Accuracy assessment of MODIS snow products

T. Masson[1], M. Dalla Mura[1], M. Dumont[2], P. Sirguey[3], S. Gascoin[4], J. Chanussot[1,5], J.-P. Dedieu[6]

1: GIPSA-lab, Grenoble-INP, Saint Martin d'Hères, France
2: Météo-France-CNRS, CNRM/CEN, UMR 3589, Grenoble, France
3: National School of Surveying, University of Otago, New-Zealand
4: Centre d'Etudes Spatiales de la Biosphère, Toulouse, France
5: Faculty of Electrical and Computer Engineering, University of Iceland, Reykjavik, Iceland
6: LTHE, CNRS/UGA/Grenoble-INP, Grenoble, France

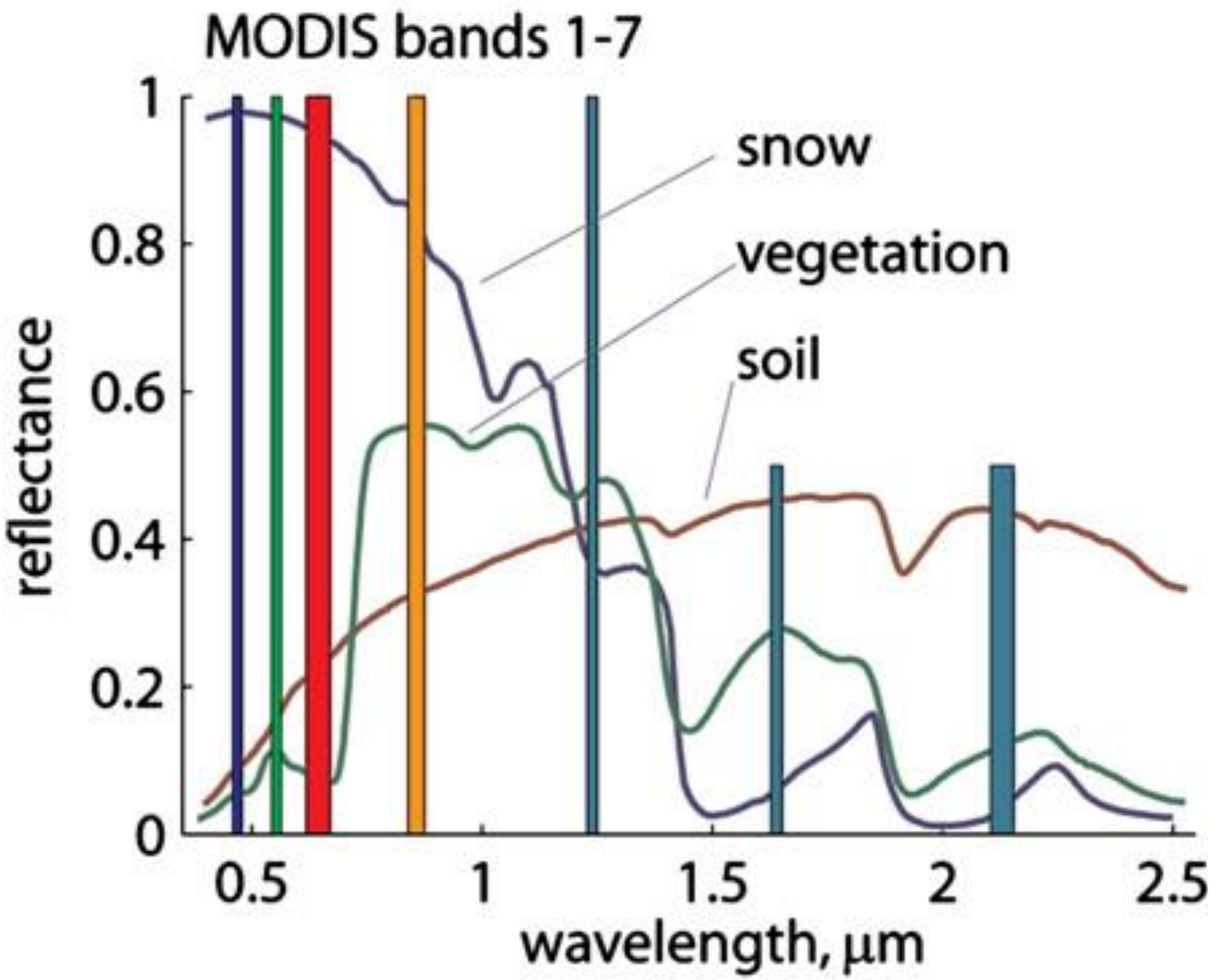
The Moderate-Resolution Imaging Spectroradiometer (MODIS)

- On Terra and Aqua satellites

- 7 bands in VIS and NIR/SWIR (2 at 250 m, 5 at 500 m)

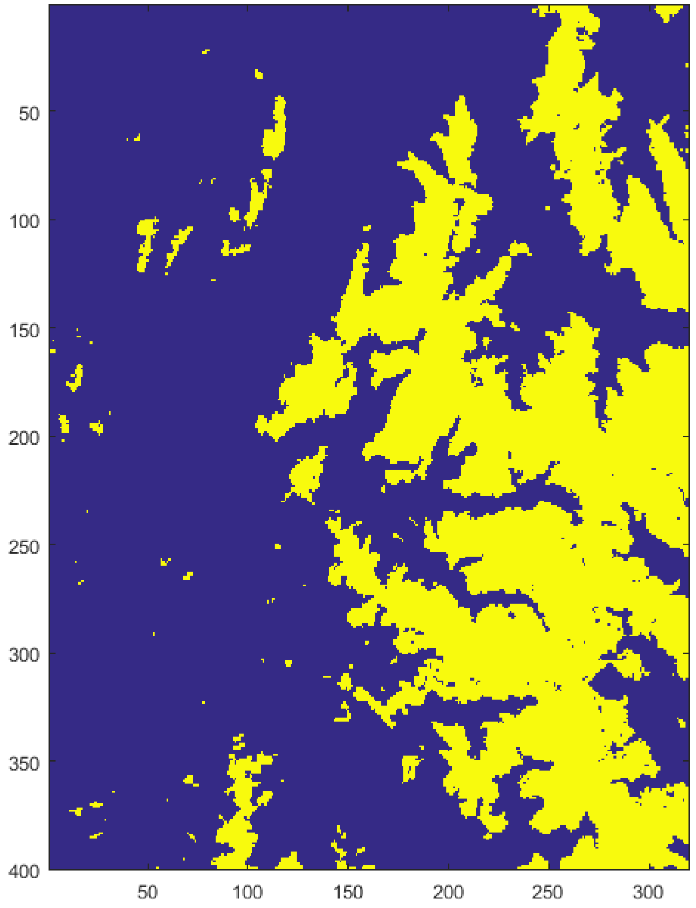
- <1 day revisit time

- Provides unique time series of snow cover (in orbit for more than 16 years)



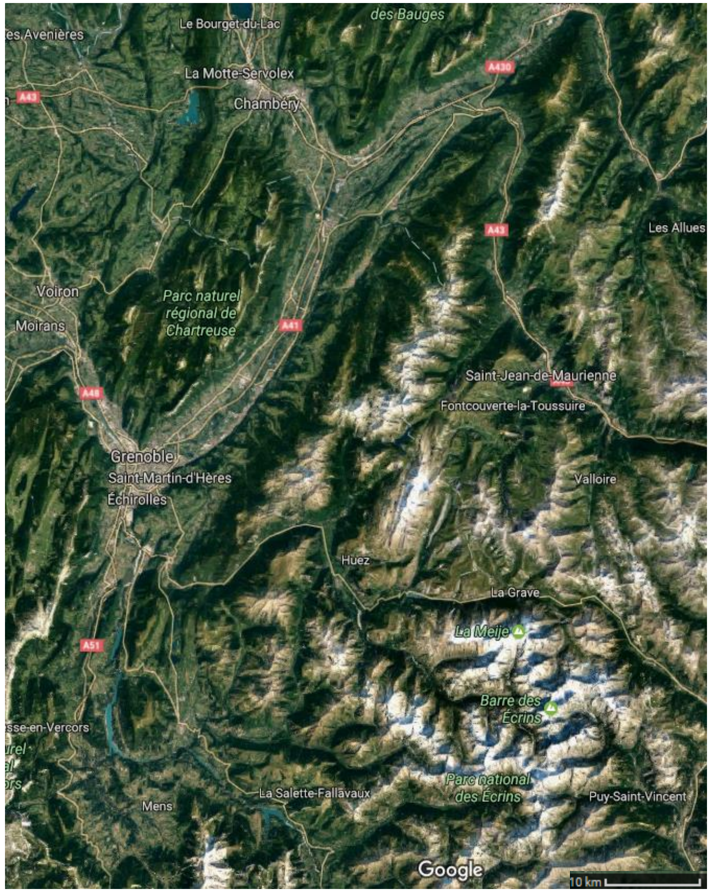
Painter et *al*, 2009

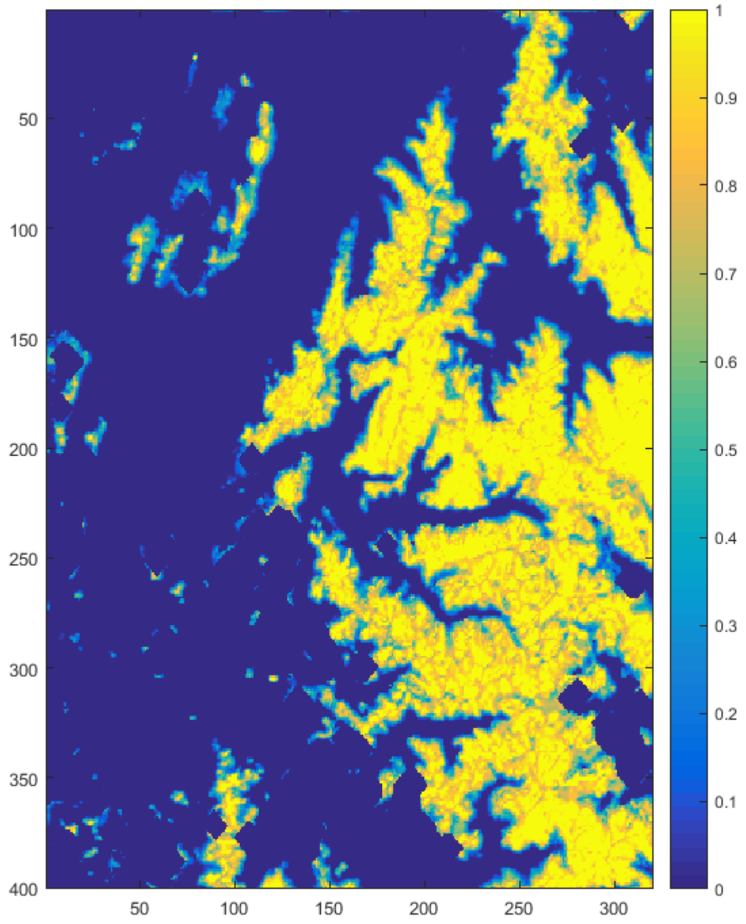
Binary vs Fractional snow product



Binary product (0 or 1)

MODIS 24/05/13





Fractional product ($0 \leq SCF \leq 1$)

MODIS 24/05/13

Snow Cover Fraction, two main approaches and multiple methods

- Normalized Difference Snow Index (NDSI) approach
- Spectral Unmixing approach

-> Several products with different characteristics

  -> Necessity of an accuracy assessment

Snow Cover Fraction, two main approaches and multiple methods

1) Based on the Normalize Difference Snow Index (NDSI)

$$\mathrm{NDSI} = \frac{R_{SWIR} - R_{VIS}}{R_{SWIR} + R_{VIS}}$$

(Dozier et *al,* 1989)

For a pixel p, the Snow Cover Fraction (SCF) is defined by

$$SCF_p = -0.001 + 1.45 NDSI_p$$

(Salomonson and Appel, 2004, 2006)

Products used in this study:

- **MOD10A1** (from the National Snow and Ice Data Center)

  -> Based on NDSI linear regression

- Input data : MOD02 (Top of the atmosphere reflectance)
- Linear regression from Salomonson and Appel, 2006
- Final products at 500 m
- Former v5
- New v6 with calibration improvement and more accurate cloud mask

Snow Cover Fraction, two main approaches and multiple methods

2) Based on Spectral Unmixing (SU)

Considering $\boldsymbol{E} = [\boldsymbol{e}_1, \dots, \boldsymbol{e}_m]$, $\boldsymbol{e}_i \in \mathbb{R}^q$ the spectral signature of endmembers in q spectral bands

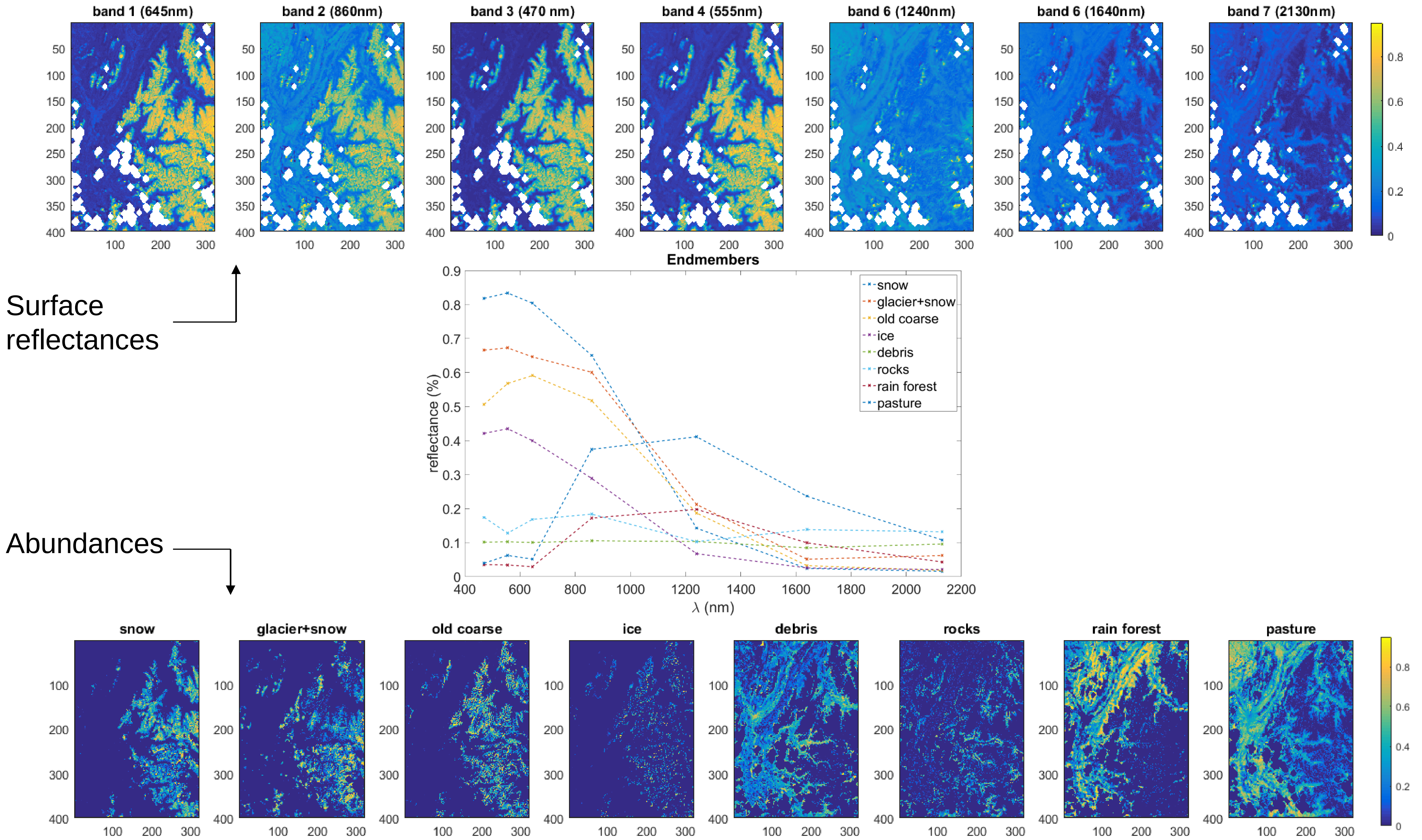
The Linear Mixing Model of the spectrum $\boldsymbol{r}$ of pixel p:

$$\boldsymbol{r}_p = \sum_{i=1}^{m} \boldsymbol{e}_i \phi_{i,p} + \boldsymbol{n}_p$$

Where $\boldsymbol{\phi}_p = [\phi_{1_p}, \dots, \phi_{m_p}]$ are fractional per pixel abundances and $\boldsymbol{n}$ is noise

$$\hat{\phi}_p = \arg\min_{\phi_p} \left\| \boldsymbol{r}_p - \sum_{i=1}^{m} \boldsymbol{e}_i \phi_{i,p} \right\|_2$$

(Bioucas-Dias et *al*, 2012)


band 1 (645nm)
band 2 (860nm)
band 3 (470 nm)
band 4 (555nm)
band 6 (1240nm)
band 6 (1640nm)
band 7 (2130nm)
Surface reflectances
Endmembers
snow
glacier+snow
old coarse
ice
debris
rocks
rain forest
pasture
reflectance (%)
λ (nm)
Abundances
snow
glacier+snow
old coarse
ice
debris
rocks
rain forest
pasture

Products used in this study:

- **MODSCAG** (Painter et *al*, 2009)

  -> Based on SU

- Input data : MOD09GA (atmospherically corrected reflectance)
- Variable set of Endmembers (with a maximum of one snow endmember)
- SU on 500 m bands (5 bands)
- Post processing : $SCF < 0.15 \; = 0$

(products courtesy of K. Rittger)

Products used in this study:

- **MODImLAB** (Sirguey et *al*, 2009)

  -> Based on SU

- Fusion step (250m product)
- Atmospheric and topographic correction in complex terrain
- 8 constant endmembers (initially designed for New-Zealand)
- Final products at 250 m
- Pre processing : pixel with $NDSI < -0.2$ are not estimated, same for dark pixels ($r_4 < 0.11$ or $r_2 < 0.10$)

Products used in this study:

Additional products :

- **Ee**

  -> Based on SU

- Fusion step (250m product)
- Atmospheric and topographic correction in complex terrain
- 8 constant endmembers (initially designed for New-Zealand)
- Final products at 250 m
- ~~Pre processing : pixel with $NDSI < -0.2$ are not estimated, same for dark pixels ($r_4 < 0.11$ or $r_2 < 0.10$)~~

Products used in this study:

Additional product :

- **NDSI_ATOPCOR**

  -> Based on NDSI linear regression

- Fusion step (250m product)
- Atmospheric and topographic correction in complex terrain
- Linear regression from Salomonson and Appel, 2006
- Final products at 250 m

NDSI Products	SU Products
MOD10A1 v5	MODImLAB
MOD10A1 v6	MODSCAG
NDSI_ATOPCOR	Ee

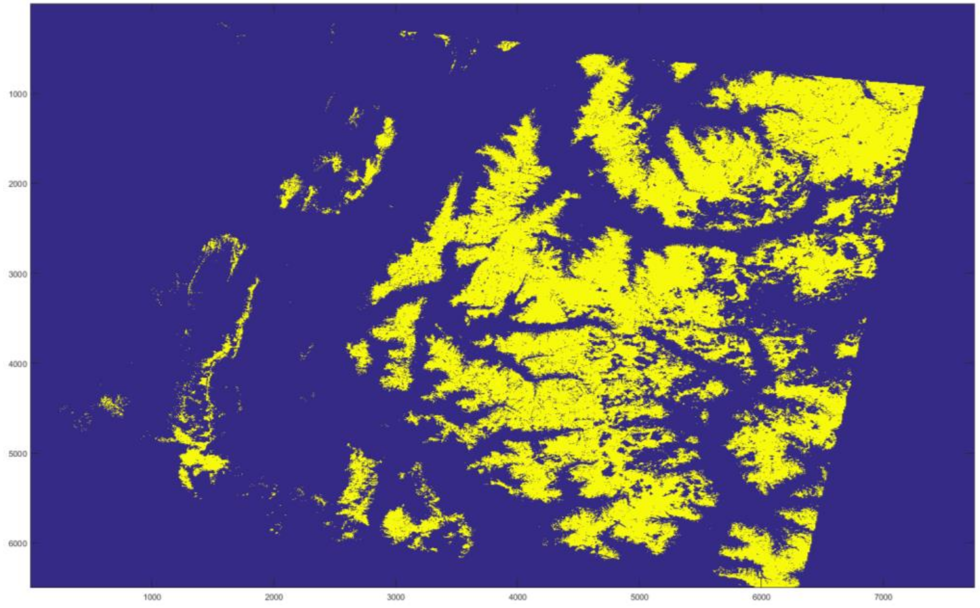
Reference snow maps

- Take-5 experiment (SPOT 4 and SPOT 5 with a 5 day return time and a spatial resolution of 20 and 10 m respectively)
- Landsat-8 (spatial resolution of 30 m)

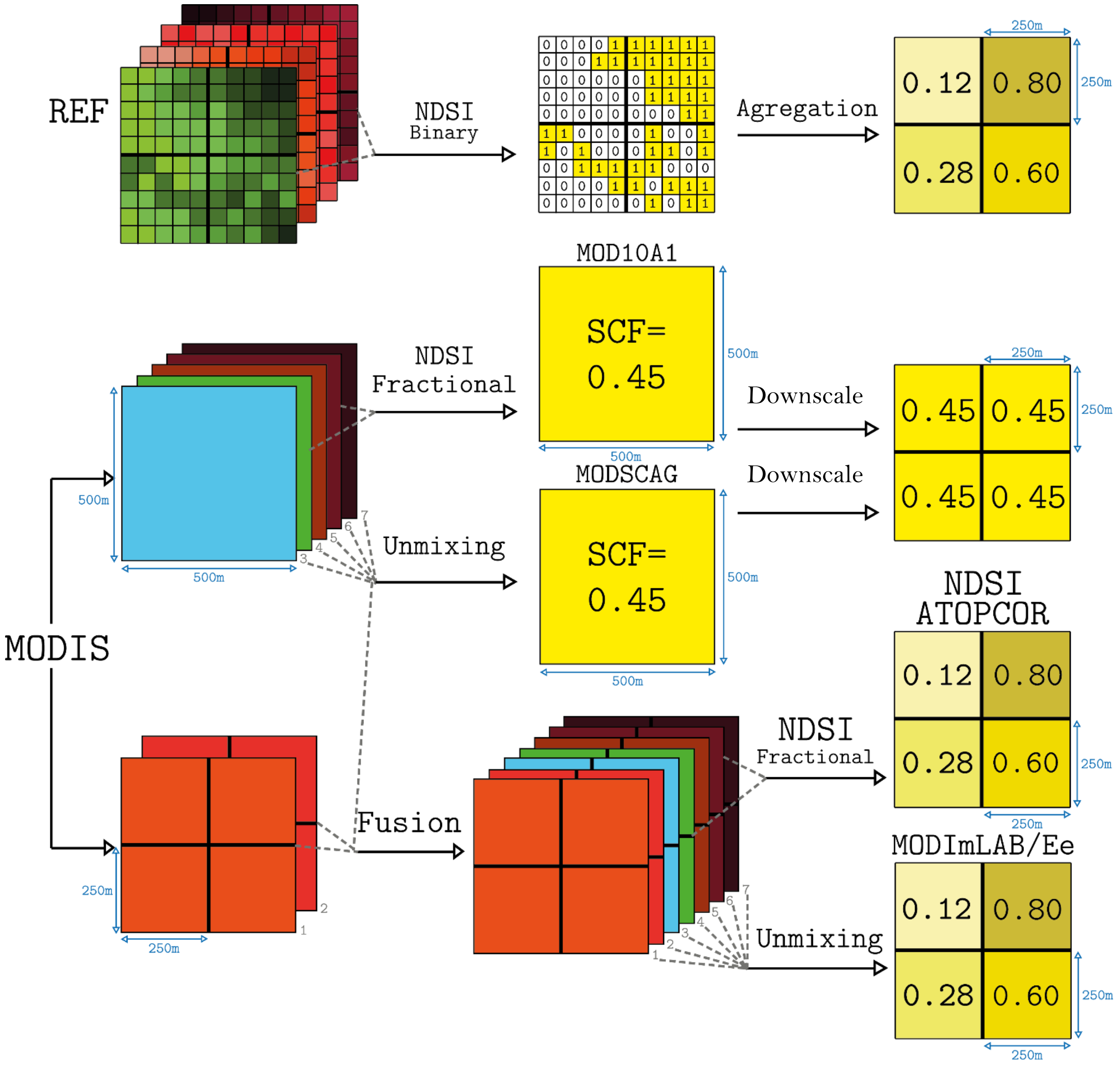
Snow products from Dedieu et *al,* (2016) and the Let-it-Snow operational chain from CESBIO (Gascoin et al, 2016)

-> Binary snow product from NDSI thresholding

(i.e., snow or not snow in a pixel)



Comparison methodology



A common cloud mask of all products and the reference is created:

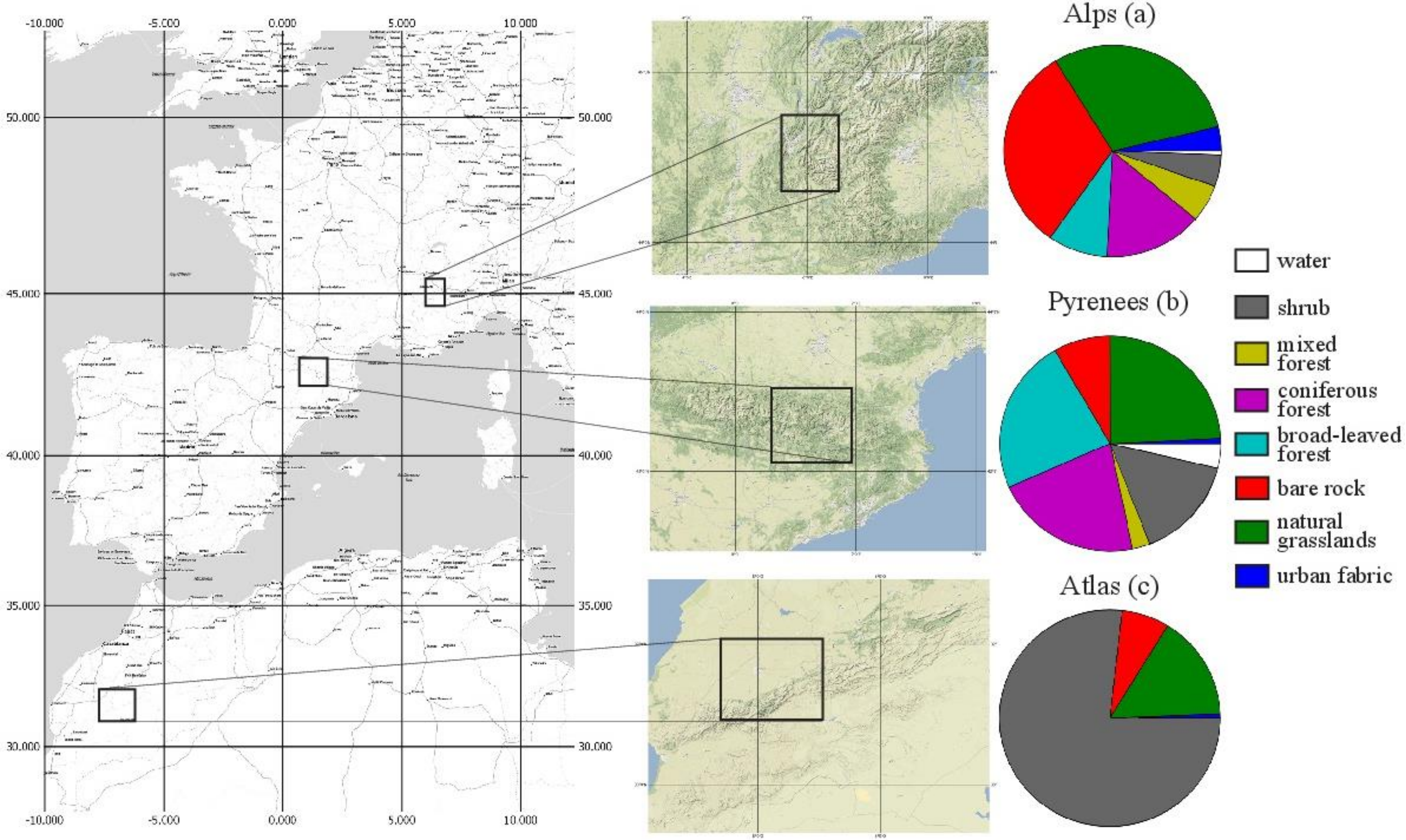
- MODIS: if pixel is cloudy (from cloud product):

  -> cloud pixel = NaN

- Reference: If more than 10% of aggregated pixels are cloudy:

  -> cloud pixel = NaN

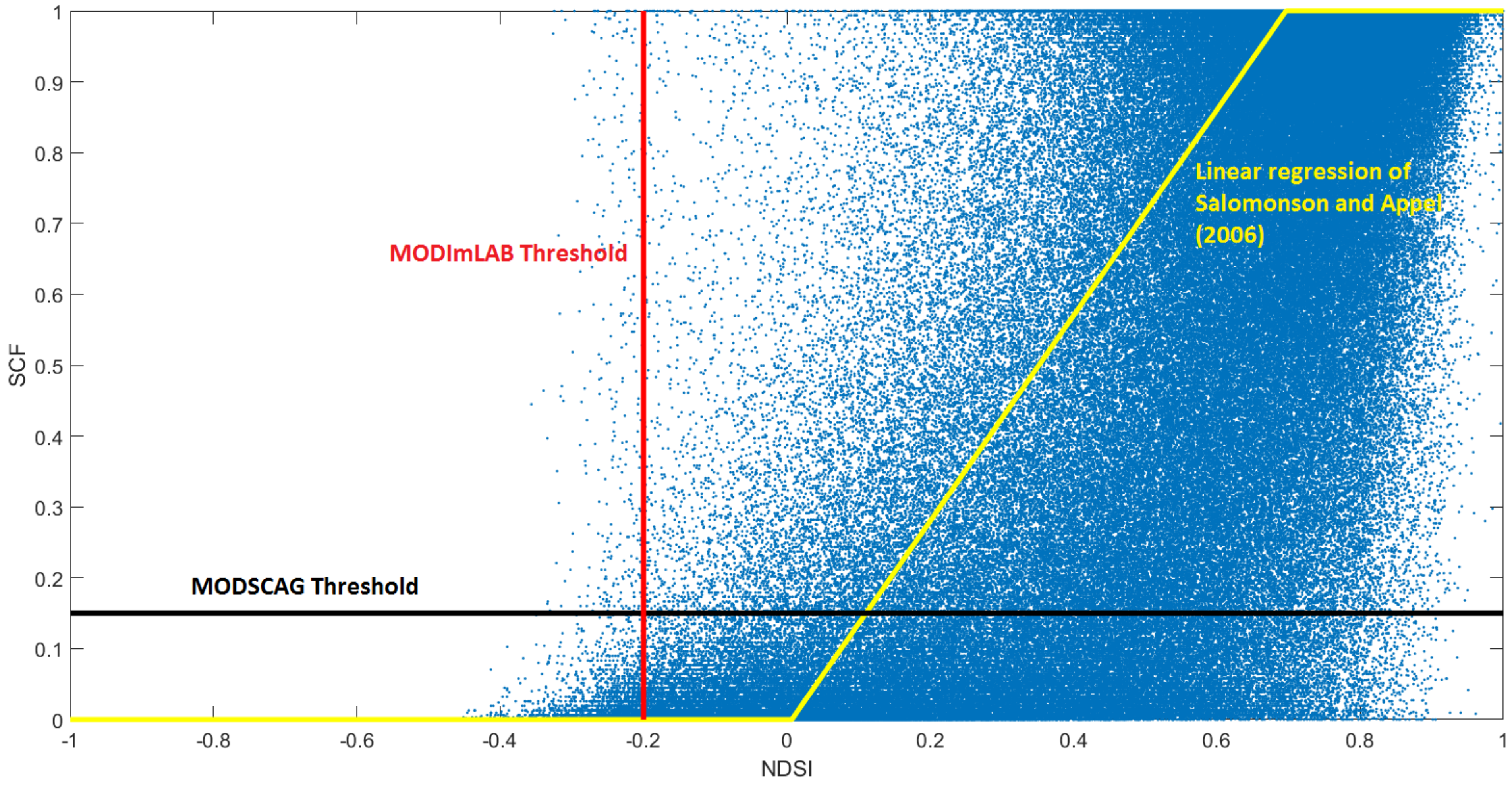
Studied Areas



Alps and Pyrenees :
Corine Land Cover library (Feranec et al, 2016)

Morocco :
Channan et al, 2014

A global view of SCF estimation difficulties



Blue point : SCF at 250 m (from the Reference) function of the NDSI (from MODIS)

Evaluation metrics

Binary

TP : True Positive

TN : True Negative

FP : False Positive

FN : False Negative

$$Precision = \frac{TP}{TP + FP}$$

Probability that a pixel where snow is detected (SCF>0) indeed contain snow.

$$Recall = \frac{TP}{TP + FN}$$

Probability of a detection of a snow-covered pixel

$$F\ score = \frac{2TP}{2TP+FP+FN}$$

F score penalizes both missing snow and falsely positive detection of snow without dependency of the total snow-free area.

Evaluation metrics

Fractional

$$RMSE = \sqrt{\frac{\sum_{p=1}^{N_p}(SCF_{R_p} - SCF_p)^2}{N_p}}$$

-> over all pixels : RMSE

-> over snow pixel (on reference or product) : RMSE_snow

Results

Binary

Alps

	MOD10A1v5	MOD10A1v6	NDSI_ATOPCOR	MODSCAG	MODImLAB	Ee
F_score	0,57410503	0,74806523	0,75499772	0,67068721	0,77188455	0,5701981
F_score min	0,01531229	0,37372758	0,36119818	0,3983866	0,4062987	0,14403173
F_score max	0,9859342	0,98870166	0,98848396	0,97886754	0,98869148	0,98932615
Precision	0,91322835	0,80752826	0,90244732	0,87395496	0,75880244	0,47705436
Precision min	0,66098081	0,3438414	0,55564807	0,61026616	0,29519674	0,07813295
Precision max	0,99992279	0,99995324	0,99995125	0,99091127	0,99995785	0,9999843
Recall	0,51612558	0,75039999	0,70459445	0,58255524	0,82959556	0,94396792
Recall min	0,00771626	0,22980873	0,22040619	0,27649147	0,25494305	0,63312463
Recall max	0,99057863	0,99735678	0,99625762	0,97323717	0,99839065	0,99994039

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Pyrennes

	MOD10A1v5	MOD10A1v6	NDSI_ATOPCOR	MODSCAG	MODImLAB	Ee
F_score	0,64864598	0,67808564	0,69738596	0,62484406	0,70623362	0,54304922
F_score min	0,01809045	0,10697284	0,05697022	0,0982244	0,20606061	0,11754733
F_score max	0,95501975	0,95598514	0,94848288	0,92253767	0,95827498	0,95754579
Precision	0,80353616	0,64340656	0,75698526	0,75407681	0,64045441	0,42804135
Precision min	0,1904863	0,08404279	0,16136919	0,1759134	0,12898666	0,06251879
Precision max	0,98795181	0,96033845	0,95636169	0,94046475	0,96022693	0,93284497
Recall	0,64041579	0,76610977	0,71361565	0,57640768	0,82562995	0,9285418
Recall min	0,00943396	0,07066223	0,03459119	0,06813417	0,20976693	0,50867052
Recall max	0,96507937	0,99238095	0,96390467	0,9129997	0,98984127	0,99757298

Morocco

	MOD10A1v5	MOD10A1v6	NDSI	MODImLAB	E_test
F_score	0,24203841	0,4155767	0,39928348	0,42676318	0,07705636
F_score min	6,69E-04	1,88E-02	7,28E-03	2,59E-02	3,83E-05
F_score max	0,7087495	0,74580628	0,75737705	0,79821439	0,29200369
Precision	0,5538278	0,52192251	0,6361326	0,44187436	0,04329967
Precision min	1,11E-02	3,12E-02	3,74E-02	2,22E-02	1,92E-05
Precision max	0,98983051	0,90123457	0,96806723	0,77488515	0,17928251
Recall	0,20868006	0,43221786	0,36702959	0,50530246	0,68403902
Recall min	0,00033478	0,01236688	0,00377877	0,03091721	0,00757576
Recall max	0,82350757	0,90177328	0,90205181	0,92925448	0,97201562

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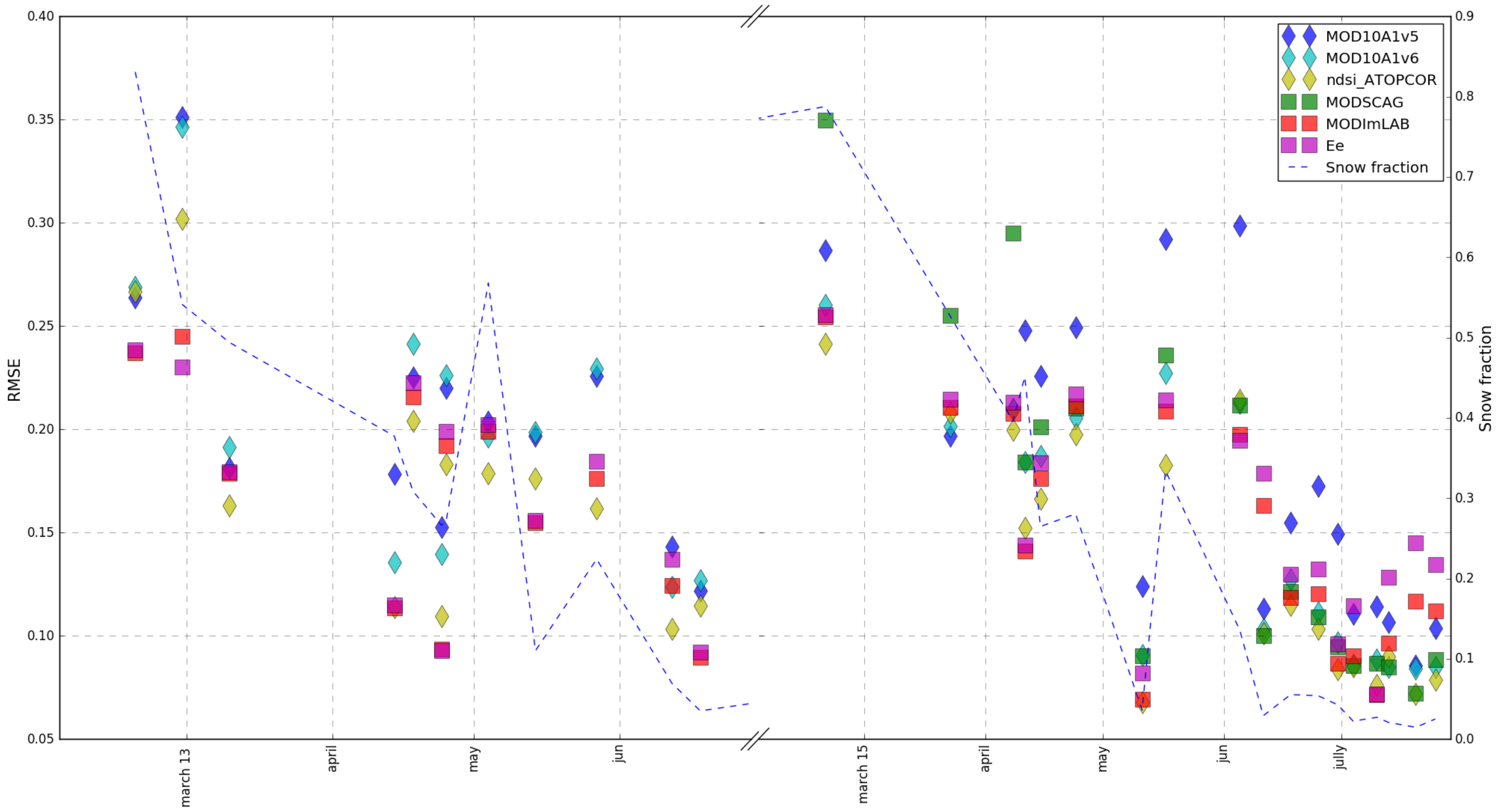
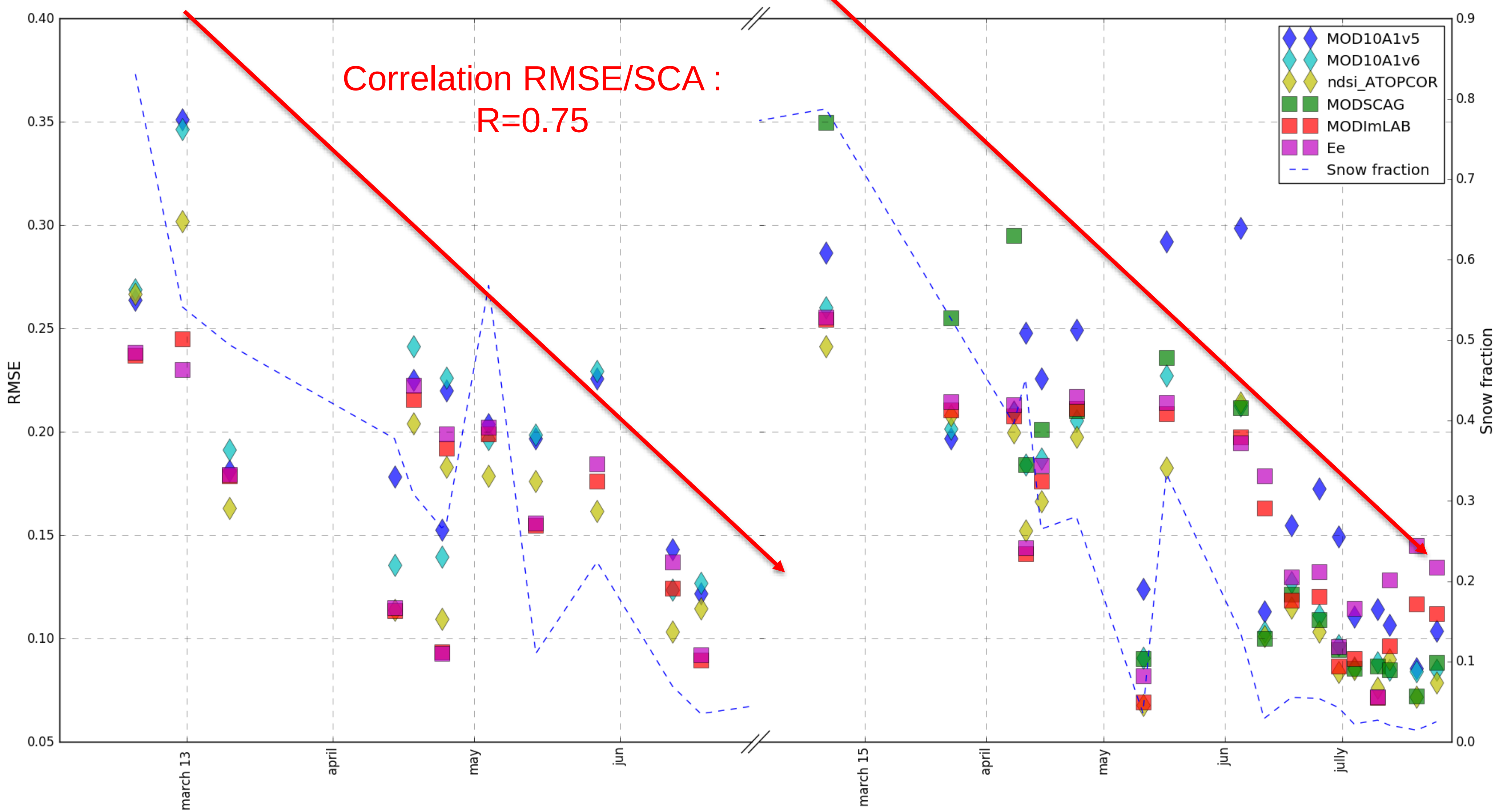
Results

RMSE over all pixels in the Alps



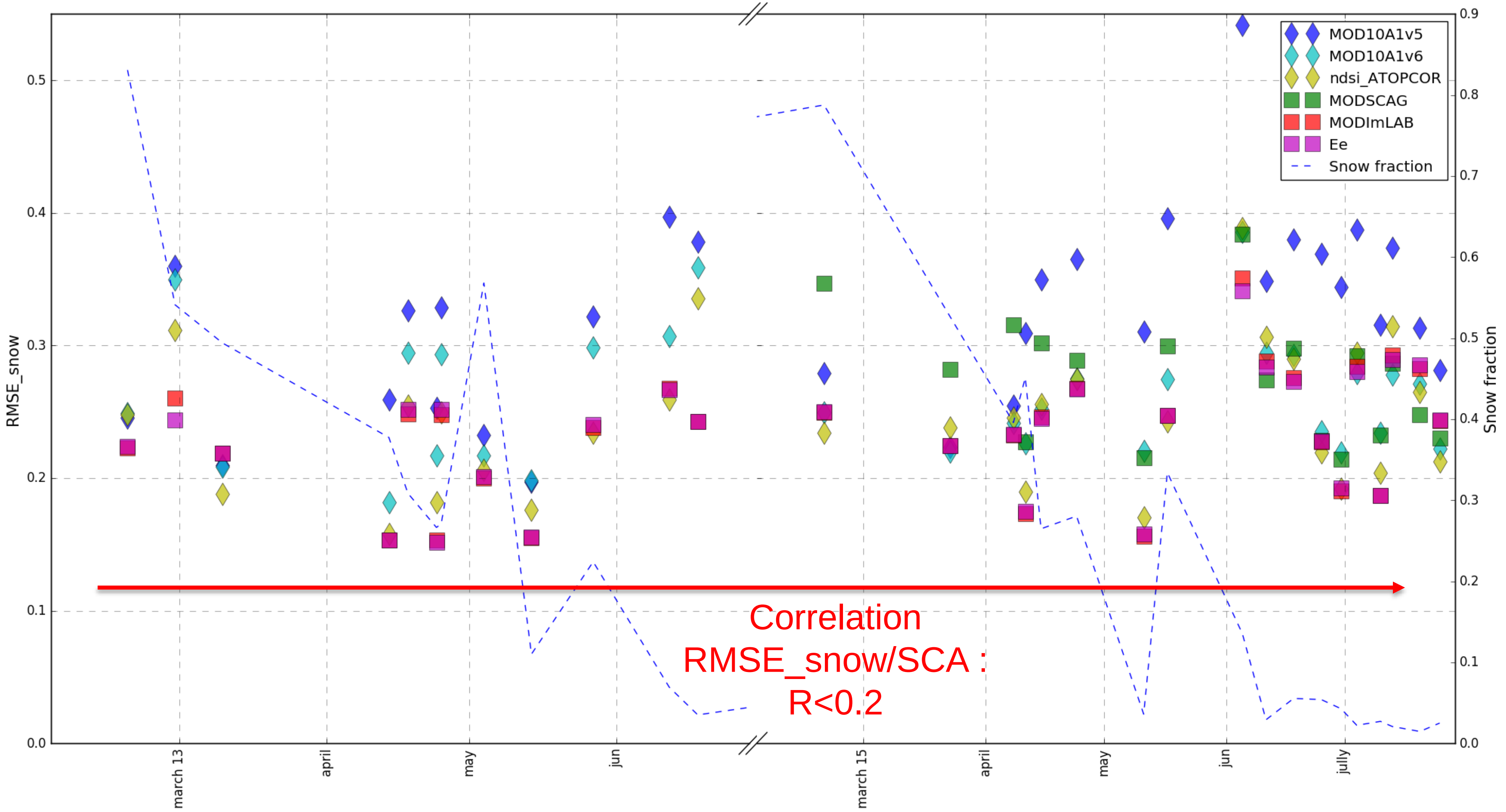
Results

RMSE in the Alps

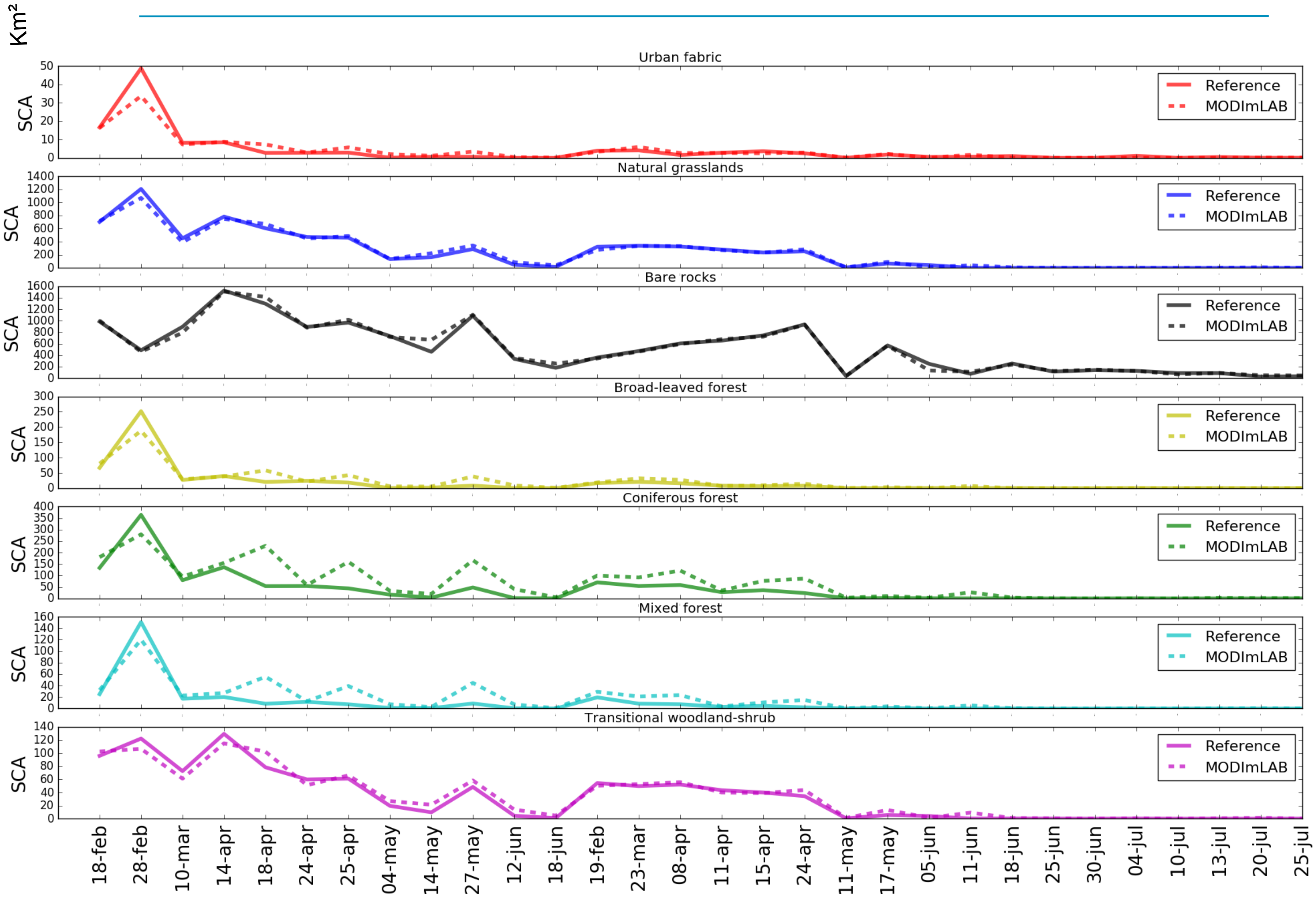


Results

RMSE over snow in the Alps



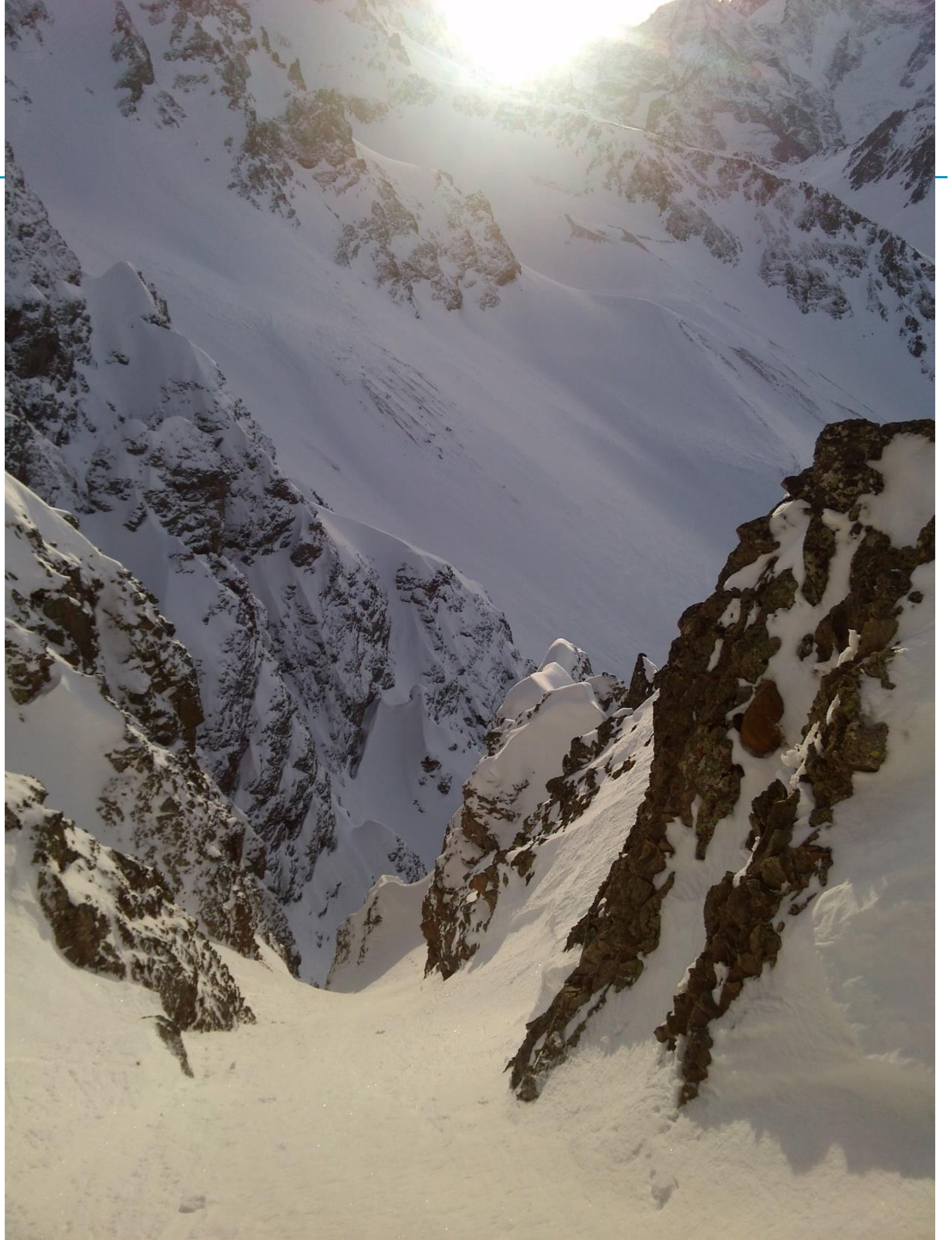
Limitations of the reference



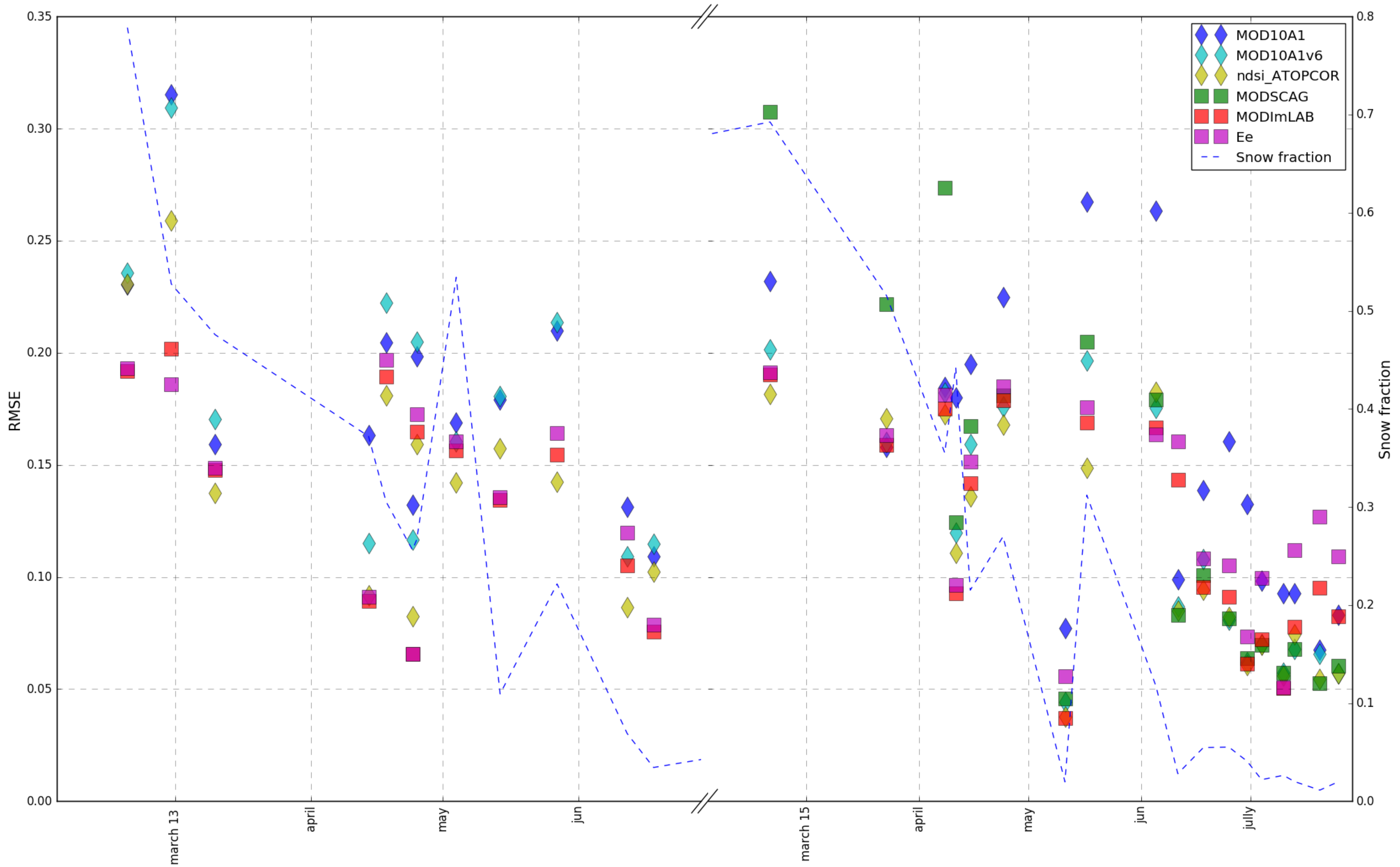
Conclusions and perspectives

- Large improvement between MOD10A1 v5 and v6
- Accurate topographic/atmospheric correction largely improved the results obtained with NDSI based methods
- Spectral unmixing :
  - Good results, especially in SCF estimation
  - Limitation : False positive, more complex implementation

- Reference maps:
  - The best that we have actually, but uncertainties in mixed areas
  - Investigation of the use of very high definition satellite (like PLEIADE)
  - Influence of the methodology used to produce the reference maps (NDSI or SU)

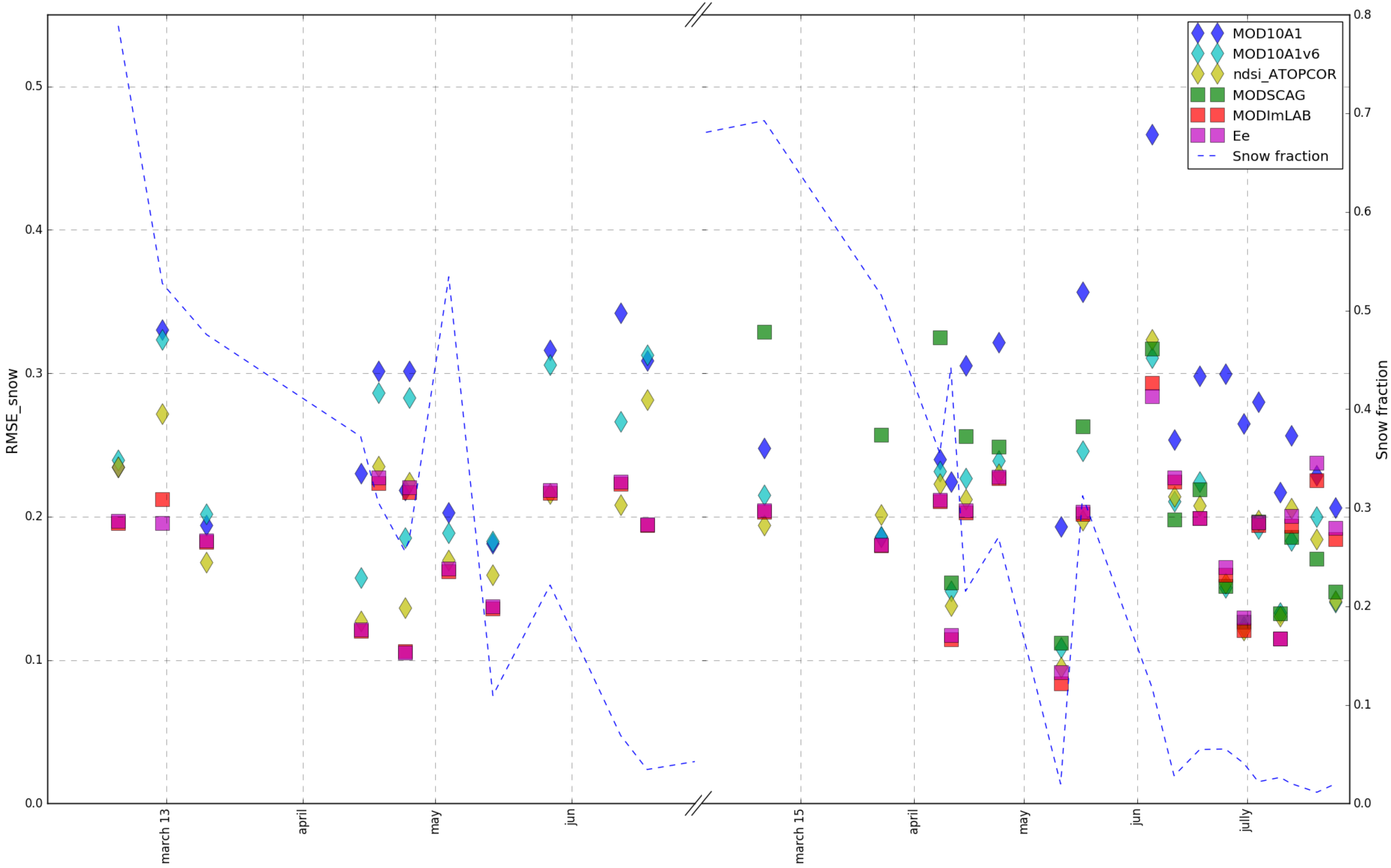


RMSE at 500 m

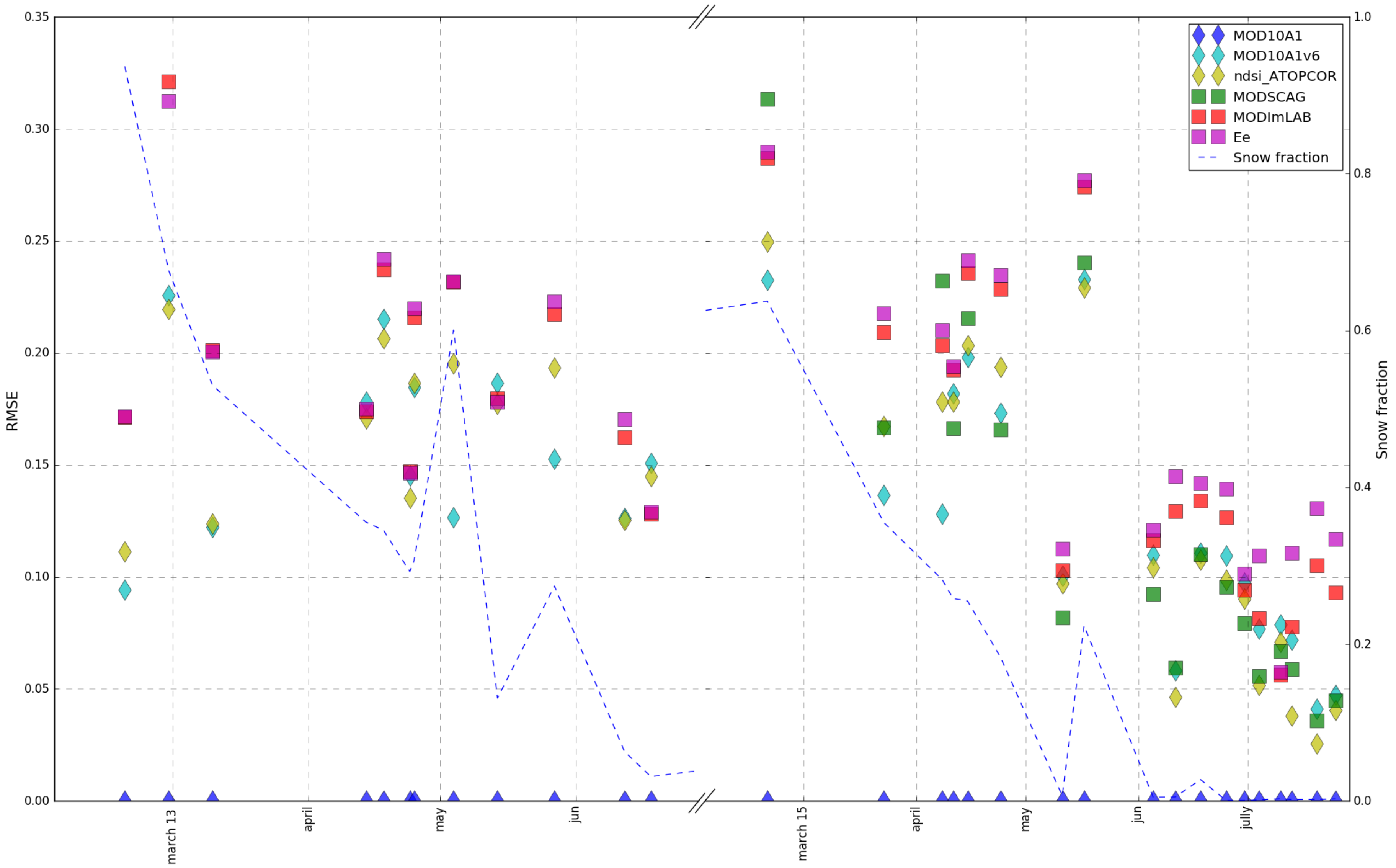


RMSE
Snow fraction
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
march 13
april
may
jun
march 15
april
may
jun
jully
MOD10A1
MOD10A1v6
ndsi_ATOPCOR
MODSCAG
MODImLAB
Ee
Snow fraction

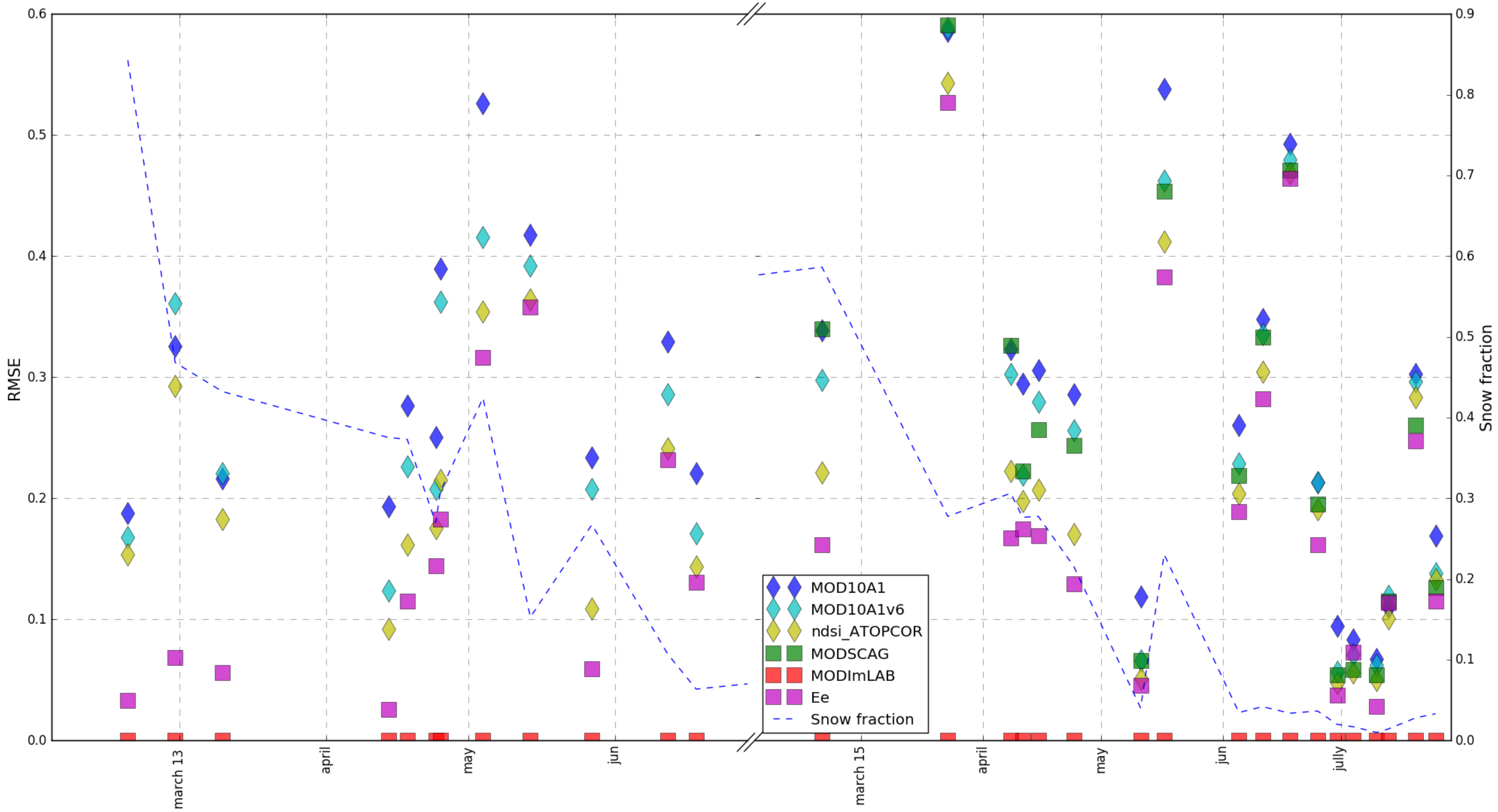
RMSE_snow at 500 m



MOD10A1v5 ref at 2500 m



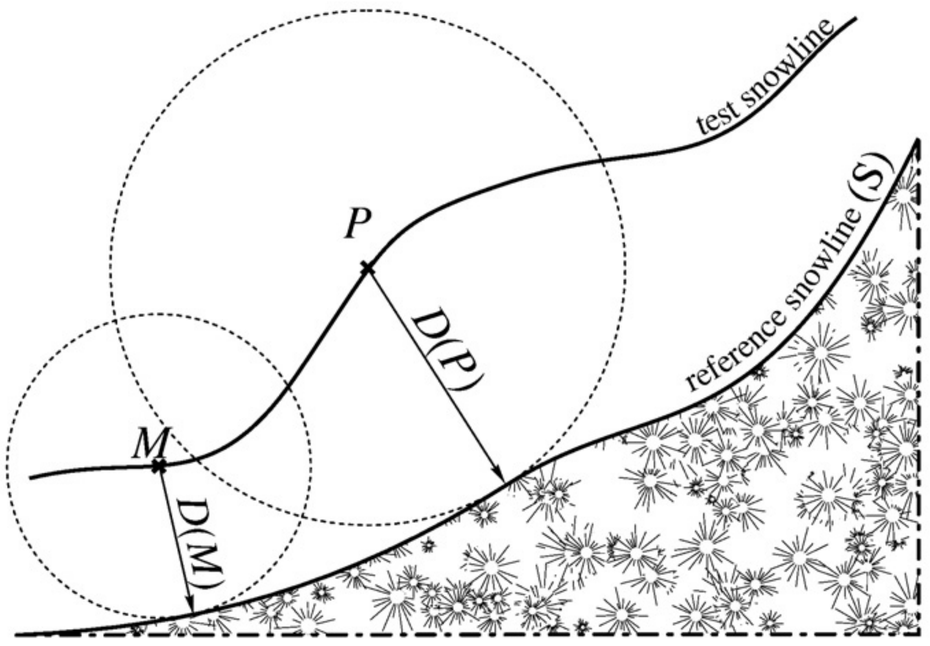
MODImLAB ref at 2500 m

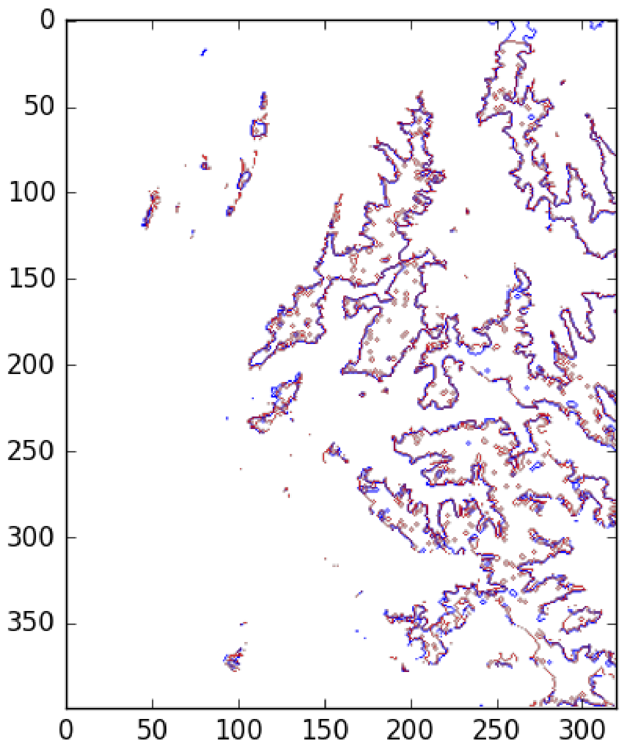


Evaluation metrics

Feature-based

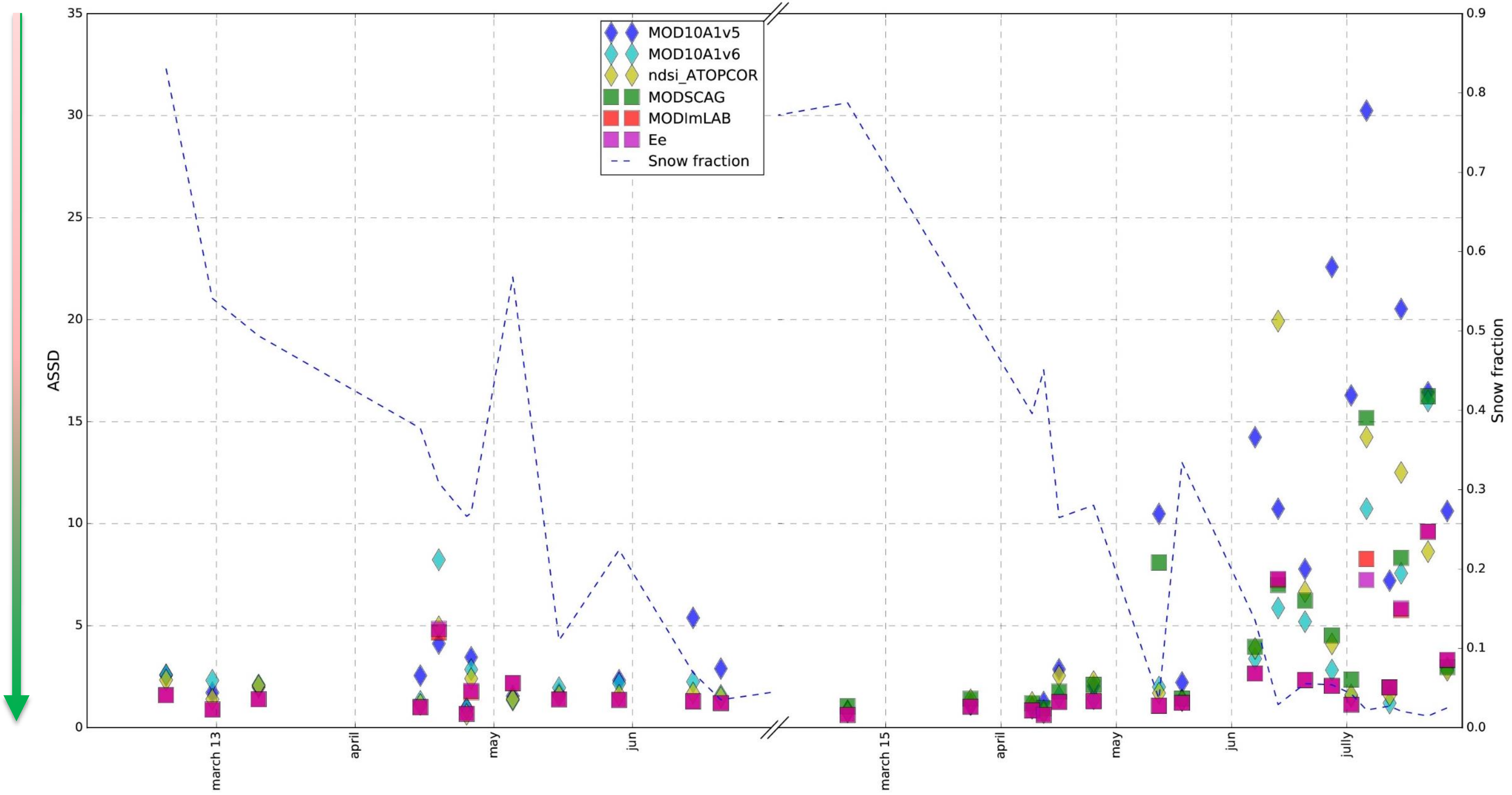
Average symmetric surface distance (ASSD) : calculate the distance between the snow line of the reference and the snow line of the product (snow line at a SCF of 50%)





Results

ASSD over snow Alps



Results

Binary

Alps

	MOD10A1v5	MOD10A1v6	NDSI_ATOPCOR	MODSCAG	MODImLAB	Ee
F_score	0,57410503	0,74806523	0,75499772	0,67068721	0,77188455	0,5701981
F_score min	0,01531229	0,37372758	0,36119818	0,3983866	0,4062987	0,14403173
F_score max	0,9859342	0,98870166	0,98848396	0,97886754	0,98869148	0,98932615
Precision	0,91322835	0,80752826	0,90244732	0,87395496	0,75880244	0,47705436
Precision min	0,66098081	0,3438414	0,55564807	0,61026616	0,29519674	0,07813295
Precision max	0,99992279	0,99995324	0,99995125	0,99091127	0,99995785	0,9999843
Recall	0,51612558	0,75039999	0,70459445	0,58255524	0,82959556	0,94396792
Recall min	0,00771626	0,22980873	0,22040619	0,27649147	0,25494305	0,63312463
Recall max	0,99057863	0,99735678	0,99625762	0,97323717	0,99839065	0,99994039

Pyrennes

	MOD10A1v5	MOD10A1v6	NDSI_ATOPCOR	MODSCAG	MODImLAB	Ee
F_score	0,64864598	0,67808564	0,69738596	0,62484406	0,70623362	0,54304922
F_score min	0,01809045	0,10697284	0,05697022	0,0982244	0,20606061	0,11754733
F_score max	0,95501975	0,95598514	0,94848288	0,92253767	0,95827498	0,95754579
Precision	0,80353616	0,64340656	0,75698526	0,75407681	0,64045441	0,42804135
Precision min	0,1904863	0,08404279	0,16136919	0,1759134	0,12898666	0,06251879
Precision max	0,98795181	0,96033845	0,95636169	0,94046475	0,96022693	0,93284497
Recall	0,64041579	0,76610977	0,71361565	0,57640768	0,82562995	0,9285418
Recall min	0,00943396	0,07066223	0,03459119	0,06813417	0,20976693	0,50867052
Recall max	0,96507937	0,99238095	0,96390467	0,9129997	0,98984127	0,99757298

Morocco

	MOD10A1v5	MOD10A1v6	NDSI	MODImLAB	E_test
F_score	0,24203841	0,4155767	0,39928348	0,42676318	0,07705636
F_score min	6,69E-04	1,88E-02	7,28E-03	2,59E-02	3,83E-05
F_score max	0,7087495	0,74580628	0,75737705	0,79821439	0,29200369
Precision	0,5538278	0,52192251	0,6361326	0,44187436	0,04329967
Precision min	1,11E-02	3,12E-02	3,74E-02	2,22E-02	1,92E-05
Precision max	0,98983051	0,90123457	0,96806723	0,77488515	0,17928251
Recall	0,20868006	0,43221786	0,36702959	0,50530246	0,68403902
Recall min	0,00033478	0,01236688	0,00377877	0,03091721	0,00757576
Recall max	0,82350757	0,90177328	0,90205181	0,92925448	0,97201562