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Nonlinear Spectral Mixture Effects for PV/NPV Cover Estimates of Typical Desert Vegetation in Western China

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Project Background

Project: Land degradation surveillance of drylands in China（ID. 32396)

Sub-project 1: Retrieval of vegetation and soil properties using multi-source optical remote sensing in drylands

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- to develop based on remote sensind data techniques and methods to retrieve vegetation bio-physical variables(PV/NPV fractional cover and NPP) in drylands at local and regional scale;
- to improve the accuracy of estimated soil properties (Soil organic matter and soil texture) based on field spectroscopy and to evaluate the potential to upscale the derived relationships in drylands at the local scale;
- to establish a relationship between PV/NPV degradation and SOM for major vegetation types in drylands.

Outline

1. Introduction
2. Study area and data acquisition
3. Methods
4. Results
5. Conclusions and discussions

Introduction

- Drylands occupy 41% of the world's whole land area.Oases are the basis of human life and social economic development, supporting more than 95% of the population.
- Desert vegetation between oasis and desert is very important, which functions as a shelter against drifting sand, and also a major food source for animals.
- A sustainable management of desert vegetation requires accurate and timely information on vegetation cover at large scale.

Introduction

- Remote sensing offers a unique opportunity for the retrieval at large scale. SMA (LSMM) was the most widely used method with the advantage of yielding clear physical interpretations and easy computations.
- However, to what extent will the linear mixture assumption lead to the errors in fpv and fnpv estimation, are the nonlinear mixture effects consistent among different desert vegetation types remains unclear.
- Therefore, investigating the nonlinear mixing effects of typical desert vegetation types has great value for improving the fpv and fnpv estimation accuracy.

Introduction

- The previous studies show that LSMMs tend to work well because plants are widely separated and thus the area of scattering is well localized covering a small area in sparsely vegetated arid regions. These results are not appropriate for retrieving PV and NPV separately for desert vegetation, where the vegetation canopy is open, PV and NPV grow closely together.
- Hence, the present study aims at investigating the nonlinear spectral mixture effects through comparing the performance of LSMM and Nonlinear Spectral Mixture Model (NSMM) for retrieving f_{pv} and f_{npv}.

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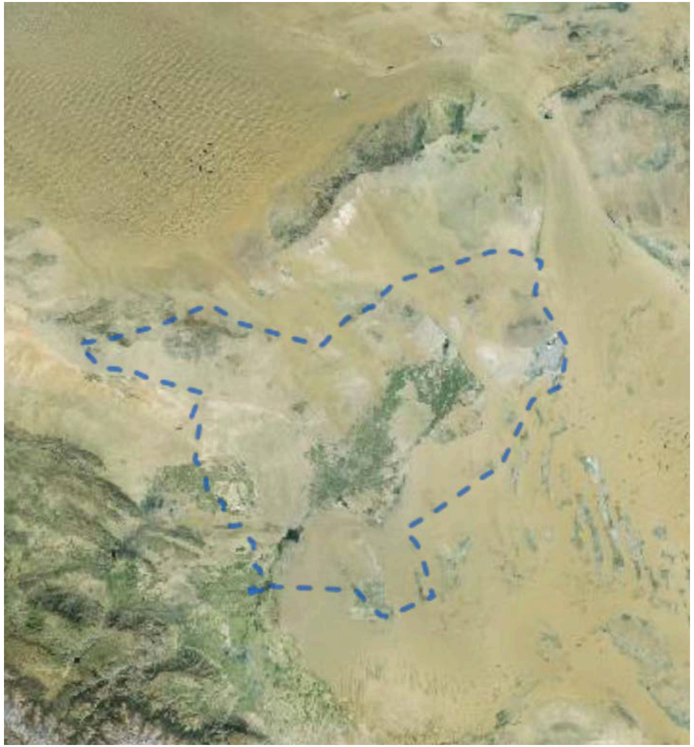
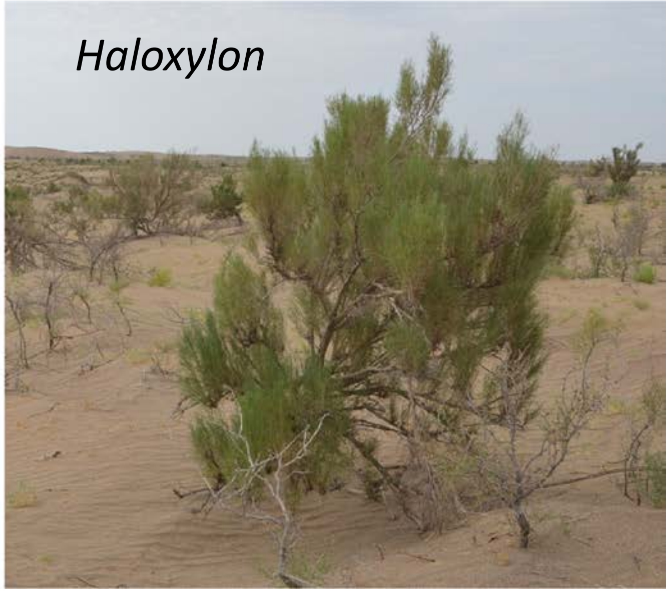
Study area

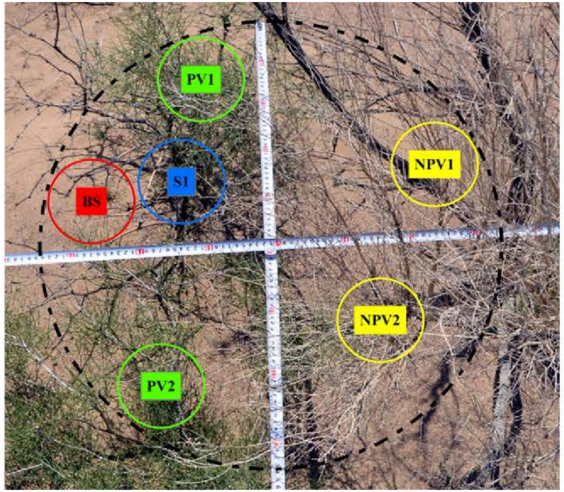
- The study area is located at the transitional zone between the oasis and the desert in the western region of Minqin County in the Gansu province.
- The natural vegetation is mainly desert vegetation. A key characteristic of the desert vegetation is that it contains few species, and only a few layers are present with a simple structure and low productivity.

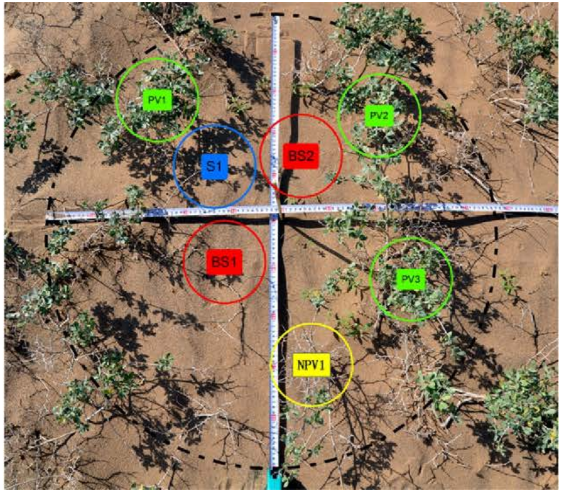


Selected desert vegetation



Spectra measurement

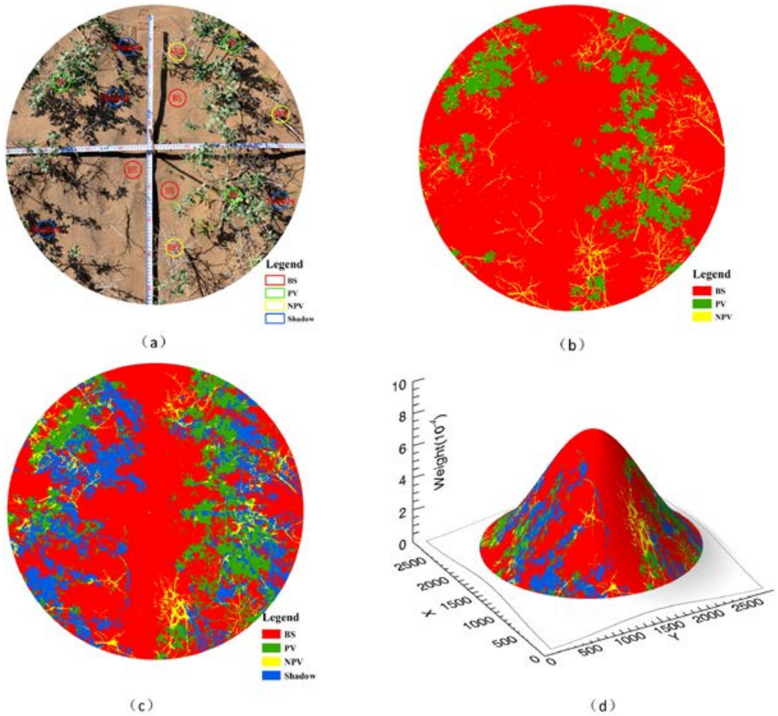




- Acquired on August, 2014, with a 25° ASD Field spectrometer
- Canopy and pure endmembers spectra for 20 *Nitraria* and 20 *Haloxylon* plots

Reference fraction

- Information on the ground cover composition of each of the measured mixed pixels was extracted from the digital photographs (positioned at nadir).
- The PSF is the Gaussian function, measurements closer to the center of the FOV will contribute more to the mixed reflectance signal.
- 3EM, 4EM, 2 scenarios considered.



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LSMM VS NLSMM

- **LSMM**

Reflectance of a pixel is assumed to be a linear combination of the reflectance of the spectra of the EMs, weighted by their fractional cover. Fully constrained least squares (FCLS) was used to retrieve the fraction.

$$f_{FCLS} = (M^T M)^{-1} M^T F - (M^T M)^{-1} \lambda$$

$$\lambda = M^T (F - M f_{FCLS})$$

LSMM VS NLSMM

- **NLSMM**

➢ **Bilinear Spectral Mixture Model**

- BSMMaccount for the presence of multiple photon interactions by introducing additional “interaction virtual” terms in the LSMM.
- Nascimento Model without considering higher-order multiple scattering, i.e., we only considered the second order between endmembers and PV/NPV themselves as scattering.

$$R_i = \sum_{j=1}^{m} (f_j W_{i,j}) + \sum_{j=1}^{m} \sum_{t=1}^{m} (f_{j,t} W_{i,j} W_{i,t}) + \varepsilon_i$$

$$f_j = f_j^{(1)} \Big/ \left(1 - \sum_{t=1}^{n} f_{j,t}^{(2)}\right)$$

LSMM VS NLSMM

■ NLSMM

➢ Kernel-Based Nonlinear Spectral Mixture Model

Principle of the KNSMM is data from the input space are mapped to the high dimensional feature space, with the nonlinear mapping, thus the nonlinear relationship is transformed into a linear one.

- radial basis function (RBF) kernel
- polynomial kernel function (PKF)

The optimal parameters in the RBF and PKF are determined by the minimum model unmixing RMSE.

LSMM VS NLSMM

- **NLSMM**

➢ **Kernel-Based Nonlinear Spectral Mixture Model**

KFCLS was used to invert the equation.

$$f_{KFCLS} = (K(M,M))^{-1}K(M,F) - (K(M,M))^{-1}\lambda_{KFCLS}$$

$$\lambda_{KFCLS} = K(M,F) - K(M,M)f_{KFCLS})$$

Accuracy assessment

$$RMSE = \sqrt{\sum_{i=1}^{n}\left(x_i - y_i\right)^2 \Big/ n}$$

$$R^2 = \frac{\left(\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})\right)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}$$

$$RRMSE = \sqrt{\left(\sum_{i=1}^{n}\left(x_i - y_i\right)^2 \Big/ n\right)} \Big/ \bar{y} * 100\%$$

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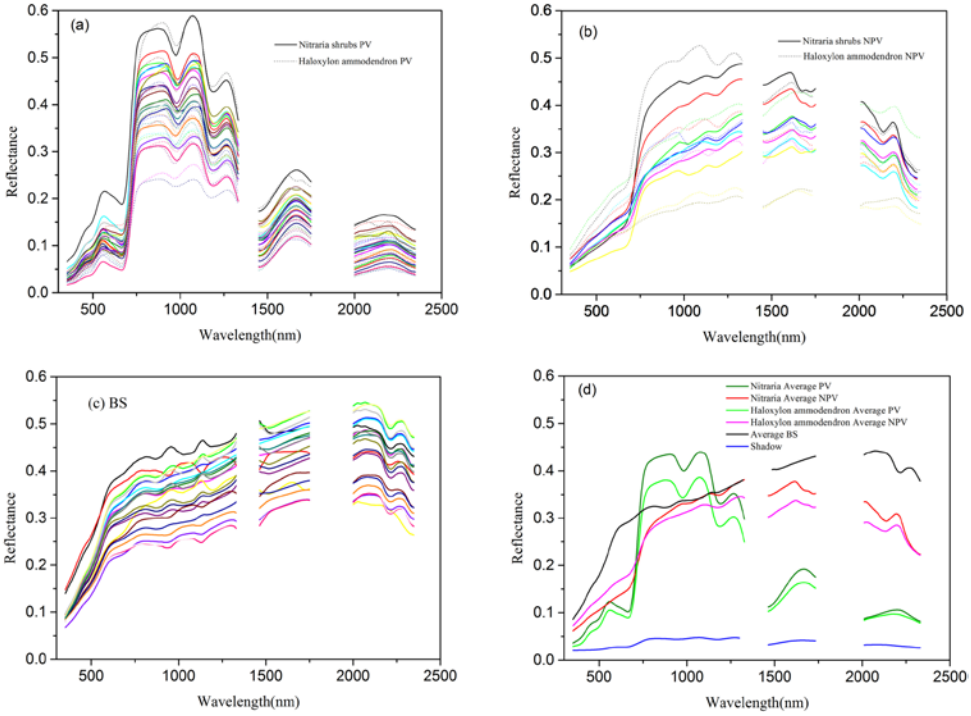
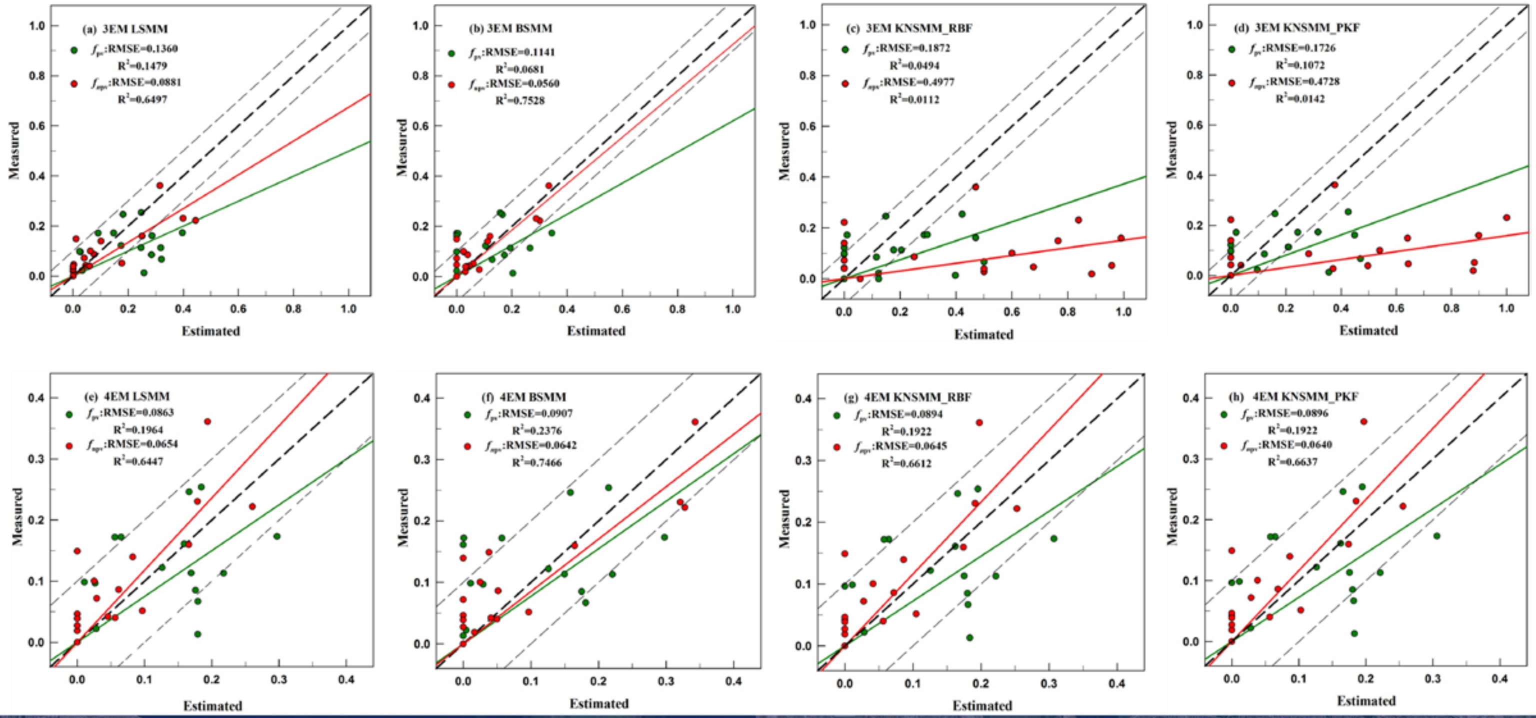
Spectral Characteristics of Endmembers

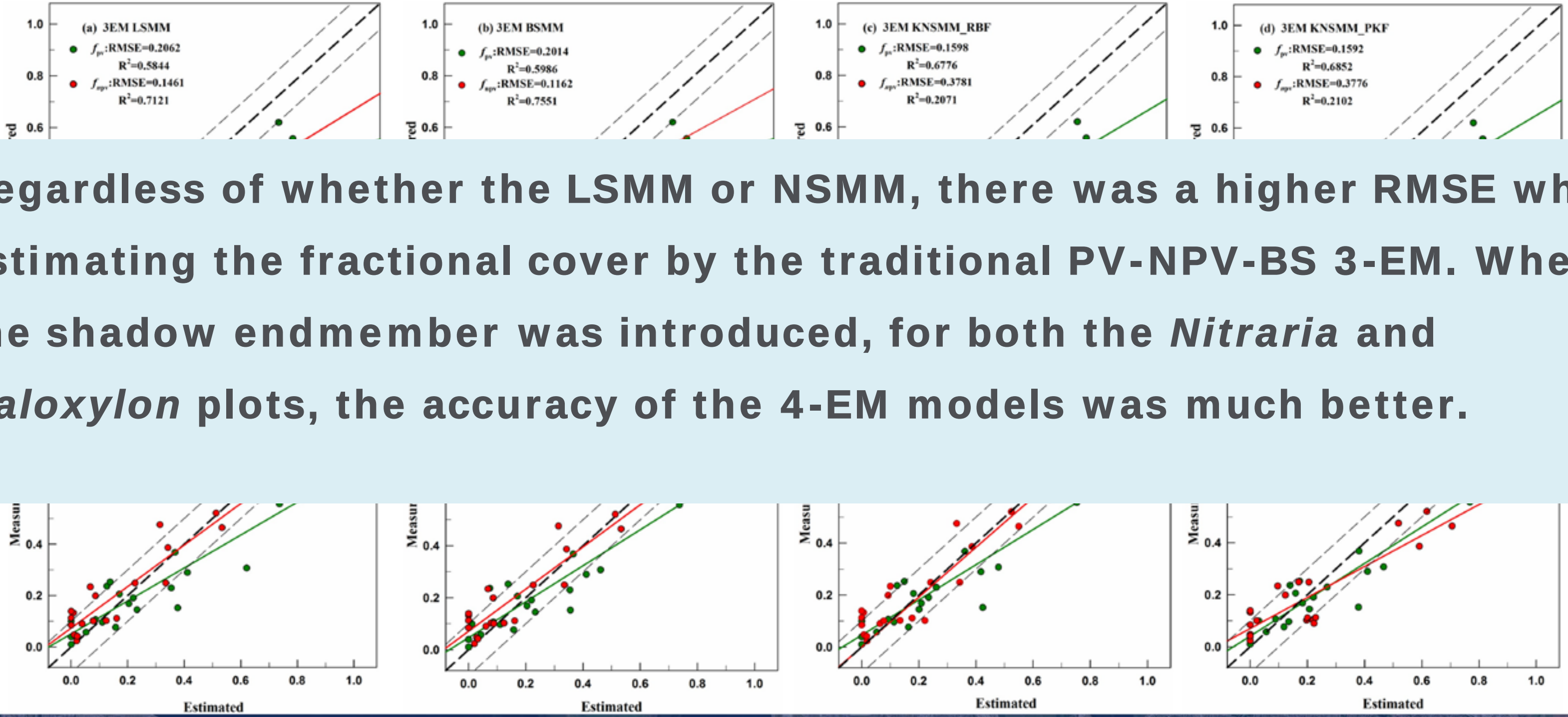
- Due to the diverse endmember forms, the endmember libraries show large intra-variability at the full wavelength range .
- PV display obvious differences in reflectance between red and near infrared reflectance, the spectra curve of the NPV endmember was different from BS in two narrow ranges, namely, 500–900 nm and around 2100 nm.



Effects of Endmember Selection(*Nitraria*)



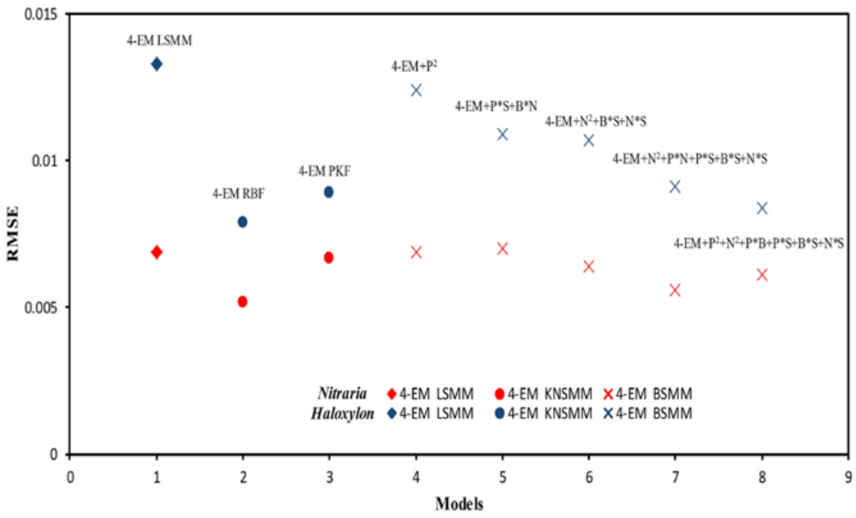
Effects of Endmember Selection(*Haloxylon*)



Regardless of whether the LSMM or NSMM, there was a higher RMSE when estimating the fractional cover by the traditional PV-NPV-BS 3-EM. When the shadow endmember was introduced, for both the *Nitraria* and *Haloxylon* plots, the accuracy of the 4-EM models was much better.

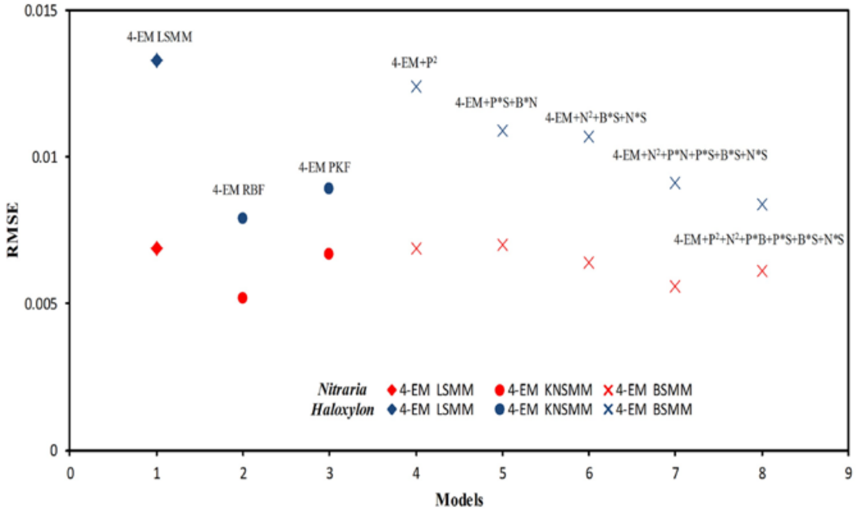
Nonlinear Spectral Mixture Effects Analysis

- For the BSMM, when the virtual terms were included, the precision of f_{pv} and f_{npv} estimation was improved, when compared to the LSMM.
- The effect of self-high-order scattering was not obvious in *Nitraria* shrubs plots, while it was slightly obvious in the *Haloxylon* plots.



Nonlinear Spectral Mixture Effects Analysis

- With the KNSMM(RBF or PKF kernel function), the model error were lower than those of the LSMM and BSMM for both vegetation types.
- For the effects of different kernel, the RBF kernel function with the NSMM was more reliable than the PKF kernel.



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Discussions

- BSMM could yield clear physical interpretations ,but suffered from over-fitting, collinearity of virtual EMs, especially, the appropriate construction of the virtual multiple photon scattering terms.
- KNSMM improved obviously compared to BSMM, especially for *Haloxylon* vegetation. However, more cautions should be given to the application of KNSMMs, since the appropriate selection of kernel functions and its parameters would play a great influence over the results.
- In spite of the NSMMs' relative better performance, LSMMs still could be applied when the non-linear spectral mixing effects was not obviously, with its incomparable advantages of simple computation and definite physical meaning results.

Discussions

- There was no consensus on whether shadows should be included or not in unmixing the mixed spectra.
- In this study, the shadow endmember could not be neglected for unmixing the desert vegetation spectra at the plot scale.
- It was worth noting the variations of the shadow endmembers were not taken into account in this study. However, the darkness differences between shadowed leaves and shaded soil in different time and place, had been found affecting the mixed spectra seriously, which should be addressed in the next step.

Discussions

- Multiple photon scattering process was comparatively more likely to happen in the *Haloxylon* plots than in the *Nitraria* shrub plots. According to the BSMM results, the spectral multiple photon scattering processes mainly occurred between PV and NPV, which means that the canopy structure is one of the primarily factors for the photon non-linear scattering.
- For the two selected desert vegetation type, *Nitraria* shrubs presents planophile canopy, characterized by short height, sparse leaf, which tends to decrease the chance of multiple photon scattering in the canopy. Instead, *Haloxylon* shows erectophile plants canopy characterized by higher height, dense and needle leaf, which is more prone to multiple photon scattering.

Conclusions

- Shadows should not be neglected. The 4-EM models, including the shadow endmember, could effectively improve the model unmixing accuracy. Therefore, the correctness of the selection of the endmembers plays a significant role in improving the unmixing accuracy.
- Generally, NSMMs work better than LSMM, which means that the non-linear mixing effects do exist in desert vegetation. For the performance of NSMMs in *Haloxylon* plots, KNSMMs are obviously better than BSMMs.
- The non-linear mixing effects are closely related to the plant canopy structure, whose strength is greater in vegetation with electrophile canopy (Haloxylon) than with planophile canopy (Nitraria shrubs).
- Considering computational complexity and accuracy requirements, the LSMM may be adopted to *Nitraria* shrubs plots for estimating f_{pv} and f_{npv}, but, for *Haloxylon* plots, NSMMs should be used to deal with the obvious non-linear mixing effects.


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THANKS FOR YOUR ATTENTION!