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Research Article

Mapping Crops in Heterogenous Landscape: Selection of Optimum Bands Combination and Period for Single-Date Classification

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ABSTRACT

Crop mapping at disaggregated level for e.g. at village or gram-panchayat level is the present requirement for various applications like local crop area and condition assessment. Availability of multispectral data like Sentinel-2 with 13 bands has created an opportunity to discriminate the crop spectrally in VNIR and SWIR region of electromagnetic spectrum. The present study has been undertaken to examine the spectral discriminability power of different Sentinel-2 band combinations for classifying different *rabi* crops in Ujjain district, Madhya Pradesh. Separability analysis using Transform Divergent (TD) were performed on single date ten band stacked image from October 2018 to March 2019. For spectral discriminability analysis eight classes of crop type i.e., Early-, Mid-, Late-Wheat, Desi-, Hybrid-Gram, Potato, Garlic and other crops were arrived from the ground observations. The four non-agriculture classes were Fallow, Scrubland, Settlements and Waterbodies. The separability matrix generated for a combination of 3-bands showed the best separable band combination of B4, B8A and B11 while 4-bands combination showed B4, B5, B8A and B11 during the mid-growing stage i.e., on 26th Dec 2018. Before 15thNovember the TD value showed significantly lower values between Early - Mid wheat and Hybrid – Desi gram compared to the best average separability indicating its lower separability. The classification result using the most separable band combination showed an highest kappa of 0.75 during the end of December. The study concluded that with a combination of Bands 4, 5, 8A and 11 of Sentinel-2 data, a significant accurate *rabi* crop map can be generated before end of December in multi crop growing environment.

Key words: Separability analysis, Transform divergent, Crop Classification, Sentinel-2

Introduction

The use of satellite data for in-season mapping and monitoring of multiple crops simultaneously has been steadily increasing in recent years because of increased spatial, temporal and spectral resolution of multispectral data. Nowadays with the availability of Sentinel-2 satellite data at an interval of five days with 10 spectral bands in 10/20 m spatial resolution has paved the way for identification and classification of crop type at more disaggregated level like village or gram panchayat. Multiple spectral bands provide opportunity for better discrimination between crop types (Moody *et al.,* 2017; Neetu *et al*., 2017) and help in getting better accuracies for single date classification. Factors affecting the accuracy of single date crop classification include the spatial resolution, number of bands of satellite data, classification

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method and the phonological stage of the crop (Inglada *et al.,* 2015). The growth of crop leads to changes in leaf composition and canopy structures and hence affects the spectral signature. Mapping of specific crop type at higher spatial resolution have various challenges like spectral similarity between crops and varieties, staggered crop calendar within a crop, different management practices etc. Classification based on the multi-spectral and multi temporal satellite data can significantly improves the accuracy (Van Niel and McVicar, 2004; Prishchepov *et al.,* 2012; Simmons *et al.,* 2016; Laurin *et al.,* 2018). The satellite data from Sentinel-2 have the added advantages of having various multispectral bands and frequent receptivity which can be exploited for crop type discrimination. Increase in the number of spectral bands and temporal resolution in one way facilitates the discriminations between crops but on other hand increases the computation and processing time (Das *et al.,* 2020). Increase in number of bands and scenes led to potentially higher data dimensionality as well as redundancy (Zhang *et al.,* 2016).

There is dearth of information on the relative discriminability power of different bands combinations of Sentinel-2 data, its optimal bands and timing for relatively accurate crop type mapping. In view of this the present study was undertaken to analyses different bands of multi-temporal Sentinel-2 data for in-season crop type mapping. The specific objectives of the study were to perform the separability analysis to identify the bands with maximum discriminating capability at different stages of the crop season for mapping of multiple crops.

Material and Methods

Study area

The study area was Ujjain district in Madhya Pradesh located in the heart of Malwa Plateau at a general elevation of 527 meter above mean sea level (Fig.1). The normal annual rainfall of Ujjain district is 914.5 mm. Ujjain district receive maximum rainfall (about 92.1%) during southwest monsoon period i.e. June to November. The total geographical area of the district is 6,130.23 sq. km and divided in seven tehsils. The irrigation facilities in Ujjain district are moderate. Groundwater is the main source of irrigation in the district.

The study was carried out for *rabi* 2018-19. The predominant crops in the *rabi* season were Wheat, Gram, Onion and Potato. *Rabi* season start in mid of September and continues till end of April. Staggered sowing is the common practice in the region for wheat crop with the majority of the area sown in the mid October. Staggered sowing was prevalent in wheat and two different types of Gram i.e. Desi and Hybrid were also present. To account for staggered sowing in wheat, 3 sub-class i.e. Early wheat (September

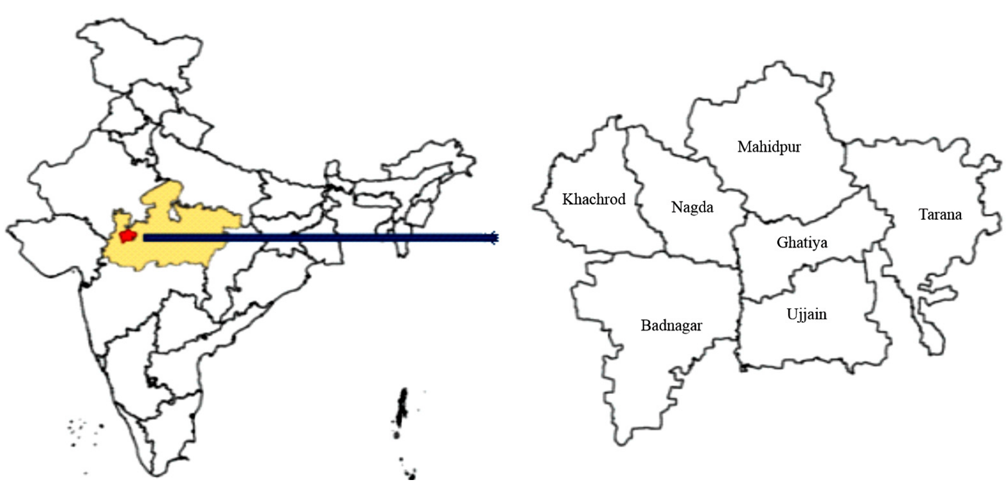

Fig. 1. Study area; Ujjain, Madhya Pradesh

sown), Mid wheat (October sown) and Late wheat (November sown) were created.

Satellite data

Cloud free level 1C Sentinel-2 (S2) data were downloaded and processed from the Copernicus open access hub for the growing season (1^{st} Oct 2018 to 30^{th} April 2019). Table 1 shows the full list of S2 data and tiles for the study area. Considering the small average field sizes (less than 1 acre) in the study area, ten bands of S2 data with the spatial resolution 10m/20m (Table 2) were selected and further used in the analysis.

Reference data and generation of classes

In situ data were collected during last week of December 2018 along with various field information like, crop type, crop stages, sowing date, crop health. Altogether 12 classes were identified in the study area for performing the classification (Table 3). Significant number of observations were collected from each class as shown in Table 3. Field boundaries for each observation were drawn manually with the support of False colour composite (FCC) image corresponding to the data collection period and all pixels within the boundary were assigned the respective class and used for further analysis. Sixty percent of pixels in each class were used for separability analysis and training classifier and rest 40% were used for accuracy assessment.

Table 1. Date of satellite pass and tiles ID

S. No.	Month Year	Date of scenes	Sentinel-2 Tiles
1	Oct- 2018	22^{nd} and 27^{th}	43QEF,
2	Nov-2018	1^{st}, 11^{th}, 16^{th} and 26^{th}	43QEG,
3	Dec-2018	1^{st}, 11^{th}, 26^{th} and 31^{st}	43QEF
4	Jan-2019	9^{th}, 20^{th} and 30^{th}	and
5	Feb-2019	14^{th}, 19^{th} and 24^{th}	43QFG
6	Mar-2019	11^{th}, 16^{th} and 21^{st}	

Table 2. Sentinel-2 bands used in the study

Sentinel-2 bands	Abbreviation	Spatial Resolution (m)
Band 2 – Blue	B2	10
Band 3 – Green	B3	10
Band 4 – Red	B4	10
Band 5 – Red edge1	B5	20
Band 6 – Red edge2	B6	20
Band 7 – Red edge3	B7	20
Band 8 – NIR	B8	10
Band 8A – Narrow NIR	B8A	20
Band 11 – SWIR1	B11	20
Band 12 – SWIR2	B12	20

Table 3. Number of ground observations and pixels used for the analysis

S. No.	Classes	Number of Ground Observations	Number of class assigned pixels
1	Early-Wheat	34	260
2	Mid-Wheat	77	593
3	Late-Wheat	26	200
4	Desi-Gram	19	148
5	Hybrid-Gram	18	135
6	Garlic	11	88
7	Potato	7	48
8	Other-Crops	18	140
9	Fallow Lands	18	138
10	Srcub land	16	125
11	Settlements	18	128
12	Waterbodies	17	155
	Total	279	2155

Separability assessment

The parametric transform divergent (TD) as a measure of spectral distance was used for separability assessment between classes. TD provides a weighted distance class means to determine whether class signatures are separable or not. TD value varies between 0 (no separability) to 2000 (completely separable). Transform divergent gives proportionally decreasing weight to increasing distances between the classes (Jansen, 1996). The transform divergent is computed as:

$$TD = 2[1\text{-}\exp(\text{-}D8);\ D=12tr\ [(c_1\text{-}c_2)\ (c_1^{-1}\text{-}c_2^{-1})]\ +1/2tr\ [(c_1^{-1}\text{-}c_2^{-1})\ (\mu1\text{-}\mu2)\ (\mu1\text{-}\mu2)^{T}]$$

Where, TD is the transform divergent between the class1 and class2, c_1 is the covariance matrix

Table 4. Best three bands combinations for separability of classes (Using calibration pixels, N= 1293)

S. No.	Date	Best separable bands	Best average separability (TD)
1	27-Oct-2018	B3, B7, B12	1925
2	11-Nov-2018	B4, B8a, B11	1941
3	21-Nov-2018	B3, B7, B8a	1976
4	06-Dec-2018	B3, B8a, B11	1991
5	26-Dec-2018	B4, B8a, B11	1998
6	10-Jan-2019	B4, B8a, B12	1997
7	30-Jan-2019	B4, B8a, B11	1996
8	09-Feb-2019	B5, B8a, B11	1991
9	11-Mar-2019	B5, B7, B11	1991

of class1 and c_2 is the covariance metric of class 2, μ_1 is the mean vector of class1and μ_2 is the mean vector of class2, tr is the matrix trace function and T is the matrix transposition function.

Class separability were assessed among twelve classes for each date of satellite pass taking 3-bands together and 4-bands together. The best separable bands in 3-bands combination and 4-bands combination were highlighted based on the best average separability. ERDAS IMAGINE ver 15.0 software was used for TD computation, classification and its accuracy assessment.

Classification and accuracy assessment

Pixel based classification approach for each individual acquisition was adopted using maximum likelihood classier. Training pixels from 10 bands were used for classifying the images. Confusion matrix was drawn using the validation pixel and classification performances were compared based on the Overall accuracy (OA) and kappa statistics (k).

Results and Discussions

Band Separability using 3-bands combinations

Table 4 shows the results of the separability analysis for each date taking 3 bands combination. It was observed that the best average separability increases from the start of the growing season reaching peak during the mid-season and remain constant till the end of the season. Separability was highest (average TD = 1998) during the peak greenness stage of major crop classes i.e., during the second fortnight of December (i.e., 26th Dec 2018) and the most separable band combination were B4 (Red), B8A (narrow NIR) and B11 (SWIR). B8A i.e., the narrow NIR band were the part of most separable bands for most of the dates (7 days out of 9 days) and reflect its importance at different growing stages in separating the crop classes. B11 i.e. Short wave Infrared (SWIR1) was another band which appeared for 6 days out of 9 days among the most separable band

Table 5. Class separability using TD taking 3 bands at a time (26th Dec 2018)

	Early wheat	Mid wheat	Late wheat	Desi Gram	Hybrid Gram	Garlic	Potato	Other crops	Fallow	Scrub-land	Settle ments	Water-bodies
Early Wheat	0											
Mid wheat	1998	0										
Late wheat	1999	1814	0									
Desi Gram	2000	2000	2000	0								
Hybrid Gram	2000	2000	2000	2000	0							
Garlic	2000	2000	2000	2000	2000	0						
Potato	2000	2000	2000	2000	2000	2000	0					
Other crops	2000	2000	2000	2000	2000	2000	2000	0				
Fallow	2000	2000	2000	2000	2000	2000	2000	2000	0			
Scrubland	2000	2000	2000	2000	2000	2000	2000	2000	2000	0		
Settlements	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	0	
Water-bodies	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	0

Table 6. Best four bands combinations for separability of classes (Using calibration pixels, N= 1293)

S. No.	Date	Best separable bands	Best average separability
1	27-Oct-2018	B3, B5, B7, B12	1944
2	11-Nov-2018	B4, B5, B8A, B11	1948
3	21-Nov-2018	B4, B5, B7, B8A	1992
4	06-Dec-2018	B3, B4, B8A, B11	1997
5	26-Dec-2018	B4, B5, B8A, B11	1998
6	10-Jan-2019	B4, B7, B8A, B11	1998
7	30-Jan-2019	B2, B5, B7, B11	1998
8	09-Feb-2019	B3, B4, B8A, B11	1998
9	11-Mar-2019	B3, B4, B7, B11	1998

combination. B4 i.e., Red band was another importance band containing maximum information to segregate classes on 4 days out of 9 days. Chlorophyll content, leaf thickness and leaf moisture are the major differentiating characteristics between the crops and hence B4, B8A and B11 might have given the best separability value together. Table 5 shows the class separability matrix for 3-bands combinations on 26th December. A complete separability was observed between all the classes. TD value among all classes were found to be maximum except between mid-wheat and hybrid-gram.

Band Separability using 4-bands combinations

Table 6 shows the results of the separability analysis for each date taking 4 bands combination. Best average separability increased from 1944 on 27th Oct 2018 to 1998 on 26th Dec 2018 and remained constant thereafter. With 4-band combination the classes were highly separable at all dates of the satellite pass. Again B8A and B4 was part of most separable bands in 6 out of 9 days followed by B5 (Red Edge 1) and B7 (Red Edge 3) bands. Four bands combination leads to a better separability value for each date. Alike 3-band combinations, here too the TD values for all classes reached to maximum on 26th December (Table 7).

Classification and accuracy assessment

Ten bands stacked data for each date were used for maximum likelihood classification using training pixels from the reference data. The classification results for selected dates are shown in fig. 2. To perform the quantitative assessment of accuracy, contingency matrix corresponding to each date were created using validation pixel data. Table 8 shows the Overall accuracy (OA) and kappa statistics (k) for each date. Both OA and kappa increases from end of October to end of December after that there were decrease in the accuracies. Kappa showed a maximum value of

Table 7. Class separability using TD taking 4 bands at a time (26th Dec 2018)

	Early wheat	Mid wheat	Late wheat	Desi Gram	Hybrid Gram	Garlic	Potato	Other crops	Fallow	Scrub-land	Settle-ments	Water-bodies
Early Wheat	0											
Mid wheat	1998	0										
Late wheat	1999	1871	0									
Desi Gram	2000	2000	2000	0								
Hybrid Gram	2000	2000	2000	2000	0							
Garlic	2000	2000	2000	2000	2000	0						
Potato	2000	2000	2000	2000	2000	2000	0					
Other crops	1781	2000	2000	2000	2000	2000	2000	0				
Fallow	2000	2000	2000	2000	2000	2000	2000	2000	0			
Scrubland	2000	2000	2000	2000	2000	2000	2000	1873	2000	0		
Settlements	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	0	
Water-bodies	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	0

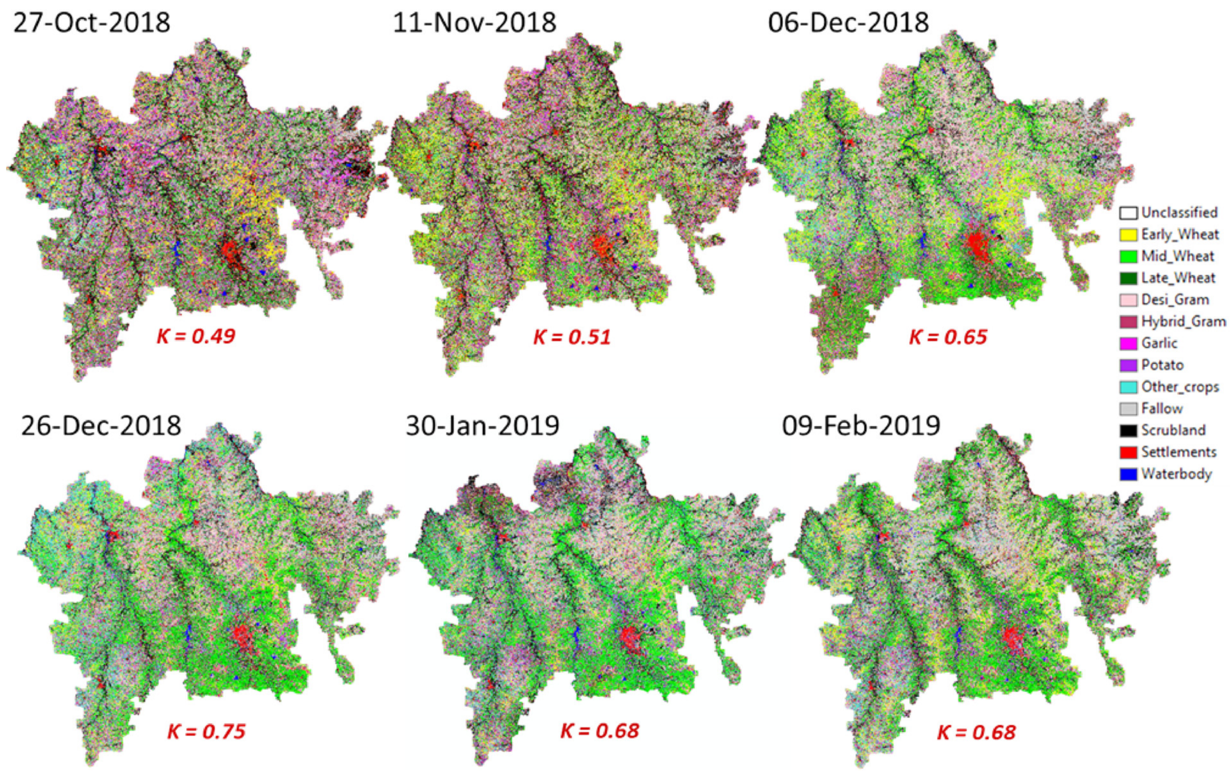

Fig. 2. Classified maps for the selected dates of satellite pass

Table 8. Classification accuracies for each date of classified crop maps (Using validation pixels, N= 865)

Date of Satellite pass	Overall Accuracy	kappa (k)
27-Oct-18	0.53	0.49
11-Nov-18	0.56	0.51
21-Nov-18	0.6	0.56
6-Dec-18	0.69	0.65
26-Dec-18	0.78	0.75
10-Jan-19	0.74	0.7
30-Jan-19	0.73	0.68
9-Feb-19	0.71	0.67
19-Feb-19	0.65	0.59
11-Mar-19	0.59	0.54

0.75 on 26th December which was coincided with the maximum separability between each class. Detailed contingency matrix for the 26th Dec 2018 is presented in Table 9. Most of the crop classes showed the Producers and Users accuracy of more than 75%. The omissions and commissions between three classes of wheat i.e., early, mid and late wheat leads to lowering of kappa. Keeping in view the heterogeneity of the area and the greater number of classes the kappa achieved is quite satisfactory for a local crop map generation.

Conclusions

Classes separability were examined between various crops and landcover classes using 3-band and 4 band combinations of Sentinel-2 data. Best separable band combinations were B4, B8A and B11 on 26th Dec 2018 in 3-band combination while B4, B5, B8A and B11 were the most separable 4-band combination. Classification result showed a trend in increasing accuracies from the start of the season to peak greenness period and declines after that. A height kappa accuracy of 0.75 were achieved through single date classification. The study confirms the band combinations of B4, B5, B8A and B11 during the second fortnight of December can be utilized to generate a significantly accurate in-season crop map.

Table 9. Contingency matrix for the classified map (26^{th} Dec 2018; using validation pixels, N= 865)

Classified	Reference Pixels												
Pixels	Early Wheat	Mid wheat	Late wheat	Desi Gram	Hybrid Gram	Garlic	Potato	Other crops	Fallow	Scrubland	Settlements	Water-bodies	Total	Users accuracy
Early Wheat	67	15	5	1	0	1	0	0	0	0	0	0	89	0.75
Mid wheat	20	176	18	1	0	0	0	3	3	0	0	0	221	0.80
Late wheat	3	35	57	0	0	0	0	0	0	0	0	0	95	0.60
Desi Gram	2	4	1	50	2	0	0	1	4	0	0	0	64	0.78
Hybrid Gram	0	2	0	3	42	1	1	2	1	0	0	1	53	0.79
Garlic	3	0	0	1	0	26	0	0	0	0	0	0	30	0.87
Potato	0	2	0	0	4	0	21	2	0	0	0	0	29	0.72
Other crops	1	5	2	2	7	1	0	40	0	1	0	0	59	0.68
Fallow	5	0	3	1	0	0	0	2	48	1	1	0	61	0.79
Scrubland	0	2	0	0	0	0	0	1	0	46	0	0	49	0.94
Settlements	2	0	0	0	0	0	0	0	4	2	40	4	52	0.77
Waterbodies	0	0	0	0	0	0	0	0	0	0	0	63	63	1.00
Total	103	241	86	59	55	29	22	51	60	50	41	68	865	
Producers accuracy	0.65	0.73	0.66	0.85	0.76	0.90	0.95	0.78	0.80	0.92	0.98	0.93		
Overall accuracy	0.78													
Kappa	0.75													

References

Das, B., Sahoo, R.N., Biswas, A., Pargal, S., Krishna, G., Verma, R., Chinnusamy, V., Sehgal, V.K. and Gupta, V.K. 2020. Discrimination of rice genotypes using field spectroradiometry. *Geocarto Int.* **35**: 64–77. https://doi.org/10.1080/10106049.2018.1506507.

Inglada, J., Arias, M., Tardy, B., Hagolle, O., Valero, S., Morin, D., Dedieu, G., Sepulcre, G., Bontemps, S., Defourny, P. and Koetz, B. 2015. Assessment of an operational system for crop type map production using high temporal and spatial resolution satellite optical imagery. *Remote Sens*. **7**: 12356–12379.

Jensen, J.R. 1996. *Introductory Digital Image Processing: A Remote Sensing Perspective*, 2nd ed.; Prentice Hall: Upper Saddle River, NJ, USA.

Laurin, G.V., Belli, C., Bianconi, R., Laranci, P. and Papale, D. 2018. Early mapping of industrial tomato in Central and Southern Italy with sentinel 2, aerial and RapidEye additional data. *J. Agric. Sci.* **156(3)**: 396-407.

Moody, D.I., Brumby, S.P., Chartrand, R., Keisler, R., Longbotham, N., Mertes, C., Skillman, S.W. and Warren, M.S. 2017. Crop classification using temporal stacks of multispectral satellite imagery. Proceedings of SPIE - *The International Society for Optical Engineering*, vol. 10198.

Neetu, Kumar, Y.P., Chakravarthi, P.K., Yadav, S.K. and Ray, S.S. 2017. Multi-date RISAT-1 FRS 2 quad polarization data analysis for various crop discrimination. *Journal of Agricultural physics* **179(1)**: 123-128.

Prishchepov, A.V., Radeloff, V.C., Dubinin, M. and Alcantara, C. 2012. The effect of Landsat ETM/ETM+ image acquisition dates on the detection of agricultural land abandonment in Eastern Europe. *Remote Sens. Environ.* **126**: 195–209.

Simmons, A., Fellous, J.-L., Ramaswamy, V., Trenberth, K., Asrar, G., Balmaseda, M., Burrows, J.P., Ciais, P., Drinkwater, M., Friedlingstein, P., Gobron, N., Guilyardi, E., Halpern, D., Heimann, M., Johannessen, J., Levelt, P.F., Lopez-Baeza, E., Penner, J., Scholes, R. and Shepherd, T. 2016. Observation and integrated earth-system science: a roadmap for 2016–2025. *Adv. Space Res.* **57**(10): 2037–2103.

Van Niel, T.G. and McVicar, T.R. 2004. Determining temporal windows for crop discrimination with remote sensing: a case study in south-eastern Australia. *Comput. Electron. Agric.* **45**(1–3): 91-108.

Zhang, X., Sun, Y., Shang, K., Zhang, L. and Wang, S. 2016. Crop classification based on feature band set construction and object-oriented approach using hyperspectral images. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* **9**(9): 74117-4128.

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