Panorama of pan-sharpening algorithms for hyperspectral images

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- A hyperspectral image at low spatial resolution
- A pansharpening image (or multispectral image) at high spatial resolution

$\Rightarrow$ Fusion of high spatial resolution with high spectral resolution i.e pansharpening

Contents

1. Some pan-sharpening methods among the state of the art
   - Component substitution
   - Multiresolution analysis
   - Bayesian approach
   - Other algorithms
2. Evaluation protocol
3. Study case 1 : Houston
4. Study case 2 : Namibia
5. Conclusion

Component substitution

Multiresolution analysis

Bayesian methods

Matrix Factorization

Hybrid methods

Algorithm

$$HX_{fusion} = HX_{zoom} \times \frac{PAN}{PAN_{low\_pass\_filtered}}$$

- where HX_{zoom} is the zoomed HX image
- PAN is the high spatial resolution image i.e. panchromatic image
- $PAN_{low\_pass\_filtered}$ is the PAN image filtered with a low-pass filter
- HX_{fusion} is the fused image

Characteristics

- Simple but robust method
- Method used at CNES into pan-sharpening processing chains for Spot 5 and Pleiades
- Resampling of PAN or HX images done while minimizing aliasing effects (depend on the choice of the chosen geometry)

Drawbacks

- Performances lower than some methods of the state of the art

Principle

- First band extracted from the PCA transform of a multispectral image looks like a panchromatic image. Switch between the first PCA band and the panchromatic image, and then inverse PCA transform

$\Rightarrow$ Fused HX image

Algorithm

- PCA transformation of the HX image
- Dynamic adaptation of the PAN image with PCA first band (histogram equalization...)
- Replace the first PCA band by the new one
- Inverse PCA transform

Gram Schmidt (GS)

- Patent by Kodak
- Orthogonal decomposition, and apply specific gains : cov() / var()

GS adaptive (GSA)

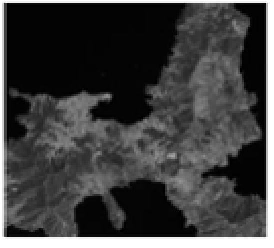
NLPCA transformation

LMVM algorithm (Local Mean and Variance Matching)

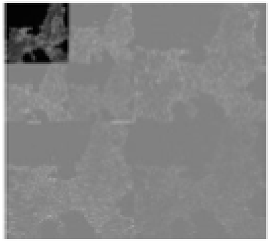
- Use of the sliding window. Compute local mean and std.

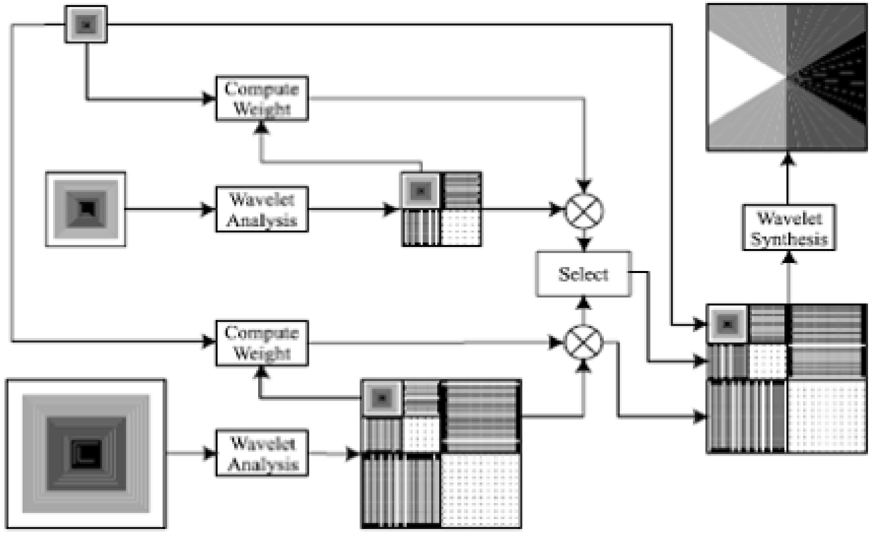
Algorithm

- Wavelet decomposition of the HX images
- Wavelet decomposition of the PAN image
- Depending on the injection model :
  - Computation of the local correlation coefficients for the low frequency coefficients PAN and HX if needed
  - Computation of the injection model
- Substitute the high frequency coefficients of HX with injection model. Use the low frequency coefficients of HX pyramid.
- Reconstruct the HX image with the wavelet pyramid



Elba isle: Landsat TM-5





Several types of wavelet may be used

- Haar wavelets
- UDWT wavelets (Undecimated Discrete Wavelet Transform)
  - Daubechies 4, 8, 12, 20
- AWT decomposition (A Trous Wavelet Transform)
- Etc.

Injection model

- The injection model is a key point of this method
- Example of models :
  - Identity model : high frequency PAN information directly use for HX
  - Affine model : affine law $a * X + b$ applied on high frequency PAN coefficients. Coefficients computed with mean and std of low frequency coefficients.
  - Mixed model : if local correlation $>$ threshold, use of affine law. Else, keep HX high frequency components
  - Etc.

References

- **Ranchin2000** : Thierry Ranchin, Lucien Wald, Ecole des Mines de Paris, Fusion of high spatial and spectral resolution images : the ARSIS concept and its implementation , "Photogrammetric Engineering Remote Sensing 66, 1 (2000) 49-61, 2000.
- **Nunez1999** : Jorge Nunez, Xavier Otazu, Octavi Fors et al. Multiresolution-based image fusion with Additive Wavelet decomposition , IEEE TGRS Vol 37, 1999.
- **Aiazzi2002** : B.Aiazzi et al. Context driven fusion of high spatial and spectral resolution images based on oversampled multiresolution analysis, IEEE Transactions on Geoscience and Remote Sensing, 2002.

Principle

- Build a pyramid of images with morphological operators (combination of opening / closing)
- Injection of the PAN high frequency content into HX
- Rebuild the HX (fused) image

Algorithm

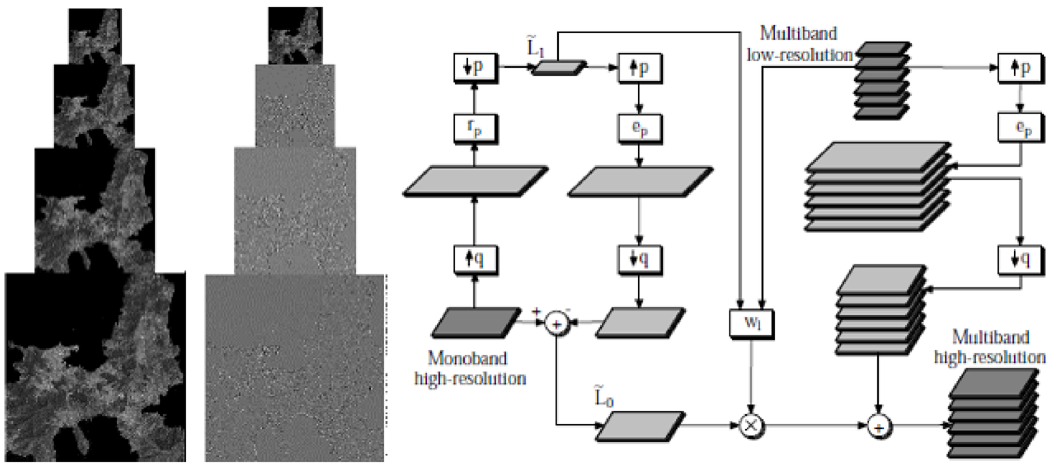
- Build the morphological pyramid of PAN image down to HX resolution, using morphological low-pass operators. Ii $\rightarrow$ IFi. Compute zoomed images : Ii+1,interp
- Compute difference images (high frequency content)
  - Dsup,filter,i = sup(Ii, IFi) – IFi
  - Dinf,filter,i = sup(Ii, IFi) – Ii
- Compute diffrence images (high frequency content)
  - Dsup,resample,i = sup(IFi, Ii+1,interp) – IFi
  - Dinf,resample,i = sup(IFi, Ii+1,interp) – Ii+1,interp
- Replace low-frequency content of PAN pyramid by HX one.
- Rebuild the image using the morphological pyramid, and so rebuild the HX (fused) image.

Principle

- Use of a Laplacian pyramid (corresponding to several resolutions of the images). Compute an injection model from the PAN image and compute high frequency HX coefficients. Rebuild the HX image.

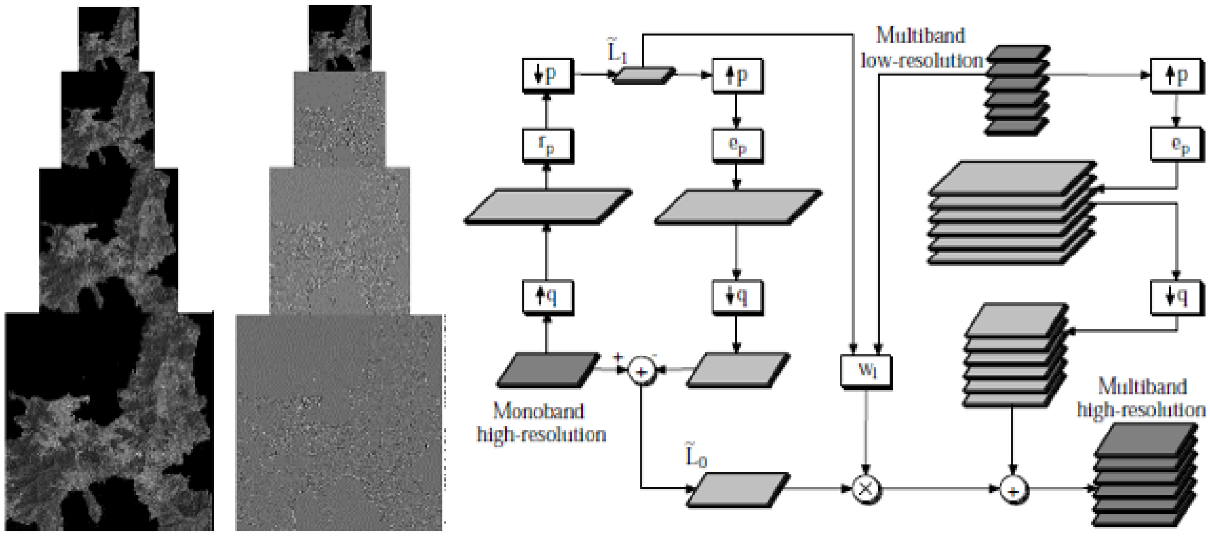
Description of the algorithm (1/2)

- Construction of GLP pyramids for PAN et HX_{zoomed} (for each spectral band)
  - $G_k = reduce_p[G_{k-1}]$
  - $L_k = G_k - expand_p[reduce_p[G_k]]$
  - $expand_p(.)$: expand the image with addition of zero coefficients and low-pass filter
  - $reduce_p(.)$: low-pass filter and decimation



Description of the algorithm (2/2)

- For each spectral band :
  - Computation of the spectral injection model I_{alpha} on low-frequency images HX and PAN (at the lower resolution into the pyramidal decomposition)
  - Computation of $HX_{fused\_low\_res}$ (at the lower resolution => last level of the pyramidal decomposition)
  - Replace HX high frequency components by PAN high frequency components with injection model
  - Inverse Laplacian transform to build the final HX fused image



Advantages

- Spectral content is more confident to the original image

Drawbacks

- The choice of the injection model may create some geometrical distortions, fuzzy edges or other visual artifacts.

Consequence : key-point of the algorithm = injection model

Model based of ECB (Enhanced Context Based)

- $\mathrm{I}_{alpha}(i,j) = \min\left(\frac{\rho(i,j)}{E(\rho(i,j))} \times \frac{std\left(\mathrm{XS}_{expanded}(i,j)\right)}{std\left(\mathrm{PAN}_{expanded\_lowRes}(i,j)\right)}, c\right)$
- where ρ is the linear correlation coefficient over a N x N window
- where $std\left(I(i,j)\right)$ standard deviation of image I over a MxM window
- where c is a constant : $2 < c < 3$

Model based on ESDM (Enhanced Spectral Distortion Minimizing)

- $\mathrm{I}_{alpha}(i,j,k) = \mathrm{I}_{beta}(i,j) \times \frac{\mathrm{XS}_{expanded}(i,j,k)}{\mathrm{PAN}_{expanded\_lowRes}(i,j)}$
- $\mathrm{I}_{beta}(i,j) = \sqrt{\frac{1}{L}\frac{\sum_k var(\mathrm{XS}_{expanded}(i,j,k))}{var(\mathrm{PAN}_{expanded\_lowRes}(i,j))}}$
- where $var(\mathrm{I}(i,j))$ is the local variance of image I over a M x M window

Modulation Transfer Function (MTF-GLP)

- Gaussian filter tuned to match the sensor modulation transfer function
- Additive and multiplicative details injection sheme

Modulation Transfer Function with High Pass Modulation (MTF-GLP-HPM)

- Additive and multiplicative details injection sheme

SFIM - Smoothing Filter based Intensity Modulation

- Pyramid based on the use of a single average box
- Injection scheme based on High Pass Modulation

References

- **Aiazzi2002a** : B. Aiazzi et al, Generalised Laplacian Pyramid based fusion of MS+P image Data with spectral distortion minimisation
- **Aiazzi2002b** : B. Aiazzi et al. Context driven fusion of high spatial and spectral resolution images based on oversampled multiresolution analysis, IEEE Transactions on Geoscience and Remote Sensing, 2002.
- **Baronti2003** : S. Baronti, B. Aiazzi, Pan sharpening of very high resolution multispectral images via generalized Laplacian pyramid fusion, SFPT N°169, 2003.
- **Aiazzi2006** : B. Aiazzi et al. MTF Tailored multiscale fusion of high resolution MS and PAN, Photogrammetric Engineering Remote Sensing imagery 2006.

Bayes Naive

- Local estimation of local Gaussian models
- Local weighting of the coefficients to build the pan-sharpen image
- Minimization function
- Optimisation problem solved with ADMM

Bayes direct

- Direct use of explicit Sylvester based equation to decrease computationnal complexity
- Reference : Q. Wei, N. Dobigeon, J.Y. Tourneret, "Fast fusion of multi-band images based on solving a Sylvester equation", 2015.

HySure

- Vector Total Variation
- Specific minimizing function
- Optimisation solver : SALSA

Matrix Factorization - CNMF

- Matrix factorization of the HX image
- Linear model for the HX image : $X = H.U$

Guided Filter PCA - GFPCA

- The upsampling function uses high frequency elements of a guidance image
- Applied on the PCA of the HX low spatial resolution image
- Liao et al. Best Paper Challenge 2014.

References

- **Loncan2015** : Laetitia Loncan, Luis B. Almeida, Jose M. Bioucas-Dias, Xavier Briottet, Jocelyn Chanussot, Nicolas Dobigeon, Sophie Fabre, Wenzhi Liao, Giorgio A. Licciardi, Miguel Simoes, Jean-Yves Tourneret, Miguel A. Veganzones, Gemine Vivone, Qi Wei and Naoto Yokoya, "Hyperspectral pansharpening : a review", 2015.
- Source code of **Loncan2015** : http://openremotesensing.net

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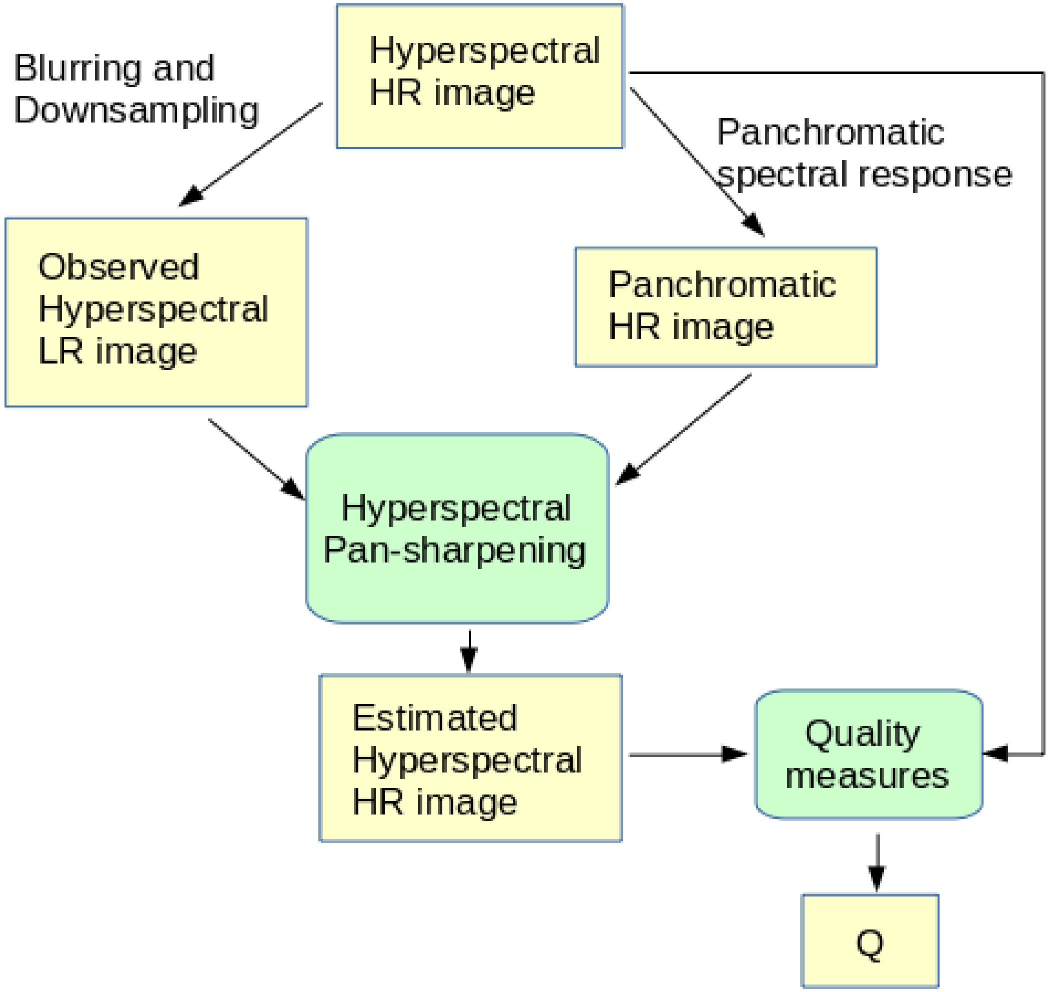
Hyperspectral HR image
Blurring and Downsampling
Panchromatic spectral response
Observed Hyperspectral LR image
Panchromatic HR image
Hyperspectral Pan-sharpening
Estimated Hyperspectral HR image
Quality measures
Q

- For each fused results, direct computation of distance measure with the original HX image
  - MSE (Mean Square Error)
  - RMSE (Root Mean Square Error)
  - MD (Maximum Difference)
  - AD (Average difference)
  - NAE (Normalized Absolute Error)
  - NCC (Normalized Cross-correlation)
  - PSNR in dB (Peak Signal to Noise Ratio)
  - SC (Structural Content)
  - UIQI (Universal Image Quality Index)
  - MSSIM (Mean Structural Similarity Index)
  - ERGAS (Relative Global Error of. Synthesis)
  - SAM (Spectral Angle Mapper)

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Description of the data

- CASI image over Houston. Data Fusion Contest 2013
- Compact Airborne Spectrographic Imager (CASI) Data
- 364 nm to 1046 nm, 144 bands
- Full image 1905 x 349 pixels

Simulation of Pleiades spectral bands

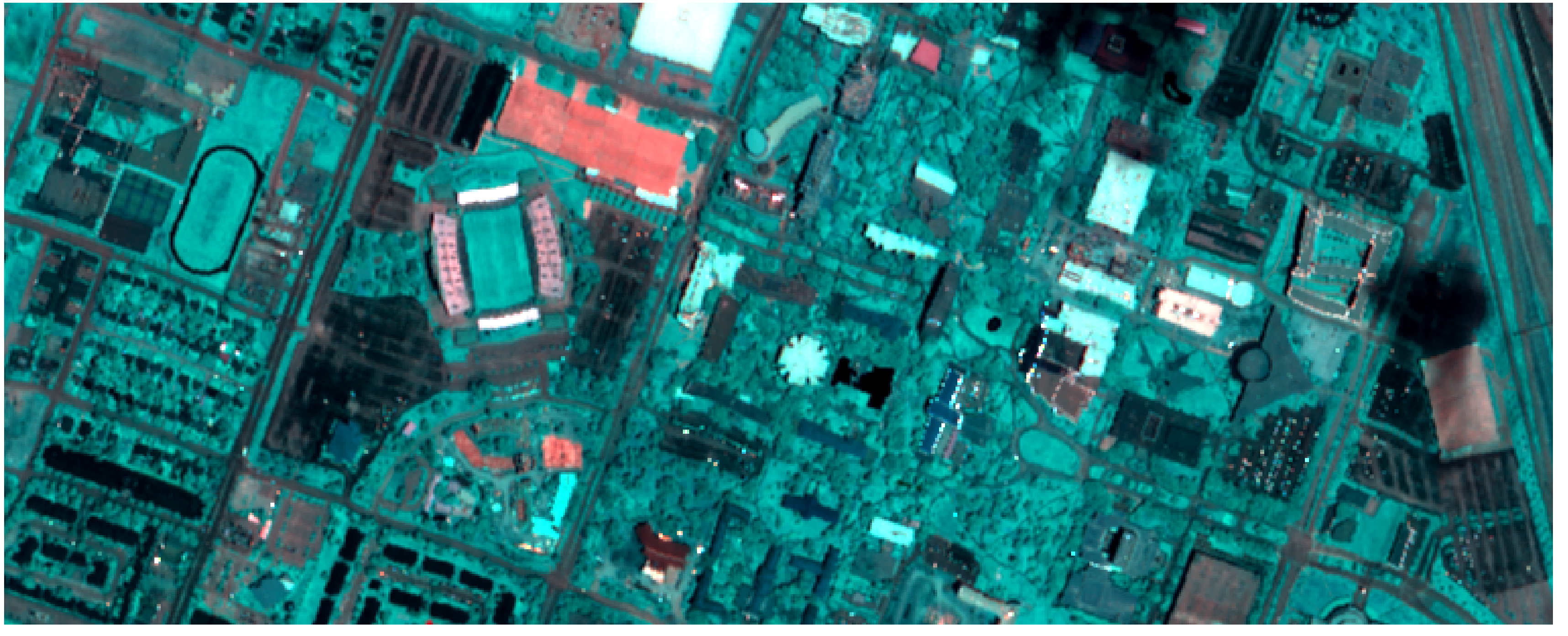
- Panchromatic PAN : 470 nm - 820 nm (CASI B23 - B97)

Evaluation of performances

- Worst case configuration for the pan-sharpening : selection of 3 bands outside of the panchromatic spectral interval : B5, B115, B142
- Evaluation of performances only with these 3 bands, on this area

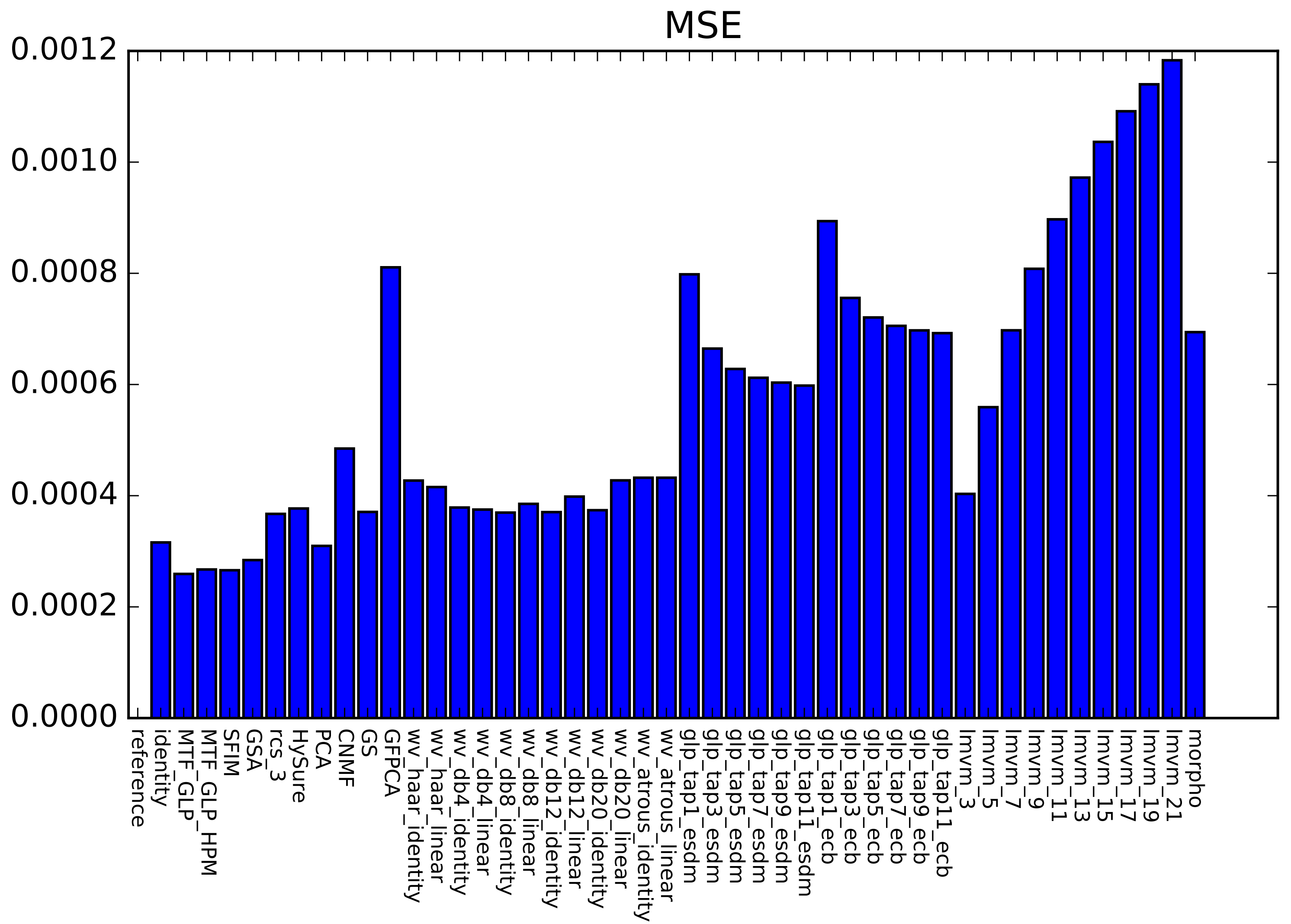
  ⇒ Direct comparison of the result with visual perception

- Use of several resolutions in order to evaluate robusteness of the algorithms



Study case 1 : Houston

Performances. Resolution ratio : 4



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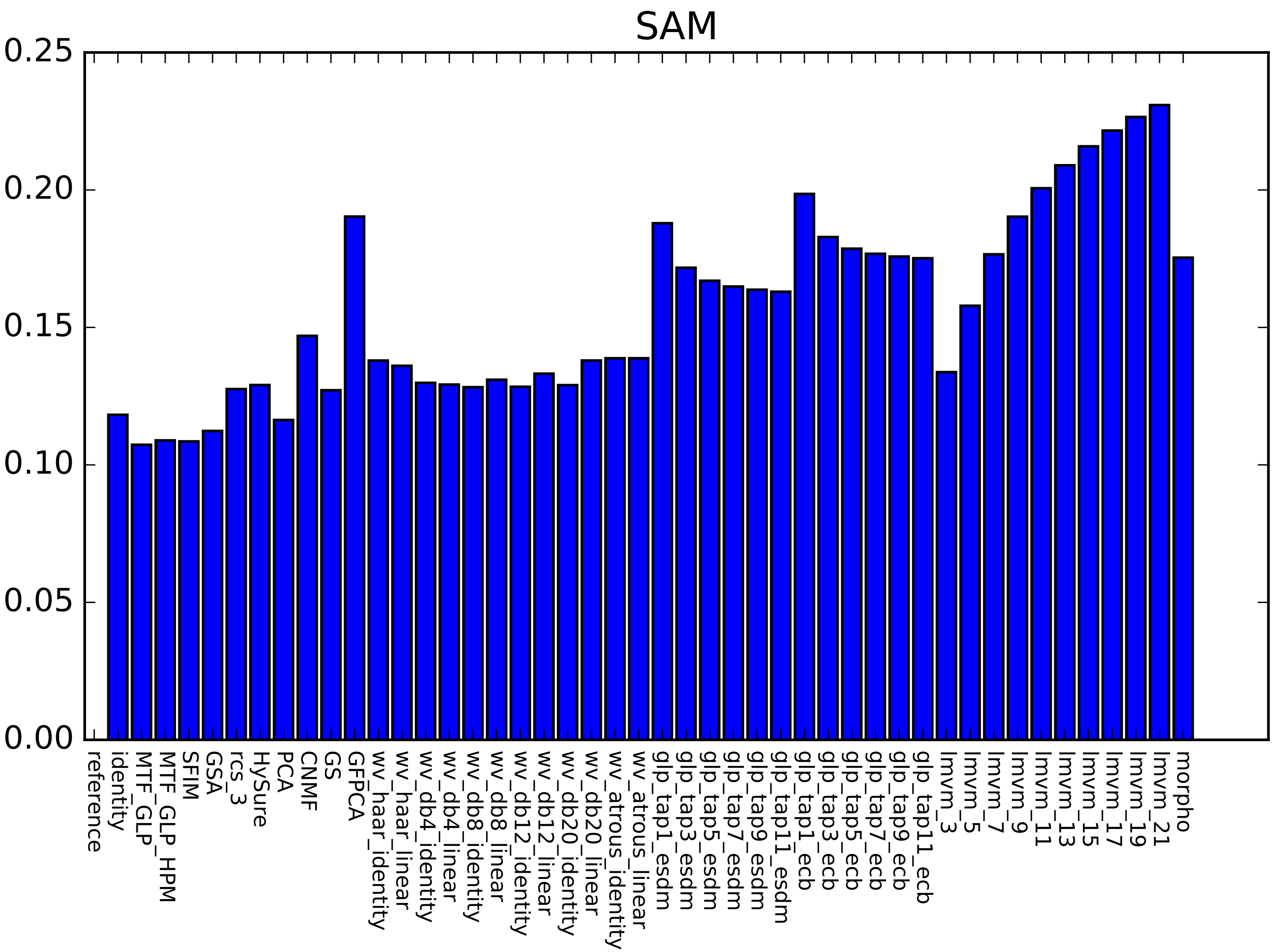

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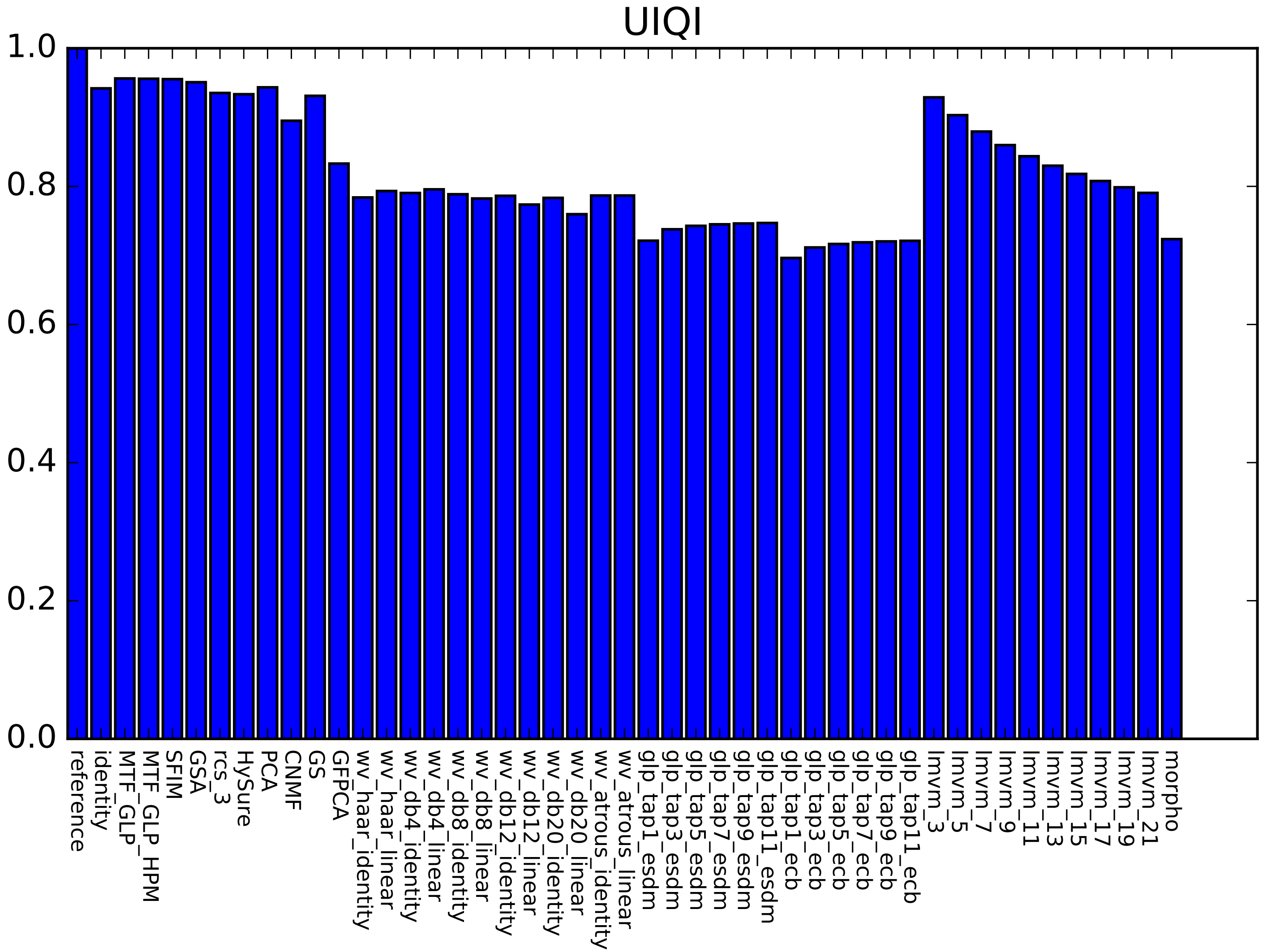
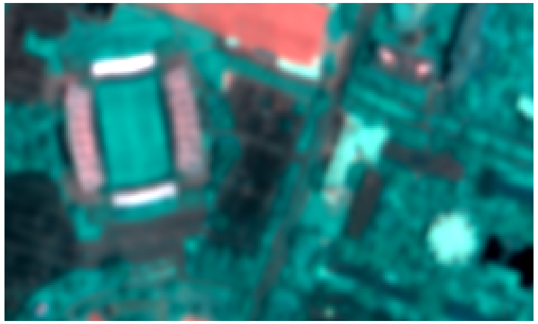
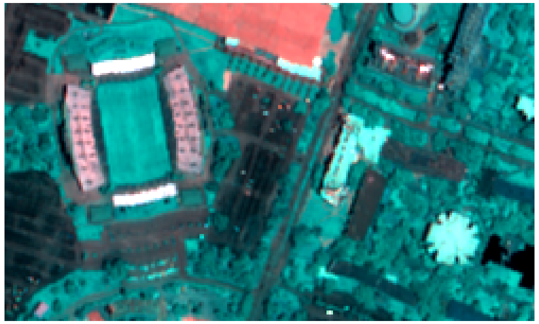
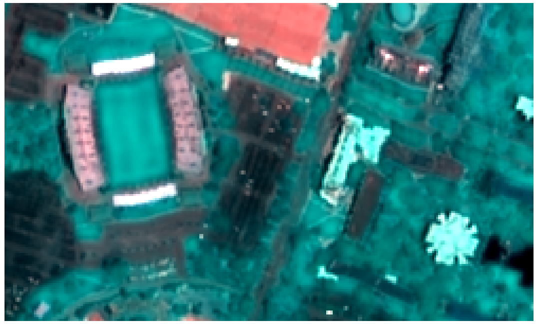


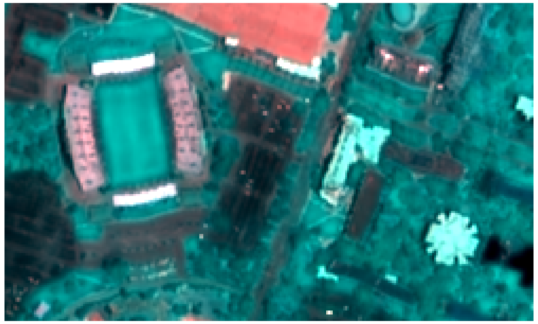
Study case 1 : Houston

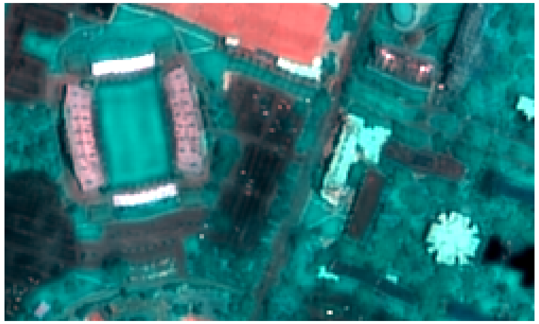
Zoom on results (1/2)

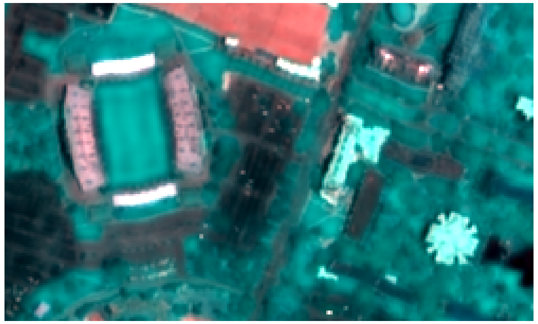
(1) 

(2) 

(3) 

(4) 

(5) 

(6) 

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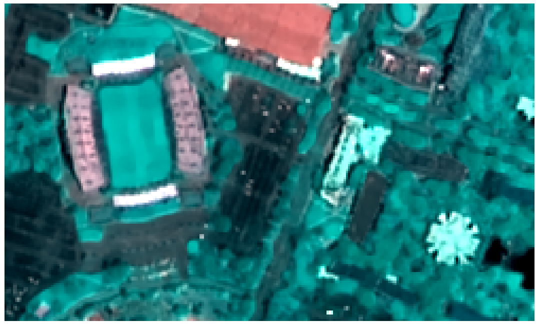
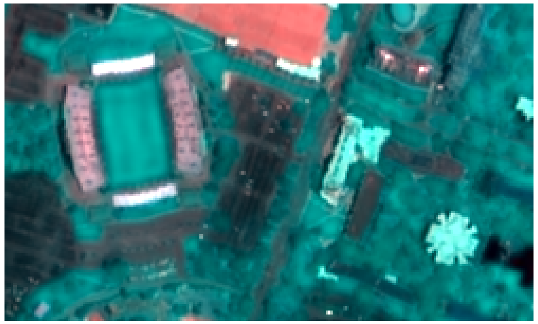
(8) 

(9) 

(1) Identity (2) Reference (3) MTF_GLP
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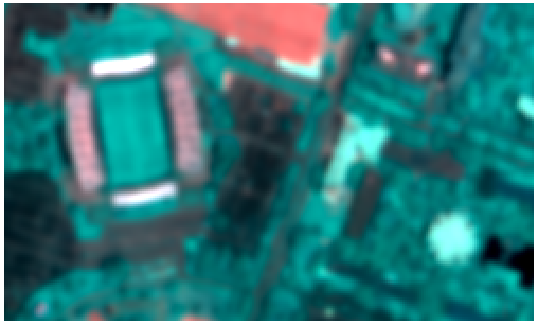
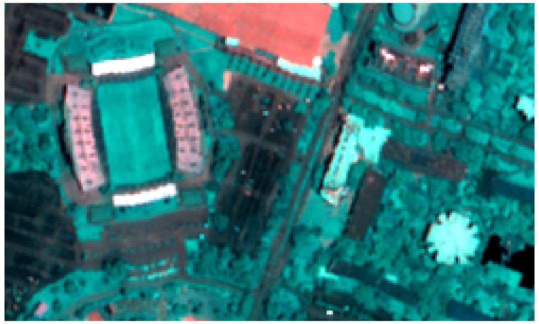
Zoom on results (2/2)

(1) 
(2) 
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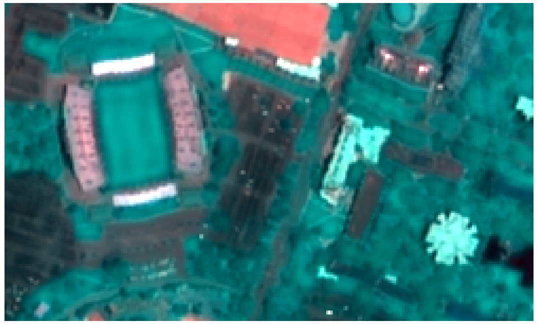
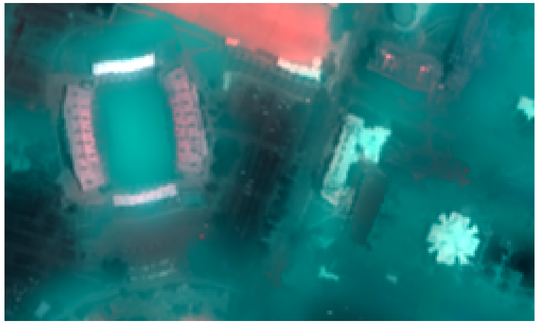
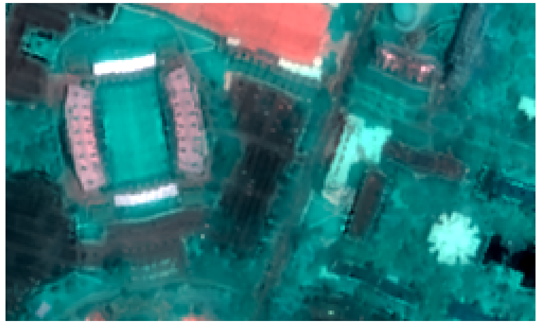
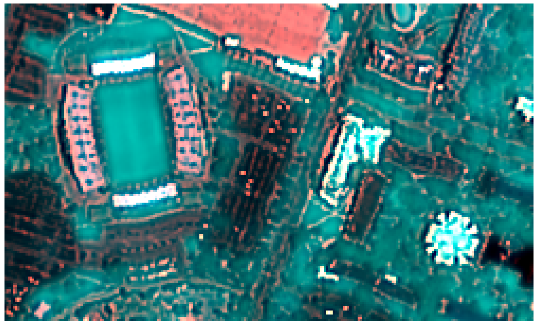
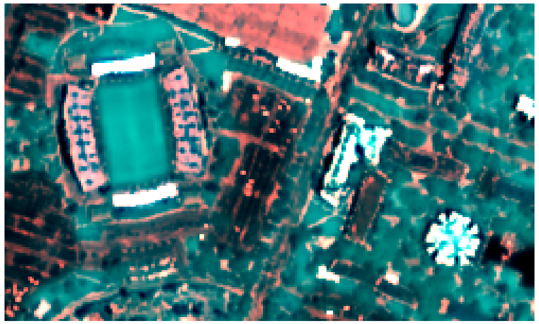
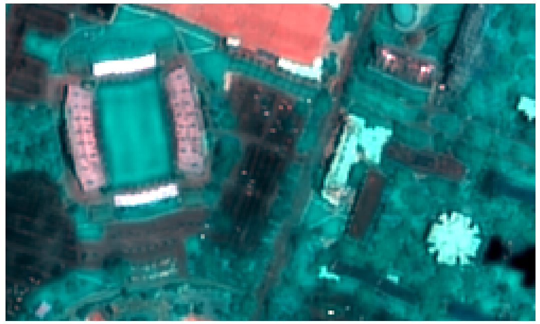
(4) 
(5) 
(6) 
(7) 
(8) 
(9) 

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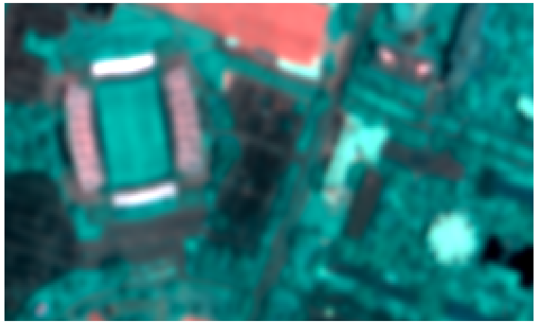
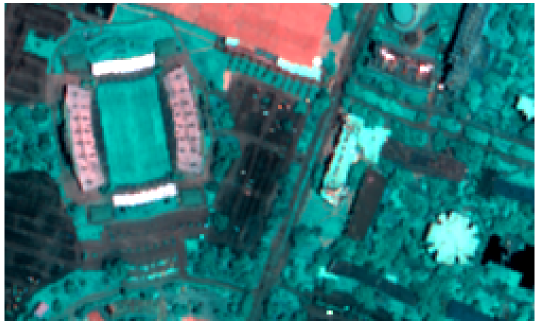
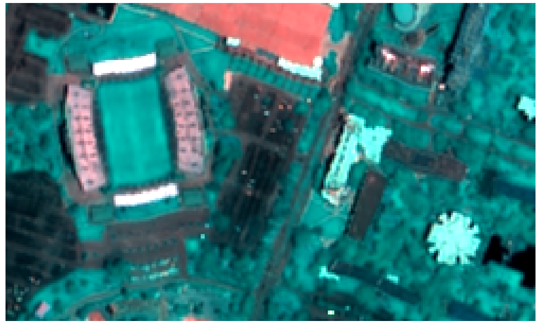
(7) wv_db4_linear (8) morpho (9) SFIM

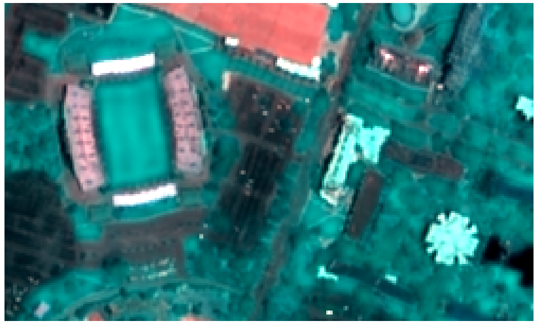
Study case 1 : Houston

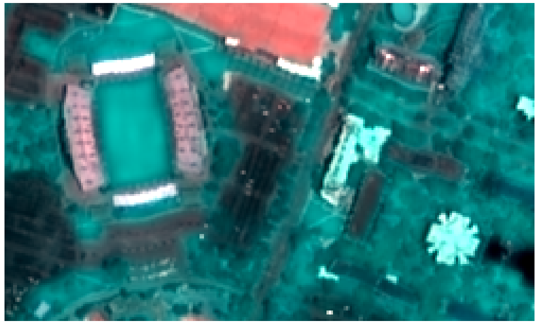
Impact of ratio - Performances with MTF_GLP

(1) 

(2) 

(3) 

(4) 

(5) 

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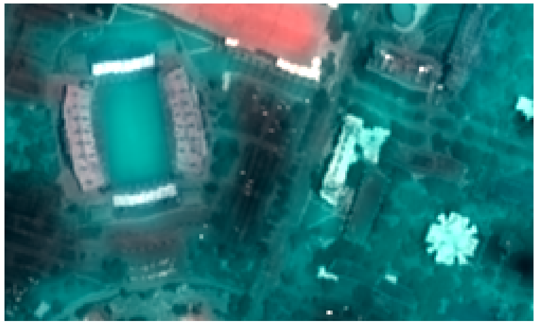
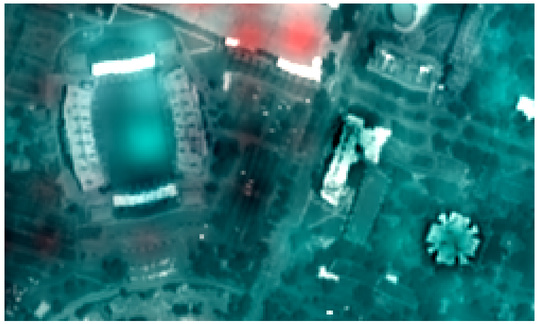
(7) 

(8) 

(1) Identity (2) Reference (3) Ratio 2
(4) Ratio 4 (5) Ratio 6 (6) Ratio 8
(7) Ratio 12 (8) Ratio 24

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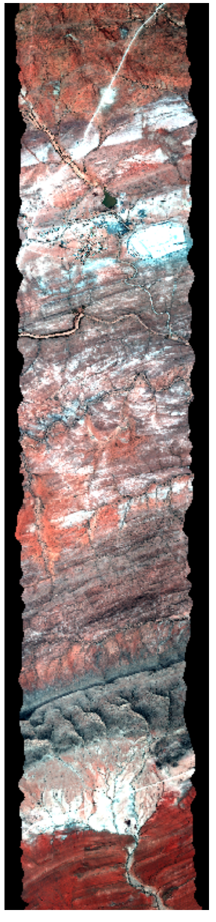
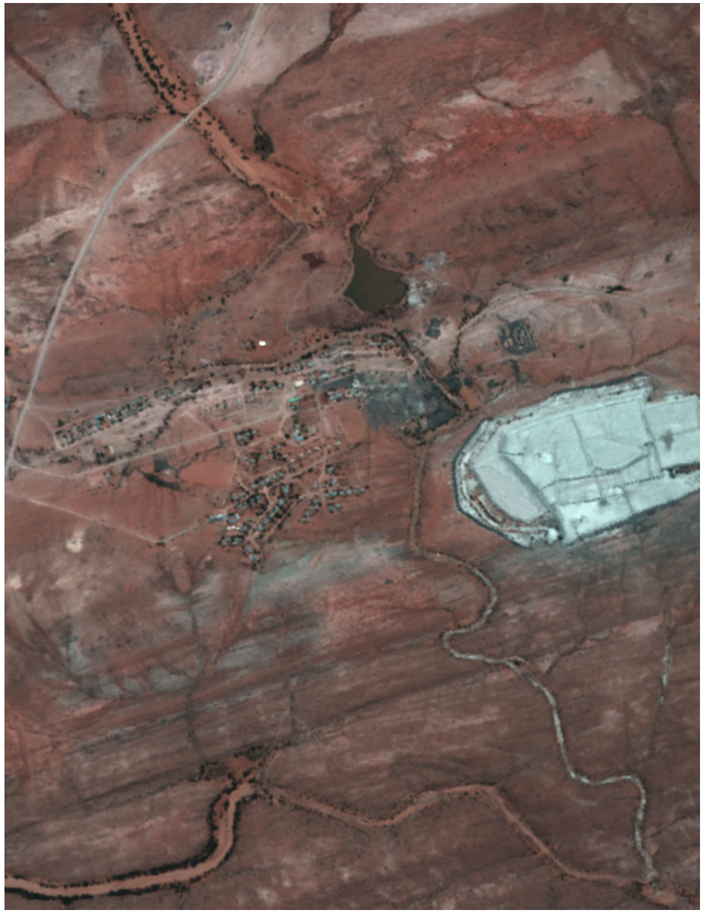
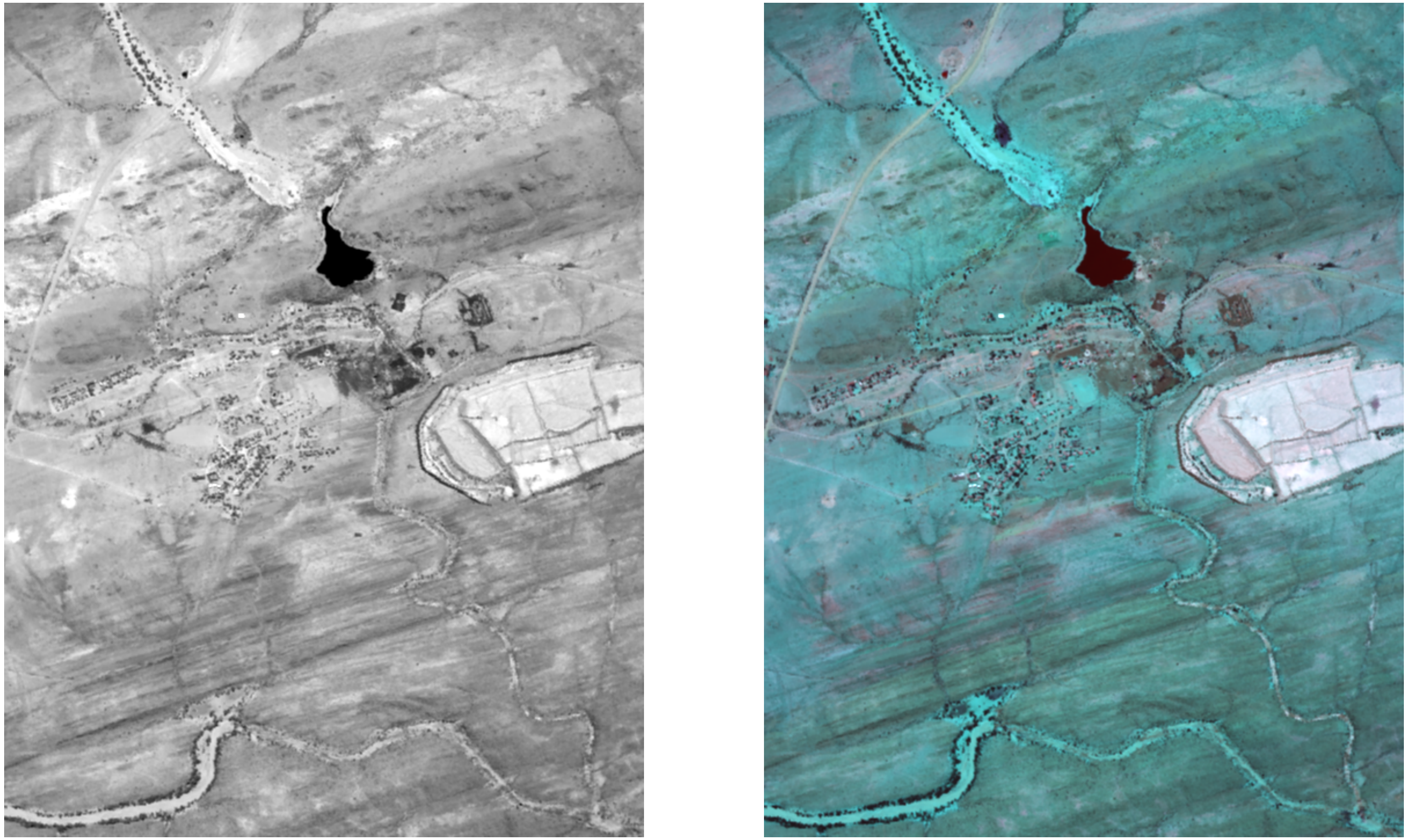
- HYMAP sensor. Airborne australian sensor
- Size : 11460 x 681 pixels
- 126 bands : 443 nm - 2482 nm
- Spatial resolution : 4.8m



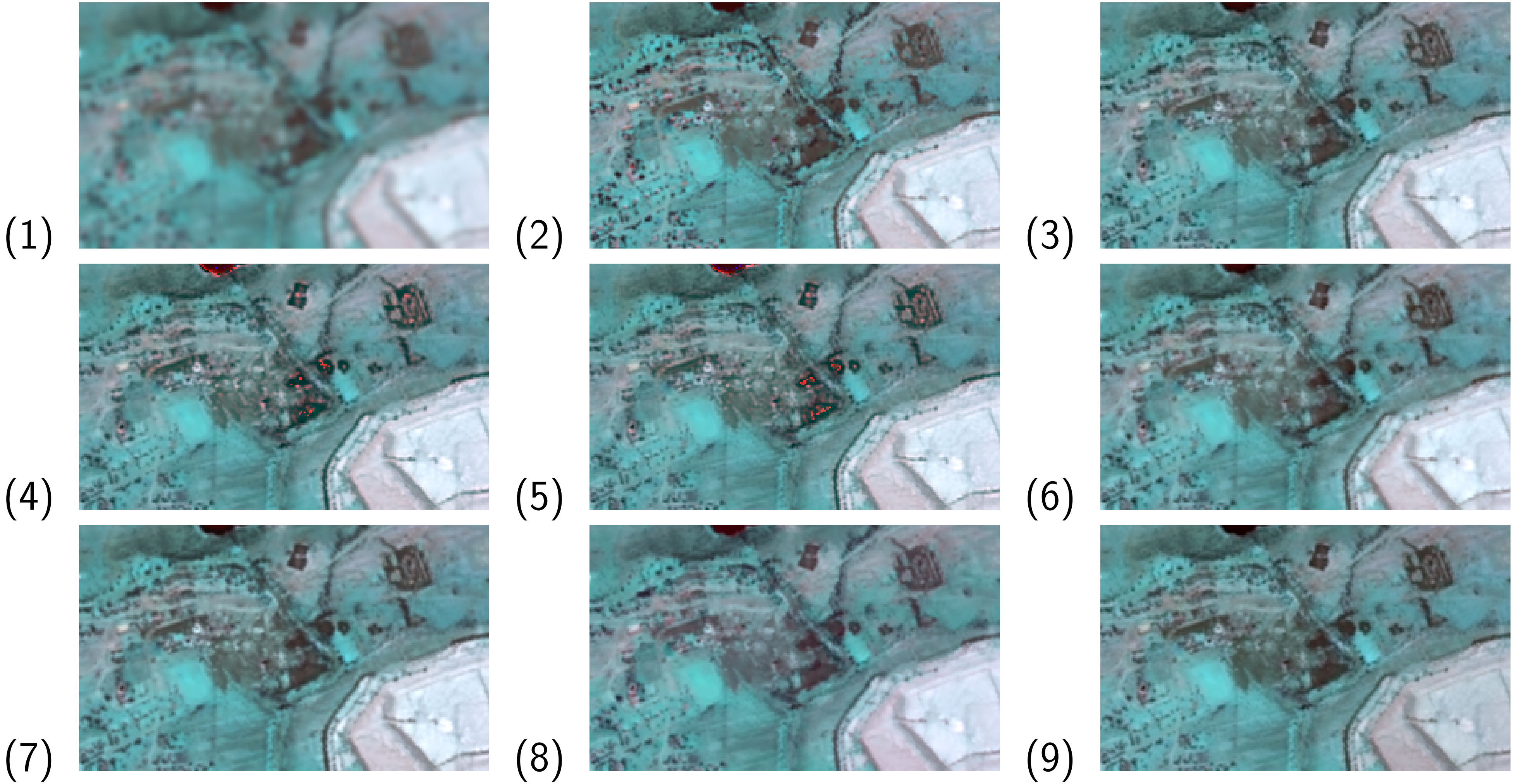


Evaluation protocol

- Simulation of panchromatic band B22-B80 (bandwidth larger than Pleiades one for the evaluation)
- Evaluation of performances on B5, B98, and B112 (outside of the PAN bandwidth)



Study case 2 : Namibia
Zoom on results (1/2)



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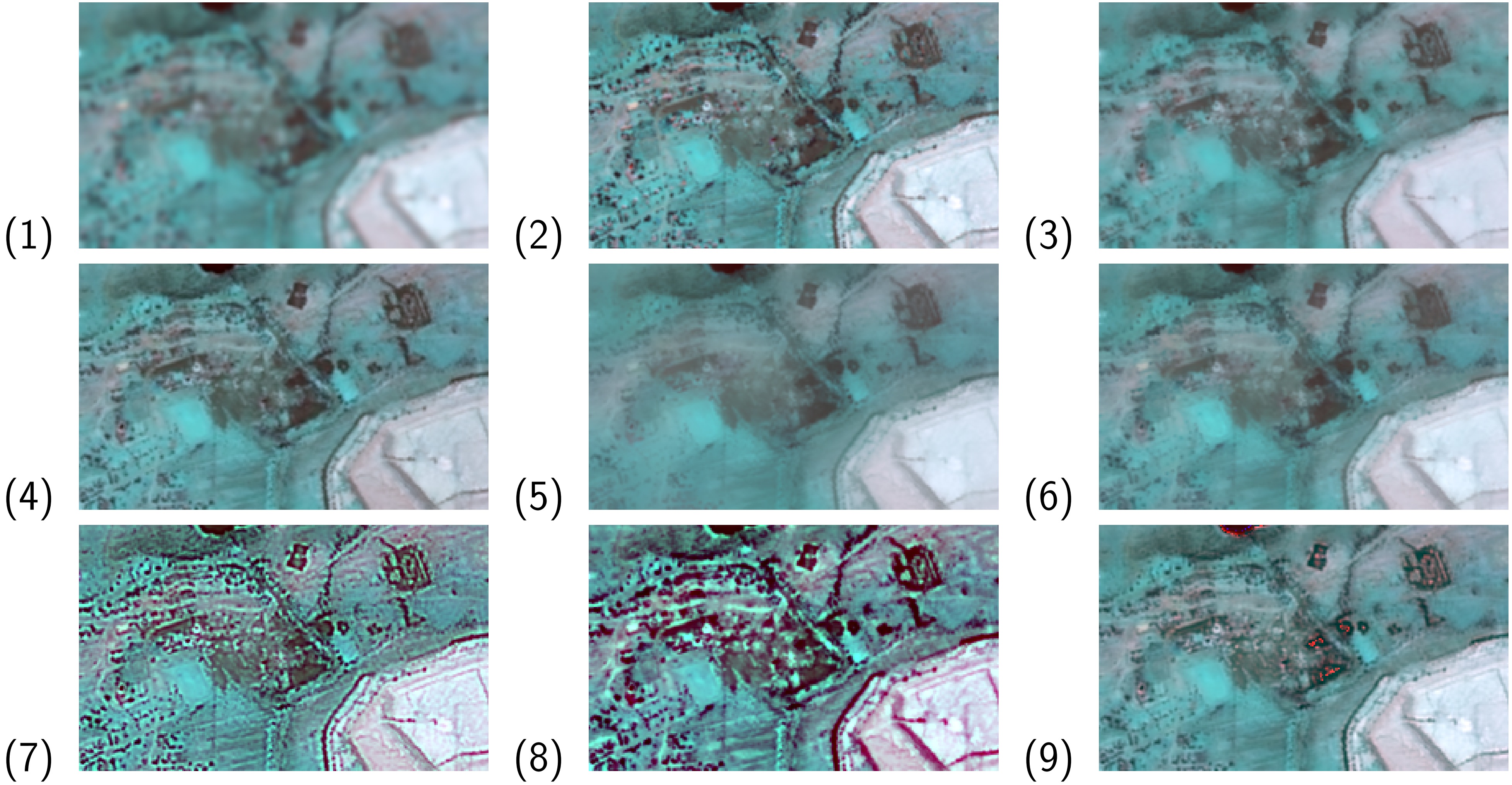

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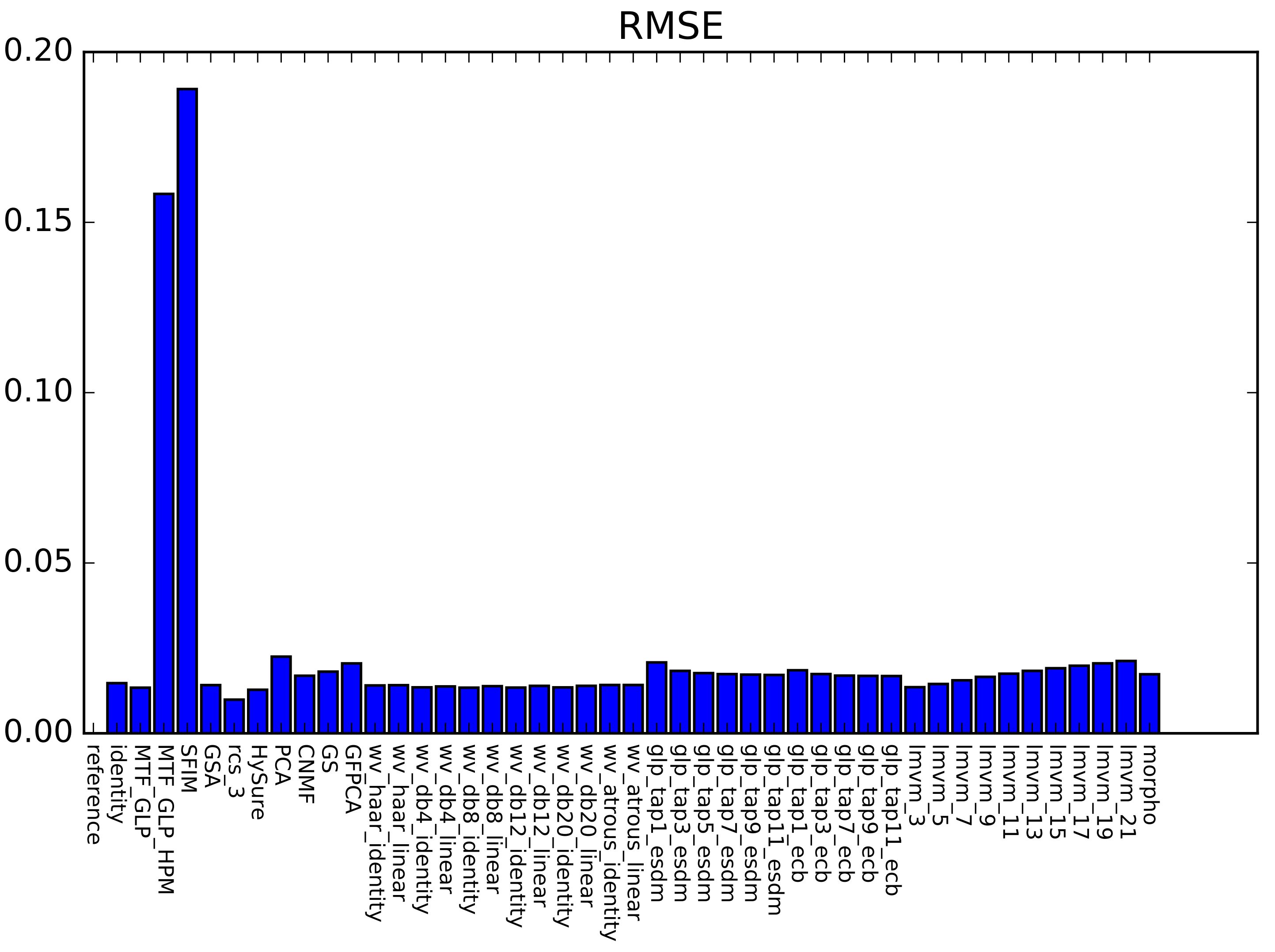
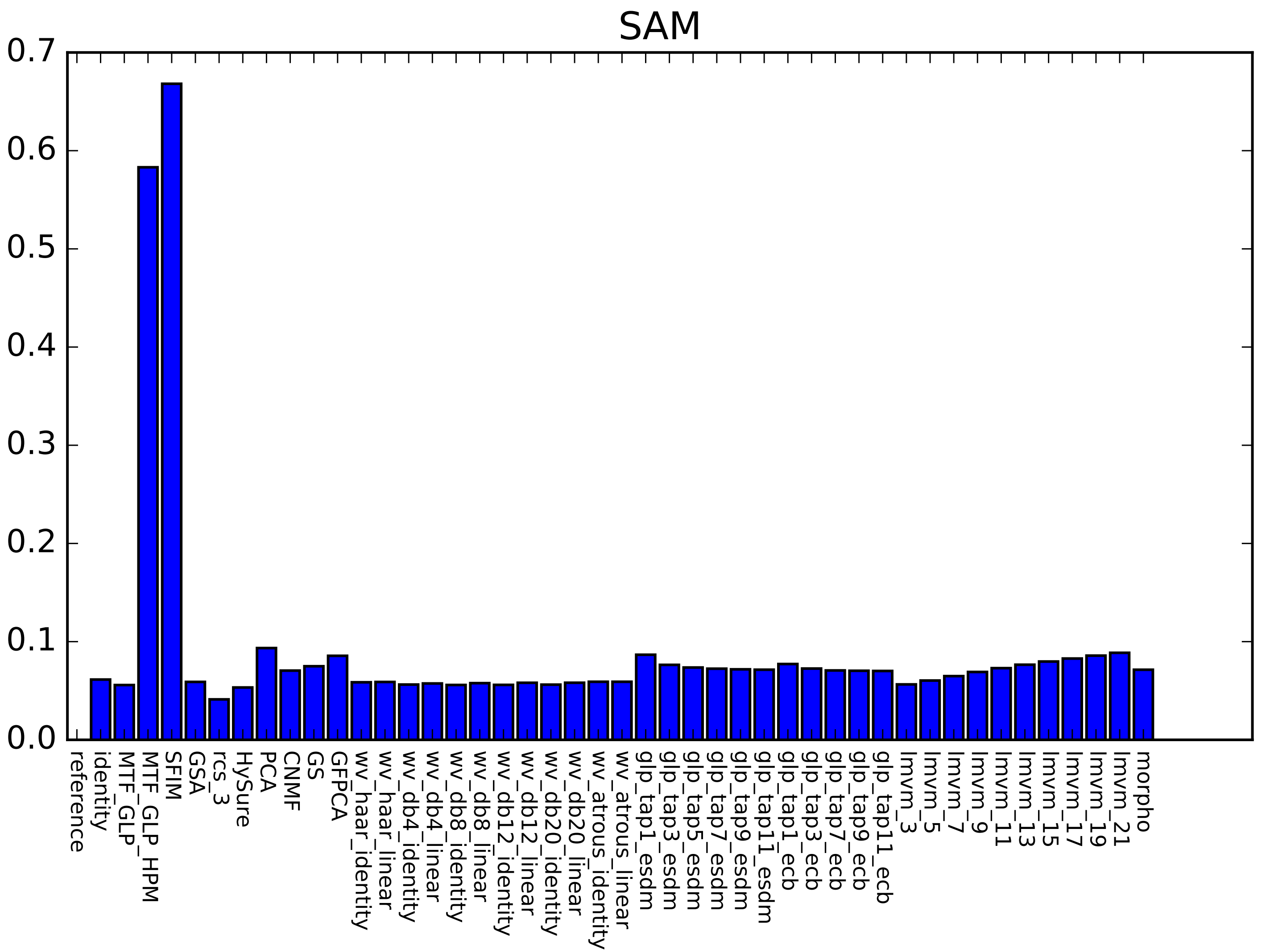
Study case 2 : Namibia

Performances. Resolution ratio : 4



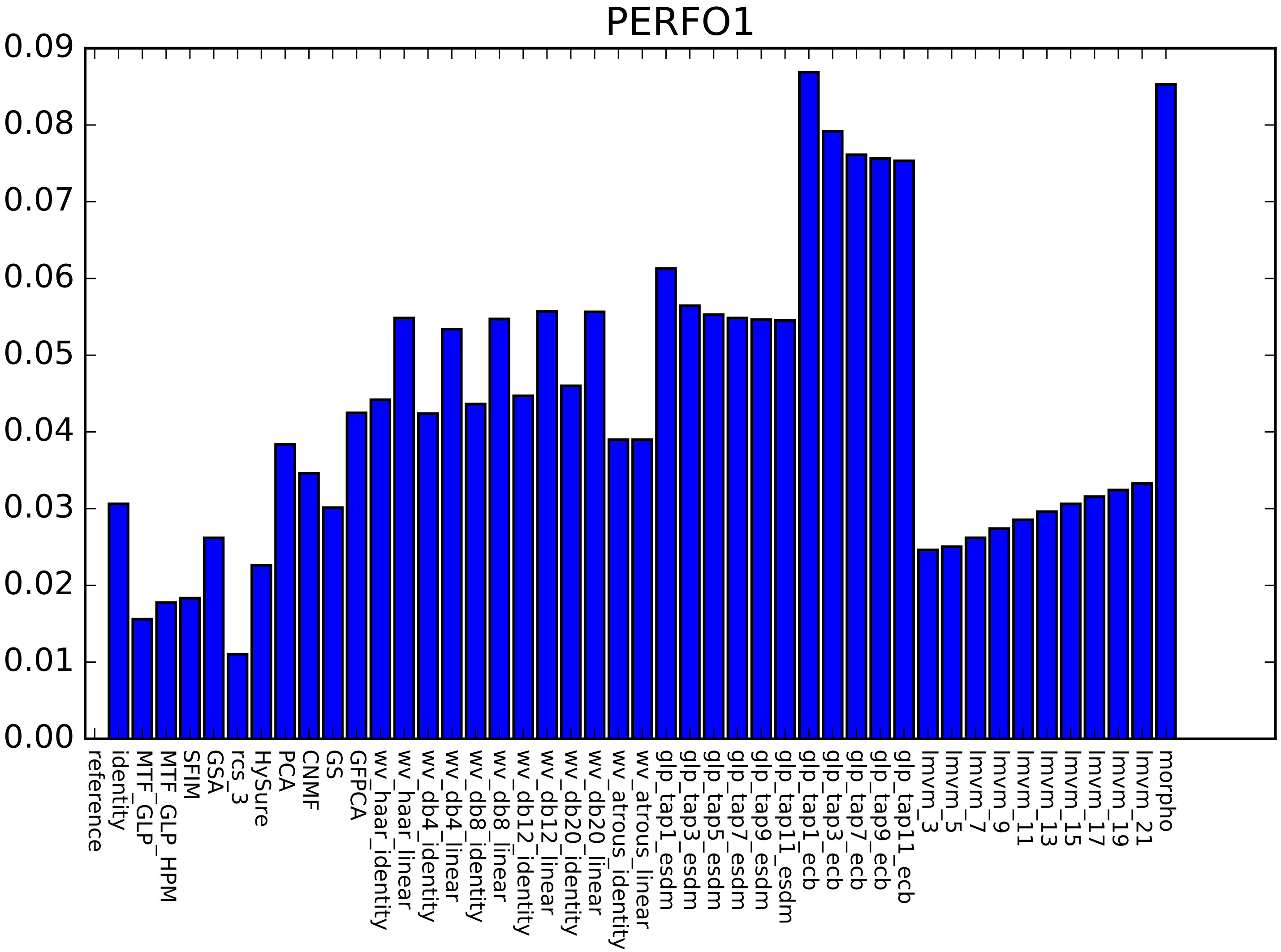
Study case 2 : Namibia

Performances. Resolution ratio : 4



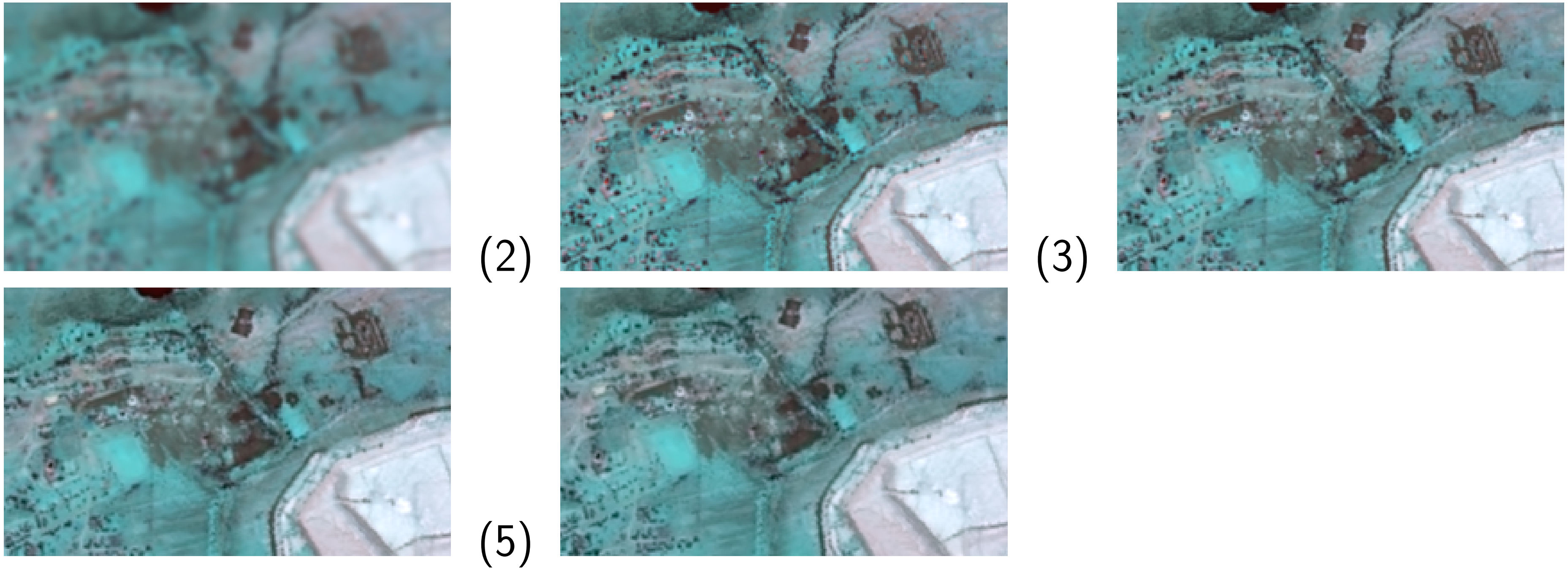
Study case 2 : Namibia

Composite metric. Resolution ratio : 4



Impact of ratio - Performances with MTF_GLP

(1) (2) (3) (4) (5)



(1) Identity (2) Reference (3) Ratio 2
(4) Ratio 4 (5) Ratio 6

Contents

1 Some pan-sharpening methods among the state of the art

2 Evaluation protocol

3 Study case 1 : Houston

4 Study case 2 : Namibia

5 Conclusion

State of the art proposes many methods with very interesting results for pan-sharpening

In general, harmonization on the evaluation protocol. But algorithms need to be evaluated also on worst cases

Evaluation code : Matlab $\Rightarrow$ Python

Bayesian methods not yet evaluated in this comparison

Good candidates :

- MTF-GLP
- MTF-GLP-HPM
- SFIM
- GSA
- HySure
- RCS
- LMVM-3

Thank you for your attention

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