EUMETSAT
H SAF
SUPPORT TO OPERATIONAL HYDROLOGY AND WATER MANAGEMENT

EUMETSAT Satellite Application Facility On Support to Operational Hydrology and Water Management (H SAF)

Product Validation Report (PVR) for product FSC-H (FSC-H (H35))

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1 Context: aim of this report

This report discusses validation results for the H-SAF snow product H35 vs. Sentinel-2 Level-2 Fractional-Snow-Cover (FSC) maps. H35 is an H-SAF snow product including daily FSC maps based on visible/near-infrared (VIS/NIR) data from the Advanced very-high-resolution Radiometer (AVHRR) on board of the National Oceanic and Atmospheric Administration (NOAA) and meteorological operational (MetOp) satellites (Piazzi et al., 2019).

The algorithm of H35 largely builds on H-SAF products H12 and H32 (see Piazzi et al., 2019). Compared to H12, which provides FSC maps over the H-SAF area (25°N to 75°N latitude, 25°W to 45°E longitude), H35 covers the whole northern Hemisphere (89.99° North to 0.01° North, -179.99° West to 179.99° East). Spatial resolution is 0.01°, that is, ~1 km. As such, H35 provides an opportunity to evaluate H-SAF snow products over larger areas than what is possible with H12 and H32.

Evaluation of H-SAF snow products has been usually performed using ground-based snow data, such as snow-depth sensors, or Sentinel-2 Scene-Classification maps (Piazzi et al., 2019). In this report, we followed the approved validation methodology for H12 applied in Piazzi et al. (2019) and we compared FSC maps from H35 vs. FSC maps derived from Sentinel-2. The validation period was the **2019-2020 early snow season** and areas of interest were the Caucasus mountain range, Belarus, Mount Atlas in Morocco, and Mount Lebanon. These areas of interest include a mixture of predominantly flat areas (Belarus) and predominantly mountainous areas (Caucasus, Mount Atlas, and Mount Lebanon). Climates are also markedly different, with Belarus, Caucasus, and both Mount Atlas and and Mount Lebanon falling in the Boreal, Boreal-to-Polar, and Warm-Temperature-to-Arid regions according to the Köppen-Geiger climate map (Kottek et al., 2006).

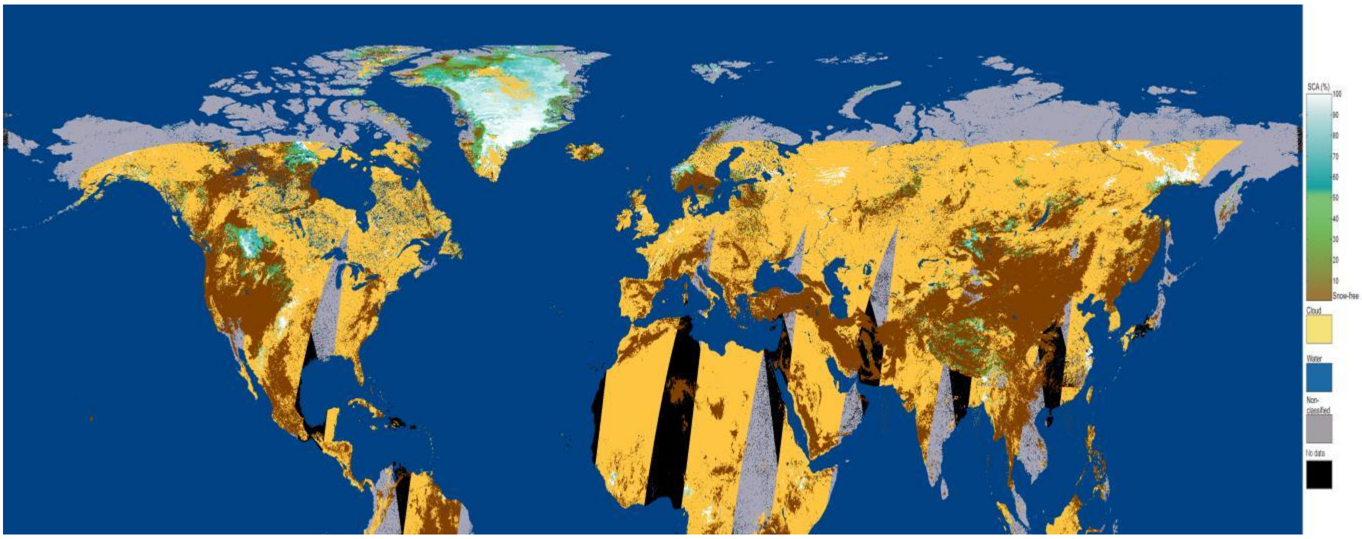


Figure 1: *Example of H-SAF H35 original FSC map for October 01 2019.*

2 Methods

Our validation approach followed the methodology discussed in Piazzi et al. (2019), which we summarized below. In this regard, it should be noted that Belarus and the Caucasus region are the most significant testing regions here and should be considered as the two reference areas of interest for flat and mountain performance of H35. Lebanon and the Atlas region were chosen as experimental study cases to test the performance of H35 in a much dryer climate. The arid climate of Lebanon and the Atlas region makes snow-cover patterns highly variable in space and time, an inherent challenge for a larger-scale product like H35. The experimental nature of our assessment in Lebanon and the Atlas region is the reason why we considered a significantly smaller number of tiles in these regions. This significantly smaller number of tiles should be kept in mind when comparing results of our performance assessment there with data-richer areas like Belarus and the Caucasus region.

The first step was the selection of the Sentinel-2 tiles over each area of interest to be compared with H35. This selection was performed by seeking a tradeoff between extensively assessing H35 performance and limiting computational times. As a result, tile selection in Caucasus and the Atlas region focused on the most mountainous areas, while in Belarus we limited ourselves to tiles that were fully included in the country and reasonably far from the Baltic Sea, which may reduce snow-cover duration due to mitigation effects. In Lebanon, we selected one tile covering a central portion of the local mountain range and not including any portion of the Mediterranean Sea. Overall, we considered 10 tiles in Belarus, 10 tiles in the Caucasus region, 3 tiles in the Atlas region, and 1 tile in Lebanon. For each tile, we then selected an orbit providing a full-square map by visually inspecting representative images on https://scihub.copernicus.eu/dhus/#/home. Figure 2 reports the location of each tile, while Table 1 summarizes how many maps for each tile we considered (after filtering images with cloud cover above 20%) and the corresponding orbit.

After tile selection, we downloaded from https://scihub.copernicus.eu/dhus/#/home all available S2MSI2A Sentinel-2 Level2A images between October 1 2019 and January 31 2020, including both Sentinel 2A and 2B. For each map, we then extracted Scene Classification maps (SCL) at 20 m (note that these Scene Classifications are directly available from https: //scihub.copernicus.eu/dhus/#/home and so no processing with Sen2Cor was performed). Scene-Classification maps provide indication of predominant land/cloud cover for each pixel in the image, including ground (ID 5), vegetation (ID 4), snow (ID 11), water (6), and various IDs for cloud and thin-cirrus cover[1]. These Scene-Classification maps represent the validation source against which to assess the performance of H35. Although SCL maps differentiate between vegetation and snow pixels, note that to our knowledge the Level-2A Algorithm applies no specific forest-correction layer. This is in contrast with the H35 algorithm and means that SCL maps provide viewable-snow rather than effective-snow cover.

All available H35 images between October 1 2019 and January 31 2020 were made internally available to CIMA by the operational chain of the Finnish Meteorological Institute (FMI). After receiving all images, we performed an image-to-image comparison between Sentinel 2 and H35 FSC with the goal of assessing H35 performance in estimating Sentinel-2 FSC. This assessment was limited to Sentinel images with overall cloud cover below 20%, as already done by Piazzi et al. (2019). The impact of clouds is particularly high in Belarus and the Caucasus region, where the number of usable images per tile was often less than 3 (see Table 1). Cloud

[1] see details at https://earth.esa.int/web/sentinel/technical-guides/sentinel-2-msi/level-2a/algorithm

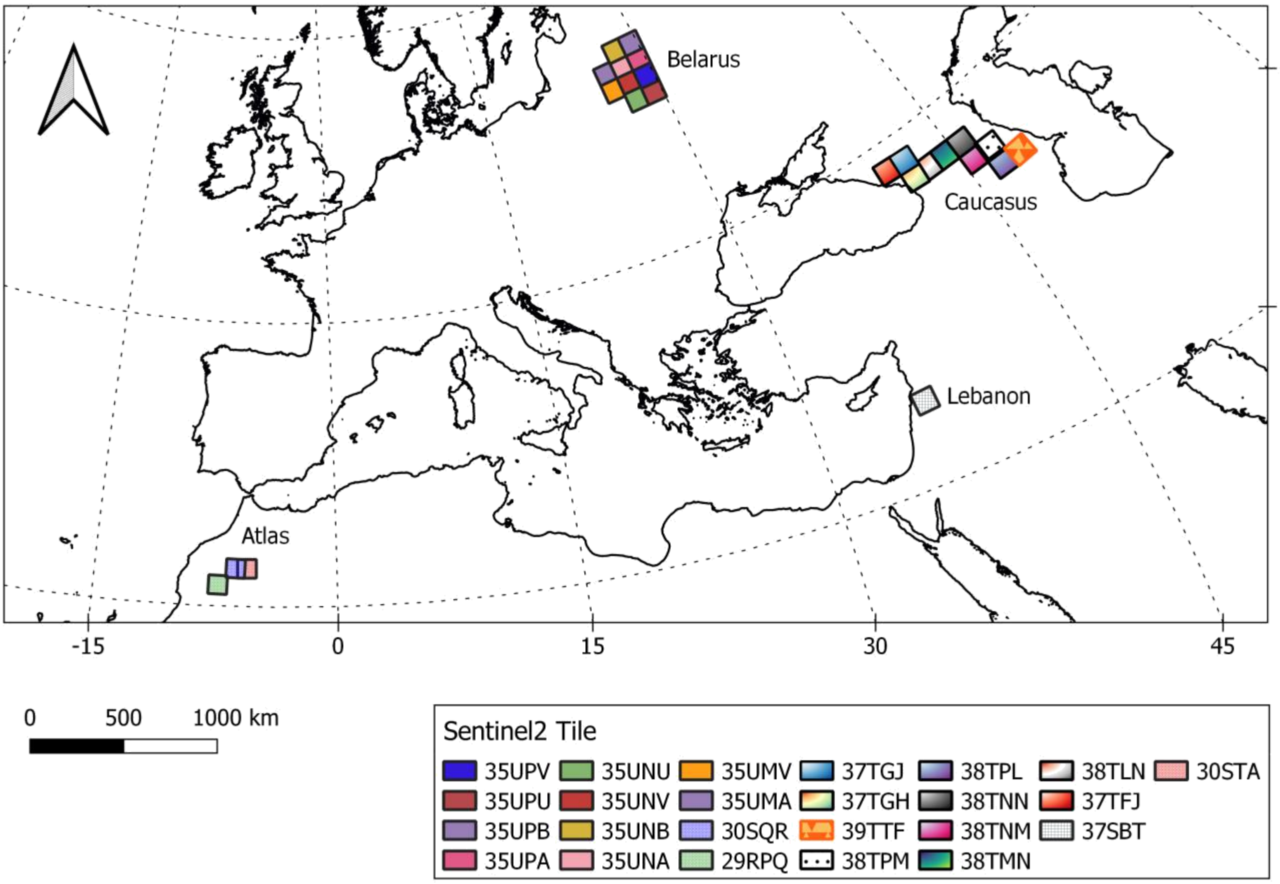


Figure 2: *Considered Sentinel-2 tiles.*

obstruction was much less significant in Lebanon and the Atlas region, in agreement with a drier climate.
The comparison procedure worked by first determining the H35 scene corresponding to each Sentinel-2 tile-map by clipping the H35 raster according to the bounding box of each Sentinel-2 image. Second, we estimated a fractional-snow-cover (FSC) map from Sentinel-2 at the coarser resolution of H35 by counting the number of Sentinel's snow pixels in each coarser pixel of H35. Any pixel where the percentage of non-snow and non-ground pixels was above 50% was set to NaN and was not considered in this evaluation (following again Piazzi et al., 2019)
Agreement between H35 and Sentinel-based SCA maps was assessed using two performance metrics, the Root Mean Square Error (RMSE) and Bias:

$$RMSE = \sqrt{\frac{\sum_{n=1}^{N} (FSC_{n,H35} - FSC_{n,S2})^2}{N}} \qquad (1)$$

$$Bias = \frac{\sum_{n=1}^{N} (FSC_{n,H35} - FSC_{n,S2})}{N}, \qquad (2)$$

Table 1: *Considered Sentinel-2 tiles, satellite orbit, and number of images for each area of interest. Images cover the period October 1 2019 through January 31 2020 and were filtered to discard those with overall cloud cover above 20% (Piazzi et al., 2019).*

Area of interest	S2 Tile	Orbit	Number of images
Caucasus	37TFJ	78	10
	37TGJ	78	13
	37TGH	78	10
	38TLN	35	9
	38TMN	35	8
	38TNN	135	6
	38TNM	135	7
	38TPM	135	7
	38TPL	92	12
	38TTF	92	12
Belarus	35UMA	136	3
	35UMV	136	2
	35UNB	93	2
	35UNA	93	1
	35UNV	93	2
	35UNU	93	1
	35UPB	93	1
	35UPA	93	1
	35UPV	93	2
	35UPU	50	3
Lebanon	37SBT	121	10
Atlas	29RPQ	137	20
	29SQR	94	15
	30STA	94	14
Total			**171**

where $FSC_{n,H35}$ is Fractional Snow Cover on a given pixel n according to H35, $FSC_{n,S2}$ is Fractional Snow Cover according to Sentinel in the same pixel n, and N is the total number of pixels across which RMSE and Bias are calculated. We computed RMSE and Bias by first aggregating all pixels across all available images from the same area of interest (Caucasus, Belarus, Atlas, and Lebanon) and then by disaggregating samples of FSC for bins of FSC according to Sentinel 2 (10% increments and one class for FSC between 0 and 1%, which was assumed to represent bare soil).

Following the methodology applied in Piazzi et al. (2019), we assumed as threshold, target, and optimal RMSE values of 50%, 30%, and 10%, respectively. In terms of bias, we assumed as threshold, target, and optimal scores values of 40%, 20%, and 10%, respectively (absolute values).

3 Results

3.1 Spatial patterns

Figure 3 reports a comparison between FSC estimates according to H35 and those according to Sentinel 2 (resampled at the coarser resolution of H35) for three days in the Caucasus region (Figure 3(a)), Lebanon (Figure 3(b)), and the Atlas region (Figure 3(c)). This comparison shows a high level of consistency in terms of snow-covered spatial patterns between H35 and Sentinel 2, including transitions between higher peaks and lower valleys.

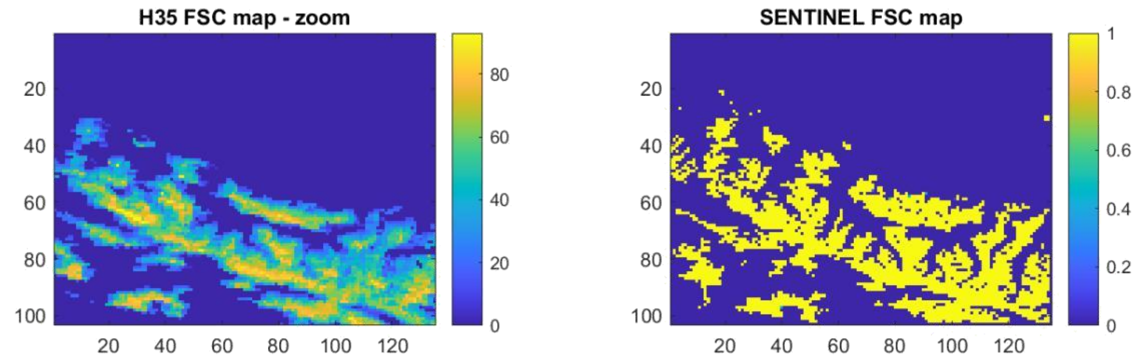
We also note that FSC values for H35 are generally smaller than Sentinel 2 values in peripheral regions. We explain this as potentially due to the fact that H35 images are natively coarser than Sentinel 2 and as such estimates by H35 may be the result of a larger footprint, an effect we attempted to reconstruct for Sentinel 2 by resampling its images at the same spatial resolution of H35. Moreover, resampled FSC estimates by Sentinel 2 are the proportion of 20-m pixels classified as snow over the sum of 20-m pixels classified as snow and land; this approach neglects area classified as vegetation, which may in fact locally decrease FSC values. This effect implies some possible overestimation of actual FSC by our resampled Sentinel-2 images.

Figure 4 compares the frequency of H35 and resampled Sentinel-2 pixels binned into 11 classes of FSC for the Caucasus region. Corresponding results for Belarus, Lebanon, and the Atlas region are reported in the Appendix as Figures A.1, A.2, and A.3, respectively. These statistics show a relatively large amount of pixels in all regions that were classified as bare soil by both products (~60% in Caucasus and larger elsewhere), owing to the validation period covering the early months of the 2019-2020 winter season. Focusing on the Caucasus region, which is the area of interest with the most consistent snowpack in the validation period, we also note a tendency of Sentinel 2 to report more pixels with FSC ≥90% and less pixels of bare soil than H35. We relate this finding to the tendency of resampled Sentinel 2 images to return a sharper transition between snow and no-snow areas that we discussed with regard to Figure 3. Overall, results in this Section confirmed that the snow spatial patterns captured by H35 and by Sentinel 2 are in good agreement.

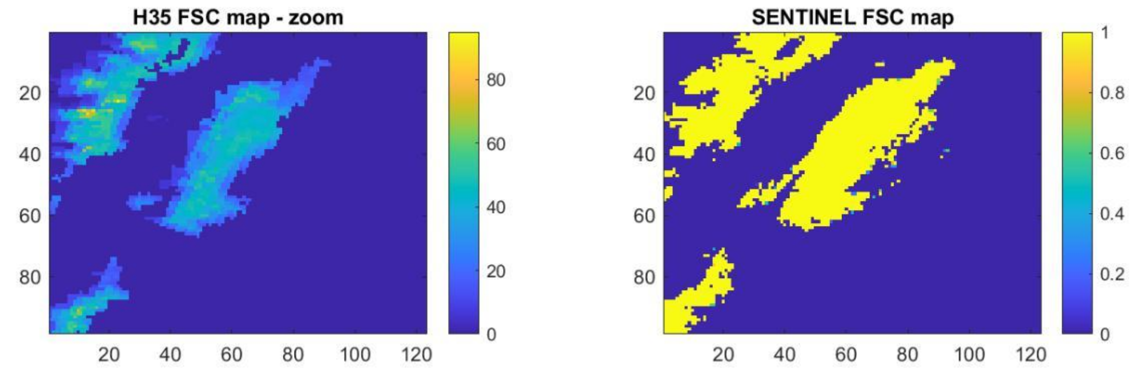
3.2 Root Mean Square Errors and Biases

Table 2 reports RMSEs and biases for the four areas of interest, aggregated considering H35 pixels with valid FSC from all images. RMSE is larger in the Caucasus region than in the other three areas of interest (37%), consistently with a mountain landscape and a longer snow season. RMSE for Caucasus is, still, close to the target RMSE of 30% and in line with previous results by Piazzi et al. (2019) in the Italian Alps (see their Figure 17). RMSEs in Belarus is remarkably small (3%), owing to the flat topography of this region and the fact that most available pixels are snow-free (Figure A.1). RMSEs for the Atlas region and Lebanon are well below the target RMSE of 30% and are smaller than RMSE in Caucasus, which is consistent with these regions being drier than Caucasus and therefore less vegetated.

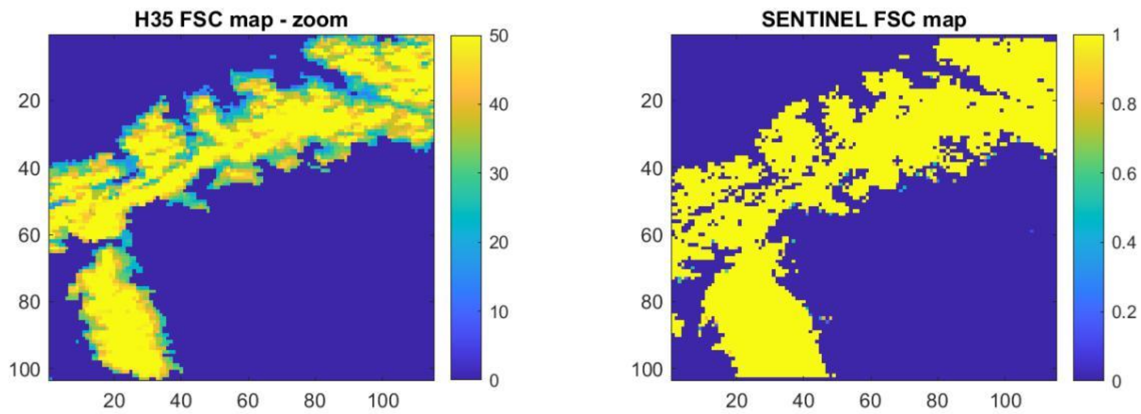
All areas of interest but Belarus report a negative bias, meaning the FSC of H35 is on average smaller than that of Sentinel 2. This outcome is, again, in agreement with the



(a)



(b)



(c)

Figure 3: *Comparison between H35 and Sentinel-2 Fractional Snow Cover in Caucasus (November 4, 2019, tile 37TFJ), Mount Atlas (January 6, 2020, tile 37SBT), and Lebanon (December 18, 2019, tile 37SBT).*

Figure 4: *Frequency of H35 and resampled Sentinel-2 pixels binned into 11 classes of FSC for the Caucasus region.*

Table 2: *Root Mean Square Error and Bias for the four areas of interest, aggregated considering all snow and soil pixels from all images between October 1, 2019 and January 31, 2020. Threshold, target and optimal scores are 50%, 30%, and 10% for RMSE and 40% 20%, and 10% for bias (absolute value)*

Area of interest	RMSE	Bias
Caucasus	38%	-20%
Belarus	3%	0.25%
Atlas	19%	-6%
Lebanon	22%	-6%

arguments in Section 3.1 and Figure 3 regarding the potential of resampled Sentinel-2 images for locally overestimating FSC in peripheral regions. The positive bias in Belarus is likely spurious. Bias for all regions is below the target value.

RMSEs and biases increase with Sentinel-2 FSC, as shown in Figure 5 for the Caucasus region and in Figures A.4 and A.5 for Lebanon and the Atlas region, respectively (results for Belarus are not reported due to the fact that most available images are snow-free). In the Caucasus region, binned RMSEs and biases exceed the theshold of 50% and -40%, respectively, only for comparatively high FSCs. These high FSCs are, nonetheless, exposed to the suspect overestimation by Sentinel 2 discussed in Section 3.1. We conclude that results for binned FSC classes are consistent with expectations and with global performance scores in Table 2.

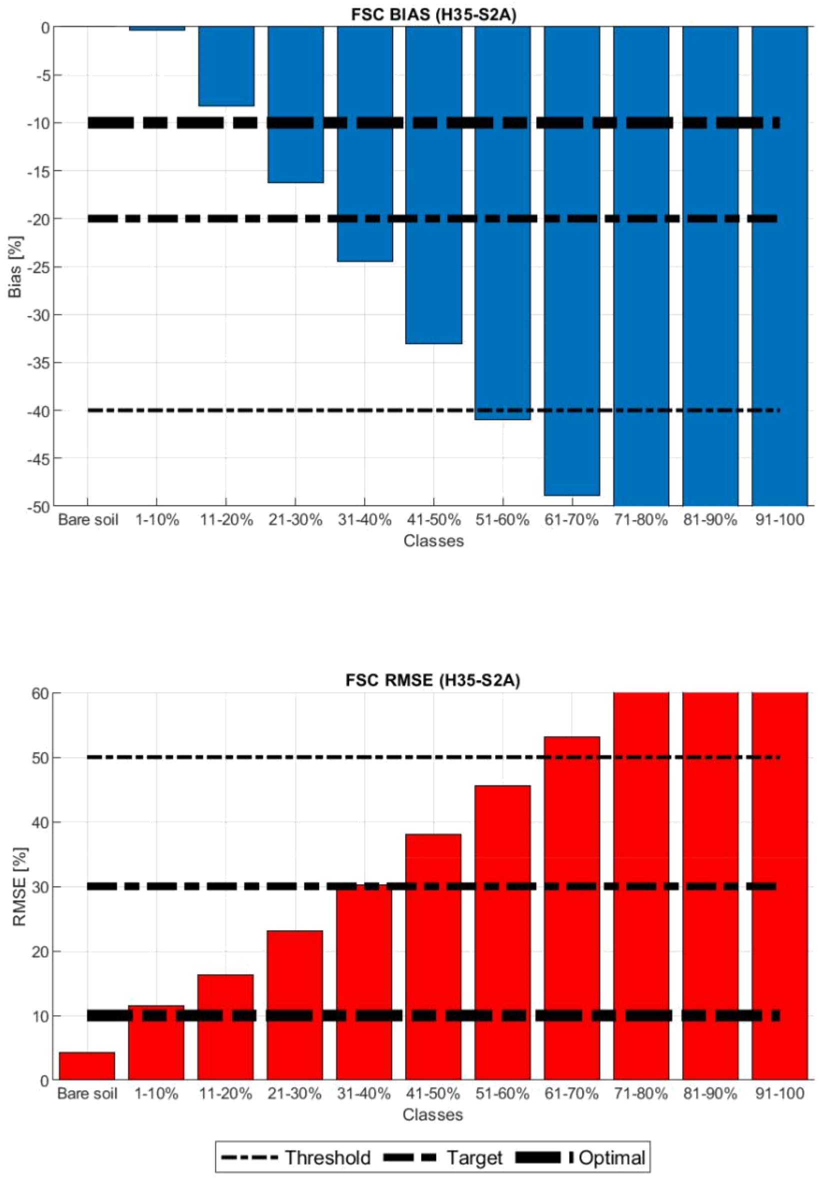


Figure 5: *RMSE and bias of H35 in the Caucasus region with regard to Sentinel-2 FSC, as a function of Sentinel-2 FSC*

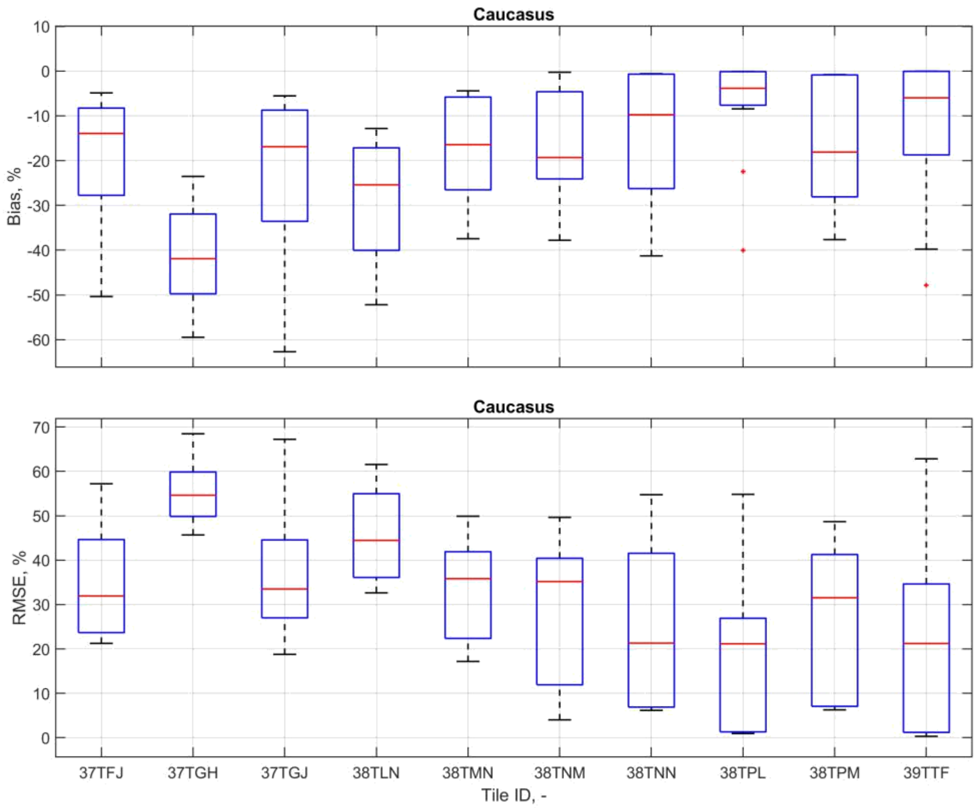


Figure 6: *Caucasus: Distribution of RMSEs and Biases for each image, by tile.*

Figure 6 reports the distribution of RMSEs and biases for each image in the Caucasus region, organized by tile as in Piazzi et al. (2019). Consistently with our findings in the same area with regard to H34 (see the companion report about validation of H-SAF H34 snow product over Caucasus, Belarus, Mount Atlas, and Lebanon using Sentinel-2 Level-2 Scene Classifications, Oct. 2018 - May 2019), we note a trend toward lower RMSEs from west (37TFJ) to east (38TTF). While we have not analyzed any vegetation product here, we note that tiles on the west side of this area of interest are closer to the Black Sea than other tiles. Being a potential source of moisture for this area, proximity to the Black Sea may imply higher vegetation cover in those tiles than elsewhere, which can hinder snow detection. As a further piece of evidence, we note that median RMSEs for all tiles but 37TGH are below the threshold of 50% and 37TGH is the closest tile to the Black Sea. This correlation between larger vegetation cover and higher RMSEs is in agreement with previous arguments by Piazzi et al. (2019).

4 Conclusions

We compared Sentinel-2 ad H35 FSC maps for early winter season 2019-2020 in Caucasus, Belarus, the Mount-Atlas region, and Lebanon. To this end, we downloaded and processed 179 Sentinel-2 Level-2A S2MSI2A images between October 1, 2019 and January 31, 2020 across 20 tiles over the four areas of interest. These images were filtered to retain those with less than 20% cloud cover, which resulted in 171 Scene-Classification maps available for comparison with H35. The comparison was performed in terms of Root Mean Square Errors and biases as proposed by Piazzi et al. (2019), both in terms of average values across all tiles and images and in terms of average results by bins of FSCs.

Results showed an overall good agreement between H35 and Sentinel 2, with all areas of interest reporting global RMSEs and biases below the threshold of 50% and 40%, respectively. This result also holds in mountain areas like Caucasus, despite small-scale snow-topographic interactions being more important in these landscapes and the scale of these interactions being sometimes smaller than the resolution of H35. We also noted that RMSEs and biases tend to increase in tiles that are likely more vegetated, which is again in agreement with previous validations (Piazzi et al., 2019). Overall, fractional-snow-cover statistics by Sentinel 2 and H35 are spatially consistent.

This report focused on four validation areas: Caucasus, Belarus, the Mount-Atlas region, and Lebanon. While these areas covered significantly different climates, they were localized in a comparatively small region around the European continent. H35 is a Northern-Hemisphere product, and opportunities exist to validate it in other regions with a significantly different snowpack (e.g., the arctic tundra, the Rocky Mountains, or Himalayas). Extending the initial validation performed here to areas in North America or Asia is a priority of future reports.

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A Appendix

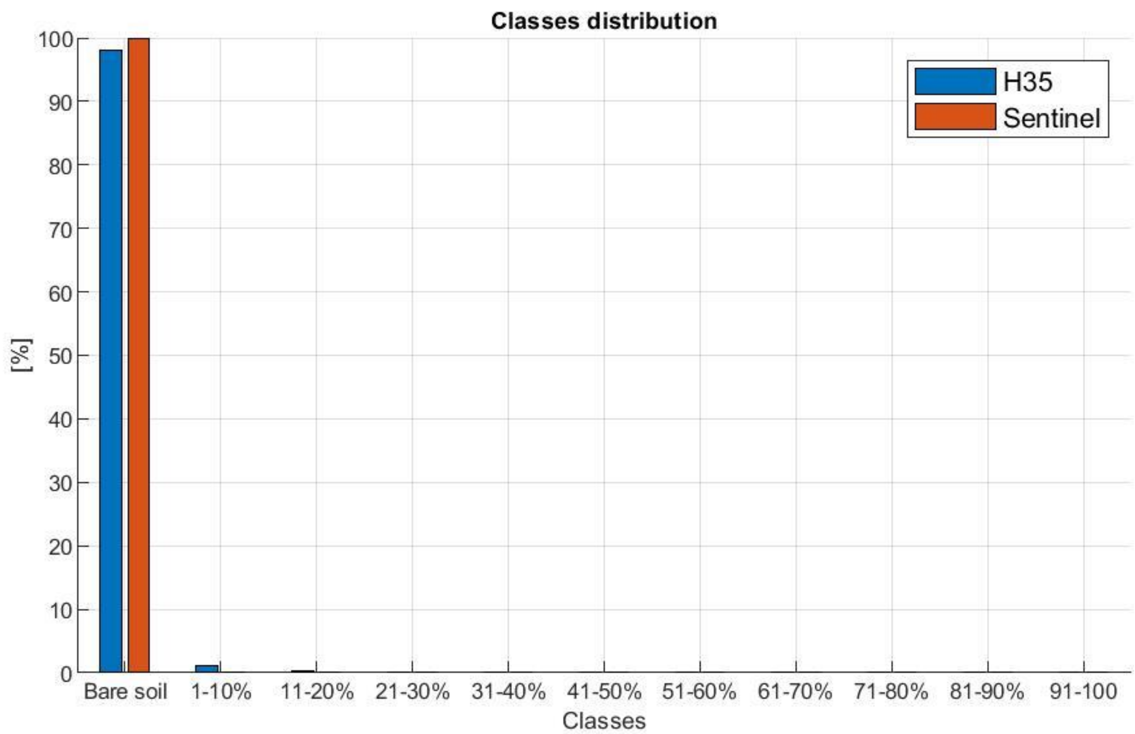


Figure A.1: *Frequency of H35 and resampled Sentinel-2 pixels binned into 11 classes of FSC for Belarus.*

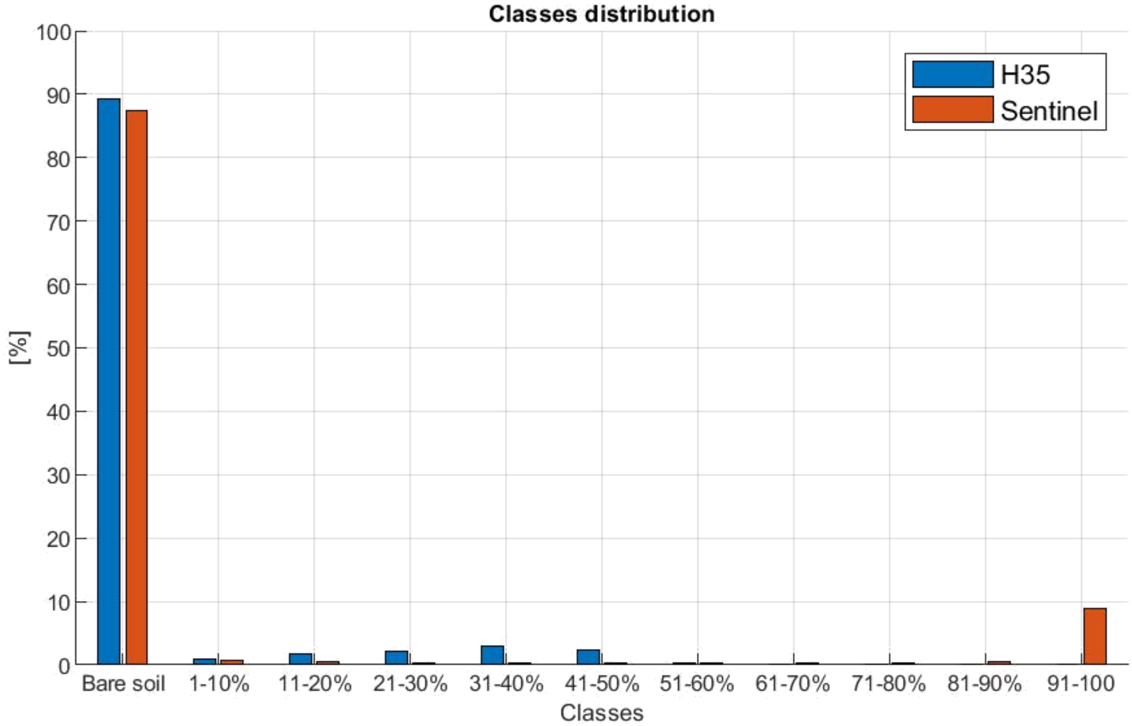


Figure A.2: *Frequency of H35 and resampled Sentinel-2 pixels binned into 11 classes of FSC for Lebanon.*

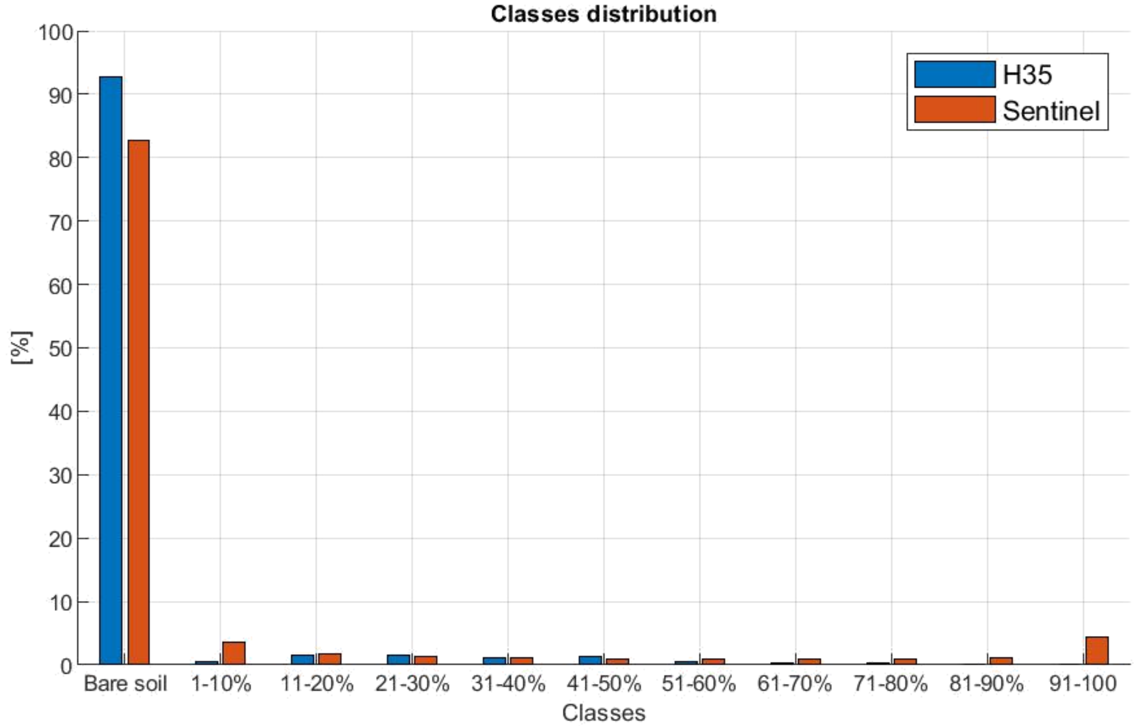
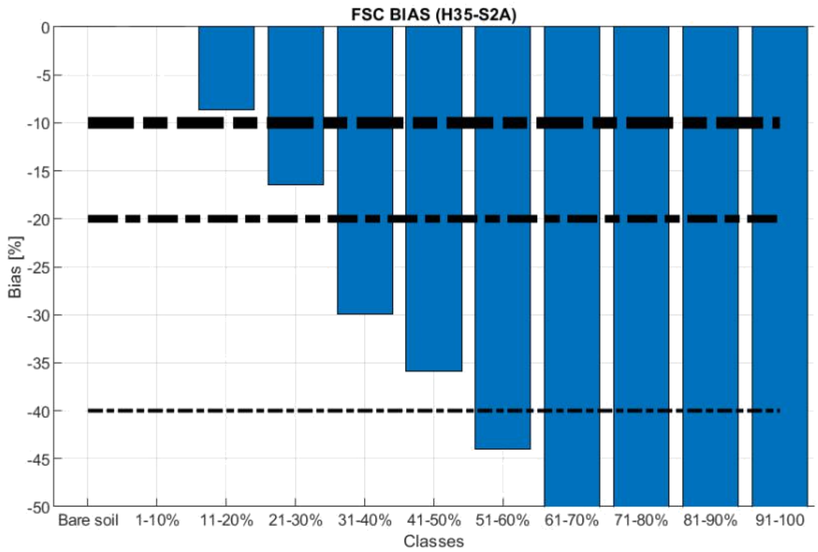


Figure A.3: *Frequency of H35 and resampled Sentinel-2 pixels binned into 11 classes of FSC for the Atlas region.*



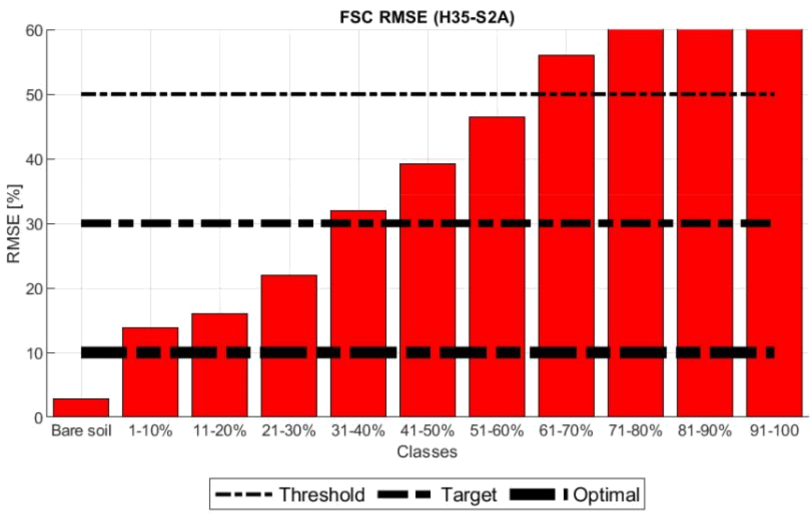
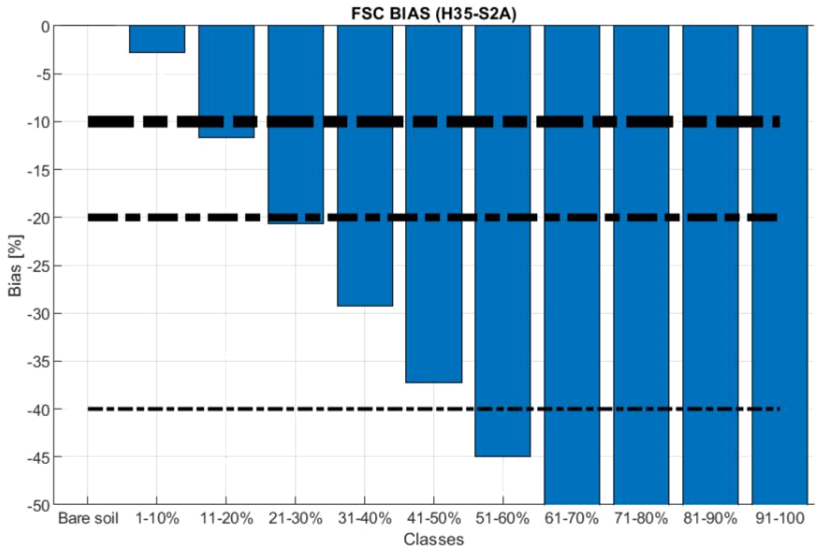


Figure A.4: *RMSE and bias of H35 in Lebanon with regard to Sentinel-2 FSC, as a function of Sentinel-2 FSC*



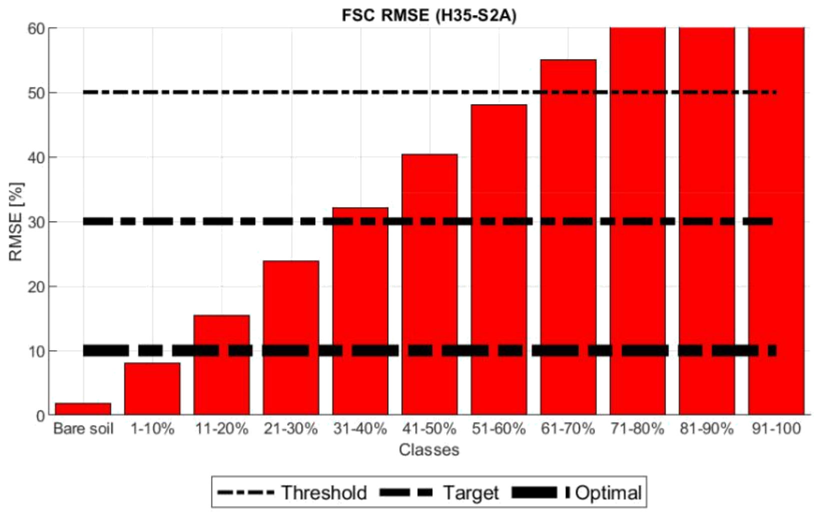


Figure A.5: *RMSE and bias of H35 in the Atlas region with regard to Sentinel-2 FSC, as a function of Sentinel-2 FSC*

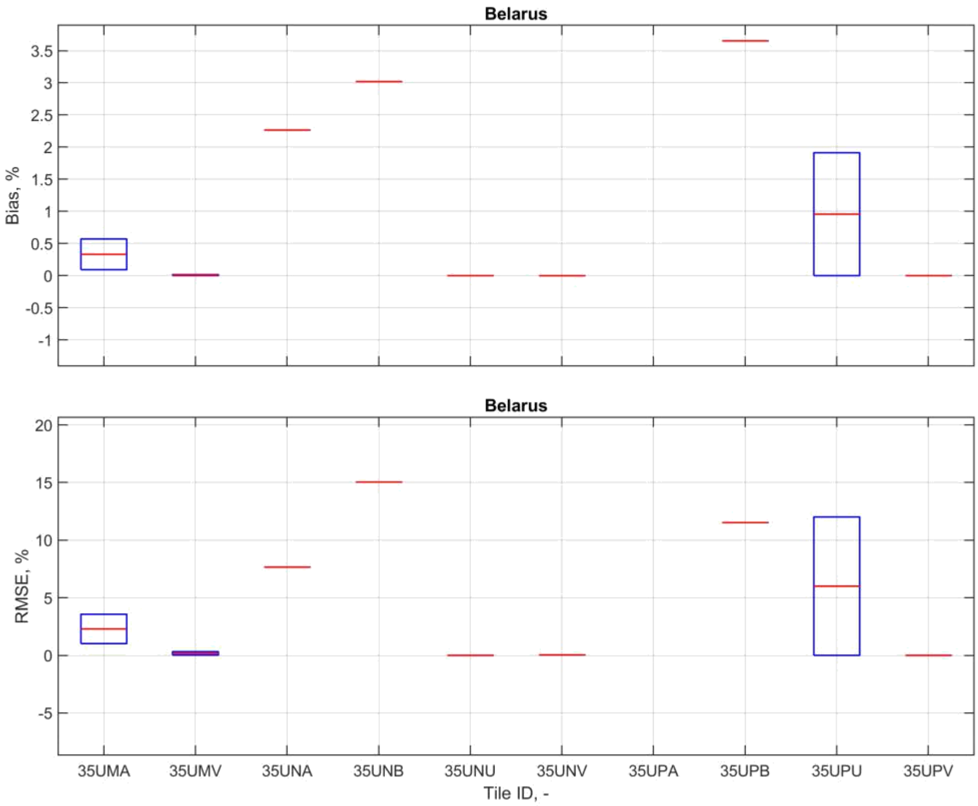


Figure A.6: *Belarus: Distribution of RMSEs and Biases for each image, by tile.*

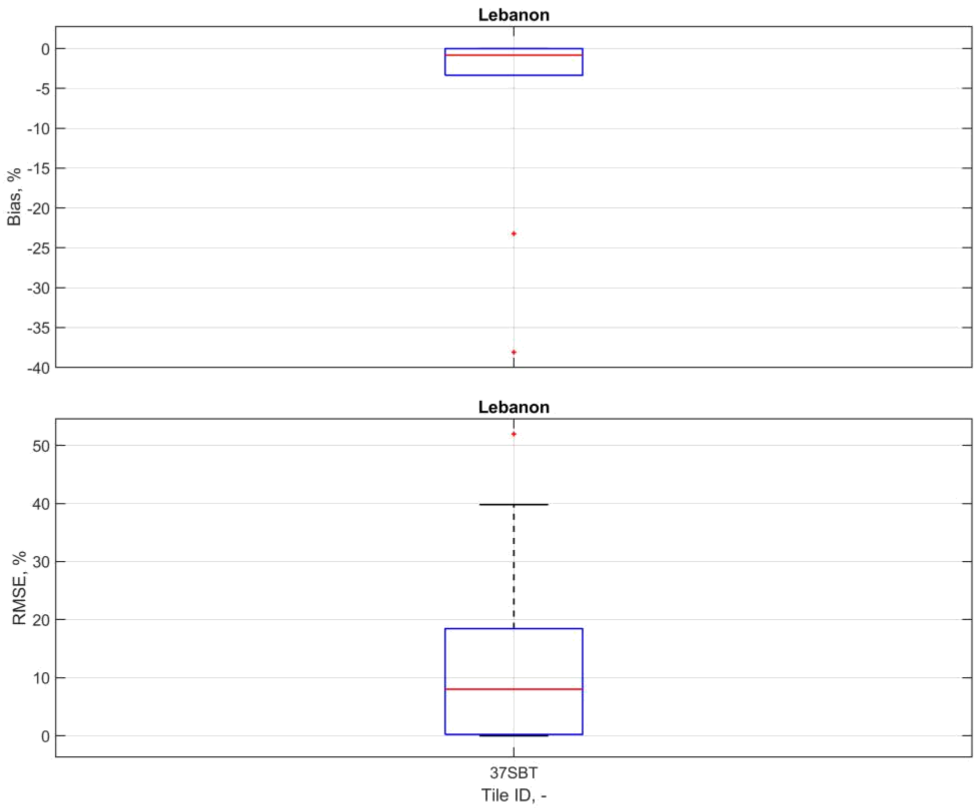


Figure A.7: *Lebanon: Distribution of RMSEs and Biases for each image, by tile.*

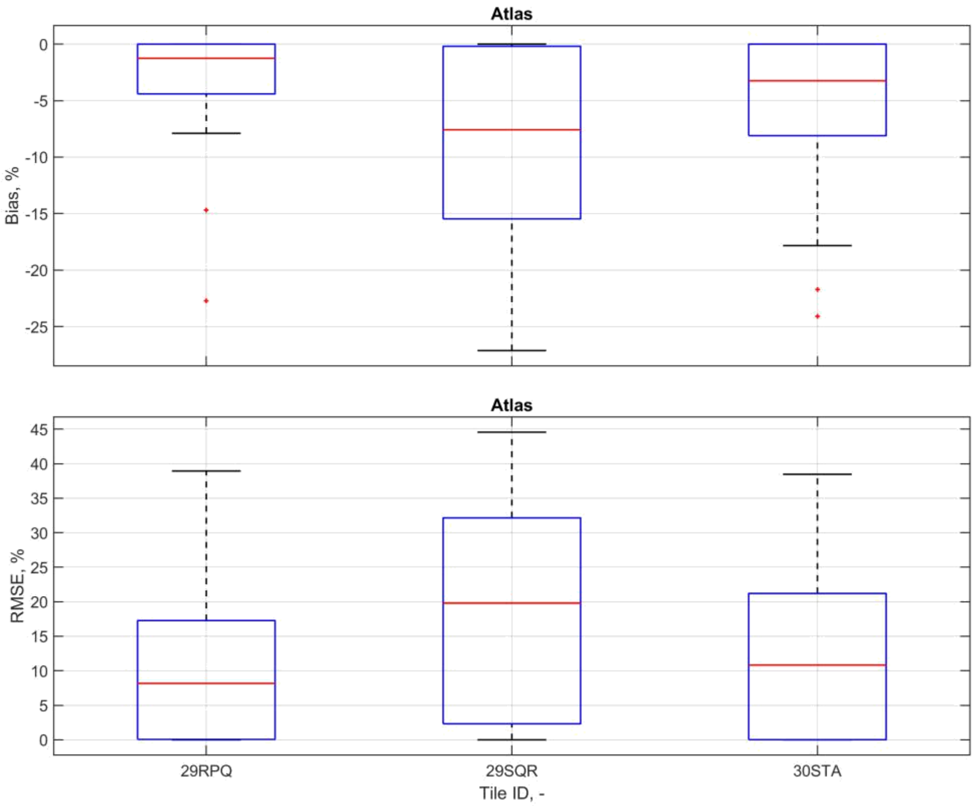


Figure A.8: *Atlas: Distribution of RMSEs and Biases for each image, by tile.*