Resolution Enhancement for Hyperspectral Images: A Super-Resolution and Fusion Approach

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1. Research Motivation

- Existing hyperspectral images have resolutions much lower than that of high resolution color images (WV-2, WV-3, etc.)
- Fusing color images with hyperspectral images will yield high spatial hyperspectral images that will enhance the performance of many applications.
- In Loncan et al.'s paper, over 10 algorithms were evaluated. We divide the methods into 3 groups:
  - Group 1: PSF is needed
  - Group 2: No need of PSF
  - Group 3: Single image super-resolution methods
- New single image super-resolution algorithms such as the PAP-ADMM appear in the literature.
- There are fusion algorithms (no need of PSF) developed by our team (hybrid color mapping (HCM)) and others (Group 2) that can be used to address the above fusion problem.

1. Research Motivations

- Q1: Since there are some new development in single image super-resolution algorithms recently, will a single-image super-resolution method alone be sufficient to produce high-resolution hyperspectral images?
- Q2: Is it possible to incorporate PSF into our HCM algorithm? If yes, how much will the single-image super-resolution improve the HCM performance?
- Q3: Will the use of PSF also help improve Group 2's performance?

2. Technical Approach

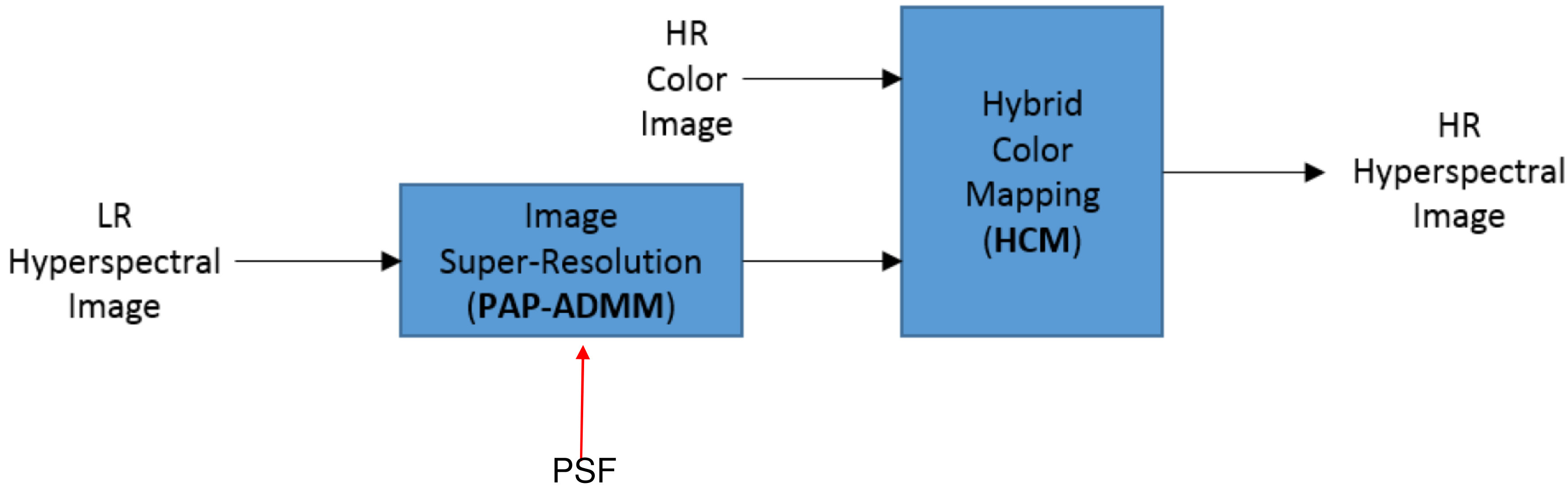
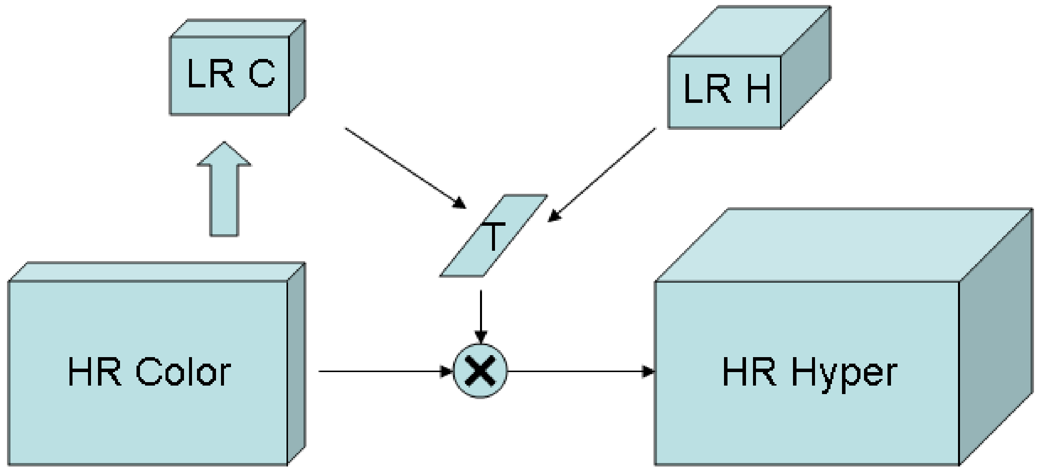


Fig. 1. Outline of the proposed method. We use hybrid color mapping (HCM) to fuse low-resolution (LR) and high-resolution (HR) images. For LR images, we use a single-image super-resolution algorithm to first enhance the resolution before feeding to the HCM.

2. Technical Approach



Color Mapping

- Step 1: Downsample HR color to LR color
- Step 2: Determine the mapping between a LR color pixel and a LR hyperspectral pixel
- Step 3: Map HR color to HR hyperspectral.

Remark 1: Hybrid Color Mapping (HCM) – Incorporate some selected bands in LR H into the LR C; also introduce a white band in LR C.

Remark 2: Local HCM – Divide the whole image into non-overlapping patches and each patch has its own transformation matrix T.

2. Technical Approach

Plug-and-Play – Alternating Direction Method of Multipliers (PAP-ADMM)

- Consider the j-th band of the hyperspectral image, the relationship between low and high resolution pixels is given by

$$\boldsymbol{s}_j^L = \boldsymbol{D}\boldsymbol{A}\boldsymbol{s}_j^H + \boldsymbol{\eta}$$

where D is downsampling matrix, A is the blur matrix containing the PSF.

- The problem of image super-resolution is to solve an optimization.

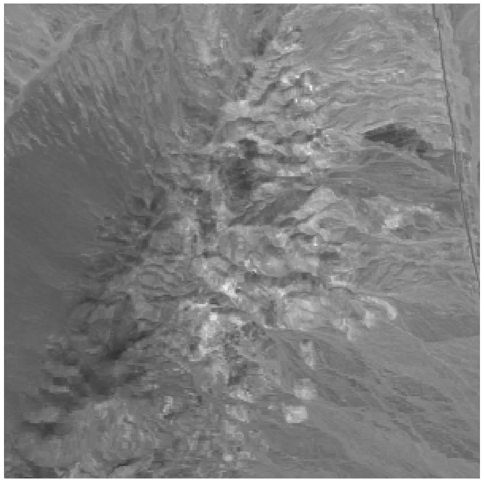
$$(\boldsymbol{s}_1^H, \ldots, \boldsymbol{s}_P^H) = \underset{\boldsymbol{s}_1^H, \ldots, \boldsymbol{s}_P^H}{\operatorname{argmin}} \sum_{j=1}^{P} \left(\|\boldsymbol{s}_j^L - \boldsymbol{D}\boldsymbol{A}\boldsymbol{s}_j^H\|^2 + \lambda g(\boldsymbol{s}_j^H) \right)$$

3. Experimental Results

Data

- AF data from the Air Force.
  - 267 x 342 x124,
  - ranging from 461nm to 901nm.
- NASA AVIRIS
  - 300 x 300 x 213,
  - ranging from 380nm to 2500nm
- To simulate the low-resolution hyperspectral images, we downsample the images spatially with a factor of K = 9 (3 x 3) using a 5 x 5 Gaussian point spread function.
- HR color images are taken from the appropriate bands of the high-resolution hyperspectral images.

AF



NASA AVIRIS

3. Experimental Results

Comparison between HCM and PAP-ADMM

Table 1: Comparison of HCM and PAP-ADMM using the NASA image.

Methods	RMSE	CC	SAM	ERGAS
PAP-ADMM [19]	66.2481	0.95311	**0.78477**	1.9783
HCM [17]	44.3475	0.94915	0.99064	2.0302
PAP-ADMM+HCM	**30.1907**	**0.96719**	0.90084	**1.7205**

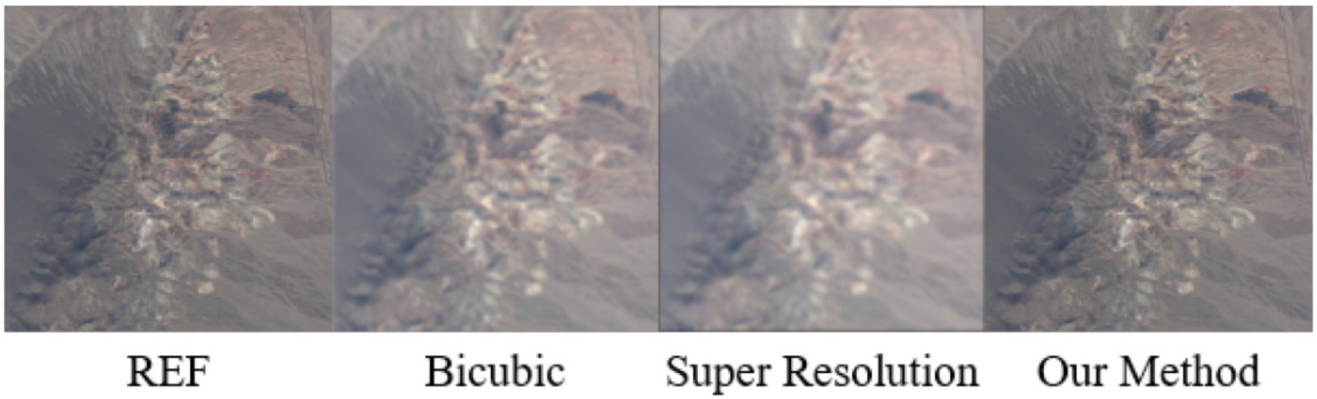


Fig. 2. AVIRIS images in visible range using different methods

- Single image resolution method is not sufficient. This answers Q1.

- Fusing PAP-ADMM with HCM can significantly improve performance. This answers Q2.

3. Experimental Results

Comparison with Groups 1 to 3 Methods

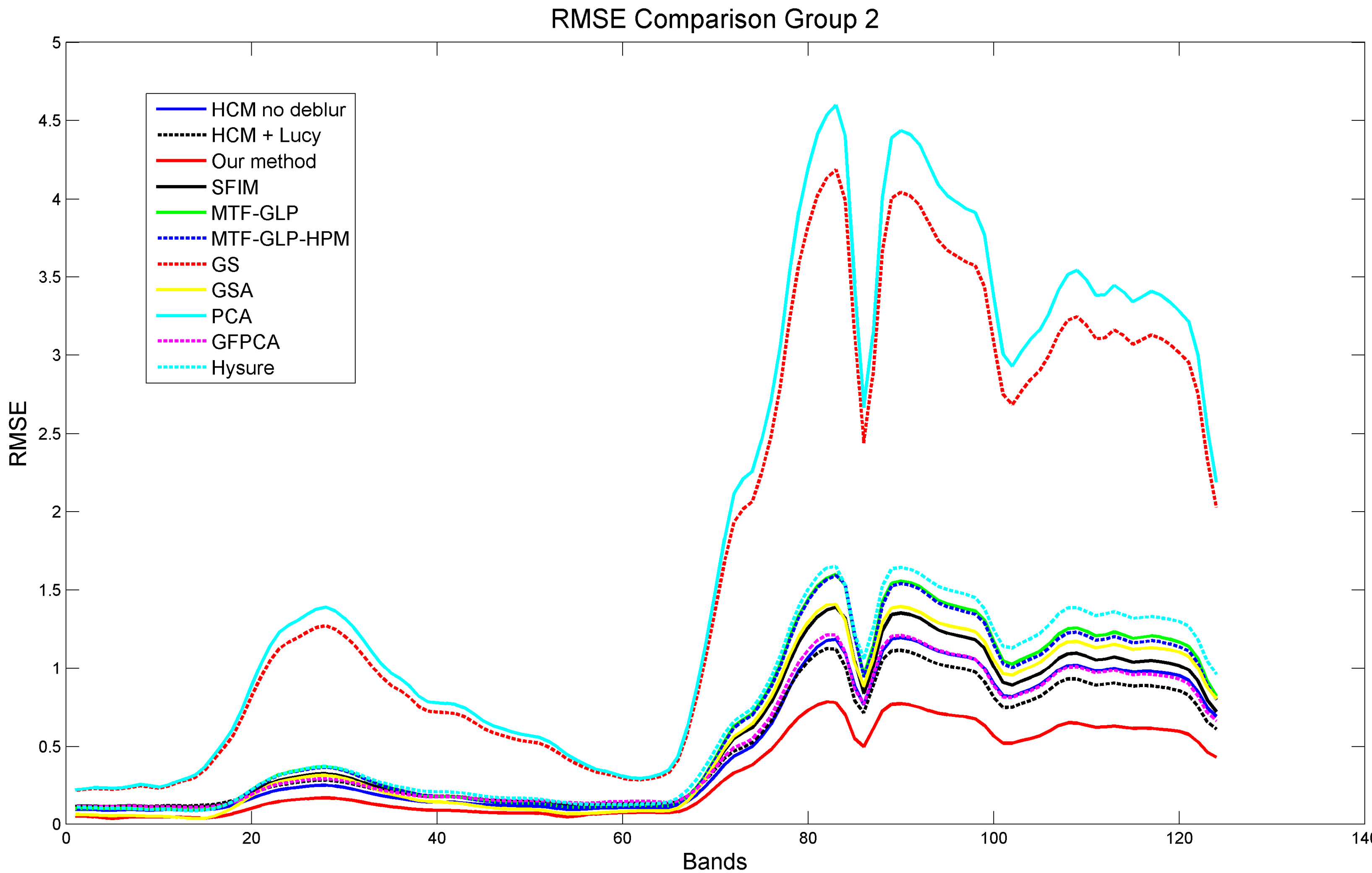
PAP-ADMM does not help Group 2 methods because Group 2 methods have built-in high frequency content injection by using pan info. Consequently, having PAP-ADMM as the pre-processing step to Group 2 methods overcompensates the images. This answers Q3.

		AF					AVIRIS				
Group	Methods	Time	RMSE	CC	SAM	ERGAS	Time	RMSE	CC	SAM	ERGAS
1	CNMF [4]	12.52	0.5992	0.9922	1.4351	1.7229	23.75	32.2868	0.9456	0.9590	2.1225
	Bayes Naive [5]	0.58	0.4357	0.9881	1.2141	1.6588	0.86	67.2879	0.9474	0.8136	2.1078
	Bayes Sparse [6]	208.82	**0.4133**	0.9900	1.2395	1.5529	235.50	51.7010	0.9619	**0.7635**	1.8657
2	SFIM [16]	0.99†	0.7176	0.9846	1.5014	2.2252	1.56†	63.7443	0.9469	0.9317	2.0790
	MTF GLP [12]	1.38†	0.8220	0.9829	1.6173	2.4702	2.25†	57.5260	0.9524	0.9254	2.0103
	MTF GLP HTM [13]	1.40†	0.8096	0.9833	1.5540	2.4387	2.23†	57.5618	0.9524	0.9201	2.0119
	GS [10]	1.05†	2.1787	0.8578	2.4462	7.0827	1.83†	54.9411	0.9554	0.9420	1.9609
	GSA [11]	1.21†	0.7485	0.9875	1.5212	2.1898	1.98†	32.4501	**0.9695**	0.8608	**1.6660**
	PCA [8]	2.37†	2.3819	0.8382	2.6398	7.7194	2.98†	48.9916	0.9603	0.9246	1.8706
	GFPCA [9]	1.17†	0.6478	0.9862	1.5370	2.0573	2.17†	61.9038	0.9391	1.1720	2.2480
	Hysure [14, 15]	117.06†	0.8683	0.9810	1.7741	2.6102	62.47†	38.8667	0.9590	1.0240	1.8667
3	PAP-ADMM [19]	2144.00	0.4308	0.9889	1.1622	1.6149	3368.00	66.2481	0.9531	0.7848	1.9783
	Super Resolution [18]	279.18	0.5232	0.9839	1.3215	1.9584	1329.59	86.7154	0.9263	0.9970	2.4110
	Bicubic [27]	**0.04**	0.5852	0.9807	1.3554	2.1560	**0.10**	92.2143	0.9118	1.0369	2.5728
Ours	HCM no deblur [17]	0.59	0.5812	0.9908	1.4223	1.7510	1.50	44.3475	0.9492	0.9906	2.0302
	HCM+Lucy [28]	1.02	0.6009	0.9879	1.3950	1.9308	1.50	37.2436	0.9518	0.9683	1.9720
	Our method	0.59†	0.4151	**0.9956**	**1.1442**	**1.2514**	1.50†	**30.1907**	0.9672	0.9008	1.7205

Table 2. Comparison of our methods with various pansharpening methods on AF and AVIRIS. †: These methods involve PAP-ADMM but we did not include PAP-ADMM's runtime in order to illustrate the differences.

3. Experimental Results

Comparison with Group 2 (AF image)



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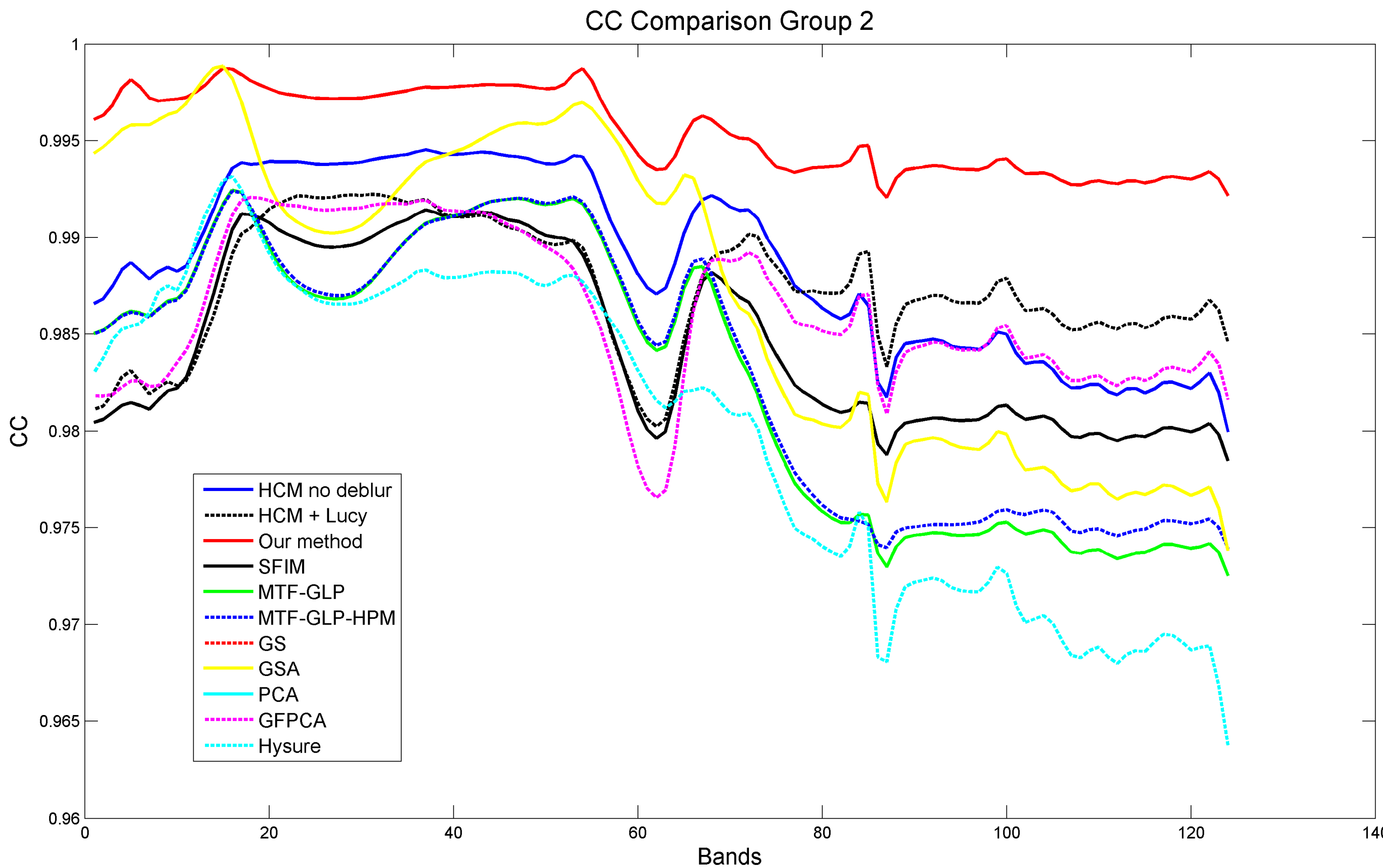
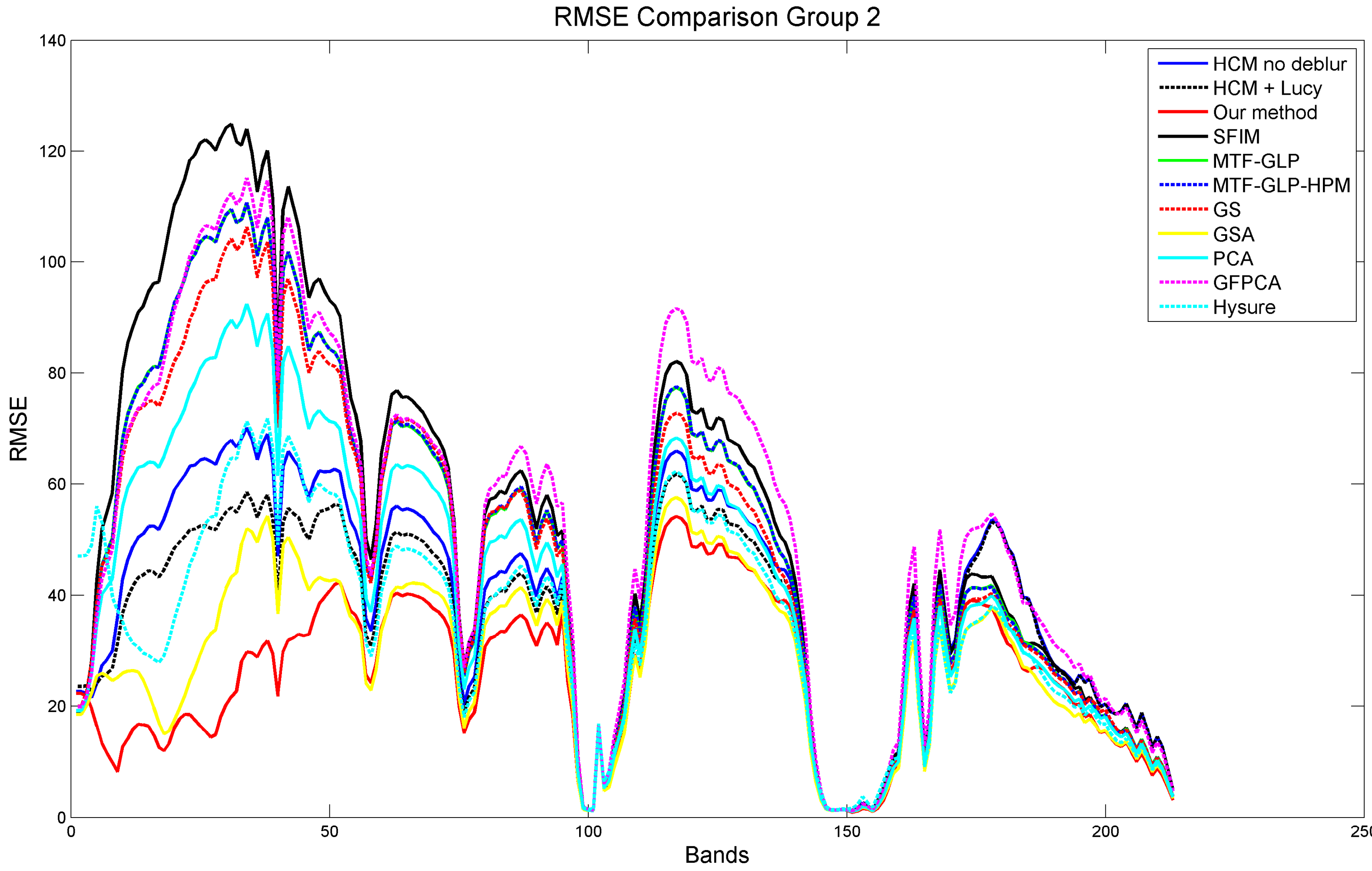
Comparison with Group 2 (AF image)



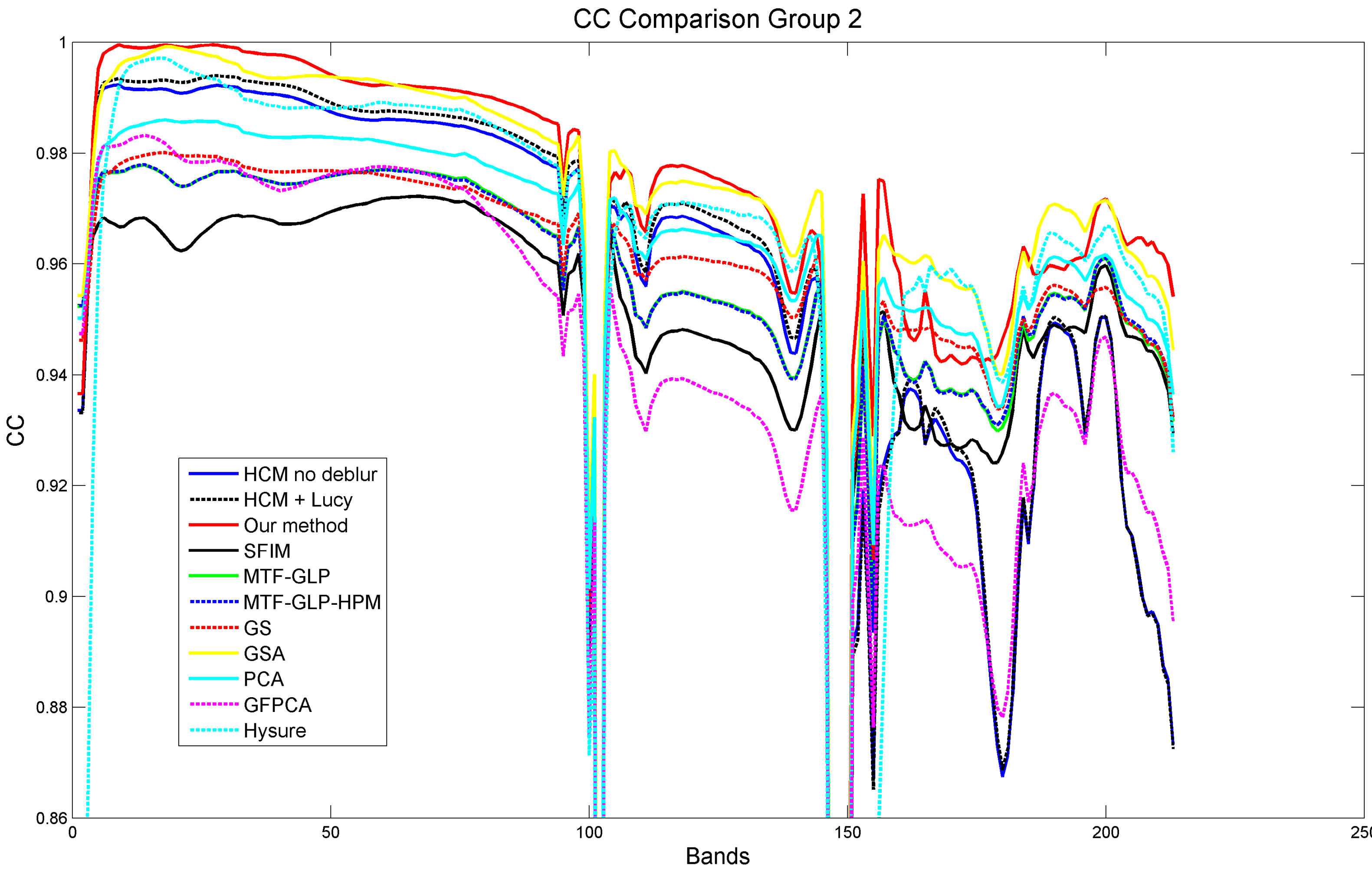
3. Experimental Results

Comparison with Group 2 (NASA AVIRIS image)



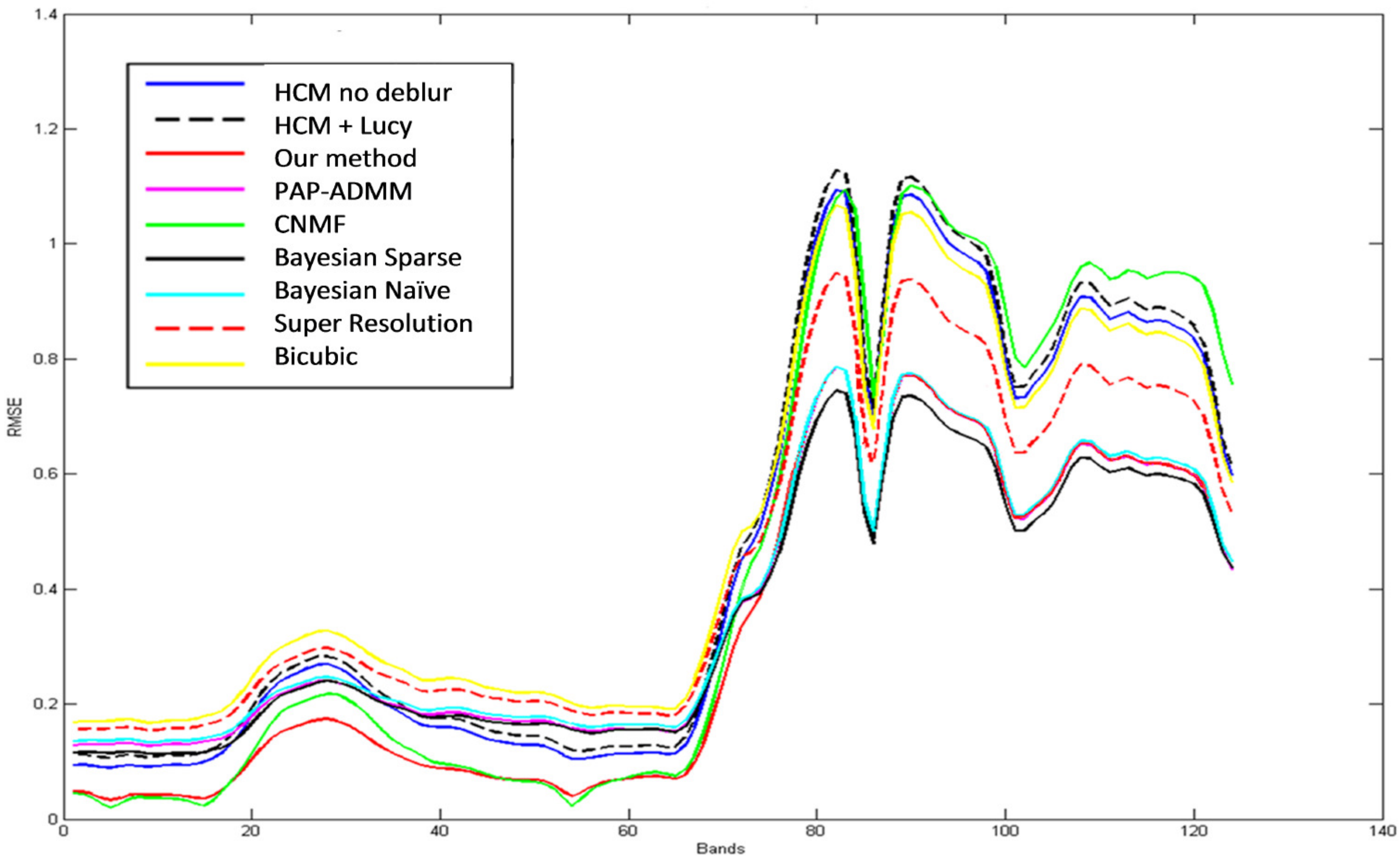
3. Experimental Results

Comparison with Group 2 (NASA AVIRIS image)



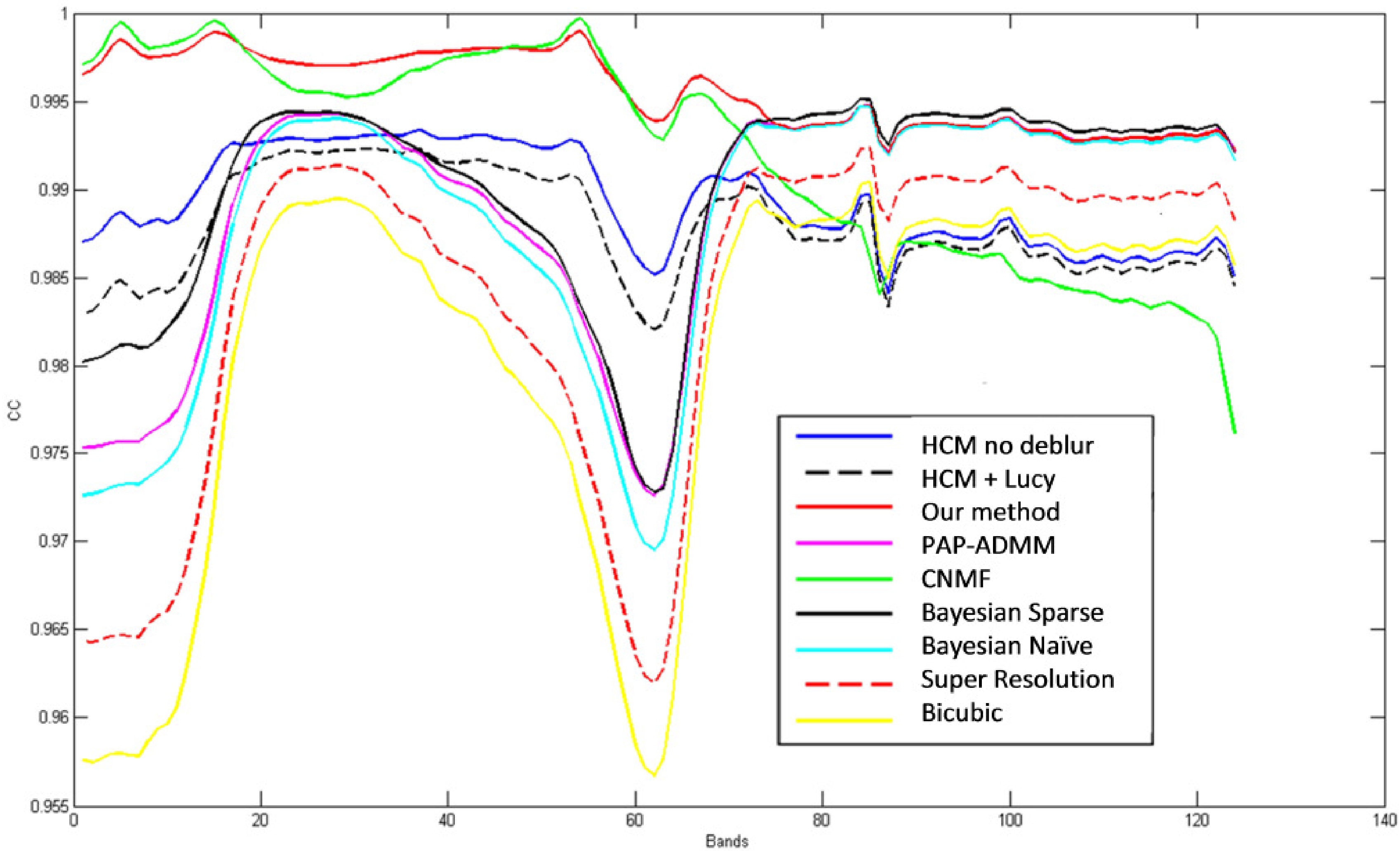
3. Experimental Results

Comparison with Groups 1 and 3 (AF image)



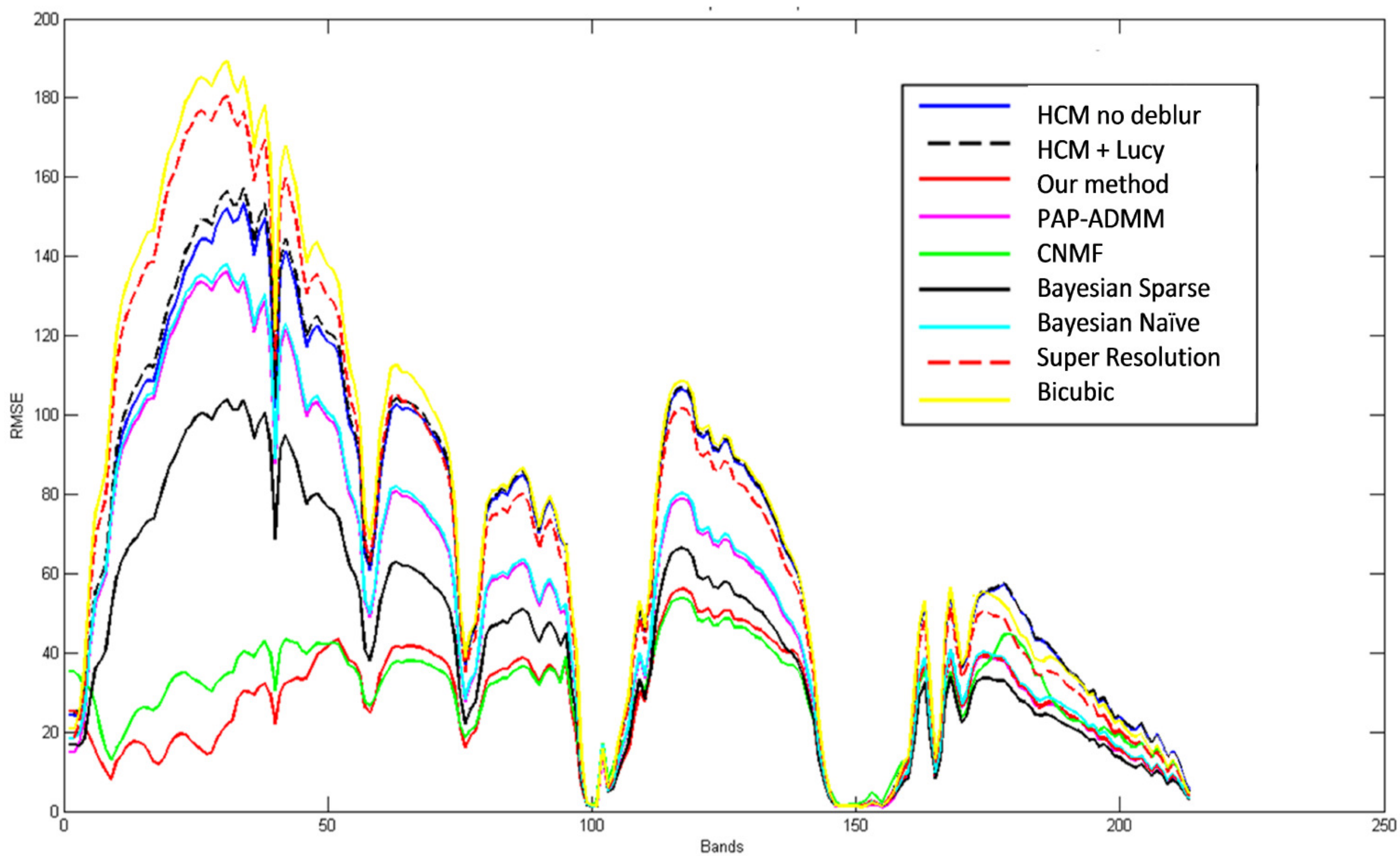
3. Experimental Results

Comparison with Groups 1 and 3 (AF image)



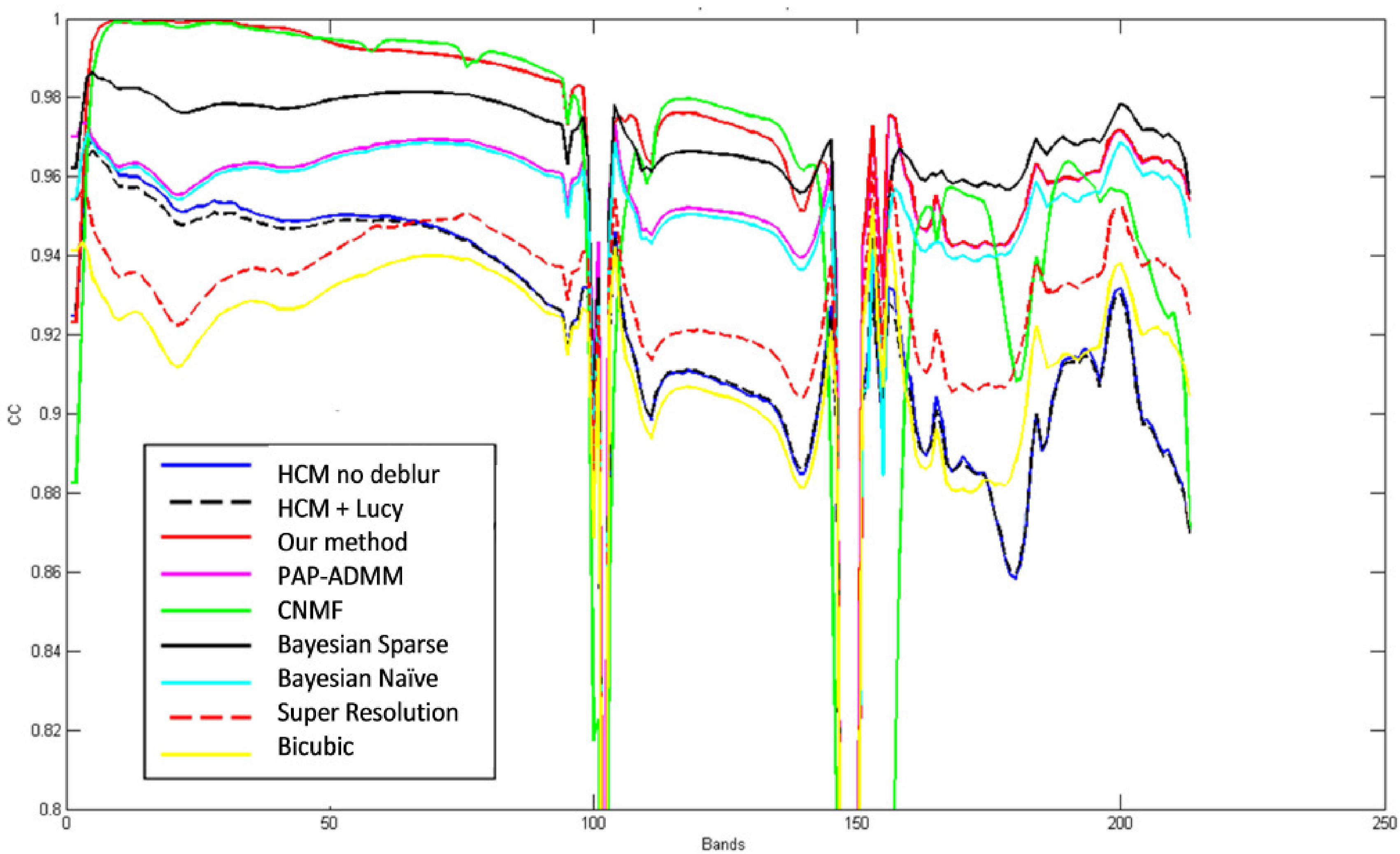
3. Experimental Results

Comparison with Groups 1 and 3 (NASA AVIRIS image)



3. Experimental Results

Comparison with Groups 1 and 3 (NASA AVIRIS image)



4. Conclusions and Future Research

- We presented a new fusion algorithm to enhance the resolution of hyperspectral images by combining high resolution color images with low resolution hyperspectral images.

- Our new algorithm is an integration of a hybrid color mapping algorithm and a single image super-resolution algorithm. While the concept of the new approach is simple, the performance is comparable to Group 1 methods and better than most of Group 2 methods.

- Future research direction will be focused on speeding up the algorithm, and investigating the performance gain in classification and other high-level vision tasks such as target detection.