Comparative Analysis of the Difference of the Vegetation Indexes between FY-3A/VIRR, FY-3A/MERSI and Terra/MODIS data

M.X. Ge
*College of Computer Science and Technology, Chongqing University of Posts and Telecommunications, Chongqing, China*

*Chinese Academy of Sciences Institute of Remote Sensing and Digital Earth State Key Laboratory of Remote Sensing, Beijing, China*

J. Zhao
*College of Computer Science and Technology, Chongqing University of Posts and Telecommunications, Chongqing, China*

B. Zhong & A.X. Yang
*Chinese Academy of Sciences Institute of Remote Sensing and Digital Earth State Key Laboratory of Remote Sensing, Beijing, China*

ABSTRACT: In order to demonstrate the feasibility of cooperative inversion of the vegetation indexes between FY-3A/VIRR, FY-3A/MERSI and Terra/MODIS, the NDVI from these data was compared. The authors selected 2012 year’s data of FY-3A/VIRR, FY-3A/MERSI and Terra/MODIS which is covering the upstream of the Heihe and less cloudiness. The statistical method was used to study correlation of NDVI from the selected data. The result shows that there are significant correlations of NDVI from the data of FY-3A/VIRR, FY-3A/MERSI and Terra/MODIS, and all the correlation coefficients exceeded 0.99. But significant differences are also exist between these data. The causes of NDVI differences were analyzed in detail, and found that spectral response function and radiometric calibration have a certain impact on vegetation index. These analyzes can provide a reference for cooperative inversion of multi-source remote sensing data.

KEYWORD: FY-3A/VIRR; FY-3A/MERSI; Terra/MODIS; NDVI; Comparative analysis; Cooperative inversion; The cause of difference

1 INTRODUCTION

FY-3A was launched from Taiyuan in Shanxi Province on 27 May 2008, which is the second generation polar-orbiting meteorological satellite series of China. It is to provide three-dimensional, quantitative, multi-spectrum global remote sensing data under global, all weather conditions, and all time conditions of continuous observation (Gallok et al, 2005). There are 11 observation instruments aboard this satellite. The visible and infrared radiometer (VIRR) is inherited observation instrument, and the medium resolution spectral imager (MERSI) is the first time aboard the satellite (Jun, 2009). Terra was launched on 18 December 1999, which is in a series of satellites among earth observing system, and it is a morning satellite. The satellite has carried a moderate resolution imaging spectrometer (MODIS). MODIS used on-orbit calibration, and it has stable performance and good calibration. MODIS has used to long-term observe the surface, biosphere, the solid Earth, atmosphere and oceans. Vegetation plays an important role in the Earth's ecosystems, and it is an important indicator of the environmental impact produced by climatic and human factors. Vegetation index is an important parameter to describe the characteristics of vegetation (Kaufman Y J et al, 1992), and long time series of vegetation index plays an important role in the terrestrial ecosystem monitoring and modeling. Normalized difference vegetation index (NDVI) is one of the more commonly used vegetation index. In order to promote the construction of FY-3A application system, and provide a reference for the application of multi-source remote sensing data, the authors compared NDVI of FY-3A/VIRR, FY-3A/MERSI and Terra/MODIS, and analyzed the causes of NDVI differences from these data in detail.

2 METHODOLOGY

2.1 Study area and data source

The study area is near the upstream of the Heihe Watershed. Its latitude and longitude are E100°15'-100°45', 38°45'-39°5'. The land use type is mainly for arable land. The L1 data products of FY-3A/VIRR and FY-3A/MERSI are provided by the National Satellite Meteorological Center site. The data of Terra/MODIS is Level 1B MOD021KM data products and its corresponding geographic coordinates MOD03 data products are produced by NASA Data Archive Center site. MOD021KM data products as for earth observation data is corrected 1km
resolution, including the re-sampled band (Tomoaki M. 2000), such as the 250m and 500m data. Those data products are less cloudiness data which covering the upstream of the Heihe Watershed transiting on the same day. The time span is from the January 2012 to December 2012, which can ensure the impact of the atmospheric conditions (Xueyi Z. 2009), solar elevation angle and solar azimuth angle are basically the same on the selected data. The spectral range of FY-3A/VIRR is 0.43 ~ 12.5 μm. It has 10 channels. The scan range is ± 55.4 °. The ground resolution is 1.1Km. The spectral range of FY-3A/MERSI is 0.41 ~ 12.5 μm, which has 20 channels. The scanning range is ± 55.4 °. The ground resolution is 250m and 1000m. The spectral range of Terra/MODIS is 0.4 ~ 14μm, which has 36 channels. The spectral range of Terra/MODIS is 0.4 ~ 14μm, which has 36 channels.

2.2 Data processing

2.2.1 Geometric correction
Take Terra/MODIS data as basemap for geometric correction of FY-3A/VIRR and FY-3A/MERSI data, and the correction accuracy is controlled within one pixel.

2.2.2 Crop, splice and projection conversion
Since the repeat transition of Terra/MODIS is a period of 16 days. Every transition remote sensing data would not include all the study area. So the crop, splice and projection conversion of data which is cover the study area is needed. The original projection of MODIS is Sinusoidal Grid, it needs to be converted to UTM projection. The paper used MRT Swath which is provided by NASA website to process the data of Terra/MODIS, and used ENVI to realize the process of the data of FY-3A/VIRR and FY-3A/MERSI.

2.2.3 Radiometric calibration
The DN value of remote sensing data is earth observation count value, which needs to be radiometric calibration through calibration coefficients of the data. The change in solar zenith angle also makes some bias to the apparent reflectance, which specifically showing apparent reflectance has larger deviation along with the increase of solar zenith angle. So the apparent reflectance should be corrected according to solar zenith angle.

The apparent reflectance of Terra/MODIS is calculated as follows:

\[
\rho_{\text{MODIS}} = \frac{\text{reflectance_scales} \times (DN - \text{reflectance_offsets})}{\cos \theta}
\]  

(1)

where \( \rho_{\text{MODIS}} \) = the apparent reflectance of Terra/MODIS; \( DN \) = earth observation count value; \( \text{reflectance_scales} \) = apparent reflectance gain coefficient; \( \text{reflectance_offsets} \) = apparent reflectance offset coefficient; \( \theta \) = Solar Zenith Angle.

The apparent reflectance of FY-3A/VIRR is calculated as follows:

\[
\rho_{\text{VIRR}} = \frac{S \times DN + I}{100 \cos \theta} \times d^2
\]  

(2)

\[
d = 1 + 0.0167 \sin(2\pi \frac{\text{days} - 93.5}{360})
\]  

(3)

where \( \rho_{\text{VIRR}} \) = the apparent reflectance of FY-3A/VIRR; \( S \) = slope; \( I \) = intercept; \( d \) = the distance from the earth to the sun; \( \text{days} \) = acquisition date of the remote sensing data in the number days of the year.

The apparent reflectance of FY-3A/MERSI is calculated as follows:

\[
\rho_{\text{MERSI}} = \frac{k_0 + k_1 \times DN + k_2 \times DN^2}{100 \cos \theta} \times d^2
\]  

(4)

where \( \rho_{\text{MERSI}} \) = the apparent reflectance of FY-3A/MERSI; \( k_0, k_1 \) and \( k_2 \) = calibration coefficients.

2.2.4 Calculation of NDVI
The apparent reflectance of FY-3A/VIRR, FY-3A/MERSI and Terra/MODIS should be calculated to normalized difference vegetation index. The NDVI is calculated as follows:

\[
\text{NDVI} = \frac{\rho_{\text{nir}} - \rho_{\text{red}}}{\rho_{\text{nir}} + \rho_{\text{red}}}
\]  

(5)

where \( \rho_{\text{red}} \) = apparent reflectance of near-infrared band; \( \rho_{\text{nir}} \) = apparent reflectance of red band.

Table 1. Comparison of correspond band between Terra/MODIS, FY-3A/VIRR and FY-3A/MERSI

<table>
<thead>
<tr>
<th>Band/MODIS</th>
<th>FY-3A/VIRR</th>
<th>FY-3B/MERSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1</td>
<td>0.620-0.670</td>
<td>0.580-0.680</td>
</tr>
<tr>
<td>Band 2</td>
<td>0.841-0.876</td>
<td>0.840-0.890</td>
</tr>
</tbody>
</table>

2.2.5 Data processing

Take Terra/MODIS data as basemap for geometric correction of FY-3A/VIRR and FY-3A/MERSI data, and the correction accuracy is controlled within one pixel.

Table 1. Comparison of correspond band between Terra/MODIS, FY-3A/VIRR and FY-3A/MERSI
3 COMPARISON OF THE VEGETATION INDEXES

Dynamic range and daily average of NDVI, FY-3A/VIRR and FY-3A/MERSI deviation with Terra/MODIS's NDVI are as shown in table 2. Daily average of NDVI is as shown in figure 1. We can see that vegetation indexes of FY-3A/VIRR, FY-3A/MERSI is very close to that of Terra/MODIS. They have a common trend and a significant correlation. All the correlation coefficients exceeded 0.99. But there are some differences of NDVI between FY-3A/VIRR, FY-3A/MERSI and Terra/MODIS. Specific performance: First, dynamic range of FY-3A/VIRR and FY-3A/MERSI is less than Terra/MODIS. The maximum value of FY-3A/VIRR and FY-3A/MERSI are 0.712 and 0.709, however the maximum value of Terra/MODIS is up to 0.765. Second, NDVI of Terra/MODIS is higher than that of FY-3A/VIRR and FY-3A/MERSI. Vegetation index of Terra/MODIS is more sensitive, and it can get more rich information of vegetation.

![Figure 1. NDVI of Terra/MODIS, FY-3A/VIRR and FY-3A/MERSI](image)

Table 2. Comparison of NDVI between Terra/MODIS, FY-3A/VIRR and FY-3A/MERSI

<table>
<thead>
<tr>
<th>Data (year-month-day)</th>
<th>MODIS</th>
<th>VIRR</th>
<th>MERSI</th>
<th>MODIS</th>
<th>VIRR</th>
<th>MERSI</th>
<th>VIRR</th>
<th>MERSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012 01 10</td>
<td>0.154</td>
<td>0.130</td>
<td>0.113</td>
<td>0.130</td>
<td>0.120</td>
<td>0.090</td>
<td>0.010</td>
<td>0.040</td>
</tr>
<tr>
<td>2012 01 11</td>
<td>0.180</td>
<td>0.178</td>
<td>0.105</td>
<td>0.144</td>
<td>0.140</td>
<td>0.095</td>
<td>0.004</td>
<td>0.049</td>
</tr>
<tr>
<td>2012 01 16</td>
<td>0.185</td>
<td>0.167</td>
<td>0.113</td>
<td>0.145</td>
<td>0.131</td>
<td>0.101</td>
<td>0.014</td>
<td>0.044</td>
</tr>
<tr>
<td>2012 02 15</td>
<td>0.172</td>
<td>0.169</td>
<td>0.122</td>
<td>0.140</td>
<td>0.137</td>
<td>0.114</td>
<td>0.003</td>
<td>0.026</td>
</tr>
<tr>
<td>2012 05 13</td>
<td>0.276</td>
<td>0.220</td>
<td>0.213</td>
<td>0.228</td>
<td>0.202</td>
<td>0.177</td>
<td>0.026</td>
<td>0.051</td>
</tr>
<tr>
<td>2012 05 15</td>
<td>0.301</td>
<td>0.295</td>
<td>0.224</td>
<td>0.242</td>
<td>0.231</td>
<td>0.185</td>
<td>0.011</td>
<td>0.057</td>
</tr>
<tr>
<td>2012 06 10</td>
<td>0.423</td>
<td>0.380</td>
<td>0.362</td>
<td>0.360</td>
<td>0.321</td>
<td>0.312</td>
<td>0.039</td>
<td>0.048</td>
</tr>
<tr>
<td>2012 06 11</td>
<td>0.469</td>
<td>0.454</td>
<td>0.438</td>
<td>0.420</td>
<td>0.359</td>
<td>0.344</td>
<td>0.061</td>
<td>0.076</td>
</tr>
<tr>
<td>2012 06 15</td>
<td>0.480</td>
<td>0.431</td>
<td>0.421</td>
<td>0.405</td>
<td>0.371</td>
<td>0.367</td>
<td>0.034</td>
<td>0.038</td>
</tr>
<tr>
<td>2012 06 29</td>
<td>0.731</td>
<td>0.671</td>
<td>0.660</td>
<td>0.681</td>
<td>0.620</td>
<td>0.599</td>
<td>0.061</td>
<td>0.082</td>
</tr>
<tr>
<td>2012 07 27</td>
<td>0.694</td>
<td>0.661</td>
<td>0.656</td>
<td>0.656</td>
<td>0.586</td>
<td>0.586</td>
<td>0.070</td>
<td>0.070</td>
</tr>
<tr>
<td>2012 08 01</td>
<td>0.715</td>
<td>0.712</td>
<td>0.709</td>
<td>0.679</td>
<td>0.661</td>
<td>0.642</td>
<td>0.018</td>
<td>0.037</td>
</tr>
<tr>
<td>2012 08 02</td>
<td>0.765</td>
<td>0.680</td>
<td>0.674</td>
<td>0.700</td>
<td>0.645</td>
<td>0.640</td>
<td>0.055</td>
<td>0.060</td>
</tr>
<tr>
<td>2012 08 18</td>
<td>0.735</td>
<td>0.655</td>
<td>0.661</td>
<td>0.671</td>
<td>0.601</td>
<td>0.600</td>
<td>0.070</td>
<td>0.071</td>
</tr>
<tr>
<td>2012 08 21</td>
<td>0.688</td>
<td>0.652</td>
<td>0.626</td>
<td>0.655</td>
<td>0.608</td>
<td>0.559</td>
<td>0.047</td>
<td>0.096</td>
</tr>
<tr>
<td>2012 08 22</td>
<td>0.682</td>
<td>0.664</td>
<td>0.646</td>
<td>0.632</td>
<td>0.617</td>
<td>0.590</td>
<td>0.015</td>
<td>0.042</td>
</tr>
<tr>
<td>2012 09 03</td>
<td>0.698</td>
<td>0.641</td>
<td>0.634</td>
<td>0.627</td>
<td>0.586</td>
<td>0.539</td>
<td>0.041</td>
<td>0.088</td>
</tr>
<tr>
<td>2012 09 08</td>
<td>0.654</td>
<td>0.593</td>
<td>0.584</td>
<td>0.603</td>
<td>0.533</td>
<td>0.516</td>
<td>0.070</td>
<td>0.087</td>
</tr>
<tr>
<td>2012 09 13</td>
<td>0.622</td>
<td>0.589</td>
<td>0.537</td>
<td>0.507</td>
<td>0.503</td>
<td>0.443</td>
<td>0.004</td>
<td>0.064</td>
</tr>
<tr>
<td>2012 09 17</td>
<td>0.543</td>
<td>0.510</td>
<td>0.483</td>
<td>0.481</td>
<td>0.440</td>
<td>0.410</td>
<td>0.041</td>
<td>0.071</td>
</tr>
<tr>
<td>2012 09 21</td>
<td>0.499</td>
<td>0.438</td>
<td>0.464</td>
<td>0.426</td>
<td>0.384</td>
<td>0.360</td>
<td>0.042</td>
<td>0.066</td>
</tr>
<tr>
<td>2012 10 10</td>
<td>0.368</td>
<td>0.350</td>
<td>0.314</td>
<td>0.310</td>
<td>0.298</td>
<td>0.241</td>
<td>0.012</td>
<td>0.069</td>
</tr>
<tr>
<td>2012 11 26</td>
<td>0.211</td>
<td>0.198</td>
<td>0.123</td>
<td>0.149</td>
<td>0.145</td>
<td>0.118</td>
<td>0.004</td>
<td>0.031</td>
</tr>
<tr>
<td>2012 12 07</td>
<td>0.173</td>
<td>0.158</td>
<td>0.104</td>
<td>0.133</td>
<td>0.106</td>
<td>0.093</td>
<td>0.027</td>
<td>0.040</td>
</tr>
</tbody>
</table>

4 RESULTS AND DISCUSSION

Vegetation index of FY-3A/VIRR and FY-3A/MERSI have a highly significant correlations with Terra/MODIS. But a certain differences also exist. Reasons for such differences are as below.

4.1 The spectral response function of sensors is different.

The spectral response functions of corresponding bands of FY-3A/VIRR and Terra/MODIS, FY-3A/MERSI and Terra/MODIS are respectively shown in figure 2 and figure 3. Red band scope of Terra/MODIS is 620-670µm, near-infrared band scope of Terra/MODIS is 841-867µm. Red band scope of FY-3A/VIRR is 580-680µm, near-infrared band scope of FY-3A/VIRR is 840-870µm. Red band scope of FY-3A/MERSI is 600-700µm, near-infrared band scope of FY-3A/MERSI is 845-915µm. To sum up, the spectral response function of corresponding band of Terra/MODIS is narrower than those of FY-3A/VIRR and FY-3A/MERSI. The spectral response function reflects sensors’ response capability of light. The sensitivity of Terra/MODIS red band and near-infrared band towards spectral changes is stronger than that of FY-3A/VIRR and FY-3A/MERSI.
4.2 Radiometric calibration

The calibration precision of FY-3A/VIRR and FY-3A/MERSI is both lower than that of Terra/MODIS. The calibration parameters of each band of FY-3A/VIRR and FY-3A/MERSI will have varying degrees of degeneration along with the changing of launch time. Terra/MODIS adopts on-orbit calibration. Its three on-orbit calibrations, which are sun scatter plate, sun scattering stability detector and spectral radiation calibration device, are used to calibrate the sun's reflection band. These calibrators can provide high-precision calibration results. Due to the uncertainty brought by calibration, NDVI from the data of Terra/MODIS can better reflect the growing situation of plants compared with that of FY-3A/VIRR and FY-3A/MERSI.

5 CONCLUSION

This paper conducts a comparison of vegetation index from the data of FY-3A/VIRR, FY-3A/MERSI and Terra/MODIS. The reasons for the differences of NDVI were analyzed. The conclusions are as follows: First, vegetation indexes of FY-3A/VIRR, FY-3A/MERSI is very close to that of Terra/MODIS. All the correlation coefficients exceeded 0.99. But there are some differences of NDVI between FY-3A/VIRR, FY-3A/MERSI and Terra/MODIS. NDVI of Terra/MODIS is more sensitive, and it can get more rich information of vegetation. Second, the differences in spectral response function and calibration precision of FY-3A/VIRR, FY-3A/MERSI and Terra/MODIS has certain influences on vegetation index. In practical application, cross-calibration can be adopted to narrow the differences of vegetation index from the data of FY-3A/VIRR and Terra/MODIS as well as FY-3A/MERSI and Terra/MODIS.

ACKNOWLEDGEMENTS

This work was supported by the National High Technology Research and Development Program of China under Grant 2013AA12A301.

REFERENCES