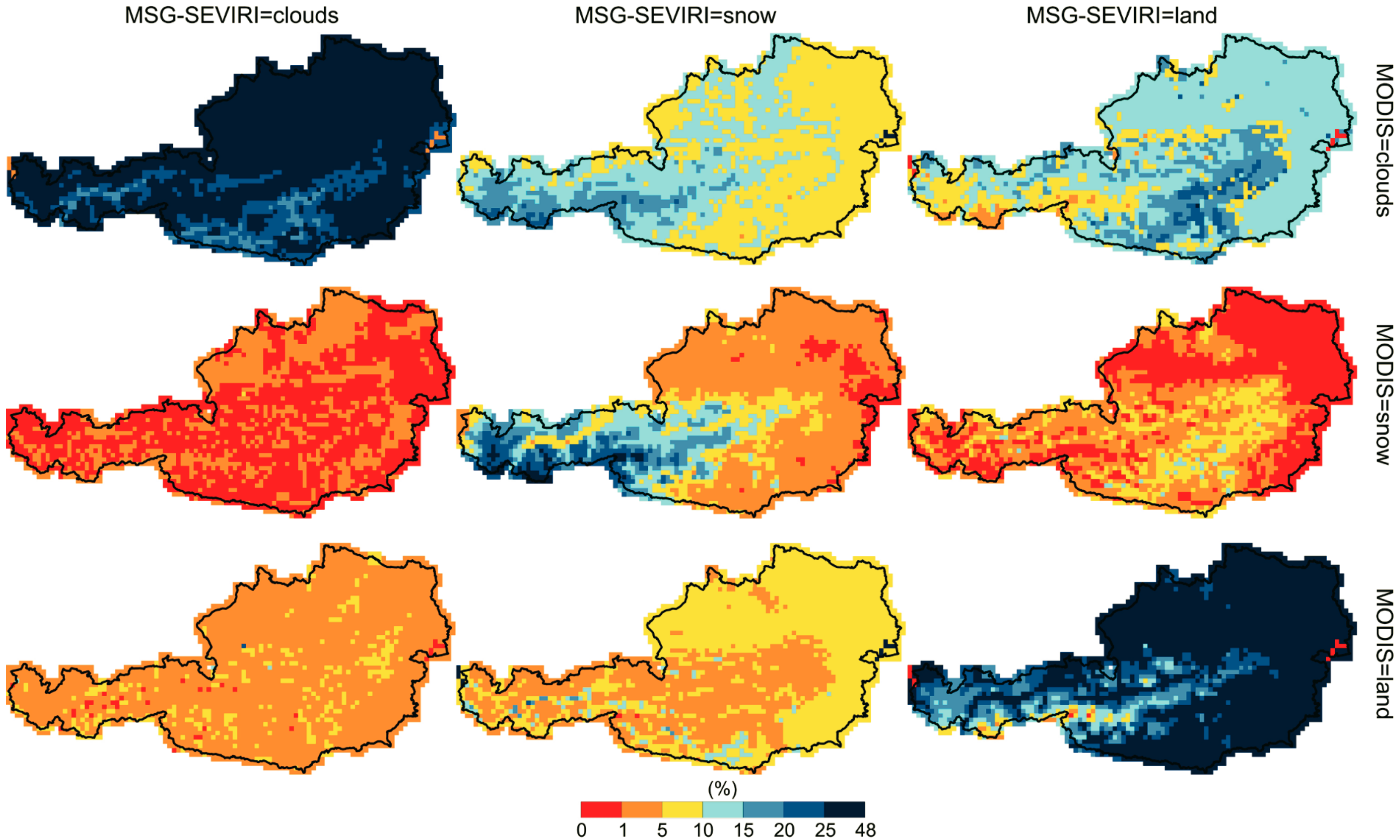
Surer , Parajka and Akyurek, 2014
Validation of the operational MSG-SEVIRI snow cover product over Austria
Hydrology Earth System Science Journal, (in print), 2014.

H10 Snow Recognition Validation Results over Austria

Seasonal frequency of overestimation (k_O) and underestimation (k_U) mapping errors (%) estimated for the MSG-SEVIRI (H10), MODIS-Terra and MODIS-combined snow cover products in the period April 2008 - June 2012.

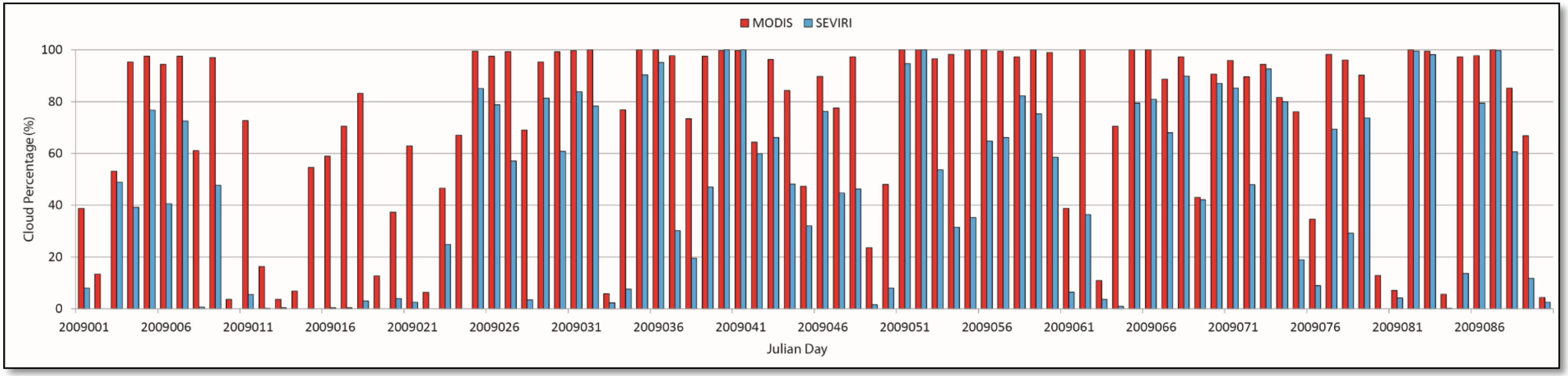
Season	MSG-SEVIRI overest. k_O (Mnt/Flat)	MSG-SEVIRI underst. k_U (Mnt/Flat)	MODIS-Terra overest. k_O (Mnt/Flat)	MODIS-Terra underest. k_U (Mnt/Flat)	MODIS-comb. overest. k_O (Mnt/Flat)	MODIS-comb. underest. k_U (Mnt/Flat)
January	4.6/0.4	6.3/2.4	1.0/1.0	1.8/0.8	1.4/1.6	2.2/1.2
February	4.3/0.4	6.8/2.6	0.7/0.7	1.5/0.6	1.1/1.2	1.8/0.8
March	6.1/0.3	5.7/1.1	1.1/0.3	1.3/0.4	1.5/0.7	1.7/0.6
April	8.8/0.1	2.5/0.2	0.8/0.1	0.7/0.2	1.4/0.5	1.0/0.2
May	5.5/0.2	1.1/0.0	0.3/0.1	0.3/0.0	0.7/0.2	0.3/0.0
June	2.2/0.1	0.4/0.0	0.1/0.0	0.1/0.0	0.3/0.2	0.1/0.0
July	1.3/0.2	0.2/0.0	0.1/0.0	0.1/0.0	0.3/0.2	0.1/0.0
August	0.9/0.2	0.4/0.0	0.1/0.0	0.1/0.0	0.3/0.1	0.2/0.0
September	1.0/0.1	0.3/0.0	0.3/0.0	0.1/0.0	1.0/0.3	0.1/0.0
October	4.0/0.2	1.1/0.0	1.2/0.2	0.3/0.0	2.4/1.2	0.4/0.0
November	6.1/0.2	7.9/0.4	1.1/0.4	0.5/0.2	2.4/2.0	0.7/0.3
December	5.1/0.5	4.6/1.5	0.9/0.7	1.6/0.5	1.4/1.6	2.0/0.6

H10 Snow Recognition Validation Results on Austria

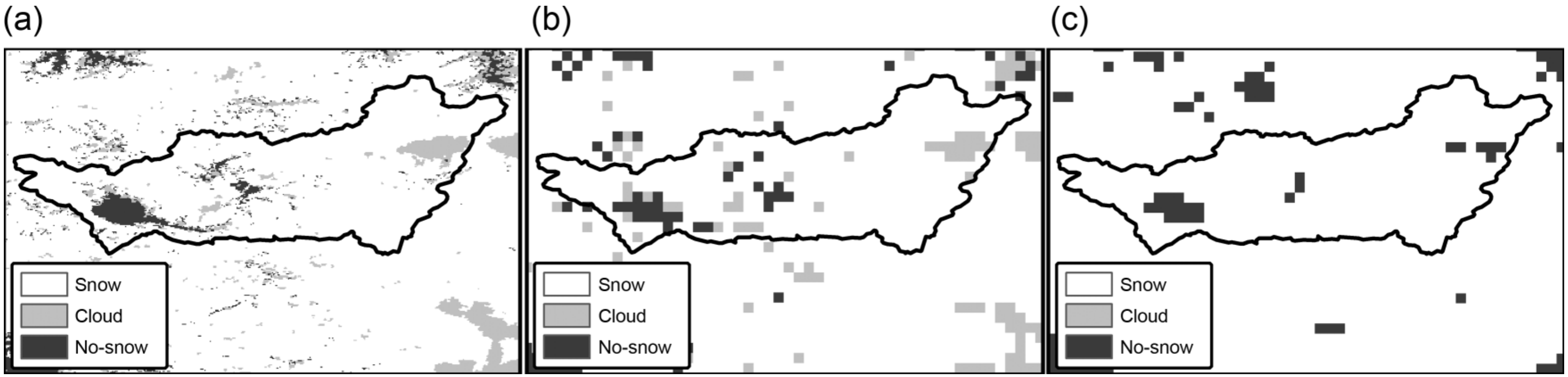


Relative frequency of days with agreement and disagreement between the MSG-SEVIRI (H10) and MODIS-combined snow cover products in the period April 2008 - June 2012.

H10 Snow Recognition Validation Results over Turkey



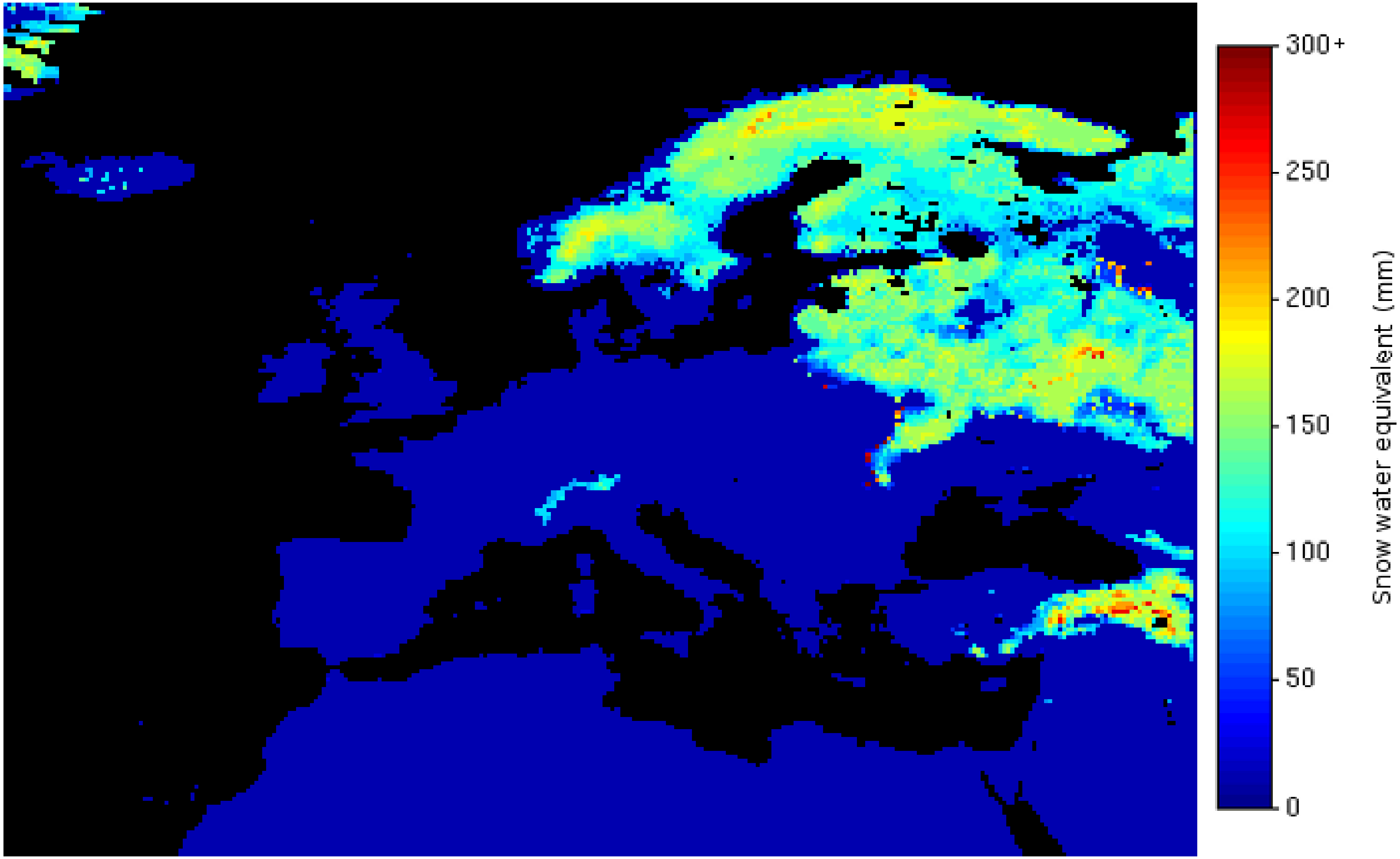
The possibility of 37% cloud cover reduction from MSG-SEVIRI compared to using only one daily observation from MODIS



22 January 2009: (a) MOD10A1 product, (b) MOD10A1 product resampled to 5 km, and (c) H10 product

Surer and Akyurek, 2012
Evaluating the utility of the EUMETSAT HSAF snow recognition product over mountainous areas of eastern Turkey
Hydrological Science Journal, 57 (8), 1-11, 2012.

H13 Snow Water Equivalent Product

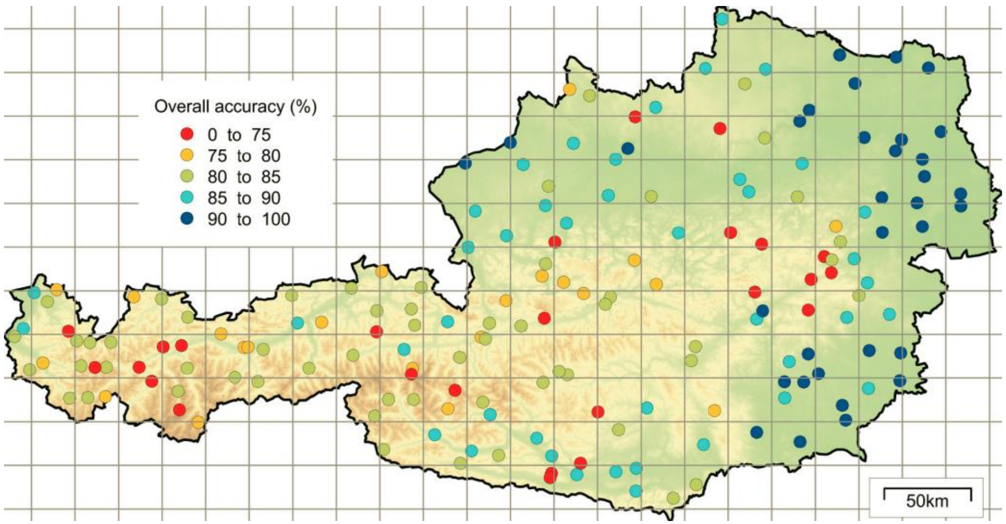


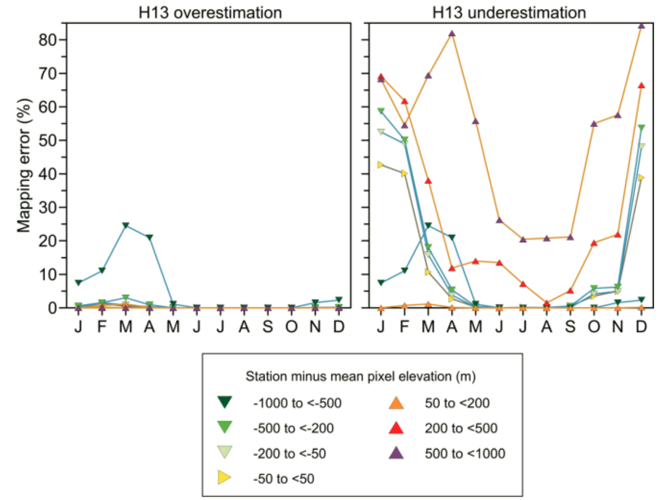
7.03.2013

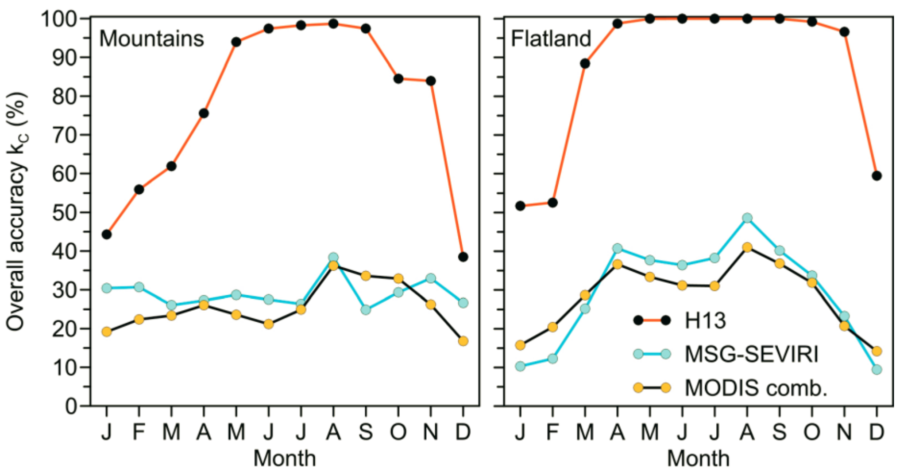
2010 RMSE= 46.14 mm
2011 RMSE= 45.24 mm
2012 RMSE= 45.54 mm
2013 RMSE= 39.62 mm

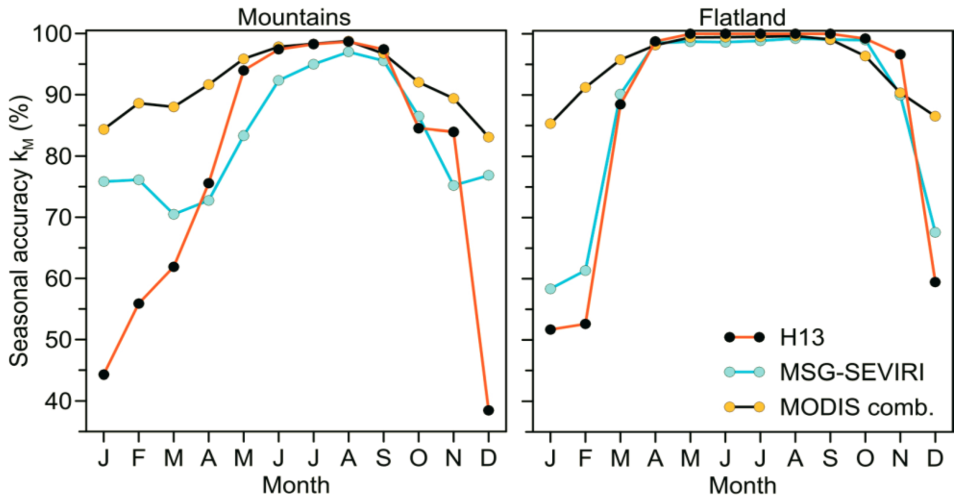
H13 SWE Validation Results over Austria

Overall accuracy (kA, %) of snow water equivalent (H13) product at 178 meteorological stations in the period April 2008-June 2012.

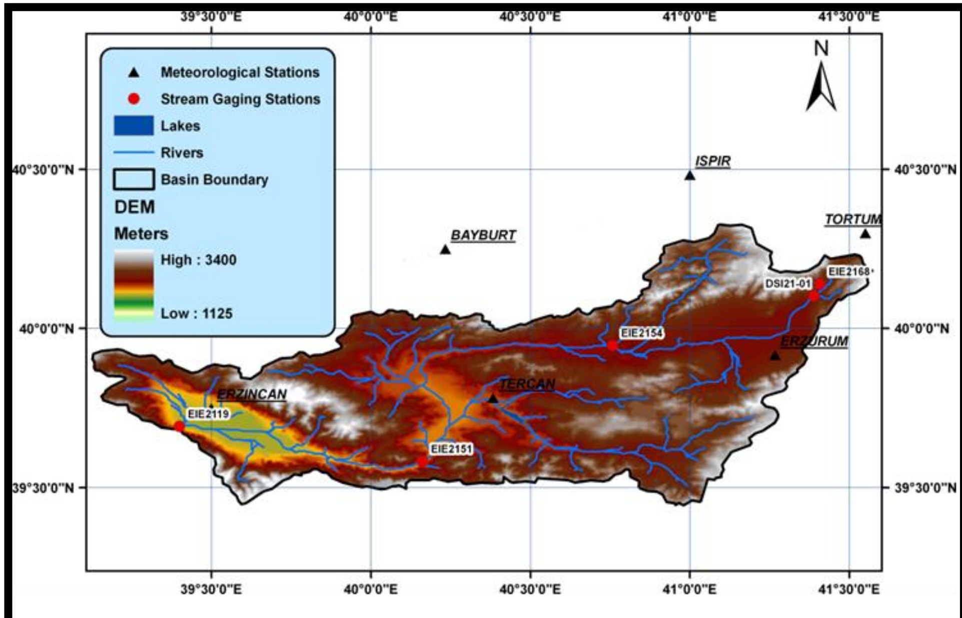




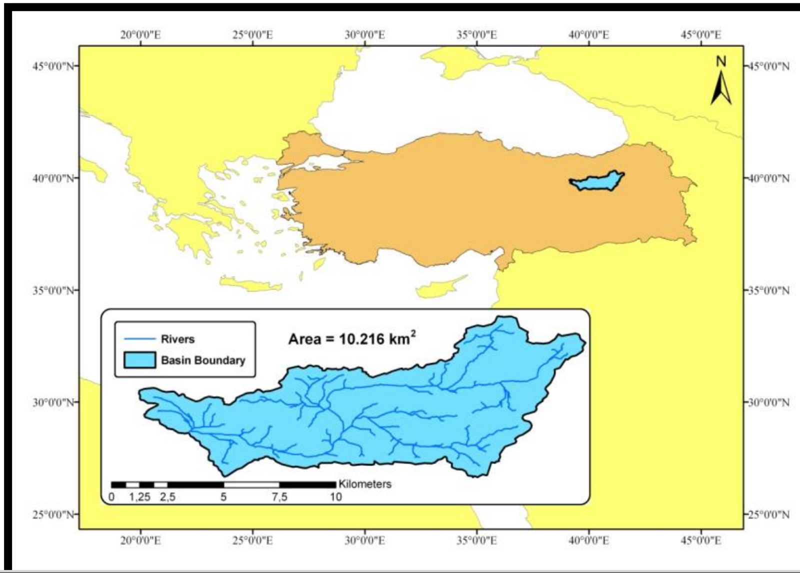


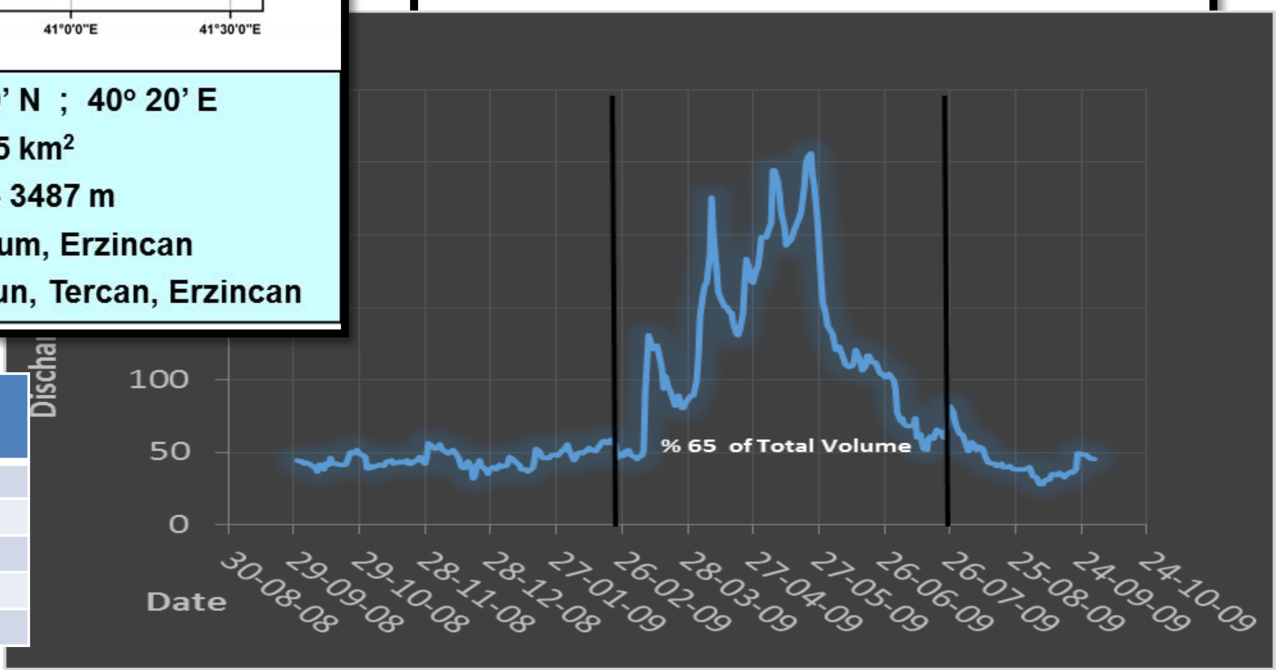


Study Area in Turkey



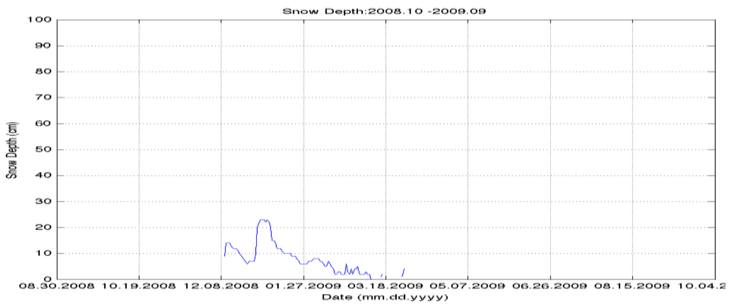
Geographic Location	39° 50' N ; 40° 20' E
Basin Area	10,275 km^2
Elevation Range	1125 - 3487 m
Cities in Basin	Erzurum, Erzincan
Dams in Basin	Kuzgun, Tercan, Erzincan

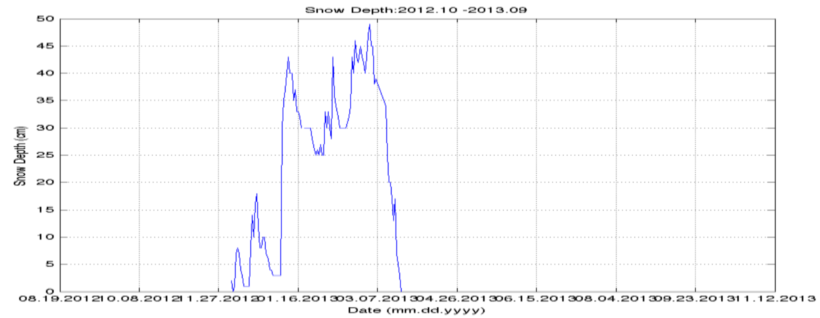


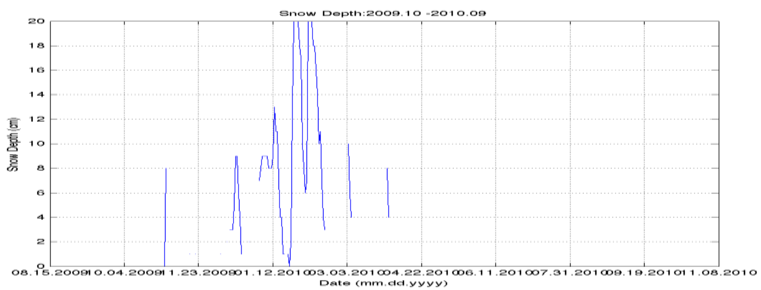


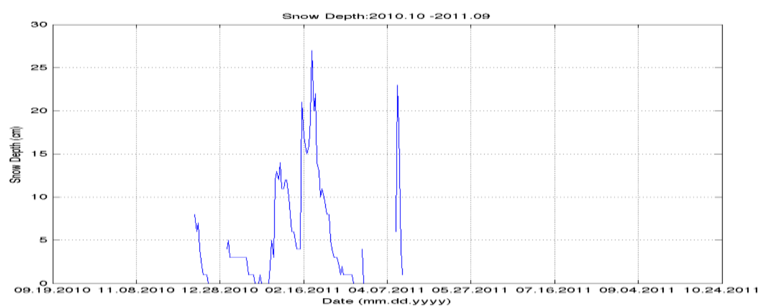
Zone	Elevation (m)	Area (km2)	Area (%)
A	1100-1500	1158	11.43
B	1500-1900	3467	34.23
C	1900-2300	3427	33.83
D	2300-2900	2012	19.86
E	2900-3400	65	0.64

Snow Depth Variation







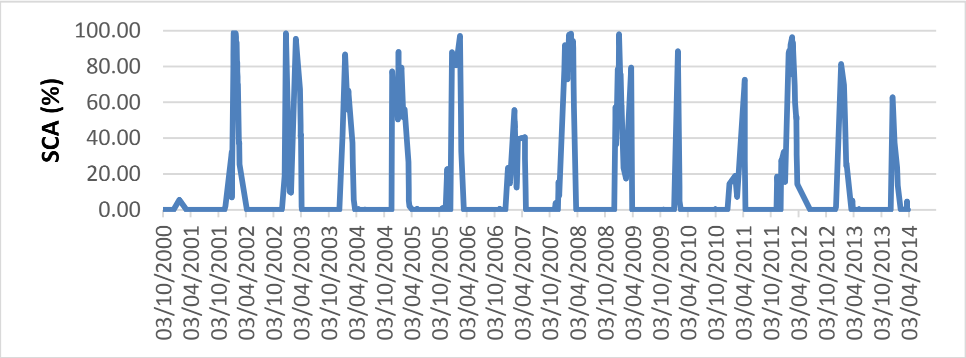


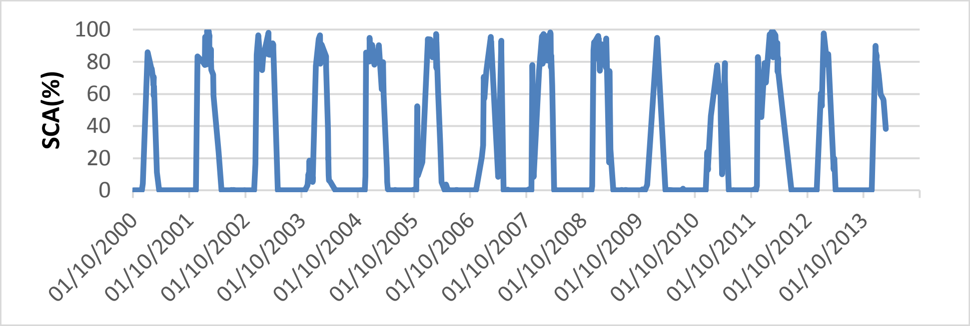
Date	*Date*	*Mean Snow Depth(cm)*	
01.01.2001	12.04.2001	16.31	
22.11.2001	09.04.2002	20,30	
07.12.2002	04.04.2003	14.85	
01.01.2004	04.04.2004	26,10	
23.11.2004	04.04.2005	28.57	
21.10.2005	26.04.2006	15.47	
15.12.2006	24.04.2007	24,11	
10.11.2007	16.03.2008	12,78	
10.12.2008	29.03.2009	9,11	
01.11.2009	31.03.2010	8,07	
13.12.2010	16.04.2011	5,90	
11.11.2011	25.03.2012	16,50	
05.12.2012	22.03.2013	23,38	

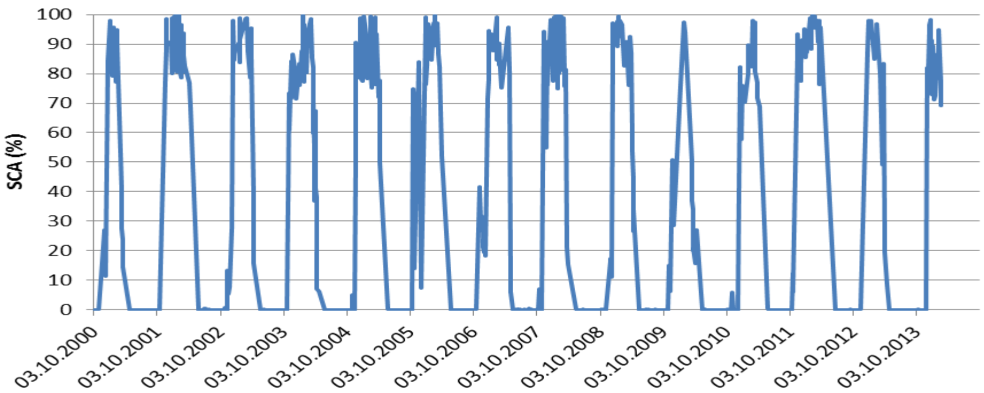
Snow Depth (cm) at Erzurum station (1758 m)

January 2014 :4.77 cm

Snow Cover Area Variation







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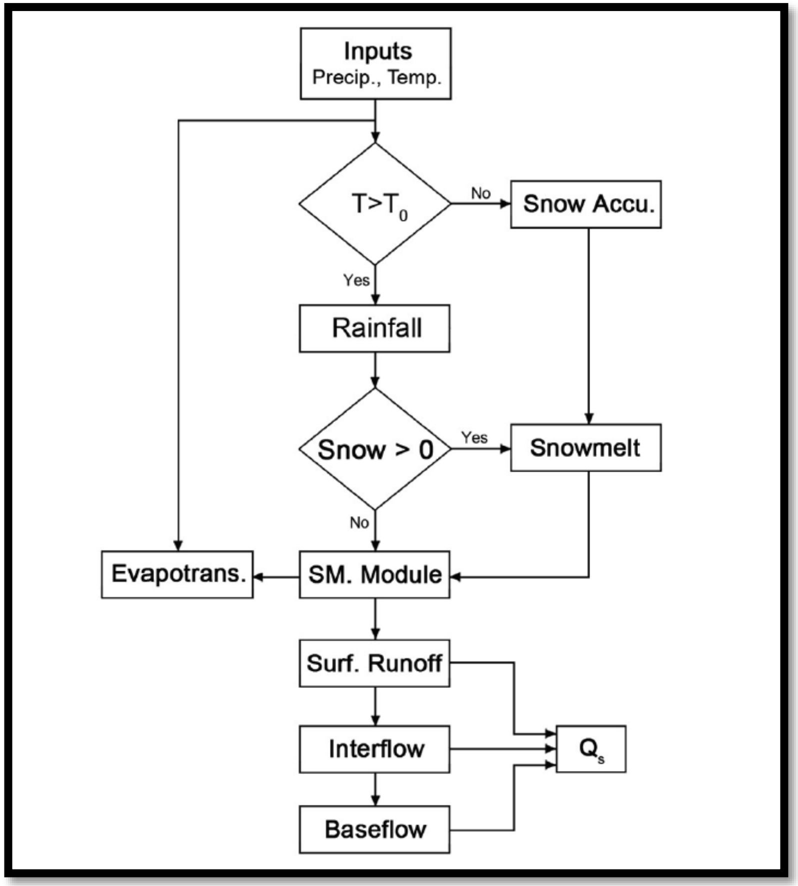
B	1500-1900	3467	34.23
C	1900-2300	3427	33.83
D	2300-2900	2012	19.86
E	2900-3400	65	0.64

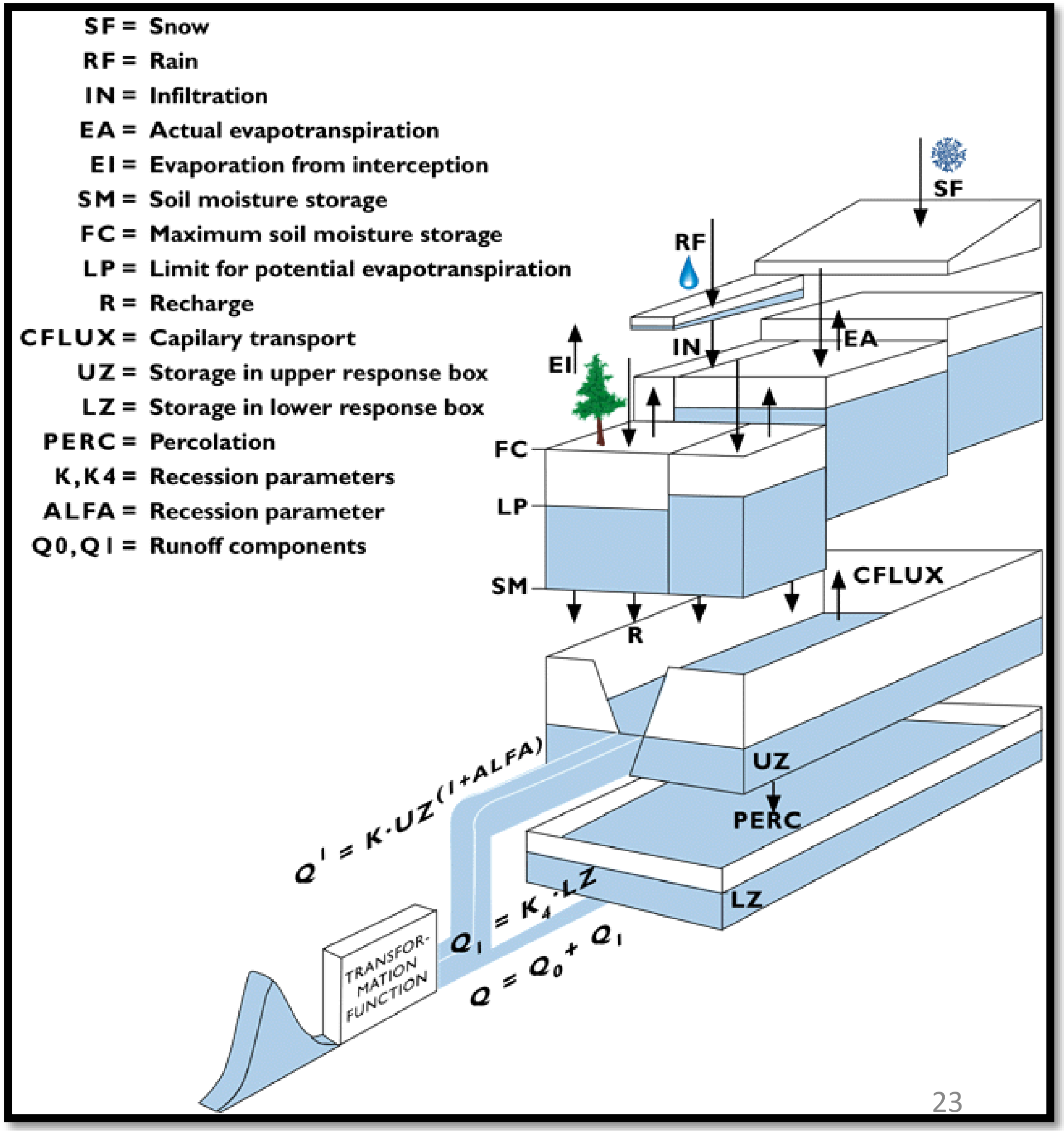
Zone A — No snow: end of March
18.02.2014

Zone B — No snow: end of April
25.03.2014

Zone C — No snow: end of May
24.04.2014

Hydrological Modelling:HBV





- The HBV model is a conceptual hydrological model designed for use in mountainous environments.
- It is semi-distributed.

Hydrological Modelling:HBV

Model parameter		Model component	Lower	Upper
Snow correction factor(-)	CSF	Snow	0	1.5
Degree Day factor(mm/ °Cday)	DDF	Snow	0	5.0
Rain air temp. Thresold (°C)	T_{rain}	Snow	2	2
Snow air temperature threshold (°C)	T_{snow}	Snow	-2	-2
Melting air temperature threshold (°C)	T_{melt}	Snow	-2.0	2.0
Soil moisture state/maximum soil moisture storage (-)	LP/FC	Soil	0	1.0
Maximum soil moisture storage (mm)	FC	Soil	0	600
Runoff generation to the soil moisture state (-)	BETA	Soil	0	20
Very Fast storage coefficient (days)	K0	Runoff	0	2.0
Fast storage coefficient (days)	K1	Runoff	2.0	30
Low storage coefficient (days)	K2	Runoff	30	250
Threshold of storage state exceedence (mm)	LSUZ	Runoff	1.0	100
Percolation rate (mm/day)	CPERC	Runoff	0	1.0
	BMAX	Runoff	10	10
Routing parameter	CROUTE	Runoff	26.5	26.5

Nash-Sutcliffe Model efficiency for high, and low flows

$$M_E = 1 - \frac{\sum_{i=1}^{n}\left(Q_{obs,i} - Q_{sim,i}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs,i} - \overline{Q_{obs}}\right)^2}$$

$$M_E^{\log} = 1 - \frac{\sum_{i=1}^{n}\left(\log(Q_{obs,i}) - \log(Q_{sim,i})\right)^2}{\sum_{i=1}^{n}\left(\log(Q_{obs,i}) - \log(\overline{Q_{obs}})\right)^2}$$

$$V_E = \frac{\sum_{i=1}^{n} Q_{sim,i} - \sum_{i=1}^{n} Q_{obs,i}}{\sum_{i=1}^{n} Q_{obs,i}}$$

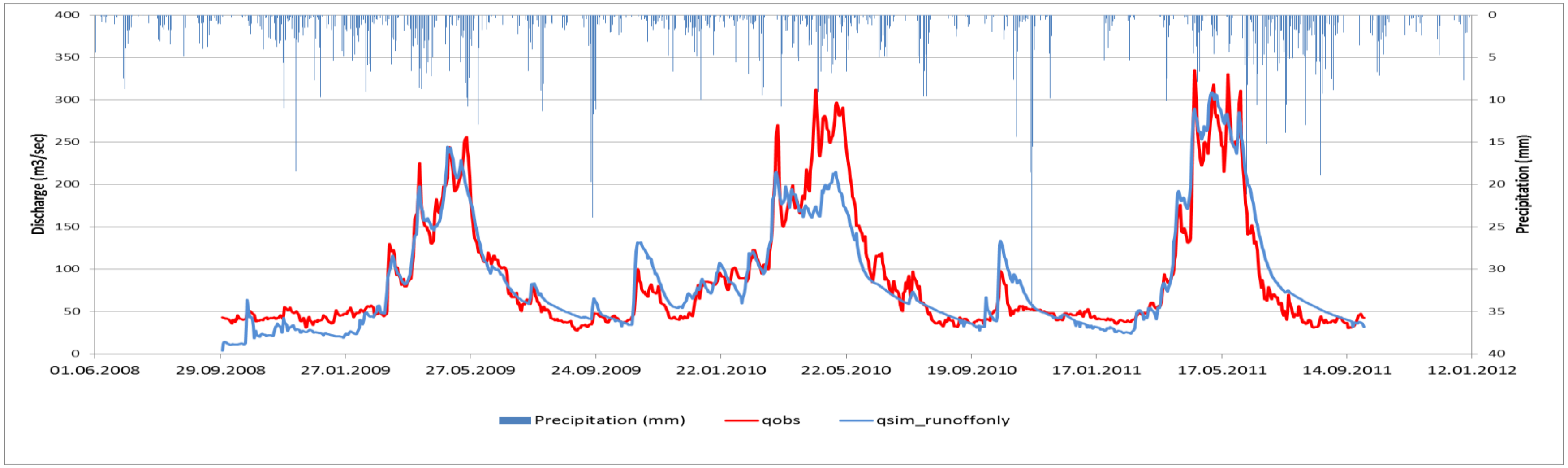
Under and Over estimation errors

$$S_E^O = \frac{1}{m \cdot l}\sum_{j=1}^{l} m_O \left| (SWE > \xi_{SWE}) \wedge (SCA = 0) \right.$$

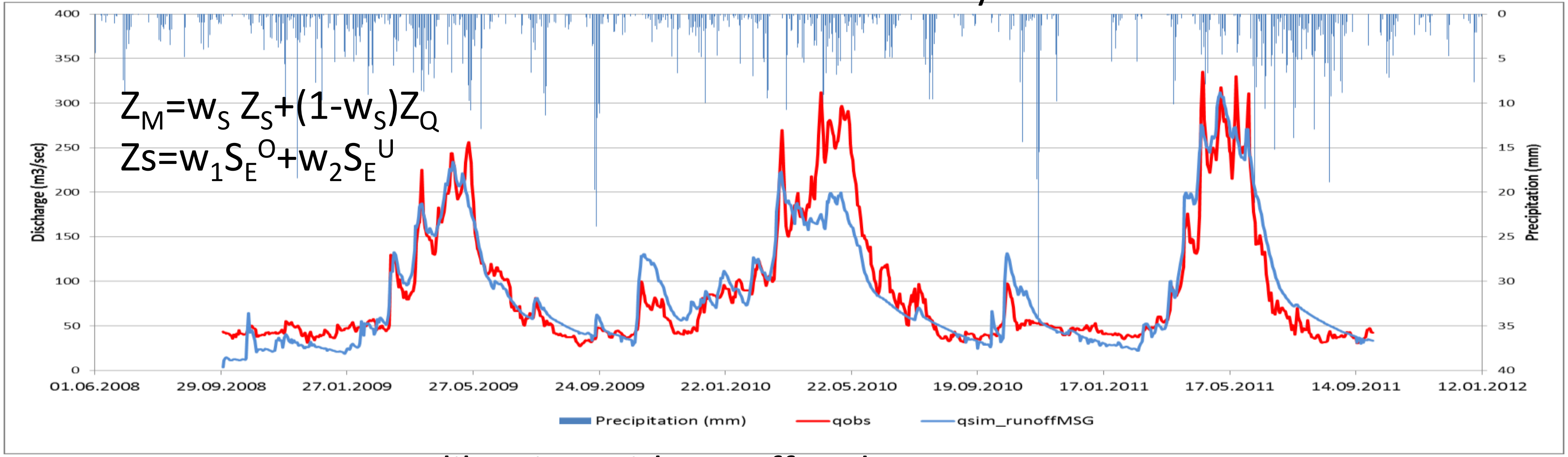
$$S_E^U = \frac{1}{m \cdot l}\sum_{j=1}^{l} m_U \left| (SWE = 0) \wedge (SCA > \xi_{SCA}) \right.$$

ζ_{SWE}=0 ζ_{SCA}=25%

Calibrating the model



Calibration with runoff only

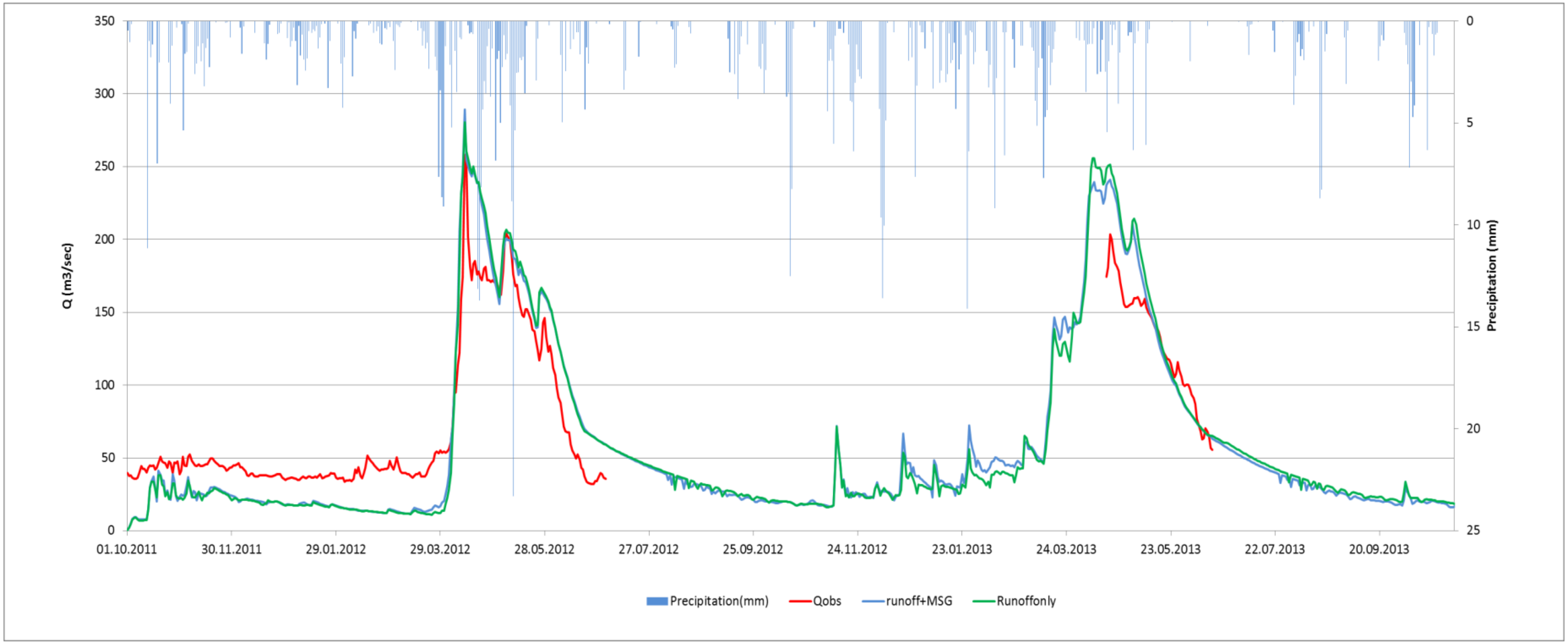


$$Z_M = w_S Z_S + (1-w_S) Z_Q$$

$$Zs = w_1 S_E^O + w_2 S_E^U$$

Calibration with runoff and MSG snow cover

Verification of the Model



	runoffonly	runoff+msg
volume error	-0.028	-0.032
snow overestimation (days)	1	0
snow underestimation	0	0
ME	0.72	0.74
logME	-0.36	-0.19

Calibrating the model over Austria

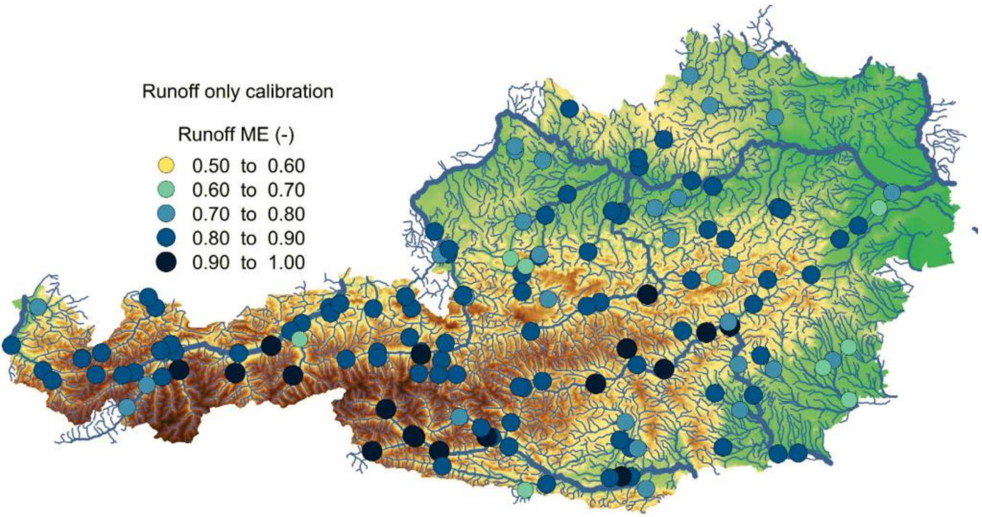
Study is performed for 144 runoff gauges.

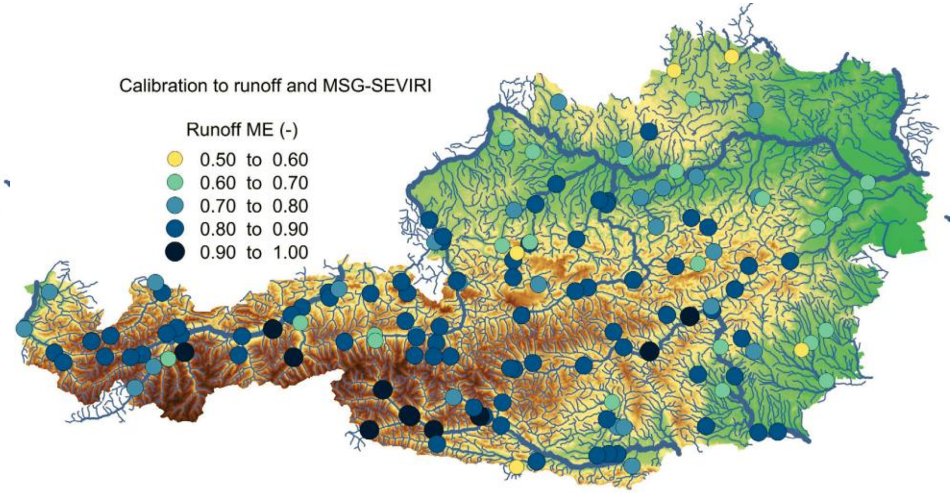
Calibration dataset, which includes the hydrologic and satellite data in the period from January, 2007 to December, 2010.

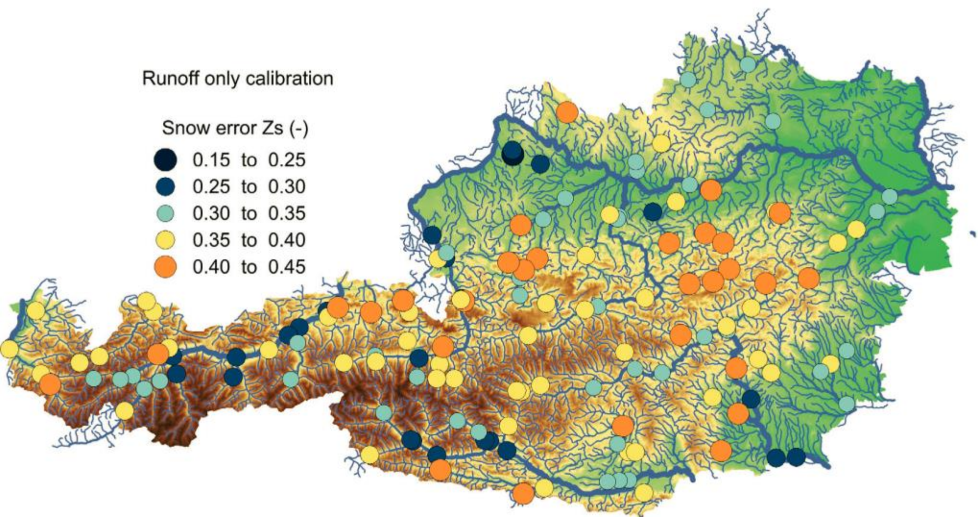
The second is a verification dataset, which includes the hydrologic data in the period from November 1, 1976 to December 31, 2006.

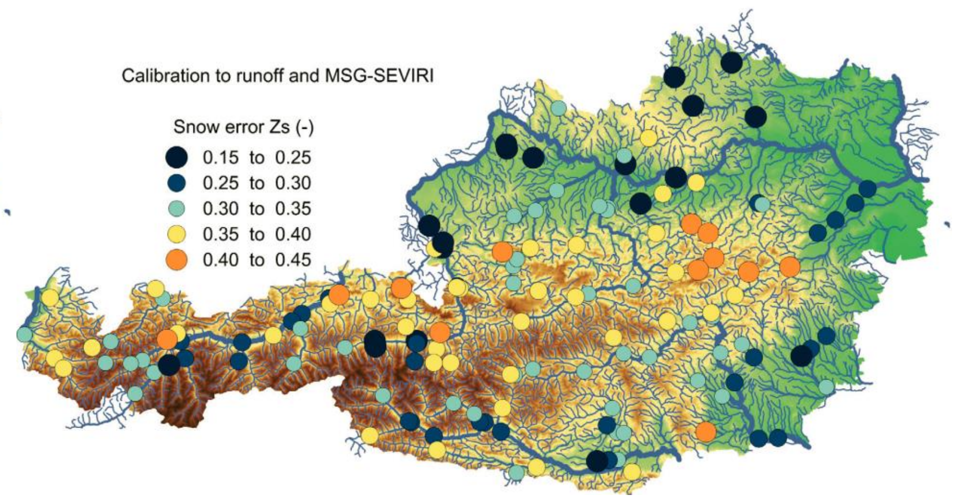
Area between 25 km2-9770 km2

Elevation between 115 m-3797 m

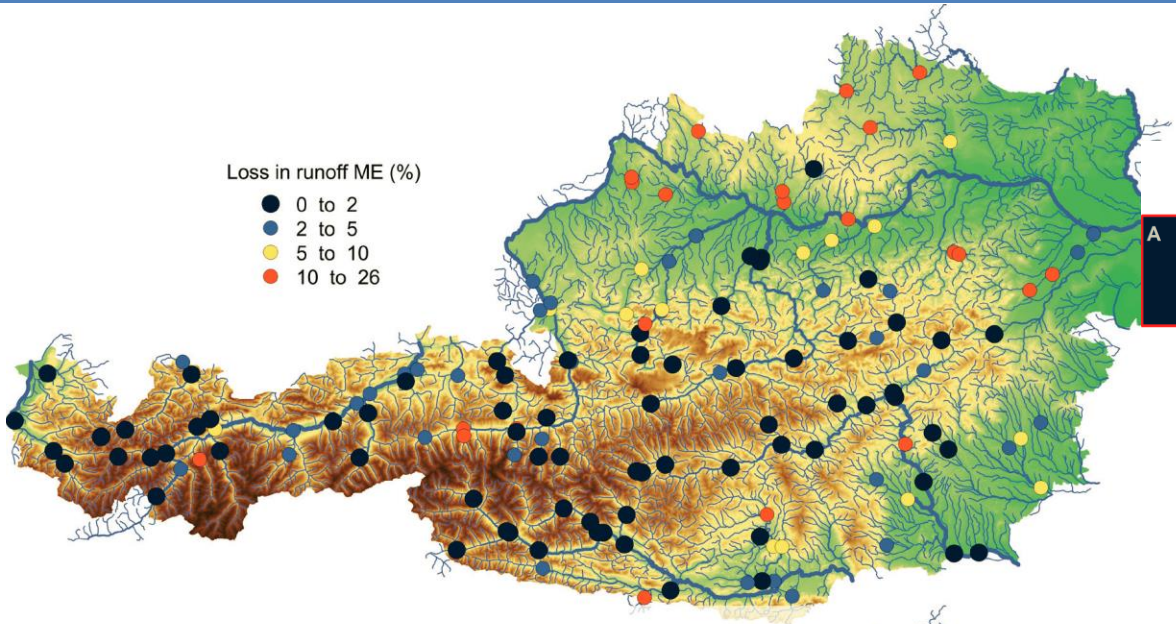


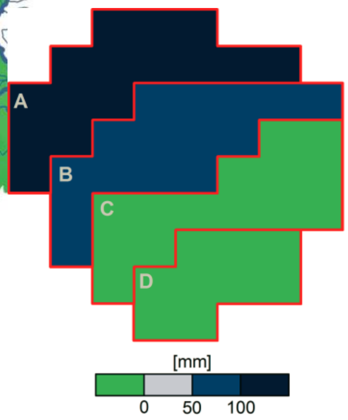


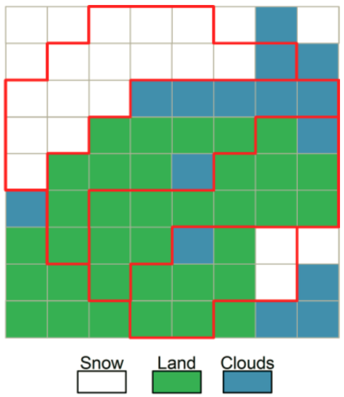


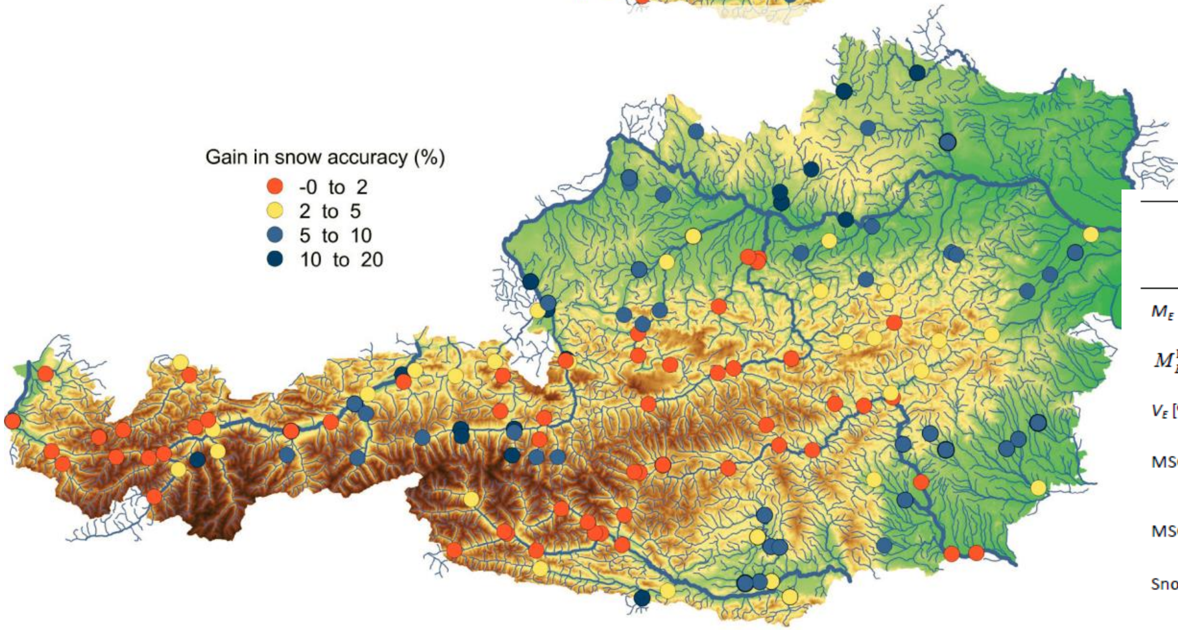


Validating the model over Austria









	Calibration period 2007-2010	Verification period 1976-2006
M_E	0.81/0.08	0.72/0.12
$M_E^{\log}$	0.87/0.09	0.79/0.15
V_E [%]	-1.4/2.1	-1.0/9.8
MSG-SEVIRI S_E^O	15.4/9.3	
MSG-SEVIRI S_E^U	20.3/6.3	
Snow depth S_D^O	1.4/3.3	5.1/6.6
Snow depth S_D^U	7.8/4.8	5.2/3.0

Results

Q max(m3/sec)				Model		H13	
Observed	Date	Model	Date	Date	SWE_{max} (mm)	SWE_{max} (mm)	Date
265	23.05.2009	216	17.05.2009	29.03.2009	113	128	25.03.2009
312	23.04.2010	198	12.05.2009	5.03.2010	47	115	19.03.2010
318	9.05.2011	315	8.05.2011	14.03.2011	93	152	15.03.2011
258	12.04.2012	261	12.04.2012	20.03.2012	118	181	20.03.2012
		241	18.04.2013	8.03.2013	128	179	8.03.2013

Table IV. Maximum SWE and Julian days of $SCA_{50\%}$, $R_{50\%}$, and SWE_{max}

	2004	2005	2006	2007	2008	2009	Mean	Standard deviation
Day of year of $SCA_{50\%}$	101	102	92	122	81	102	100	13
Day of year of $R_{50\%}$	121	122	122	130	105	130	122	9
SWE_{max} (mm)	197·5	185·34	171·78	191·0	174·14	185·03	184·13	9·8
Day of year SWE_{max}	73	73	71	71	53	76	70	8

73:14 March

Akyurek et al., 2011 «Investigation of the snow-cover dynamics in the Upper Euphrates Basin of Turkey using remotely sensed snow-cover products and hydrometeorological Data» HYDROLOGICAL PROCESSES
Hydrol. Process. 25, 3637–3648

Discussion

- The cloud clearance capability of MSG-SEVIRI snow product would make the product usable in hydrological modeling, especially for the areas where high cloud coverage may be seen during snow season.
- Product can be an alternative for different filtering methods for cloud reduction in optical remote sensing snow products.
- Merging of snow products having comparatively better spatial resolution (MODIS) and temporal resolution (MSG-SEVIRI) can be also studied.
- Calibration against SCA in addition to runoff improved the simulated runoff considerably. Particularly in catchments with lower elevations (mean elevation below 900 m.s.l.) and in catchments with absent or sparse precipitation measurements.
- The snow model efficiency is improved. Important for representing the internal variables correctly especially for climate warming scenarios.
- H13 maximum SWE estimates are comparatively larger than model maximum SWE simulations. But their timing matches properly.