Supplementary Material

Paper Title: **DARecNet-BS: Unsupervised Dual Attention Reconstruction Network for Hyperspectral Band Selection**

Authors: **Swalpa Kumar Roy, Sayantan Das, Tiecheng Song, and Bhabatosh Chanda**

Experiments on Indian Pines dataset :

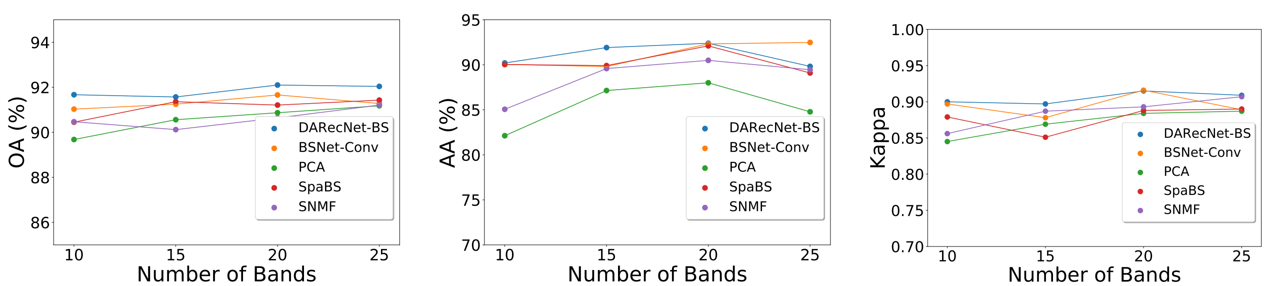
The Indian Pines (IP) dataset was gathered by AVIRIS (Airborne Visible/Infrared Imaging Spectrometer) sensor over the Indian Pines test site in North-western Indiana in 1992. The IP dataset has images with 145×145 spatial dimension and 200 spectral bands and the ground truth available is designated into 16 classes of vegetation.

Table I shows the selected bands of Indian Pines using different band selection methods. Fig. 1(a)-(c) show the classification performance in term of OA, AA, and Kappa using different band subset sizes. A counter-intuitive phenomenon, Hughes phenomenon, which means that the accuracy increases and then decreases for larger number of band subsets, is observed in the AA curve shown in Fig. 1(b).

Fig. 2(a)-(c) show the classification performance in term of OA, AA, and Kappa of the various methods with different training sizes. Fig. 3(a)-(b) show the MSD and Sum of Entropy on using different band selection methods. Fig. 4 shows the classification maps generated using different band selection methods, i.e., PCA, SpaBS, SNMF, BSNet-Conv and DARecNet-BS, respectively. The confusion matrix for IP dataset is shown in Fig. 13(a). The results of ablation study are shown in Table VI.

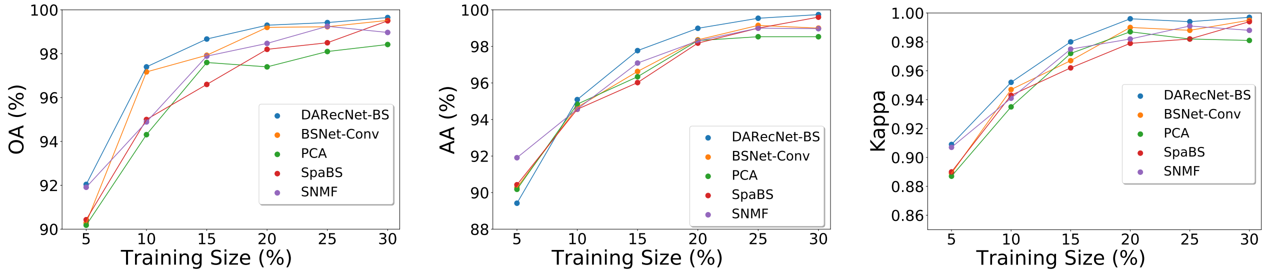
Table I: Selected bands using different band selection methods on IP dataset

Methods	Selected Bands
BS-Net-Conv	[46, 33, 140, 161, 80, 35, 178, 44, 126, 36, 138, 71, 180, 66, 192, 16, 53, 152, 185, 119, 24, 28, 26, 156, 83]
SpaBS	[7, 96, 52, 171, 53, 3, 76, 75, 74, 95, 77, 73, 78, 54, 81,94,88,91,71,72,79,80,55,92,56]
PCA	[167, 74, 168, 0, 147, 165, 161, 162, 152, 19, 160, 119, 164, 159, 157, 163, 158, 156, 20, 154, 118, 148, 153, 149, 155]
SNMF	[23, 197, 198, 94, 76, 2, 87, 105, 143, 145, 11, 84, 132, 108, 28, 104, 144, 34, 44, 74, 71, 96, 75, 171, 162]
DARecNet-BS	[154, 12, 112, 88, 133, 127, 158, 13, 113, 51, 152, 125, 30, 58, 126, 168, 95, 32, 75, 31, 82, 22, 142, 86, 123]



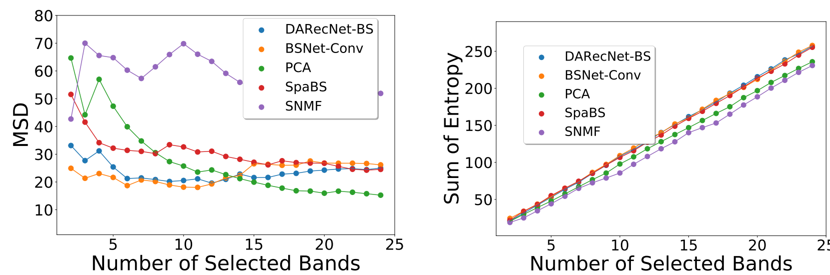
(a) (b) (c)

Figure 1: OA, AA and Kappa versus number of selected bands on IP dataset.



(a) (b) (c)

Figure 2: OA, AA and Kappa versus training sizes on IP dataset.



(a) (b)

Figure 3: MSD and sum of entropy versus selected bands on IP dataset.

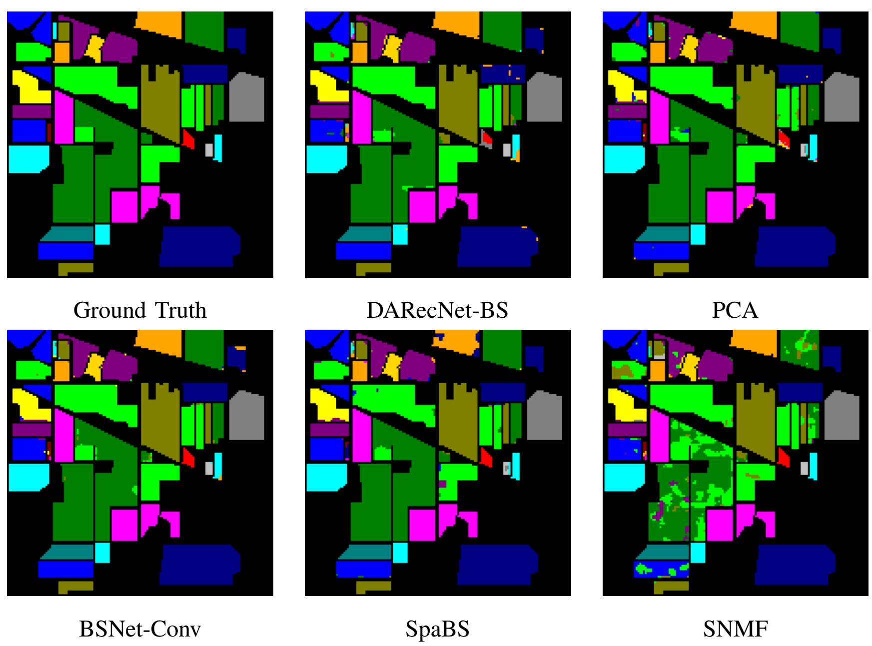


Figure 4: SSRN is used on selected band dataset of IP to generate classification maps.

Experiments on University of Pavia dataset:

The University of Pavia (UP) dataset was acquired by the ROSIS (Reflective Optics System Imaging Spectrometer) sensor during a flight campaign over Pavia, Northern Italy in 2001. The UP dataset consists of 610×340 spatial dimension pixels with 103 spectral bands and the ground truth is divided into 9 urban land-cover classes. Similar experiments like IP dataset were carried out on UP dataset.

Table II shows the selected bands of University of Pavia using different band selection methods. Table III shows the OA, AA, Kappa, and classwise accuracy of different methods using 15 bands using 5% of traning samples for UP dataset. 15 was found to be optimal for this through Virtual Dimensionality (VD) analysis with false alarm probability $p_f = 10^{-5}$. As observed, ours achieves superior performance in terms of OA, AA, and Kappa indices.

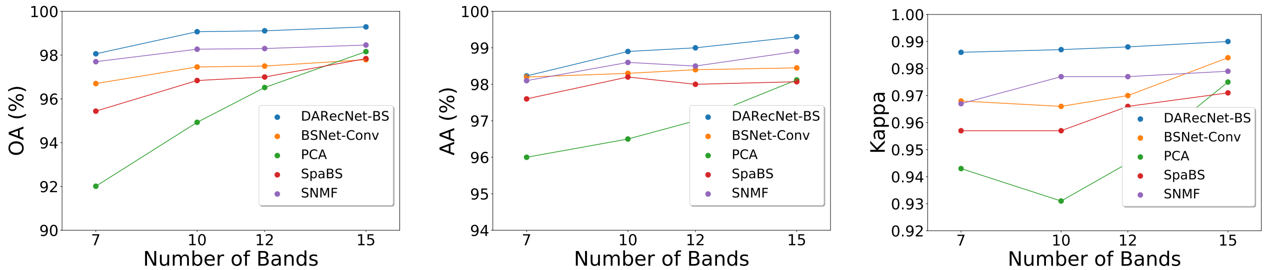
Fig. 5(a)-(c) show the classification performance of the different methods under different band subset sizes. Fig. 6(a)-(c) show the classification performance of the different methods under different training sizes. We keep 15 bands as constant in our experiments for the same reason of VD analysis. Fig. 7(a)-(b) show the MSD and Sum of Entropy using different band selection methods. The classification maps for University of Pavia using PCA, SpaBS, SNMF, BSNet-Conv and DARecNet, respectively are shown in Fig. 8. The confusion matrix and entropy for each bands are shown in Fig. 13(b) and Fig. 14(a), respectively. The results of ablation study are shown in Table VI.

Table II: Selected bands using different band selection methods on UP dataset

Methods	Selected Bands
BS-Net-Conv	[90, 42, 16, 48, 71, 3, 78, 38, 80, 53, 7, 31, 4, 99, 98]
SpaBS	[50, 48, 16, 22, 4, 102, 21, 25, 23, 47, 24, 20, 31, 26, 42]
PCA	[48, 22, 51, 16, 52, 21, 65, 17, 20, 53, 18, 54, 19, 55, 76]
SNMF	[92, 53, 43, 66, 22, 89, 82, 30, 51, 5, 83, 77, 80, 2, 48]
DARecNet-BS	[93, 14, 38, 50, 68, 95, 59, 5, 72, 6, 52, 60, 99, 25, 12]

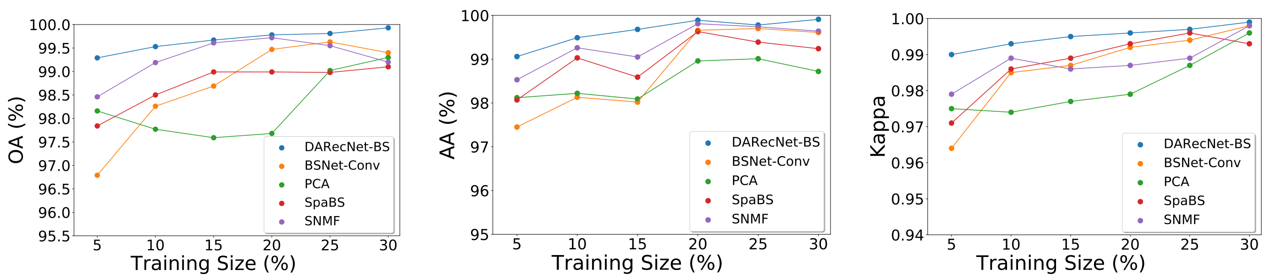
Table III: Classification performance using 15 bands on UP dataset with 5% training size.

No	SpaBS	PCA	SNMF	BSNet-Conv	DARecNet-BS
1	99.38 ± 0.27	99.56 ± 0.09	99.55 ± 0.28	99.13 ± 0.06	**99.61 ± 0.52**
2	98.80 ± 0.27	98.30 ± 0.82	99.31 ± 0.56	99.36 ± 0.05	**99.53 ± 0.56**
3	**99.28 ± 0.48**	90.44 ± 8.21	95.93 ± 3.27	84.36 ± 11.6	98.73 ± 0.45
4	99.97 ± 0.03	99.98 ± 0.01	99.72 ± 0.20	99.98 ± 0.01	**99.98 ± 0.02**
5	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	99.97 ± 0.03	**100.00 ± 0.00**
6	94.53 ± 0.00	98.87 ± 0.49	99.20 ± 0.36	98.84 ± 0.04	**99.86 ± 0.04**
7	**98.77 ± 4.27**	99.48 ± 0.66	94.88 ± 4.17	76.30 ± 28.8	96.96 ± 2.99
8	91.87 ± 0.58	96.42 ± 1.88	92.88 ± 5.92	92.16 ± 3.92	**97.04 ± 0.30**
9	**100.00 ± 0.00**	100.00 ± 0.00	99.92 ± 0.11	99.96 ± 0.05	99.84 ± 0.22
OA(%)	97.84 ± 0.78	98.16 ± 0.47	98.46 ± 0.90	97.48 ± 1.21	**99.29 ± 0.32**
AA(%)	98.07 ± 0.77	98.12 ± 0.76	97.93 ± 0.91	98.75 ± 0.64	**99.06 ± 0.25**
Kappa	0.971 ± 0.01	0.975 ± 0.01	0.979 ± 0.01	0.972 ± 0.01	**0.990 ± 0.00**



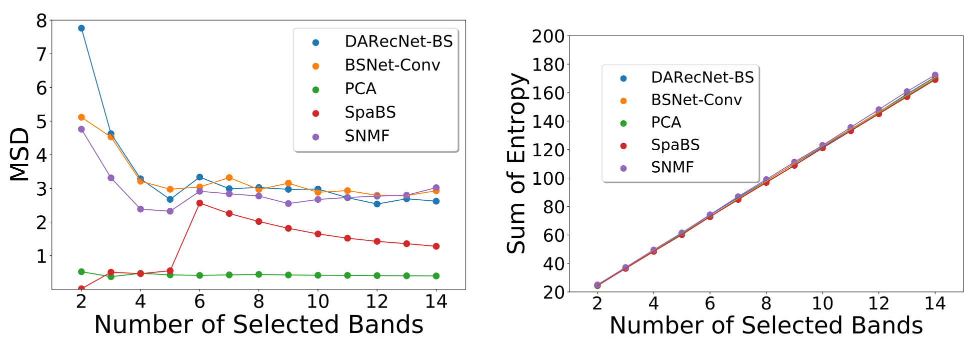
(a) (b) (c)

Figure 5: OA, AA and Kappa versus number of bands on UP dataset.



(a) (b) (c)

Figure 6: OA, AA and Kappa versus training size on UP dataset.



(a) (b)

Figure 7: MSD and sum of entropy versus selected bands on UP dataset

Experiments on Salinas dataset:

The Salinas (SA) scene dataset was collected by the 224-band AVIRIS sensor over Salinas Valley, California in 1998. The SA dataset contains the images with 512×217 spatial dimension and 224 spectral bands, which also contains in total 16 classes. The experimental set up for Salinas dataset was exactly the same as that used for UP dataset.

Table IV shows the selected bands of Salinas by different band selection methods. Table V shows the classification performance at 5% training size for different methods of band selection using the

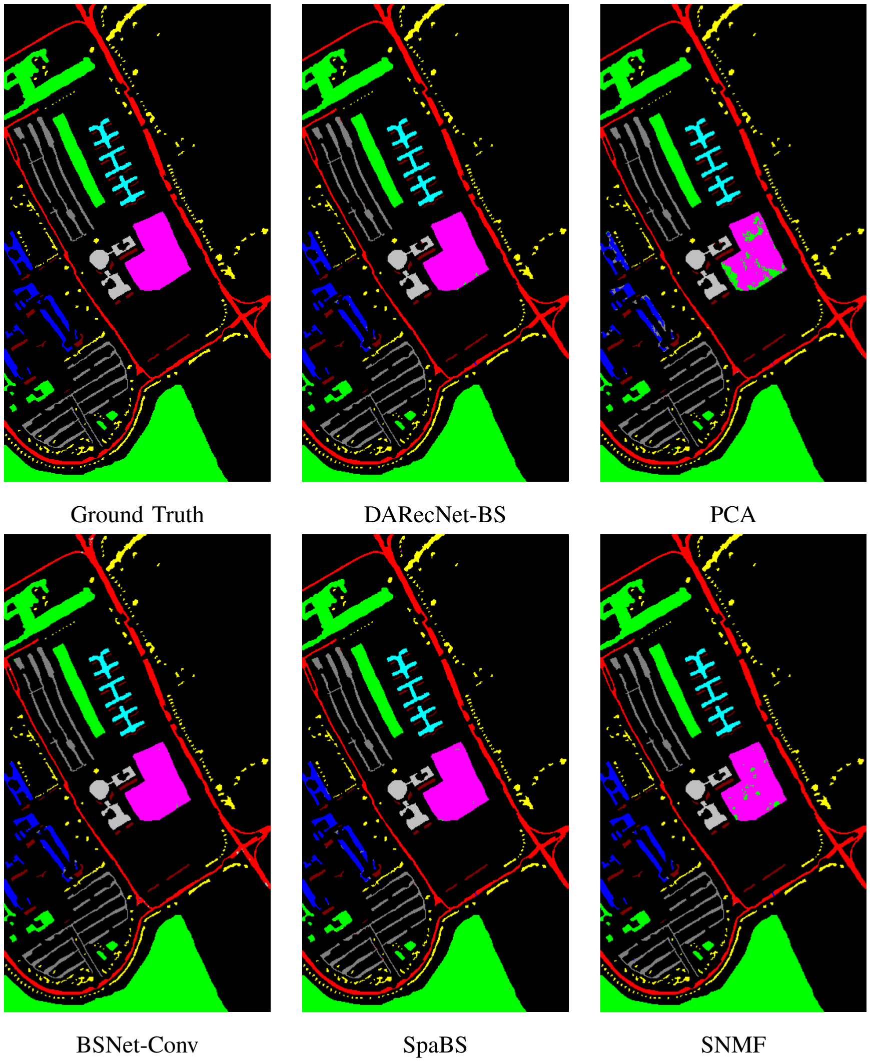


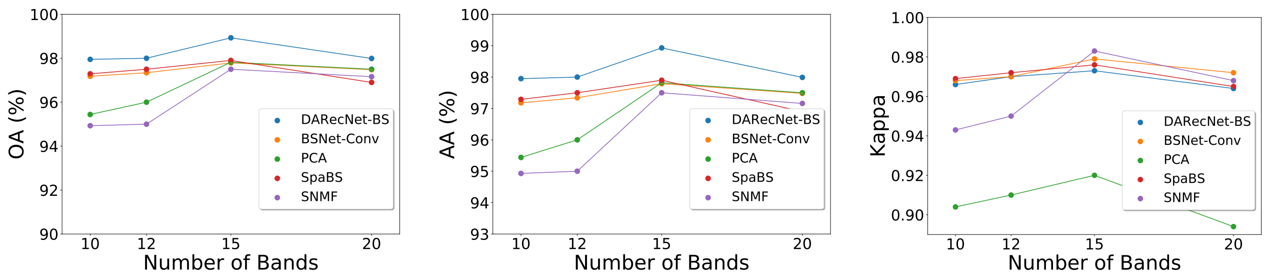
Figure 8: SSRN is used on selected band dataset of UP to generate classification maps.

Table IV: Selected bands using different band selection methods on SA dataset.

Methods	Selected Bands
BS-Net-Conv	[116, 153, 19, 189, 97, 179, 171, 141, 95, 144, 142, 46, 104, 203, 91, 18, 176, 108, 150, 194]
SpaBS	[0, 79, 166, 80, 203, 78, 77, 76, 55, 81, 97, 5, 23, 75, 2, 82, 56, 74, 143, 85]
PCA	[169, 67, 168, 63, 68, 78, 167, 166, 165, 69, 164, 163, 77, 162, 70, 62, 160, 161, 76, 158]
SNMF	[24, 1, 105, 196, 203, 0, 39, 116, 38, 60, 89, 104, 198, 147, 158, 3, 146, 4, 93, 88]
DARecNet-BS	[24, 42, 63, 77, 57, 49, 35, 68, 64, 69, 50, 44, 43, 15, 90, 37, 48, 72, 54, 79]

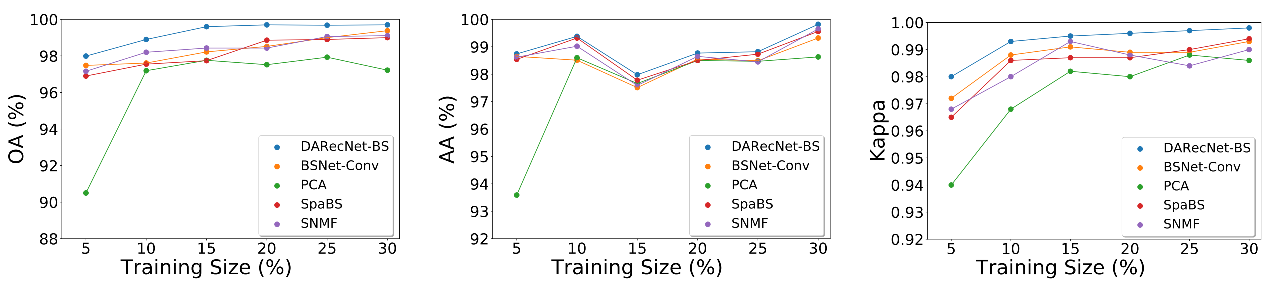
Table V: Classification performance using 20 bands on SA dataset with 5% training size.

No	SpaBS	PCA	SNMF	BSNet-Conv	DARecNet-BS
1	99.96 ± 0.05	99.96 ± 0.05	99.58 ± 0.44	99.36 ± 0.30	**100.00** ± **0.00**
2	99.67 ± 0.21	99.67 ± 0.21	99.95 ± 0.037	98.97 ± 1.32	**99.97** ± **0.04**
3	96.31 ± 2.29	96.31 ± 2.29	98.47 ± 0.18	98.18 ± 1.33	**98.40** ± **3.50**
4	98.63 ± 1.93	98.63 ± 1.93	99.34 ± 0.70	**99.68** ± **0.33**	99.29 ± 0.06
5	99.43 ± 0.37	99.43 ± 0.38	99.45 ± 0.68	**100.00** ± **0.00**	99.68 ± 0.41
6	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	99.99 ± 0.01	**100.00** ± **0.00**
7	99.97 ± 0.03	99.97 ± 0.03	100.00 ± 0.00	100.00 ± 0.00	**100.00** ± **0.00**
8	90.96 ± 4.20	90.96 ± 4.20	98.14 ± 1.18	94.74 ± 0.68	**98.35** ± **3.80**
9	99.88 ± 0.09	99.88 ± 0.09	99.98 ± 0.02	99.89 ± 0.09	**99.91** ± **0.72**
10	99.08 ± 0.36	99.08 ± 0.36	96.87 ± 3.85	98.43 ± 1.27	**99.92** ± **0.44**
11	99.34 ± 0.31	99.34 ± 0.31	99.89 ± 0.14	**99.82** ± **0.24**	78.47 ± 17.04
12	**99.90** ± **0.03**	99.90 ± 0.02	99.73 ± 0.11	99.88 ± 0.08	97.48 ± 2.82
13	99.79 ± 0.29	99.79 ± 0.28	99.95 ± 0.05	99.47 ± 0.73	98.08 ± 1.52
14	99.23 ± 0.38	99.23 ± 0.38	99.72 ± 0.17	99.55 ± 0.63	**100.00** ± **0.00**
15	94.57 ± 3.08	94.57 ± 3.08	87.14 ± 8.59	92.09 ± 6.15	**95.29** ± **13.72**
16	99.89 ± 0.07	99.89 ± 0.07	99.69 ± 0.42	99.95 ± 0.02	99.68 ± 0.44
OA(%)	96.90 ± 0.70	90.50 ± 1.07	97.16 ± 1.31	97.48 ± 1.21	**97.99** ± **1.96**
AA(%)	98.54 ± 0.30	93.59 ± 1.19	98.62 ± 0.48	98.65 ± 0.64	**98.74** ± **0.46**
Kappa	0.965 ± 0.00	0.894 ± 0.01	0.968 ± 0.01	0.972 ± 0.01	**0.981** ± **0.52**



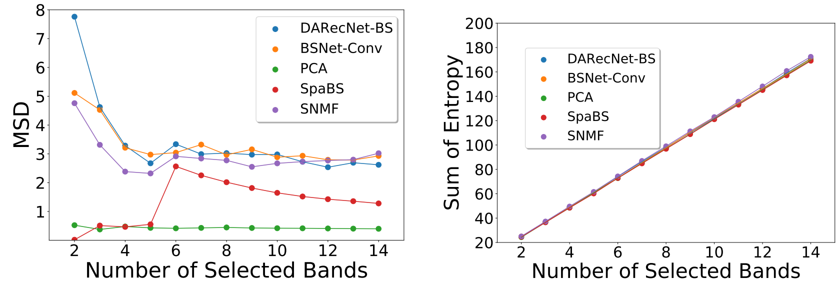
(a) (b) (c)

Figure 9: OA, AA and Kappa versus number of bands on SA dataset.



(a) (b) (c)

Figure 10: OA, AA and Kappa versus training size on SA dataset.



(a) (b)

Figure 11: MSD and sum of entropy versus selected bands on SA dataset.

Table VI: Performance comparison between the modules with PAM, CAM and No attention.

No.	IP			UP			SA		
	PAM	CAM	No Attention	PAM	CAM	No Attention	PAM	CAM	No Attention
1	90.22 ± 1.09	85.00 ± 1.94	82.73 ± 24.42	99.36 ± 0.40	99.67 ± 0.28	99.16 ± 0.53	99.76 ± 0.05	99.92 ± 0.10	99.94 ± 0.07
2	92.28 ± 4.23	86.54 ± 10.4	86.42 ± 10.13	99.24 ± 0.48	99.53 ± 0.23	99.81 ± 0.19	99.99 ± 0.01	100.00 ± 0.00	87.03 ± 18.2
3	91.19 ± 1.91	92.63 ± 3.70	92.78 ± 3.15	98.34 ± 1.28	98.69 ± 0.73	99.04 ± 1.02	99.86 ± 0.10	99.44 ± 0.31	98.39 ± 1.13
4	92.91 ± 6.24	86.17 ± 2.93	90.54 ± 1.66	99.98 ± 0.01	99.90 ± 0.06	99.97 ± 0.03	99.60 ± 0.45	99.29 ± 0.82	90.59 ± 12.2
5	92.82 ± 3.76	90.17 ± 0.30	92.51 ± 0.52	99.88 ± 0.10	100.00 ± 0.00	100.00 ± 0.00	92.61 ± 6.08	99.75 ± 0.22	99.58 ± 0.38
6	90.12 ± 1.05	90.50 ± 0.50	92.59 ± 0.40	98.94 ± 0.62	97.49 ± 1.15	97.26 ± 3.55	99.96 ± 0.03	99.99 ± 0.01	99.96 ± 0.05
7	82.88 ± 15.71	90.48 ± 2.14	83.41 ± 14.57	96.61 ± 2.36	94.96 ± 5.20	96.08 ± 3.78	100.00 ± 0.00	99.93 ± 0.08	99.94 ± 0.03
8	91.12 ± 2.76	90.80 ± 1.68	95.30 ± 2.39	94.84 ± 2.85	95.86 ± 1.57	95.23 ± 3.18	90.36 ± 10.40	94.13 ± 0.90	98.89 ± 1.22
9	91.03 ± 2.77	91.02 ± 8.86	91.73 ± 7.44	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	99.66 ± 0.36	99.88 ± 0.14	99.63 ± 0.42
10	82.10 ± 10.4	87.45 ± 7.93	94.08 ± 2.10				99.79 ± 0.12	99.31 ± 0.30	98.93 ± 0.79
11	91.09 ± 1.75	92.06 ± 1.55	91.60 ± 1.11				98.38 ± 1.60	99.14 ± 0.39	97.50 ± 1.50
12	92.76 ± 0.48	92.49 ± 0.82	90.05 ± 2.80				99.61 ± 0.17	99.90 ± 0.13	98.96 ± 1.10
13	92.82 ± 0.25	100.00 ± 0.00	92.94 ± 1.49				99.75 ± 0.33	99.28 ± 1.01	99.47 ± 0.44
14	91.96 ± 0.98	95.21 ± 2.23	92.49 ± 2.23				99.61 ± 0.13	99.58 ± 0.58	99.27 ± 0.44
15	93.01 ± 0.70	90.15 ± 7.22	91.89 ± 3.53				94.53 ± 4.73	92.62 ± 6.48	71.94 ± 19.9
16	90.62 ± 1.94	100.00 ± 0.00	92.85 ± 3.10				99.95 ± 0.05	99.89 ± 0.10	99.69 ± 0.27
OA(%)	**91.66 ± 2.64**	91.08 ± 2.4	90.15 ± 3.08	98.78 ± 0.59	98.82 ± 0.28	**98.82 ± 0.38**	96.12 ± 2.79	**97.54 ± 0.84**	90.55 ± 8.91
AA(%)	**90.50 ± 1.66**	90.45 ± 1.79	89.49 ± 2.57	**98.58 ± 0.64**	98.45 ± 0.61	98.50 ± 0.07	98.34 ± 0.88	**98.88 ± 0.36**	96.23 ± 2.34
Kappa	**0.909 ± 0.10**	0.909 ± 0.00	0.913 ± 0.00	0.983 ± 0.00	0.984 ± 0.00	**0.984 ± 0.00**	0.956 ± 0.03	**0.972 ± 0.00**	0.895 ± 0.09

subset size 20. 20 was found to be optimal for this through Virtual Dimensionality Analysis (DV) with false alarm probability $p_f = 10^{-5}$. As observed, ours achieves superior performance in terms of OA, AA, and Kappa indices.

Fig. 9(a)-(c) show the classification performance of the different methods under different band subset sizes. Fig. 10(a)-(c) show the classification performance of the different methods under different training sizes. We keep 15 bands as constant in our experiments for the same reason of Virtual Dimensionality (VD) analysis. The MSD and Sum of Entropy using different band selection methods have been shown in Fig. 11. The classification maps generated using different band selection methods are shown in Fig. 12. The confusion matrix and entropy for each bands are shown in Fig. 13(c) and Fig. 14(b), respectively. The results of ablation study are shown in Table VI.

Experiments on University of Houston dataset:

The University of Houston (UH) is known to be complex scenes collected through compact airborne spectrographic imager (CASI) over the Houston university campus in June 2013. The dataset contains 15 urban land-cover classes. The spatial dimensions are 349×1905 with 144 spectral bands and

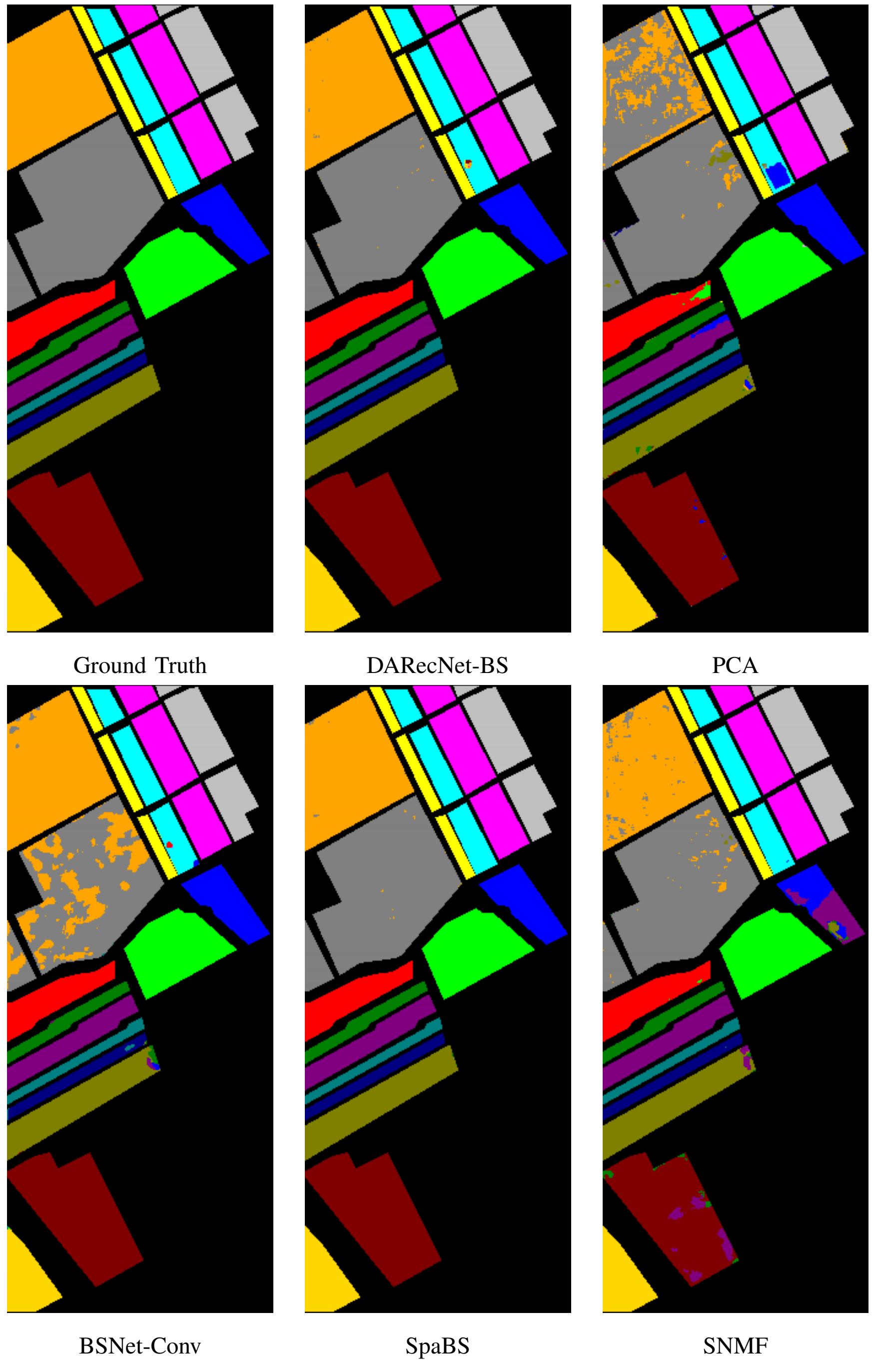
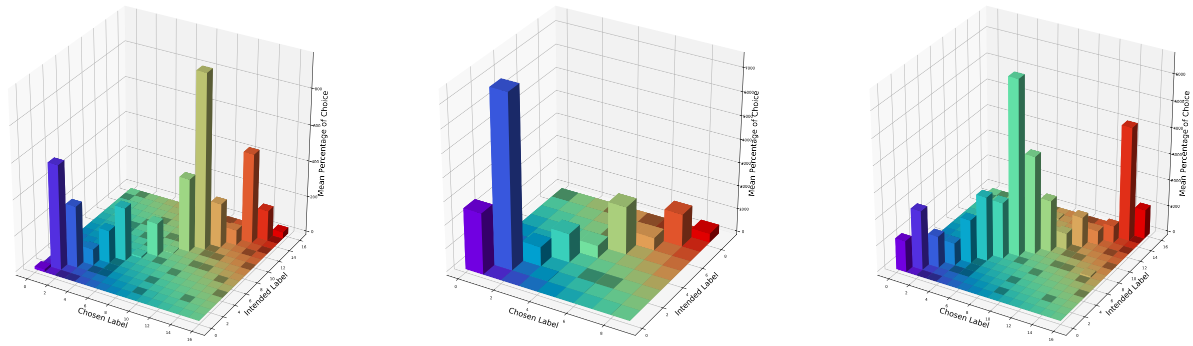


Figure 12: SSRN is used on selected band dataset of SA to generate classification maps.

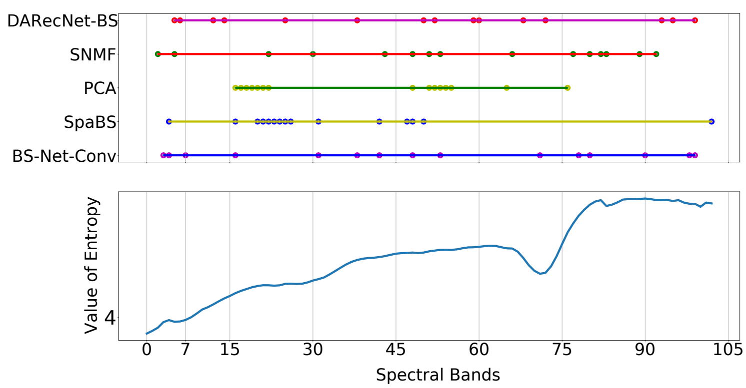
wavelength ranging from 380 to 1050 nm.

Table VII shows the results where three performance measure indices, i.e., OA, AA, and Kappa along with class-wise accuracies are computed under subset of 25 bands with limited training samples of 5%. One can see that the proposed `DARecNet-BS` achieves better results than BSNet-Conv in terms of OA, AA and Kappa on the UH dataset.

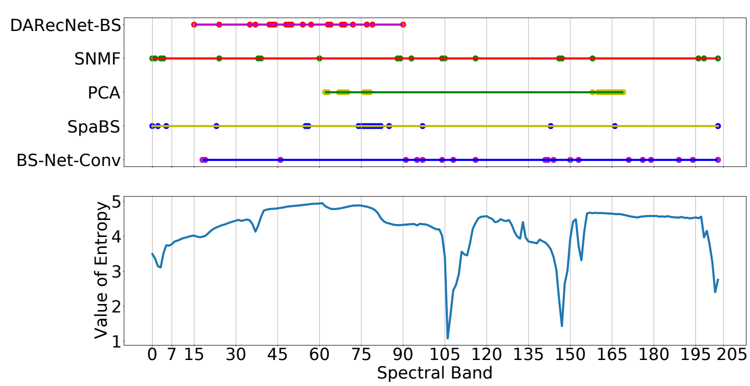


(a) (b) (c)

Figure 13: The confusion matrix for (a) IP (b) UP and (c) SA datasets, respectively.



(a)



(b)

Figure 14: Top 15 selected bands and entropy values for each band: (a) UP, (b) SA.

Table VII: Classification performance using 25 bands on UH dataset with 5% training size.

No	BSNet-Conv	DARecNet-BS
1	95.89 ± 4.3	97.62 ± 0.94
2	93.92 ± 6.9	99.51 ± 0.37
3	100.00 ± 0.0	68.98 ± 22.3
4	95.67 ± 5.9	99.65 ± 0.31
5	98.31 ± 0.4	98.51 ± 0.96
6	31.96 ± 7.2	25.03 ± 12.9
7	59.39 ± 4.9	93.49 ± 2.85
8	88.02 ± 2.6	65.77 ± 5.82
9	88.77 ± 8.9	89.96 ± 0.60
10	76.38 ± 3.5	84.77 ± 2.25
11	69.69 ± 13.0	75.43 ± 10.0
12	68.49 ± 9.9	90.34 ± 0.94
13	95.78 ± 2.2	83.00 ± 14.9
14	83.47 ± 6.1	97.57 ± 3.43
15	99.72 ± 0.2	96.02 ± 0.75
OA(%)	80.81 ± 3.02	**83.69** ± **1.11**
AA(%)	83.03 ± 1.48	**84.38** ± **0.68**
Kappa	0.790 ± 0.03	**0.818** ± **0.00**

Network parameters for Indian Pines dataset:

The layerwise detailed network parameters for Indian Pines dataset are shown in Fig. 15.

Layer (type)	Output Shape	Param #
Conv2d-1	[-1, 25, 7, 7]	5,025
Conv2d-2	[-1, 25, 7, 7]	5,025
Softmax-3	[-1, 49, 49]	0
Conv2d-4	[-1, 200, 7, 7]	40,200
PAM_Module-5	[-1, 200, 7, 7]	0
Softmax-6	[-1, 200, 200]	0
CAM_Module-7	[-1, 200, 7, 7]	0
Conv3d-8	[-1, 128, 200, 5, 5]	1,280
BatchNorm3d-9	[-1, 128, 200, 5, 5]	256
PReLU-10	[-1, 128, 200, 5, 5]	1
Conv3d-11	[-1, 64, 200, 3, 3]	73,792
BatchNorm3d-12	[-1, 64, 200, 3, 3]	128
PReLU-13	[-1, 64, 200, 3, 3]	1
MaxPool3d-14	[-1, 64, 200, 3, 3]	0
ConvTranspose3d-15	[-1, 128, 200, 5, 5]	73,856
BatchNorm3d-16	[-1, 128, 200, 5, 5]	256
PReLU-17	[-1, 128, 200, 5, 5]	1
ConvTranspose3d-18	[-1, 1, 200, 7, 7]	1,153
BatchNorm3d-19	[-1, 1, 200, 7, 7]	2
RecNet-20	[-1, 200, 7, 7]	0

```
Total params: 200,976
Trainable params: 200,976
Non-trainable params: 0
----------------------------------------------------------------
Input size (MB): 0.04
Forward/backward pass size (MB): 33.60
Params size (MB): 0.77
Estimated Total Size (MB): 34.41
----------------------------------------------------------------
```

Figure 15: Layerwise network parameters of the `DARecNet-BS` architecture for Indian Pines dataset