

Using MOD09 Data to Produce a Natural-color Image from the Blue-lacked Multispectral Remote Sensing Data

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Abstract

Because of atmospheric effects, some satellite sensors cover only two visual spectral bands (green and red bands) in addition to bands in the near-infrared to thermal-infrared regions, and lack a blue band. As a result, a natural-color image cannot be obtained, as the blue band is necessary in combining red, green, and blue to produce natural color. This greatly affects the application of remote sensing in many areas such as virtual reality, terrain simulation, and visual interpretation. In this study, the MODIS land surface product (MOD09) was used as reference imagery from which to select pixel samples, and a non-linear regression analysis model—a back-propagation artificial neural network (BPN)—was used to fit the spectral reflectance relationship among the blue band and red, green, and near-infrared bands. Landsat TM/MSS, ZY1-02C and SPOT blue bands were then simulated with the trained fitting model, and a natural-color image was output. The experiment result shows that the MOD09 samples trained BPN model well simulated the blue band of a multispectral image and even more informative blue band, more importantly; it can eliminate the influence of the atmospheric for the blue band to some degree. With the simulated blue band, a more realistic and informative natural-color image was acquired.

Keywords: Natural-color; MOD09; Spectral fitting; SPOT; ZY1-02C

Introduction

In Satellite sensors imaging process, the reflected electromagnetic signal passes through the atmosphere twice and is greatly affected by the atmosphere. However, the shorter-wavelength blue band suffers more from Rayleigh scattering than other visual bands. Rayleigh scattering is the main cause of radiation distortion and image blurring in remote-sensing imagery, reducing the clarity and contrast of the image [1]. Because it is difficult to obtain large amounts of information in the blue band and because of the effect on the quality of remote-sensing imagery, a number of satellite sensors (e.g., MSS, SPOT, Aster, IRS-P6, ZY1-02C) do not make observations in the blue band. Despite much information being contained in the other image bands, however, a natural-color image cannot be created without the blue band, which greatly limits the application of imagery in terrain simulation, virtual reality, mapping, graphics, non-professional image interpretation, and so forth. Therefore, it is necessary to simulate a natural-color image from existing remote-sensing data to expand the application of remote-sensing data.

Multispectral remote sensing image reflects the ground targets response to different wavelengths of the electromagnetic wave. To be sure that the same ground targets with the same image band relations, while, the different ground targets image's band relationship is not necessarily the same. There is a complex relationship among the spectral reflectance bands of the remote sensing image which formed by variety of ground objects. The main idea in simulating a natural-color image is to fully determine and use a true spectral band relationship. Because too simple describes the relationship of the remote sensing bands, the linear model is difficult to obtain good simulation results [2-5]. Even nonlinear models also were used by some scholars to fit the relationship between remote sensing bands and then simulate blue band, however, due to the samples used to train the model often are inconsistent with the target image in imaging time, the trained model is also difficult to be used for target image's band fitting [6-10].

In addition to these methods, much commercial software has been developed to provide special models to solve various problems in the simulation of natural-color images. For example, the Nature Color

model for ERDAS imagery [11] and Spectral Transformer Fc2Tc-CIR [12] can simulate natural color with the input of an {NIR, red, green}-band composite image. Additionally, Pixel Factory [13] software can carry out natural-color simulation of SPOT imagery. Especially, Spectral Transformer B742B321 [12], Terra Color [14], and Natural Hue [15] software can carry out natural-color simulation of Geocover imagery.

It can be seen that the key of high quality band simulation and natural-color image synthesis includes two aspects: the nonlinear fitting model and the samples that consistent with the target image in time and space. In this study, we use the MODIS surface spectral reflectance product (MOD09) as the reference image to select samples, and then train the BPN non-linear regression fitting model, and finally simulate the natural color of target multispectral image. There are two reasons for selecting the MOD09 image as the reference image. Firstly, the MODIS sensor observes the Earth with high temporal resolution (daily data are available); although there are some poor-quality images, much data can be used. Secondly, the MOD09 data is well corrected for the effects of atmospheric gases, aerosols, and thin cirrus clouds as if there was no atmospheric scattering or absorption. Therefore, MOD09 describes the true relative relationship among bands for ground objects, allowing for the development of a more effective regression fitting model.

Methodology

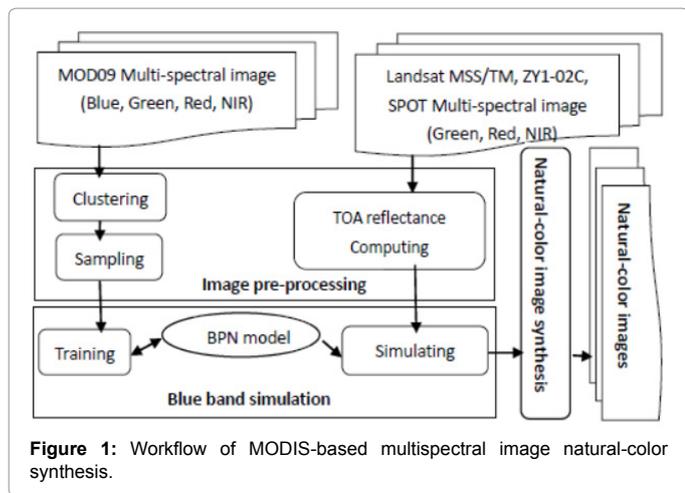
There are two steps to our work. The first is sampling the MODIS image and training the fitting model, and the second is simulating the Landsat

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TM/MSS, ZY1-02C and SPOT5 blue-band images, and then synthesizing the natural-color image. The workflow is described in Figure 1.

Image Pre-processing

In the image pre-processing step, besides common pre-processes such as re-projection, mosaicing, sub setting and data-type conversion, the MODIS image was clustered on the basis of its spectral character and the pixel sample was then collected. The spectral-band relationships differ for different ground objects. Therefore, the image pixels were firstly clustered before sampling, and clusters were sampled separately. For each cluster, the sampling was random.

Another task that needs to be carried out in the image pre-processing step is top-of-atmosphere (TOA) reflectance calculation for the target image. The TOA reflectance needs to be calculated to determine the true spectral relationship of the heterogeneous image. There are two steps to the TOA reflectance calculation: conversion to at-sensor radiance and conversion to TOA reflectance. The calculation method employed here was presented in detail [16].

Blue-band simulation

The most important step in natural-color simulation is to simulate the atmosphere-affected or lacking blue band. There are two sub-steps in blue-band simulation: training of the spectral fitting model and simulation with the model. Spectral fitting models describe the relationship between the target variant and input variant by training with a group of {input ->target} pair samples. The predicted value is thus obtained from the new input variant value. As stated earlier, the nonlinear fitting model and the samples that consistent with the target image in time and space are two key factors for high quality band simulation. In the study, the BPN non-linear regression model was used as fitting model, and three {green, red, NIR} MOD09 bands was used as the input variant and the MOD09 {blue} band as the target variant to train the fitting model, and then the {blue} band of the multispectral image was predicted from the input {green, red, NIR} bands.

In the case of our MOD09 {{green, red, NIR} -> {blue}} pixel samples, the three-layer BPN structure is shown in Figure 2. After sampling, the sample pair array {{red, green, NIR} -> {blue}} was input into the BPN fitting model. After training, a model that described the relationship between {red, green, NIR} and {blue} spectral bands was output. With the trained BPN fitting model, the blue band of the multispectral image obtained from other sensors could be simulated with their {red, green, NIR} band reflectance values [17].

Natural-color image synthesis

With the simulated blue band and existing green and red bands, a natural-color image can be synthesized. However, the synthesized natural-color image is always too dark or too bright owing to the effect of abnormal pixels. Additionally, the image pixel values are always concentrated in a relatively narrow range, which leads to lower contrast in the image. Therefore, further adjustment of the brightness and contrast of the synthesized natural-color image is required. Furthermore, we used the TOA reflectance of the target image instead of the atmosphere-calibrated value to simulate the blue band. Although atmospheric effects on the {green, red, NIR} bands are small, their atmosphere-influenced pixel values can be used to simulate the atmosphere-influenced blue-band pixel value. The different degrees of the atmospheric effect on the {red, green, blue} bands lead to a weak visual effect in the natural-color image, and the {red, green, blue} channels were thus adjusted separately in this study. Applying these post-process, a highly realistic natural-color image can be produced.

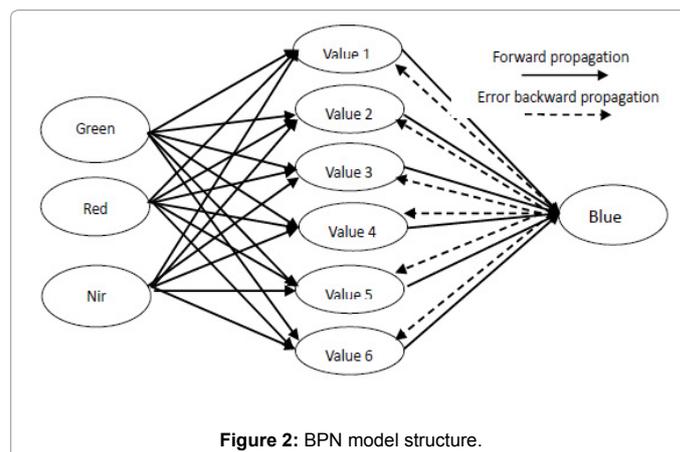
Experiment Results and Analysis

Data

The proposed method relies more on the time of image acquisition the composition of ground objects, and is independent of the specific study area. In this study, we took Xi shuang banna autonomous prefecture of Yunnan province as study area, and the MOD09, Landsat MSS, Landsat TM, ZY1-02C and SPOT sensor image data were selected for testing, as they have similar band settings (Table 1). Detailed information about these images is given in Table 2. The MOD09 image is already a reflectance product, and the Landsat MSS/TM, ZY1-02C, and SPOT5 images are reflectance products calculated with ENVI 5.1 software.

MOD09 natural-color image simulation

The pixels in the MOD09 image were clustered and more than



Correlation	Band 1 (Red)	Band 2 (NIR)	Band 3 (Blue)	Band 4 (Green)	Band 5	Band 6	Band 7
Band 1	1	0.76	0.88	0.95	0.12	0.47	0.27
Band 2	0.76	1	0.57	0.64	0.23	0.63	0.42
Band 3	0.88	0.57	1	0.97	0.03	0.06	0.03
Band 4	0.95	0.64	0.97	1	0.07	0.22	0.08
Band 5	0.12	0.23	0.03	0.07	1	0.24	0.15
Band 6	0.47	0.63	0.06	0.22	0.24	1	0.54
Band 7	0.27	0.42	0.03	0.08	0.15	0.54	1

Table 1: MODIS image band correlations.

Sensor Band	Landsat TM	SPOT-5	Landsat2 MSS	ZY1-02C	MODIS
Blue	0.452–0.518 (0.485)	–	–	–	0.459–0.479 (0.469)
Green	0.528–0.609 (0.569)	0.50–0.59 (0.545)	0.497–0.598 (0.548)	0.52–0.59(0.55)	0.545–0.565 (0.555)
Red	0.626–0.693 (0.660)	0.61–0.68 (0.645)	0.607–0.710 (0.659)	0.63–0.69(0.66)	0.620–0.670 (0.635)
NIR	0.776–0.904 (0.840)	0.78–0.89 (0.835)	0.697–0.802 (0.750)	0.77–0.89(0.83)	0.841–0.876 (0.858)
			0.807–0.990 (0.899)		

Table 2: Summary of the band settings and acquisition times for the test data.

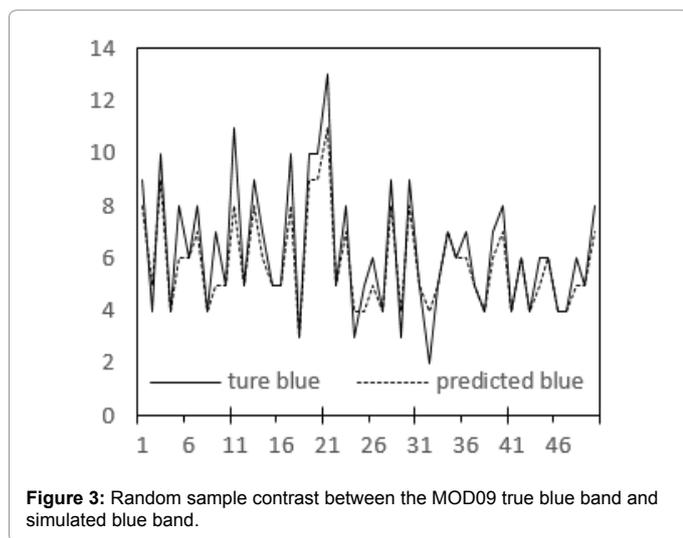


Figure 3: Random sample contrast between the MOD09 true blue band and simulated blue band.

Reference MOD09 Images		Target Images		
Date	H/V	Date	Path/Row	Sensor Type
2009-02-10	27/04	2009.02.11	130/045	Landsat5 TM
2009-02-10	27/04	1973.02.13	140/045	Landsat2 MSS
2009-02-10	27/04	2009.02.10	259/306	SPOT5 HRG2
2009-02-10	27/04	2013.02.07	\	ZY1-02C
2009-11-09	27/04	2009.11.06	260/307	SPOT5 HRG2

Table 3: Summary of the test image data.

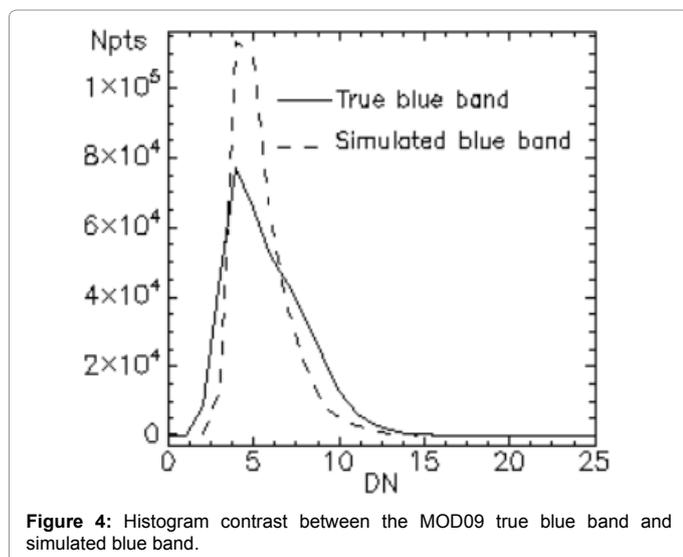


Figure 4: Histogram contrast between the MOD09 true blue band and simulated blue band.

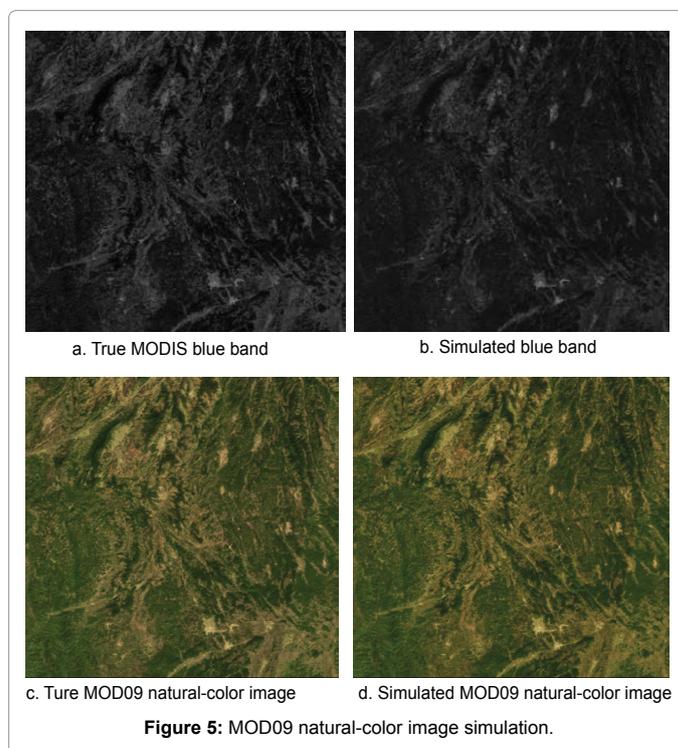


Figure 5: MOD09 natural-color image simulation.

3000 samples collected to train the BPN model. Before target-image simulation, we firstly simulated the reference MOD09 image itself to verify the effectiveness of the model. The BPN models were trained with these samples, the blue band was predicted, and a natural-color image was produced. Both the random-sample contrast and histogram contrast between the true blue band and simulated blue band show that the BPN model well fitted the spectral band relationship between {green, red, NIR} and {blue} bands and produced a nearly true blue band (Figures 3 and 4). The statistics show that the true blue band and the simulated blue band have a high correlation value (0.946, Table 3). Figure 5 also shows that in terms of both the separate blue-band comparison and natural-color image comparison, the true blue band and simulated blue band and their natural-color images are almost

--	Min	Max	Mean	Stdev	Correlation
True-Blue	0	25	5.76	2.32	0.946
Simu-Blue	2	38	5.42	1.72	

Table 4: Statistics of the MOD09 true blue band and simulated blue band.

the same visually. However, Table 4 shows that the simulated blue band has a standard deviation lower than that of the true blue band; Figure 4 shows that the pixels of the simulated blue band distribution more concentrated; Figure 5 also shows that simulated blue band and corresponding natural color image has a relative lower contrast. These result indicate that even though the simulated blue band close to the true blue band to some extent, the amount of information still not good as true blue band.

TM natural-color image simulation

The Landsat TM blue band is seriously affected by the atmosphere.

In this experiment, the TOA-calibrated TM {green, red, NIR} bands were used to predict the blue band employing the BPN fitting model trained with the corresponding MOD09 image samples. Table 5 shows that the simulated blue bands have higher standard deviation than the corresponding primary blue band, and that the simulations correlate well with the corresponding primary blue band. As mentioned above, the shorter wavelength blue band suffer more Rayleigh scattering than other band. With the {Green, Red, NIR} bands that less affected by the atmosphere, the blue band that less affected by the atmosphere also

--	Min	Max	Mean	Stdev	Correlation
True-blue band	1	112	25.46	5.08	0.90
Simulated-blue band	2	236	8.87	9.64	

Table 5: Statistics of the TM true blue band and simulated blue band.

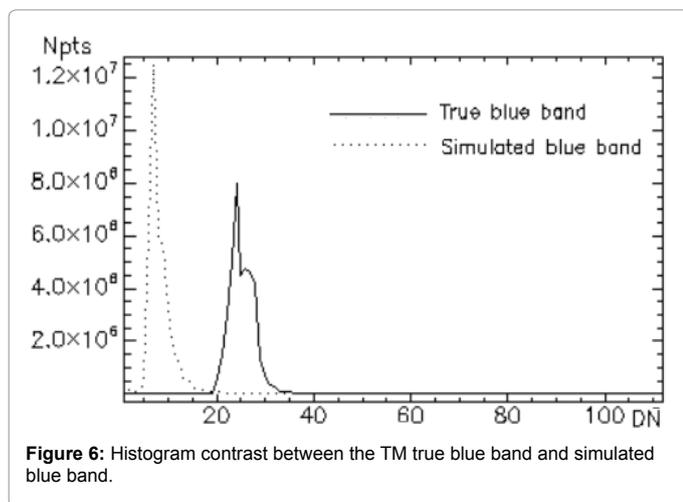


Figure 6: Histogram contrast between the TM true blue band and simulated blue band.

should be simulated. From Figure 6, it can be found that the histogram of the simulated blue band move to left in a whole, since the simulated blue band weakened the atmosphere effect.

Figure 7 shows the visual contrast of the different natural-color images. Figure 6a,6b) contrast the primary natural-color image composited from the TOA reflectance blue band and the natural-color image composited from the simulated blue band. The primary image with the seriously atmosphere affected blue band has lower contrast, and seems to be covered with a thin blue film on the whole. But the simulated natural-color image with the higher contrast seems more natural than the primary image. Figure 6c-6h shows that no matter bared land, forest, farmland, and even city in simulated natural color image seems better than that of the true color image visually. Figure 6c and 6d show some difference for the water body, with the latter being a greener than the former visually.

Landsat MSS, ZY1-02C and SPOT5 blue bands and natural-color image simulations

The Landsat MSS has two NIR bands (Table 1), and here we select the one with a central wavelength (0.899 μm) nearest that of the MODIS NIR band. After calculation of TOA reflectance, the MSS, ZY1-02C and SPOT5 {green, red, NIR} bands were input into the corresponding MOD09-trained fitting model, and the predicted blue band and final natural-color image were thus obtained. Figures 8-10 show that the MSS, ZY1-02C and SPOT simulation results appear natural overall visually.

Conclusion

Our approach describes a complex relationship among image bands using quantitative spectrum-fitting analysis with nonlinear BPN regression models. Experiments demonstrate that the blue band and a highly realistic natural-color image can be produced with the

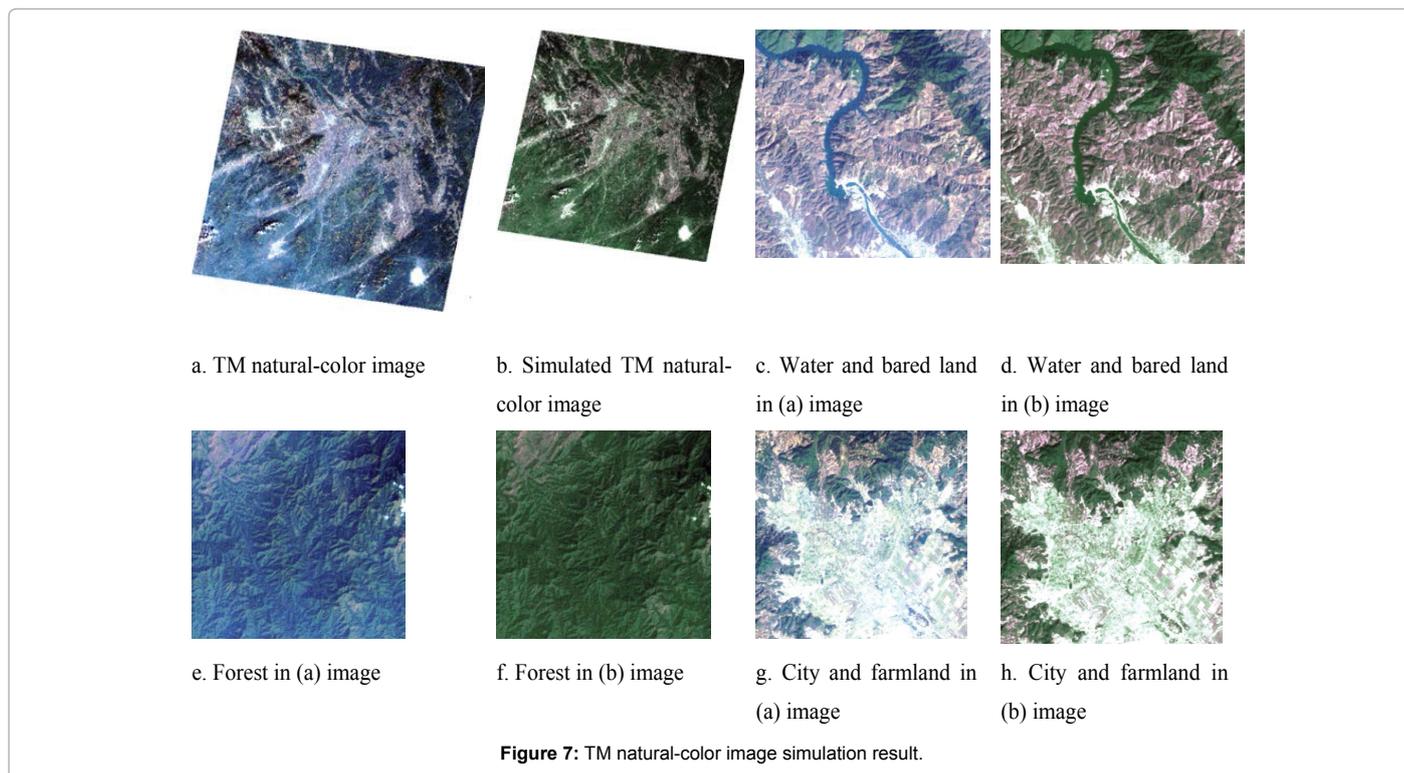


Figure 7: TM natural-color image simulation result.

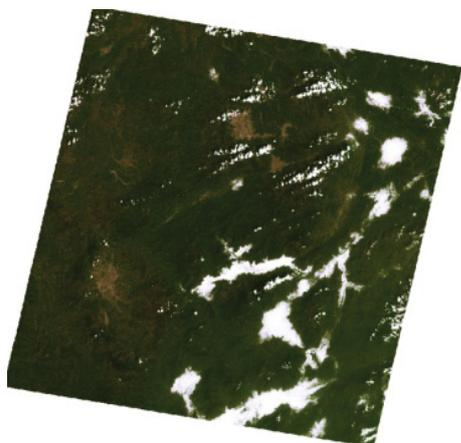


Figure 8: MSS natural-color image simulation.



Figure 9: ZY1-02C natural-color image simulation.

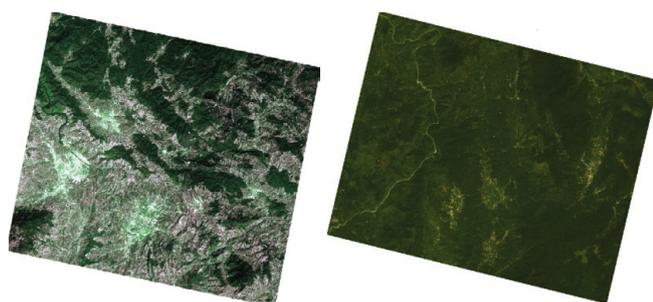


Figure 10: SPOT natural-color image simulation.

MOD09 samples trained BPN spectral fitting model. In this study, we used TOA-calibrated {green, red, NIR} bands to predict the blue band, and ignored the atmospheric influence. Experiments demonstrated the higher quality of simulated blue band and natural-color images could be obtained with the less atmosphere affected {Green, Red, NIR} TOA reflectance and the MOD09 trained BPN model, and thus, only the TOA reflectance calculation and not the complex atmospheric calibration is required. In future work, using “band-to-band” relative radiation calibration with the MODIS image to calibrate {green, red, NIR} bands, a truer blue band should be predicted. This study helps

extend the application of “image-to-image” cross-spectral fitting. Using the complement of multi-source imagery, we can expand spatial, spectral, and temporal dimensions to some degree.

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