(NASA-CR-157393) EVALUATION OF WAVELENGTH GROUPS FOR DISCRIMINATION OF AGRICULTURAL COVER TYPES (Instituto de Pesquisas Espaciais, Sao Jose) 13 p HC A03/MF A01 CSCL 02C G3/43

N78-29536

Unclas

27955

CONSELHO NACIONAL DE DESENVOLVIMENTO CIENTÍFICO E TECNOLÓGICO

INSTITUTO DE PESQUISAS ESPACIAIS

1.Classification *INPE-COM.10/PE*
C.D.U.: 621.38SR: 681.3.05

2.Period

4.Distribution Criterion

internal [ ]

external [X]

3.Key Words (selected by the author)

WAVELENGTHS
AUTOMATIC PATTERN RECOGNITION
REMOTE SENSING

5.Report Nº

INPE-1210-PE/120

6.Date

April, 1978

7.Revised by

C.R. Souza
Celso de Renna e Souza

8. Title and Sub-title

EVALUATION OF WAVELENGTH GROUPS FOR DISCRIMINATION OF AGRICULTURAL COVER TYPES

9.Authorized by

Parada
Nelson de Jesus Parada
Diretor

10.Sector *DSE/DIN* Code

11.Nº of Copies *16*

12.Authorship *Ravindra Kumar*

14.Nº of Pages *11*

15.Price

13.Signature of the responsible Ravindra Kumar

16.Summary/Notes

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17.Remarks *Submitted to Proceedings of the Twelfth International Symposium on Remote Sensing of Environment.*

EVALUATION OF WAVELENGTH GROUPS FOR DISCRIMINATION OF AGRICULTURAL COVER TYPES

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ABSTRACT

Multispectral scanner data in twelve spectral channels, in the wavelength range 0.46 to 11.7 μm, acquired in July 1971 for three flightlines, were analysed by applying automatic pattern recognition techniques. These twelve spectral channels were divided into four wavelength groups (W1, W2, W3 and W4), each consisting of three wavelength groups -- with respect to their estimated probability of correct classification (P_c) -- in discriminating agricultural cover types The same analysis was also done for the data acquired in August, to investigate the effect of time on these results. The effect of deletion of each of the wavelength groups on P_c, in the subsets of one to nine channels, is given. Values of P_c for all possible combinations of wavelength groups, in the subsets of one to eleven channels are also given.

1. INTRODUCTION

Multispectral scanner (MSS) data were analysed in subsets of one to twelve spectral channels, in the wavelength range 0.46 to 11.7 μm, for selected flightlines of the 1971 Corn Blight Watch Experiment[1]. These twelve spectral channels were divided into four wavelength groups (W1, W2, W3 and W4), each consisting of three spectral channels (Table I). The purpose of this study was to determine the statistical separability of multispectral measurements from agricultural cover types for evaluation of these wavelength groups. The agricultural cover types selected were: corn, soybeans, green forage (hay & pasture), and forest. In particular, the objectives of the study were: (1) To study the effect of deletion of all possible combinations of the four wavelength groups -- W1, W2, W3 and W4, on the statistical separability and corresponding estimated probability of correct classification (P_c) of the agricultural cover types. (2) To develop a criterion for evaluation of a combination of wavelength groups, based on the estimation of the probability of correct classification obtained by using this combination of wavelength groups in discrimination of agricultural cover types. (3) To investigate the effect of time on these results.

The literature review of the statistical separability of agricultural cover types was done by Kumar and Silva (1977)[2]. In addition, they analysed the multispectral scanner data in wavelength range 0.46 to 11.7 μm for three flightlines. They found that in the subsets of one to six spectral channels, the combination of wavelength regions (where V, N, M and T denote the visible, near infrared, middle infrared and thermal infrared wavelength regions, respectively): V, VM, VNM, VNMT, VVNMT, VVNMMT, respectively, were found to be the best choices for getting good overall statistical separability of the agricultural cover types for the data acquired on July 16 as well as August 12.

An effort was made to explain these results on the basis of spectral properties of agricultural cover types. The overall statistical separability of the agricultural cover types was found to be greater for the data of August 12 than the data of July 16. Kumar[3] (1977) did a further analysis of similar nature, to evaluate explicitly each spectral channel, each wavelength region and all possible combinations of wavelength regions for statistical separability, in terms of estimated probability of correct classification for agricultural cover types. Deletion of the channel 7 (0.61 to 0.70 µm) reduced P_c by about two percent. The deletion of each of the other channels caused no reduction, or less reduction, in the values of P_c, as compared to this channel. The deletion of the spectral channels constituting the visible wavelength region caused more reduction in P_c, as compared to the spectral channels constituting any of the other wavelength regions. The deletion of the spectral channels of near infrared wavelength region caused relatively small changes in the values of P_c. In the subsets of one to six spectral channels, the combination of wavelength regions V, VM, VMT, VNMT, VVNMT, VVNMMT; and T, NT, VNT or VMT, VNMT, VVNMT or VNMMT, VVNMMT were found to be the best choices for the data of middle of July and middle of August respectively.

Since the spectral channels were divided into four wavelength regions, the results obtained could be interpreted on a physical basis; on the other hand, each wavelength region (V, N, M, T) is not represented equally, in the sense that each wavelength region does not have the same number of spectral channels. The author does not have data of a multispectral scanner where each wavelength region has equal number of channels. However, the author felt a definate need for doing an analysis of similar nature by dividing the available twelve spectral channels (Table I) into four wavelength groups -- W1, W2, W3 and W4, each wavelength group consisting of three channels, so that each wavelength group is equally represented in the sense that it has an equal number of channels. In addition, this analysis is more complete in the following aspects: (1) The effect of deletion of all possible combinations of the four wavelength groups on the estimated value of P_c is given. (2) In addition to the average values of P_c, maximum as well as minimum values of P_c for all possible combinations of wavelength groups in the subsets of one to twelve spectral channels are give .

2. METHOD OF ANALYSIS

Multispectral scanner data in twelve spectral channels in the wavelength range 0.46 to 11. µm, collected with an optical-mechanical scanner at altitudes of 914 to 2133 meters (3000 to 7000 feet) over Western Indiana were analysed by applying automatic pattern recognition techniques. The wavelength bands of these twelve spectral channels are given in Table I. The data of three selected flightlines, acquired in July of 1971, were analysed. Each of these three flightlines had fair or good amount of each of the four agricultural cover types: corn, soybeans, green forage and forest. These three flightlines were selected carefully so that these combined could be considered to be representative of the four agricultural cover types in the Western Indiana.

Black and white photography and gray scale printouts of the spectral channels of the flightlines were used to aid in locating the boundaries of the fields on the Digital Display. Sufficient number of fields of each agricultural cover type were selected carefully so that they could be assumed to be representative of the flightline.

Using the same three flightlines and twelve spectral channels, an identical analysis was performed on the data acquired in August of 1971, to study the effect of time on the statistical separability of agricultural cover types. The multispectral scanner data was acquired on both dates (July and August) between 10.30 a.m. and noon time (local solar time). In addition, these data were of good quality and free from problems like lack of sufficient ground observations, excessive cloud cover, etc. The analysis was done for the data acquired in July and August, because corn and soybeans have reached their maximum vegetative growth by these times, and one month of time is sufficient for significant changes to occur in the spectral properties of agricultural cover types. The author wanted to avoid the analysis of data from late

September afterwards, because soybeans are harvested in September-October. The author tried to keep all the variables other than time uniform in the two (July and August) sets of data as far as possible. For example, an effort was made to select about the same field boundaries for the two sets of data. A total of more than 550 fields taken from three flightlines were analysed.

Each field was treated as an independent unit and the fields of the same agricultural cover type were put in the same class. The statistics algorithm was used to compute the mean vector and covariance matrix (mean and standard deviation) of the classes. Histograms of the agricultural classes defined above were used to check unimodality of the statistical distributions in individual channels. The classes were redefined to eliminate distinct multiple modes. Divergence is defined for any two density functions. In the case of normal variables with unequal covariance matrices, divergence in n spectral channels $C_1, C_2, \ldots, C_n$ is given in terms of mean vectors and covariance matrices of the classes[4,5].

A modified form of the divergence D_T, referred to as "transformed divergence", has a behavior[4,6] more like the probability of correct classification than the divergence, D.

$$D_T = 2\{1 - \exp(-D/8)\} \quad (1)$$

Transformed divergence has been used throughout this study.

Although divergence only provides a measure of the distance between two class densities, its use has been extended to the multiclass case by taking the average over all pairs[7]. Let D_{Tij} denote the divergence between classes i and j of a certain flightline, then the average divergence over all class pairs of four classes (each agricultural cover was treated as a separate class) is given by

$$D_{TAVG} = \frac{1}{6}\left[D_{T12} + D_{T13} + D_{T14} + D_{T23} + D_{T24} + D_{T34}\right] \quad (2)$$

$$\text{Let } D_{TMIN} = \text{minimum of } \left\{D_{T12}, D_{T13}, D_{T14}, D_{T23}, D_{T24}, D_{T34}\right\} \quad (3)$$

Let superscripts 1 and 2 with the symbol "D_T" denote the values of transformed divergence for the data acquired in middle of July and middle of August respectively. Let D^1_{TMIN1}, D^1_{TMIN2}, and D^1_{TMIN3} be the values of D_{TMIN} (see eq. (3)) in first, second and third flightline, respectively, for the data acquired in middle of July.

$$\text{Let } \bar{D}^i_{TAVG} = \frac{1}{3}\left[D^i_{TAVG1} + D^i_{TAVG2} + D^i_{TAVG3}\right], \quad i = 1, 2 \quad (4)$$

$$\text{Let } \bar{D}^i_{TMIN} = \text{minimum of } \left[D^i_{TMIN1}, D^i_{TMIN2}, D^i_{TMIN3}\right], \quad i = 1, 2 \quad (5)$$

Assuming each agricultural class has a multivariate gaussian distribution, the feature selection processor was used to find $\bar{D}^i_{TAVG}$ and $\bar{D}^i_{TMIN}$ in all possible combinations of one to twelve spectral channels out of the available twelve spectral channels.

$$\text{Let } \bar{D}^i_{TMAX}\left\{\text{subset of r spectral channels}\right\} = \max\left\{\bar{D}^i_{TAVG}\right\}, \quad i = 1, 2 \quad (6)$$

maximized over all possible subsets of r spectral channels out of the available twelve spectral channels. From the values of the average transformed divergence, classification accuracy can be reasonably predicted from the results of Swain et al. (1973)[6].

Table I gives the wavelength interval and the corresponding wavelength group of each of the twelve spectral channels. Tables II and III give the effect of deletion of each of the four wavelength groups and all possible combinations of the four wavelength groups respectively on $\bar{D}^1_{TMAX}$ and $\bar{D}^2_{TMAX}$, in terms of the corresponding estimated probability of correct classification (P_c).

To fulfill one of the main objectives of the study -- evaluation of all possible combinations of wavelength groups -- the following criterion is proposed.

Each of 12 available channels of the multispectral scanner can be placed in one of the four wavelength groups W1, W2, W3 and W4 (Table I). Thus, any combination of spectral channels can be called as the corresponding combination of the wavelength groups. For example, channel combination 1 4 7 10 is called "combination of wavelength groups W1 W2 W3 W4". For a given combination of wavelength groups, for example, W1 W2 W3 W4, D_{TAVG} and the corresponding value of P_c were calculated using the curve of Swain and King[6], for all possible combinations of four spectral channels that constitute the combination W1 W2 W3 W4. The minimum, maximum and the mean of these values of P_c were calculated for all possible combinations of wavelength groups, in the subsets of one to twelve spectral channels, and is shown in Table IV, for the data of middle of July as well as middle of August.

3. RESULTS AND DISCUSSION

Table II shows that deletion of each of the wavelength groups causes the following maximum reductions in P_c for the data of July: W1 (0.5, subset of five channels), W2 (0.4, subset of four channels), W3 (1.0, subset of one channel), W4 (2.3, subset of two channels). The corresponding values for reductions of P_c for the data acquired in August are: W1 (0.2, subset of nine channels) W2 (0.3 subset of nine channels) W3 (0.5, subset of three channels), W4 (1.5, subset of one channel).

Each wavelength region (visible, near infrared, middle infrared and thermal infrared) contains independent valuable information. Deletion of W4 causes more reduction in P_c than deletion of any of the other wavelength groups because it is the only group that contains all the spectral channels of two wavelength regions -- middle infrared and thermal infrared. Deletion of W3 causes more reduction in P_c than W1 or W2 because it has one spectral channel in the visible and two in the near infrared wavelength region, whereas W1 or W2 has the spectral channels only in the visible wavelength region.

Similarly Table III shows that, among the combinations of two wavelength groups, the deletion of W3 and W4 causes most reduction in P_c, because it has all the spectral channels of the near infrared, middle infrared and thermal infrared wavelength regions and one spectral channel of the visible wavelength region. Similarly, among the combinations of three wavelength groups, deletion of W2, W3 and W4 causes the most reduction.

Table IV is quite useful, since it evaluates all possible combinations of wavelength groups in the subsets of one to eleven spectral channels, in terms of P_c. It shows that in the subset of one channel, W1 has the highest value of P_c. This is mainly because channel 7 (red) is an excellent channel for discriminating agricultural cover types. Besides other reasons pointed out by Kumar and Silva[2] (1977), the separability of agricultural cover types in this channel was relatively high due to their low variance in this channel. In the subset of two to four spectral channels, the combination of wavelength groups W2 W4, W2 W3 W4 and W1 W3 (2W4), respectively, for the data of July; and W3 W4, W2 W3 W4 and W2 W3 (2W4), respectively, for the data of August, are found to be the best choices. This work has much application to feature selection (i.e. selecting best subset of m spectral channels, out of N available channels, of the existing multispectral scanners), and deciding wavelength bands of future satellites.

The author gratefully acknowledges: the Laboratory for Applications of Remote Sensing, Purdue University, for their permission to use the multispectral scanner data, obtained under the NASA Grant No. 15-005-112; Dr. Nelson de Jesus Parada, the Director of the Instituto de Pesquisas Espaciais (INPE), for his permission to publish this work; Dr. Celso de Renna e Souza and Dr. Derli Chaves Machado da Silva, for their continuous encouragement and assistance; Mr. Nandamudi L. Vijay Kumar, for his help in preparation of the tables.

REFERENCES

1. Bauer, M.E., in M.E. Bauer (ed.), "1971 Corn Blight Watch Experiment Final Report", National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas, 1974.
2. Kumar, R. and L. Silva, "Separability of Agricultural Cover Types by Remote Sensing in the Visible and Infrared Wavelength Regions", IEEE Transactions on Geoscience Electronics, Jan. 1977.
3. Kumar, R., "Evaluation of Spectral Channels and Wavelength Regions for Separability of Agricultural Cover Types", Proceedings of the Eleventh International Symposium on Remote Sensing of Environment, Environmental Research Institute of Michigan, Ann Arbor, Michigan, 1977.
4. Swain, P.H., "Pattern Recognition: A Basis for Remote Sensing Data Analysis", LARS Information Note 111572, Laboratory for Applications of Remote Sensing, Purdue University, W. Lafayette, Indiana, 40 p., 1972.
5. Marill, T. and D.M. Green, "On the Effectiveness of Receptors in Recognition Systems", IEEE Trans. on Information Theory, Vol. IT-9, pp. 11-17, 1963.
6. Swain, P.H. and R.C. King, "Two Effective Feature Selection Criteria for Multispectral Remote Sensing", in International Joint Conference on Pattern Recognition (LARS Information Note 042673, Purdue University). Washington, D.C., 1973.
7. Fu, K.S. and P.J. Min, "On Feature Selection in Multiclass Pattern Recognition", Technical Report TR-EE 68-17, School of Electrical Engineering, Purdue University, W. Lafayette, Indiana, 1968.

TABLE I. WAVELENGTH BANDS OF THE SPECTRAL CHANNELS

Channel No.	Wavelength Band (Micrometers)	Wavelength Region	Wavelength Group
1	0.46 - 0.49	visible	1
2	0.48 - 0.51	visible	1
3	0.50 - 0.54	visible	1
4	0.52 - 0.57	visible	2
5	0.54 - 0.60	visible	2
6	0.58 - 0.65	visible	2
7	0.61 - 0.70	visible	3
8	0.72 - 0.92	near infrared	3
9	1.00 - 1.40	near infrared	3
10	1.50 - 1.80	middle infrared	4
11	2.00 - 2.60	middle infrared	4
12	9.30 - 11.70	thermal infrared	4

TABLE II. EFFECT OF DELETION OF EACH WAVELENGTH GROUP ON THE PERCENTAGE OF CORRECT CLASSIFICATION

Number of channels in the subset	Values of Probability of Correct Classification Estimated from $\bar{D}_{TMAX}$									
	A_0	A_1	A_2	A_3	A_4	B_0	B_1	B_2	B_3	B_4
1	84.3	84.3	84.3	83.3	84.3	85.4	85.4	85.4	83.9	85.4
2	89.2	89.2	89.2	88.3	86.9	91.1	91.1	91.1	90.8	90.4
3	90.9	90.9	90.9	90.2	90.0	94.3	94.2	94.3	93.6	93.5
4	92.6	92.6	92.3	92.2	90.6	96.2	96.2	96.1	95.0	95.0
5	93.9	93.7	93.7	93.8	91.8	96.8	96.8	96.7	96.7	95.9
6	94.6	94.2	94.2	94.4	92.4	97.3	97.3	97.1	97.1	96.2
7	95.0	94.6	94.7	94.7	93.0	97.5	97.5	97.3	97.2	96.4
8	95.4	95.0	95.1	94.9	93.5	97.7	97.6	97.5	97.3	96.5
9	95.7	95.2	95.4	95.0	93.7	97.8	97.6	97.5	97.3	96.5
10	95.9	np	np	np	np	97.8	np	np	np	np
11	96.0	np	np	np	np	97.8	np	np	np	np
12	96.1	np	np	np	np	97.9	np	np	np	np

Note: This table gives the values of percentage probability of correct classification (P_C) estimated from the values of D_{TMAX} (see eq. (6)), Swain and King (1973)[6]. A_0, A_1, A_2, A_3 and A_4 denote the values of P_C when using all available channels, deleting spectral channels in the wavelength groups 1, 2, 3 and 4 respectively for the data acquired in the middle of July. B_0, B_1, B_2, B_3 and B_4 denote corresponding quantities as A_0, A_1, A_2, A_3 and A_4 respectively for the data acquired in the middle of August. "np" denotes that this channel combination was not possible.

TABLE III. EFFECT OF DELETION OF COMBINATION OF WAVELENGTH GROUPS ON THE PERCENTAGE OF CORRECT CLASSIFICATION

DATA OF JULY

(A) Values of Probability of Correct Classification (P_C) Estimated from $\bar{D}_{TMAX}$ (see eq. (6)) After Deletion of Combination of Wavelength Regions

N	P_c^*	W1W2	W1W3	W1W4	W2W3	W2W4	W3W4	W1W2W3	W1W2W4	W1W3W4	W2W3W4
1	84.3	84.3	83.30	84.3	82.68	84.3	83.30	82.68	84.3	83.30	81.59
2	89.2	89.2	88.33	86.38	86.85	85.79	84.74	86.12	86.88	86.06	83.70
3	90.9	90.9	90.18	86.96	90.84	89.62	86.40	88.56	89.51	86.45	83.94
4	92.6	96.26	92.25	90.50	91.21	90.87	88.86	np	np	np	np
5	93.9	92.89	92.90	91.35	91.93	91.64	91.64	np	np	np	np
6	94.6	93.89	93.62	92.29	92.91	92.68	92.67	np	np	np	np

DATA OF AUGUST

(B) Values of Probability of Correct Classification (P_C) Estimated from $\bar{D}_{TMAX}$ (see eq. (6)) After Deletion of Combination of Wavelength Regions

N	P_c^*	W1W2	W1W3	W1W4	W2W3	W2W4	W3W4	W1W2W3	W1W2W4	W1W3W4	W2W3W4
1	85.4	85.4	83.88	85.4	83.88	84.05	83.51	83.62	83.88	83.51	83.51
2	91.1	91.1	90.95	90.57	90.01	90.26	88.14	90.88	90.71	88.93	84.20
3	94.3	91.64	93.95	93.55	93.62	92.33	90.53	92.17	92.10	89.36	85.47
4	96.2	95.77	95.96	95.01	95.16	94.50	90.71	np	np	np	np
5	96.8	96.44	96.69	96.26	96.05	95.88	92.05	np	np	np	np
6	97.3	96.77	96.77	96.38	96.18	96.01	93.89	np	np	np	np

Note: "np" denotes that deletion of combination of wavelength regions was not possible. W1, W2, W3 and W4 denote wavelength groups 1, 2, 3 and 4 respectively (see Table I).
N = Number of channels in the subset
P_c^* = P_c Without Deletion

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TABLE IV. EVALUATION OF COMBINATION OF WAVELENGTH GROUPS

WGC	(A) P_c Avg	(A) P_c Min	(A) P_c Max	(B) P_c Avg	(B) P_c Min	(B) P_c Max
N = 1						
W1	80.7	79.87	81.59	82.7	81.91	83.51
W2	80.4	78.15	83.33	82.6	81.93	83.51
W3	75.8	66.01	84.30	84.7	83.80	85.39
W4	81.2	80.37	82.65	[illegible]	[illegible]	[illegible]
N = 2						
2W1	83.1	82.37	83.70	84.3	83.52	85.03
W1W2	83.8	82.50	84.74	85.1	83.51	88.14
W1W3	85.2	84.20	85.79	89.4	85.52	90.36
W1W4	86.3	85.39	86.85	89.4	88.82	90.01
2W2	84.3	82.82	86.06	86.4	85.24	88.93
W2W3	85.2	83.74	86.38	89.7	86.18	90.57
W2W4	86.4	85.14	88.83	89.7	89.24	90.36
2W3	84.3	77.44	86.88	89.1	85.13	90.71
W3W4	85.5	83.59	89.21	90.5	89.21	90.84
2W4	85.3	84.56	86.12	89.8	86.82	90.88
N = 3						
3W1	83.9	83.9	83.9	85.46	85.46	85.46
(2W1)W2	84.9	83.96	86.22	86.4	84.90	88.71
(2W1)W3	86.3	85.36	87.97	90.6	86.45	91.88
(2W1)W4	88.3	86.82	88.55	90.7	89.44	91.00
W1(2W2)	86.0	84.93	88.40	89.3	88.17	90.88
W1W2W3	86.8	85.60	88.75	90.7	88.40	93.53
W1W2W4	89.0	86.17	89.83	90.9	90.19	92.70
W1(2W3)	88.5	86.90	89.62	91.7	90.89	92.50
W1(2W4)	89.9	89.13	90.44	92.2	90.36	93.62
W1W3W4	89.2	88.51	90.51	92.3	91.10	94.29
3W2	86.4	86.40	86.40	89.4	89.4	89.4
(2W2)W3	86.8	85.74	89.54	90.6	89.15	92.42
(2W2)W4	89.0	86.12	90.61	91.6	90.49	92.81
W2(2W3)	88.9	86.61	89.96	92.3	91.51	93.55
W2W3W4	90.0	88.15	90.89	92.7	90.89	94.15
W2(2W4)	89.8	88.59	90.18	92.5	90.73	93.95
3W3	89.5	89.50	89.50	92.1	92.10	92.10
(2W3)W4	89.5	85.55	90.33	92.5	91.14	93.60
W3(2W4)	8[illegible].1	86.26	90.86	92.5	91.93	93.00
(3W4)	88.6	88.60	88.60	92.2	92.2	[illegible].2

WGC	(A) P_c Avg	(A) P_c Min	(A) P_c Max	(B) P_c Avg	(B) P_c Min	(B) P_c Max
N = 4						
(3W1)W2	85.6	85.23	86.83	88.4	86.67	89.18
(3W1)W3	88.3	86.89	88.53	90.8	89.55	92.28
(3W1)W4	89.4	89.27	89.53	91.0	90.14	91.50
(2W1)(2W2)	86.8	85.91	88.86	90.2	89.59	90.71
(2W1)W2W3	88.8	88.01	90.07	92.7	89.24	94.06
(2W1)(2W3)	89.8	88.89	90.66	92.7	91.62	93.93
(2W1)W2W4	89.9	89.01	90.22	92.8	90.74	93.72
(2W1)W3W4	90.7	90.09	90.96	93.8	90.28	95.10
(2W1)(2W4)	90.2	89.83	91.06	93.6	91.21	94.80
W1(3W2)	88.6	88.30	88.84	90.9	90.57	91.41
W1(2W2)W3	89.4	88.43	90.93	92.2	90.24	94.46
W1(2W2)W4	90.6	89.71	91.14	93.5	91.78	94.93
W1W2(2W3)	90.3	89.06	90.62	94.0	92.39	94.95
W1W (2W4)	90.6	89.89	91.77	94.5	92.02	96.02
W1W.W3W4	90.3	89.67	91.38	94.6	91.45	96.07
W1(3W3)	90.7	90.50	90.87	93.8	92.87	94.50
W1(2W3)	90.7	90.53	91.70	94.6	93.76	95.45
(2W3)(2W4)	90.7	89.75	92.26	95.0	94.82	95.77
W1(3W4)	90.9	90.81	91.21	95.0	94.82	95.16
(3W2)W3	89.5	88.85	89.90	91.6	90.54	92.78
(3W2)W4	90.8	90.48	91.17	92.8	92.36	93.62
(2W2)(2W3)	90.2	89.08	90.85	93.7	92.66	94.46
(2W2)W3W4	90.2	90.10	91.42	94.3	91.85	95.66
(2W2)(2W4)	90.6	89.85	92.25	95.0	92.84	95.96
W2(3W3)	90.9	90.53	91.30	94.5	93.87	95.01
W2(2W3)W4	90.7	90.09	91.94	95.1	94.15	95.88
W2W3(2W4)	91.0	90.45	92.55	95.5	94.08	96.17
W2(3W4)	90.6	90.34	91.24	95.3	95.16	95.45
(3W3)W4	90.9	90.62	91.29	94.7	94.36	94.82
W3(3W4)	90.8	89.81	91.74	95.2	95.10	95.30
W1W3(2W4)	91.1	90.75	92.09	95.1	92.89	96.11
N = 5						
(3W1)(2W2)	90.8	90.7	90.9	93.5	93.41	93.62
(3W1)W2W3	89.5	89.4	89.57	94.3	94.21	94.46
(3W1)W2W4	90.6	90.48	90.68	90.7	90.6	90.8
(3W1)(2W3)	91.8	91.71	91.93	93.5	93.4	93.63
(3W1)W3W4	91.26	91.21	91.35	95.3	95.07	95.47
(3W1)(2W4)	91.6	91.50	91.69	55.2	95.14	95.32

TABLE IV. CONTINUATION

WGC	(A) P_c Avg	(A) P_c Min	(A) P_c Max	(B) P_c Avg	(B) P_c Min	(B) P_c Max
(2W1)(3W2)	88.6	88.38	88.90	95.04	95.01	95.08
(2W1)(2W2)W3	92.2	92.0	92.4	95.2	95.03	95.35
(2W1)(2W2)W4	91.4	91.26	91.56	95.2	94.99	95.39
(2W1)W2(2W3)	91.2	91.16	91.26	95.6	94.95	96.43
(2W1)W2W3W4	91.5	91.19	92.09	96.0	95.64	96.42
(2W1)W2(2W4)	91.8	91.22	92.56	95.1	95.05	95.15
(2W1)(3W3)	91.7	91.13	92.41	95.5	94.95	96.00
(2W1)(2W3)W4	91.8	91.21	92.50	95.9	94.97	96.57
(2W1)W3(2W4)	92.2	91.50	92.94	95.7	95.28	96.05
(2W1)(3W4)	91.8	91.46	92.01	95.0	94.95	95.12
W1(3W2)W3	91.3	91.25	91.5	95.1	95.03	95.22
W1(3W2)W4	91.4	91.29	91.56	95.2	94.93	95.64
W1(2W2)2W3)	91.3	91.24	91.45	95.8	94.97	96.59
W1(2W2)W3W4	91.7	91.18	92.62	96.0	94.97	96.76
W1(2W2)(2W4)	92.9	91.83	93.77	95.6	94.97	95.90
W1(2W2)(2W3)	91.5	91.19	91.83	[illegible]	95.10	96.70
W1W2(2W3)W4	91.9	91.26	92.89	[illegible]	95.01	96.81
W1W2(2W4)W3	92.3	91.16	93.95	96.4	95.71	96.65
W1W2(3W4)	92.2	91.38	92.62	95.7	95.16	96.26
W1(3W3)W4	92.0	91.56	92.34	96.2	95.24	96.63
W1(2W3)(2W4)	92.9	91.90	93.94	96.3	95.85	[illegible]
W1W3(3W4)	92.4	91.94	92.74	95.4	95.0	95.70
(3W2)(2W3)	91.4	91.20	91.55	95.5	95.05	95.81
(3W2)W3W4	91.5	91.22	91.67	95.6	95.26	95.94
(3W2)(2W4)	92.5	92.42	[illegible]	95.8	95.16	96.09
(2W2)(3W3)	92.7	92.6	92.75	95.4	95.29	95.48
(2W2)(2W3)W4	92.0	91.50	92.42	95.8	95.18	96.45
(2W2)W3(2W4)	92.3	91.22	92.97	96.3	95.12	96.69
(2W2)(3W4)	92.1	90.40	92.90	96.4	96.26	96.69
W2(3W3)W4	92.1	91.56	92.58	96.2	95.43	96.44
W2(2W3)(2W4)	92.4	91.32	93.70	96.3	95.71	96.81
W2W3(3W4)	92.3	91.64	93.64	96.6	96.34	96.80
(3W3)(2W4)	92.4	91.95	92.89	96.1	95.77	96.42
(2W3)(3W4)	92.6	92.55	92.72	96.4	96.21	96.54
N = 6						
(3W1)(3W2)	94.0	94.0	94.0	96.4	96.4	96.4
(3W1)(2W2)W3	92.3	92.12	92.53	94.9	94.75	95.18
(3W1)(2W2)W4	92.0	91.82	92.23	96.3	96.12	96.45
(3W1)W2(2W3)	92.57	92.51	92.65	96.3	96.15	96.42
(3W1)W2W3W4	93.25	92.97	93.55	96.3	96.15	[illegible]

WGC	(A) P_c Avg	(A) P_c Min	(A) P_c Max	(B) P_c Avg	(B) P_c Min	(B) P_c Max
(3W1)W2(2W4)	93.5	93.31	93.68	97.2	97.05	97.37
(3W1)(3W3)	93.0	93.0	93.0	96.2	96.2	96.2
(3W1)(2W3)W4	93.0	92.58	93.81	96.3	96.13	96.50
(2W1)W3(2W4)	93.0	92.62	93.78	96.4	96.34	96.52
(3W1)(3W4)	92.5	92.5	92.5	96.3	96.3	96.3
(2W1)(3W2)W3	92.61	92.47	92.70	97.0	96.91	97.14
(2W1)(3W2)W4	92.65	92.55	92.78	97.3	97.12	97.44
(2W1)(2W2)(2W3)	92.74	92.55	92.97	96.4	96.38	96.69
(2W1)(2W2)W3W4	92.7	92.62	94.15	96.4	96.32	96.69
(2W1)(2W2)(2W4)	93.5	93.22	93.81	97.1	96.85	97.31
(2W1)W2(3W3)	92.81	92.54	93.87	96.4	96.38	96.71
(2W1)W2(2W3)W4	92.8	92.53	94.33	96.6	96.38	96.98
(2W1)W2W3(2W4)	93.6	92.60	93.76	96.6	96.44	96.87
(2W1)W2(3W3)	92.9	92.63	93.51	96.4	96.35	96.48
(2W1)(3W3)W4	92.8	92.55	94.21	96.6	96.40	96.86
(2W1)(2W3)(2W4)	93.7	92.63	94.02	96.7	96.44	96.92
(2W1)W3(3W4)	93.0	92.91	93.12	96.67	96.44	96.82
W1(3W2)(2W3)	92.70	92.55	92.87	96.45	96.40	96.56
W1(3W2)W3W4	93.7	92.92	94.08	96.5	96.36	96.60
W1(3W2)(2W4)	93.8	93.62	94.81	97.2	97.08	97.35
W1(2W2)(3W3)	93.2	92.52	93.95	96.52	96.40	96.74
W1(2W2)(2W3)W4	92.9	92.54	94.34	96.7	96.47	97.11
W1(2W2)W3(2W4)	[illegible]	92.52	94.42	96.8	96.60	97.08
W1(2W2)(3W4)	93.6	92.63	94.02	96.6	96.32	96.86
W1W2(3W3)W4	93.0	92.55	94.59	96.8	96.40	97.19
W1W2(2W3)(2W4)	93.8	92.55	94.55	97.0	96.6	97.26
W1W2W3(3W4)	93.8	92.63	94.25	96.6	96.49	96.96
W1(3W3)(2W4)	94.02	92.84	94.25	97.0	96.63	97.13
W1(2W3)(3W4)	94.65	94.41	94.82	97.2	96.92	97.35
(3W2)(3W3)	92.75	92.75	92.75	96.41	96.41	96.41
(3W2)(2W3)W4	93.32	92.81	93.74	96.5	96.42	96.80
(3W2)W3(2W4)	93.6	93.51	93.72	96.57	96.50	96.91
(3W2)(3W4)	93.6	93.6	93.6	96.77	96.77	96.77
(2W2)(2W3)(2W4)	93.7	92.55	94.14	96.7	96.47	97.05
(2W2)W3(3W4)	93.7	92.60	94.08	97.0	96.68	97.22
W2(3W3)(2W4)	93.8	92.55	94.25	96.8	96.51	97.16
W2(2W3)(3W4)	93.7	92.68	94.23	97.0	96.80	97.26
(3W3)(3W4)	94.50	94.50	94.50	96.8	96.8	96.8
(2W2)(3W3)W4	92.8	92.71	93.00	96.4	96.43	96.60

TABLE IV. CONTINUATION

WGC	P_c Avg	(A) P_c Min	P_c Max	P_c Avg	(B) P_c Min	P_c Max
N = 7						
(3W1)(3W2)W3	93.8	93.65	94.02	96.5	96.41	96.65
(3W1)(3W2)W4	93.92	93.72	94.13	96.65	96.52	96.78
(3W1)(2W3)(2W3)	93.9	93.65	94.17	97.0	96.73	97.29
(3W1)(2W2)W3W4	94.0	93.78	94.35	96.6	96.35	96.91
(3W1)(2W2)(2W4)	94.12	93.91	94.42	96.72	96.41	97.17
(3W1)W2(3W3)	93.93	93.68	94.21	96.73	96.6	97.08
(3W1)W2(2W3)W4	94.0	93.81	94.48	96.81	96.69	96.96
(3W1)W2W3(2W4)	94.32	94.25	94.45	96.8	96.57	97.11
(3W1)W2(3W4)	94.3	93.98	94.65	96.82	96.60	96.95
(3W1)(3W3)W4	94.0	93.68	94.59	96.91	96.83	97.02
(3W1)(2W3)(2W4)	94.3	93.87	94.42	96.92	96.81	97.15
(3W1)W3(3W4)	94.41	94.25	94.61	[illegible]	96.92	97.23
(2W1)(3W2)(2W3)	94.15	93.85	94.37	[illegible]	[illegible]	[illegible]
(2W1)(3W2)W3W4	94.21	93.95	94.45	96.72	96.68	96.80
(2W1)(3W2)(2W4)	94.2	93.98	94.36	96.70	96.51	96.85
(2W1)(2W2)(3W3)	94.03	93.68	94.31	96.74	96.60	96.93
(2W1)(2W2)(2W3)W4	93.9	93.68	94.80	96.95	96.87	97.22
(2W1)(2W2)W3(2W4)	94.3	93.83	94.74	97.0	96.60	97.24
(2W1)(2W2)(3W4)	94.2	93.68	94.36	96.8	96.69	97.31
(2W1)W2(3W3)W4	94.0	93.70	94.93	97.0	96.71	97.38
(2W1)W2(2W3)(2W4)	94.4	93.81	94.88	97.1	96.60	97.33
(2W1)W2W3(3W4)	94.3	[illegible]	94.69	96.9	96.74	97.28
(2W1)(3W3)(2W4)	94.4	93.79	94.67	97.1	96.95	97.33
(2W1)(2W3)(3W4)	94.4	93.85	94.72	[illegible]	[illegible]	97.45
W1(3W2)(3W3)	93.9	93.65	94.23	96.8	96.61	97.13
W1(3W2)(2W3)W4	93.9	93.68	94.29	96.7	96.60	96.93
W1(3W2)W3(2W4)	94.4	93.81	94.71	96.9	96.60	97.22
W1(3W2)(3W4)	94.5	94.17	94.69	97.1	97.04	97.16
W1(2W2)(3W3)W4	94.1	93.68	94.38	96.8	96.60	97.07
W1(2W2)(2W3)(2W4)	94.4	93.71	95.01	97.0	96.66	97.78
W1(2W2)W3(3W4)	94.5	93.68	94.93	97.2	96.93	97.49
W1W2(3W3)(2W4)	94.5	93.76	95.05	97.1	96.71	97.43
W1W2(2W3)(3W4)	94.85	94.05	95.32	97.3	97.02	97.52
W1(3W3)(3W4)	94.71	94.67	94.92	97.2	97.04	97.32
(3W2)(3W3)W4	93.92	93.85	94.01	96.66	96.66	96.66
(3W2)(2W3)(2W4)	94.2	93.68	94.44	96.9	96.84	97.14
(3W2)W3(3W4)	94.2	94.14	94.36	97.2	96.96	97.29
(2W2)(3W3)(2W4)	94.3	93.77	94.65	97.0	96.84	97.28
(2W2)(2W3)(3W4)	94.4	93.98	94.63	97.3	97.16	97.46
W2(3W3)(3W4)	94.5	94.31	94.69	97.4	97.21	97.50

WGC	P_c Avg	(A) P_c Min	P_c Max	P_c Avg	(B) P_c Min	P_c Max
N = 8						
(3W1)(3W2)(2W3)	92.3	92.07	92.39	96.2	96.02	96.42
(3W1)(3W2)W3W4	92.9	92.50	93.83	96.4	95.14	96.90
(3W1)(3W2)(2W4)	94.1	92.86	94.48	96.7	96.45	96.87
(3W1)(2W2)(3W3)	92.8	92.76	92.86	96.38	96.34	96.47
(3W1)(2W2)(2W3)W4	93.9	92.71	[illegible]	96.8	96.42	97.05
(3W1)(2W2)W3(2W4)	94.2	92.63	94.90	97.0	96.38	97.32
(3W1)(2W2)(3W4)	94.4	94.12	94.84	97.2	97.08	97.28
(3W1)W2(3W3)W4	94.2	94.02	94.50	96.9	96.56	97.14
(3W1)W2(2W3)(2W4)	94.5	92.90	95.01	97.1	96.68	97.37
(3W1)W2W3(3W4)	94.7	94.34	94.97	97.3	97.17	97.46
(3W1)(3W3)(2W4)	94.7	94.23	95.03	97.1	97.01	97.23
(3W1)(2W3)(3W4)	94.8	94.46	94.99	97.3	97.25	97.35
(2W1)(3W2)(3W3)	92.9	92.81	93.62	96.4	96.33	96.44
(2W1)(2W2)(2W3)W4	94.1	93.72	94.53	96.8	96.51	97.10
(2W1)(3W2)W3(2W4)	94.5	93.51	94.97	97.0	96.53	97.34
(2W1)(3W2)(3W4)	94.8	94.69	94.93	97.25	97.23	97.28
(2W1)(2W2)(3W3)W4	94.5	94.10	94.76	97.0	96.72	97.22
(2W1)(2W2)(2W3)(2W4)	94.6	93.51	95.28	97.2	96.87	97.44
(2W1)(2W2)W3(3W4)	94.8	94.28	95.22	97.4	97.14	97.56
(2W1)W2(3W3)(2W4)	94.8	94.23	95.31	97.3	96.89	97.52
(2W1)W2(2W3)(3W4)	94.9	94.44	95.31	97.4	97.17	97.61
(2W1)(3W3)(3W4)	95.0	94.91	95.09	97.4	97.19	97.46
W1(3W2)(3W3)W4	94.4	94.08	94.78	97.0	96.83	97.11
W1(3W2)(2W3)(2W4)	94.7	93.91	95.24	97.2	96.93	97.65
W1(3W2)W3(3W4)	94.9	94.66	95.16	97.51	97.49	97.55
W1(2W2)(3W3)(2W4)	94.9	94.25	95.57	97.3	97.13	97.53
W1(2W2)(2W3)(3W4)	95.0	94.31	95.37	97.5	97.34	97.64
W1W2(3W3)(3W4)	95.1	94.86	95.37	97.5	[illegible]	97.68
(3W2)(3W3)(2W4)	94.6	94.19	94.88	97.2	[illegible]	97.34
(3W2)(3W3)(3W4)	94.8	94.63	94.88	97.4	97.35	97.53
(2W2)(3W3)(3W4)	94.9	94.84	95.01	97.5	97.44	97.59
N = 9						
(3W1)(3W2)(3W3)	93.7	93.70	93.70	96.55	96.55	96.55
(3W1)(3W2)(2W3)W4	94.3	94.12	94.67	97.0	96.83	97.20
(3W1)(3W2)W3(2W4)	94.7	93.89	95.09	97.2	96.72	97.40
(3W1)(3W2)(3W4)	95.03	95.03	95.03	97.34	97.34	97.34
(3W1)(2W2)(3W3)W4	94.6	94.44	94.84	97.1	96.92	97.31
(3W1)(2W2)(2W3)(2W4)	94.9	93.96	95.33	97.3	97.05	97.52
(3W1)(2W2)W3(3W4)	95.1	94.71	95.29	97.5	97.29	97.62

TABLE IV. CONTINUATION

WGC	(A) P_c Avg	P_c Min	P_c Max	(B) P_c Avg	P_c Min	P_c Max
(3W1)W2(3W3)(2W4)	95.1	94.65	95.39	97.4	97.16	97.58
(3W1)W2(2W3)(3W4)	95.2	94.84	95.39	97.5	97.37	97.65
(3W1)(3W3)(3W4)	95.37	95.37	95.37	97.52	97.52	97.52
(2W1)(3W2)(3W3)W4	94.7	94.51	94.97	97.1	97.05	97.28
(2W1)(3W2)(2W3)(2W4)	95.0	94.40	95.43	97.[illegible]	97.14	97.53
(2W1)(3W2)(3W4)	95.2	95.09	95.37	[illegible]	[illegible]	[illegible]
(2W1)(2W3)(3W3)(2W4)	95.2	94.67	95.62	97.5	97.29	97.61
(2W1)(2W2)(2W3)(3W4)	95.3	94.78	95.62	97.6	97.46	97.70
(2W1)W2(3W3)(3W4)	95.4	95.37	95.60	97.6	97.43	97.74
W1(3W2)(3W3)(2W4)	95.2	94.67	95.60	97.5	97.38	97.56
W1(3W2)(2W3)(3W4)	95.4	95.07	95.58	97.6	97.50	97.71
W1(2W2)(3W3)(3W4)	95.5	95.28	95.67	97.7	97.59	97.76
(3W2)(3W3)(3W4)	95.2[illegible]	95.22	95.22	97.64	97.64	97.64
N = 10						
(3W1)(3W2)(3W3)W4	95.0	94.84	95.10	97.3	97.19	97.35
(3W1)(3W2)(2W3)(2W4)	95.2	94.72	95.52	97.5	97.28	97.59
(3W1)(3W2)W3(3W4)	95.45	95.41	95.47	97.6	97.46	97.68
(3W1)(2W2)(3W3)(2W4)	95.4	94.95	95.71	97.5	97.43	97.67
(3W1)(2W2)(2W3)(3W4)	95.5	95.14	95.69	97.7	97.56	97.76
(3W1)W2(3W3)(3W4)	95.66	95.64	95.67	97.7	97.59	97.79
(2W1)(3W2)(3W3)(2W4)	95.5	95.05	95.82	97.6	97.52	97.65
(2W1)(3W2)(2W3)(3W4)	95.6	95.45	95.82	97.7	97.62	97.76
(2W1)(2W2)(3W3)(3W4)	95.7	95.60	95.88	97.8	97.68	97.82
W1(3W2)(3W3)(3W4)	95.7	95.58	95.85	97.8	97.74	97.82
N = 11						
(3W1)(3W2)(3W3)(2W4)	95.6	95.33	95.87	97.6	97.59	97.70
(3W1)(3W2)(2W3)(3W4)	95.8	95.73	95.85	97.7	97.68	97.80
(3W1)(2W2)(3W3)(3W4)	95.9	95.83	95.98	97.82	97.76	97.85
(2W1)(3W2)(3W3)(3W4)	96.0	95.88	96.02	97.80	97.80	97.83
N = 12						
(3W1)(3W2)(3W3)(3W4)	96.15	96.15	96.15	97.88	97.[illegible]8	97.83

Note: (A) and (B) denote the data of July and August respectively. P_c Avg, P_c Min, and P_c Max denote the average, minimum and maximum values of the probability of correct classification respectively. W1 W2 W3 W4 denotes all channel combinations constituting this combination of wavelength groups in the subset of four channels. For example: 1 4 7 10, 2 5 8 11, 3 6 9 12 etc.

WGC = denotes wavelength group combination in N channels.

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