A NEW PROMPT ALGORITHM FOR REMOVING THE BOWTIE EFFECT OF MODIS L1B DATA

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ABSTRACT:

A new algorithm for removing Bowtie Effect of Moderate resolution Imaging Spectrometer (MODIS) data without utilizing the ephemeris data is proposed in this paper. Based on a thoroughly study of the observation characteristics of MODIS, and a comprehensive comparison and evaluation among the existing algorithms for removing Bowtie Effect, the new algorithm is derived with correlation coefficient method from the disciplinarian exhibited by the experiments in China, United States and Australia (mainly with MODIS data of 500 meters resolution), it turned out a second order polynomial describes the disciplinarian well. The results demonstrate that, without ephemeris data, the new algorithm is able to eliminate the Bowtie effect of MODIS L1B data effectively with no information lost.

1. INTRODUCTION

MODIS data is one of the best sources for research in geosciences. However, because of the imaging characteristics of MODIS sensors, the MODIS detector array acquires images over a scan range of –55° to +55°, resulting in the length of each swath is 10 km at nadir, while about 20 km at the edge of the scene (Liu, 2005). Along with impacts of other factors, such as the field’s geometric characteristics of Earth observation by MODIS detectors, the Earth's surface curvature, undulating topography and the twitter of MODIS sensor during the imaging processing, geometric distortion is introduced into MODIS L1B data by the sensor’s characteristics, which is defined as Bowtie effect, as shown in Figure 1.

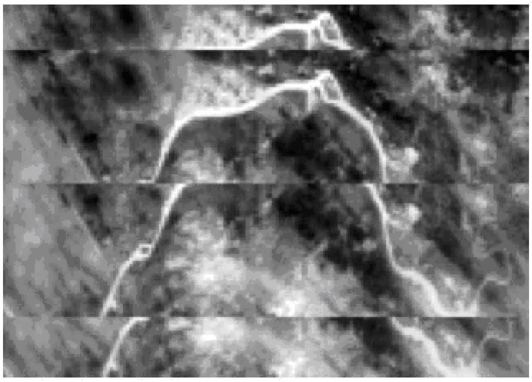

Figure 1. Bowtie Effect in MODIS data (Liu, 2007)

Bowtie Effect takes place when the sensor scanning angle reach to 15 °, and as the angle increases, the effect becomes more apparent. It is demonstrated in Figure 2 that data affected by Bowtie effect occupies a considerable part of the image. Consequently, we have to remove Bowtie Effect before any application with MODIS data could be issued. The first and third scan are represented by the light grids, while the second scan is shown in black in Figure 2.

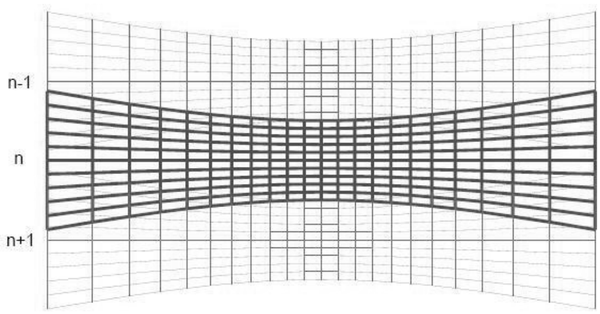

Figure 2. Three consecutive MODIS scans each consisting of ten 1km lines (Deutsches Zentrum für Luft- und Raumfahrt, 2004)

2. GENERAL ALGORITHMS AND PROBLEMS

Currently, there are mainly two kinds of algorithm to remove Bowtie effect: Ephemeris method and non-Ephemeris method. Based on satellite’s ephemeris, Ephemeris method generates standard geographic grid, projects data to this grid, thus data will be matched according to its geographical coordinates with Bowtie effect eliminated at the same time. This method is used in MODIS L1B data processing both by International MODIS/AIRS Processing Package and Goddard Space Flight Centre, United States National Aeronautics and Space Administration (NASA/GSFC) (Space Science and Engineering Center, University of Wisconsin-Madison, 2005). MS2GT software, developed by the U.S. National Snow and Ice Data Centre, also uses this principle (National Snow and Ice Data Centre , 2003). However, as the Terra’s and Aqua’s MODIS L1B data products don’t have ephemeris included, general users can not use the algorithm mentioned above to remove Bowtie effect.

Since Bowtie effect restricts the application of MODIS data, a lot of studies have been issued to remove in MODIS data without satellite ephemeris both in China and abroad. “Modistools” module developed by the Russian company R & D ScanEx could remove Bowtie effectively (R&D center ScanEx, 2004), but it must be used in ENVI, which limits its application. Dundee Satellite Receiving Station assumes that reprojection could be used to remove Bowtie effect, make geometrical information in MODIS L1B data, such as the zenith angle, processed with the same treatment (Dundee Satellite Receiving Station, 2007). Xu Meng from Nanjing University removes Bowtie Effect with projection transformation after interpolating longitude and latitude in MODIS data (Xu Meng , 2005). Guo Guangmeng from the Chinese Academy of Sciences has calculated the correlation coefficient for the overlapped lines between adjacent scanning strips (Guo Guangmeng ,2003). Yu Junhui from Nanjing University also proposed the same idea that, with the method used in digital photogrammetry to find the homo-points in adjacent images, Bowtie Effect could be removed without ephemeris by searching for the overlapped lines between adjacent scanning strips and removing the overlapped parts (Yu Junhui,2004). This method lacks practicability due to its heavy calculating task and low efficiency.

However, the algorithm proposed in this paper could resolve all these limitations with high efficiency and accuracy. In the following part, the theoretical basis of the algorithm as well as the major steps are discussed in section 3.

3. ALGORITHM DESCRIPTION

3.1 The Theoretical Basis of the Algorithm

In view of the disadvantages of non-Ephemeris mentioned above, a fast removing Bowtie effect algorithm based on statistical method is proposed in this paper. The basic idea is that the geometric distortion of the MODIS L1B data has a consanguineous relationship with the imaging features of MODIS sensors, as shown in Figure 2. While sensors scanning from left to the right side, overlapped lines of the two sides are nearly symmetric according to the nadir. Moreover, the count of overlapped lines is determined by the scanning characteristics, it is irrelevant with image differences. That means, there is a certain discipline that Bowtie effect follows in MODIS L1B data, and this discipline could be retrieved from the statistics accumulated through enough MODIS data. Since the overlapped lines are symmetric according to the flying direction, this discipline can be simulated with a symmetric function, such as

$$Y = a * X^2 + b \qquad (1)$$

Where Y = overlapped lines, from 1 to 10

X = samples away from nadir, ranged from -1354 to 1354

With equation (1) we can eliminate Bowtie effect in MODIS L1B data effectively according to method described as follows.

3.2 Algorithm Description

In this paper the correlation coefficient method of Photogrammetry (Zhang Jianqing, 2003) was introduced to the MODIS data processing. Taking the MODIS data with 500m spatial resolution for example, one scanning strip consists of 2,708 pixels and 20 rows, and there are 203 strips in a standard NASA 500m-resolution MODIS L1B product. Bowtie effect takes place between every two adjacent strips.

First of all, the amount of overlapped rows between two neighbouring strips should be calculated. Taking into account the random noise and the transverse movement of two neighbouring strips, the target zone with a window size of 3*39 was selected, while a window with a size of 20*39 was selected as the searching area (Yu Junhui,2004). Then the following steps were applied to remove Bowtie effect.

(1) The numbers of overlapped lines between every two adjacent strips at 20th sample were calculated with correlation coefficient method;

(2) The amount with the highest frequency was selected as the figure of overlapped lines at 20th sample of the image.

(3) The same treatment was applied to calculate the amount of overlapped lines of the whole image at every column from left to right, except for the first 19 samples and the last 19 samples, and the amount of overlapped lines for the first 19 samples of the left side and last 19 sample of the right side could be calculated by linear extrapolate.

(4) Step (1) to (3) were repeated to process abundant 500m-resolution MODIS L1B data over a certain area, and the figures of overlapped lines from 4 to 10 are calculated and averaged. That means, for this area, statistical method is used to abstract the information of all the 2708 samples, to check that how many samples is 10 lines overlapped, how many samples is 9 lines overlapped, how many samples is 8 lines overlapped and so on.

(5) With the results summarized from the last step, a polynomial would be simulated with a curve function, and with this polynomial the amount of 3、2、1 and no overlapped lines can be calculated. The number of samples with un-overlapped can be calculated by 1354 minus the sum of 10 lines overlapped to 1 line overlapped.

(6) Every strip of the MODIS L1B data will be separated to several segments with different treatment: For the part of 10 overlapped rows on one side, the centre of the strip has no un-overlapped rows, as shown in Figure 3, and the 20 rows strip is separated to 4 parts, each part consists of 5 rows. 10 rows of data are read into the computer from the 6th line of every strip ,as shown in Figure 3, then the 10 rows are re-sampled to 20 rows; for the part of 9 overlapped rows, there are 2 un-overlapped lines in the centre, as shown in Figure 4. Every strip is separated to two 5 rows parts, two 4 rows parts and one 2 rows part, 11 rows of data from the 6th row is selected and re-sampled to 20 rows. The similar process is applied to the rest of the image, and nothing will be done to the part with un-overlapped lines. Thus, while this kind of process has been applied to the whole image, an image with no overlapped lines will be generated, that is to say, Bowtie Effect has been removed.

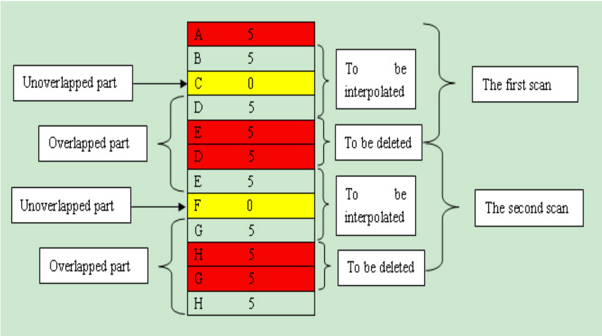

Figure 3. 10 overlapped lines of each scan

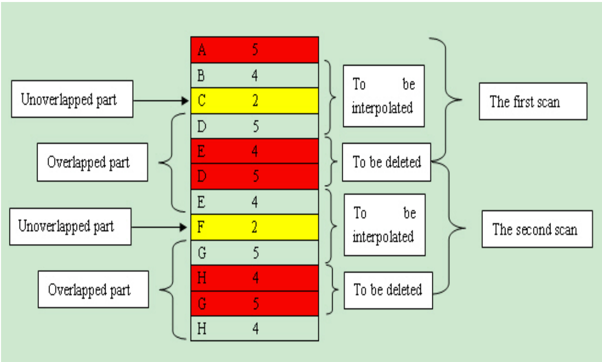

Figure 4. 9 overlapped lines of each scan

4. EXPERIMENTS AND DISCUSSION

MODIS L1B data over three different regions were chosen in this study, which are China, United States and Australia, along with their adjacent areas. United States was selected due to its similar latitude as China, while located in western hemisphere and China in eastern one. Australia was collected because it locates in the south hemisphere. Satellite Terra does not move along an absolute circular orbit, so it calls for MODIS L1B data over different locations to demonstrate whether Bowtie effect variants among different regions.

50 images of MODIS L1B data over China were processed and the result is shown in the following Table1:

lines overlapped	Left	Right	Average
10	45(44.94)	33(32.52)	39(38.73)
9	69(68.84)	68(68.46)	69(68.65)
8	74(73.7)	73(73.3)	74(73.5)
7	80(80.28)	80(79.9)	80(80.09)
6	85(85.4)	86(86.46)	86(85.93)
5	95(95.4)	95(95.3)	95(95.35)
4	106(105.84)	106(106.34)	106(106.09)

Table 1. Statistics of MODIS Data Over China

Statistics inside the brackets are the average number of lines directly calculated by arithmetic mean, while integral outside the bracket is the nearest integer to the digital. According to the result shown in Table1, the numbers of overlapped lines turned out to be symmetric from 9 overlapped lines to 4 overlapped lines, except for the 10 overlapped lines. This demonstrates that the left and right side of an image is symmetric according to nadir sample, which agrees with the characteristics of the imaging of MODIS detectors. Thus, a symmetric curve function (i.e. $Y = a * X^2 + b$) could be used to describe the distribution of overlapped lines.

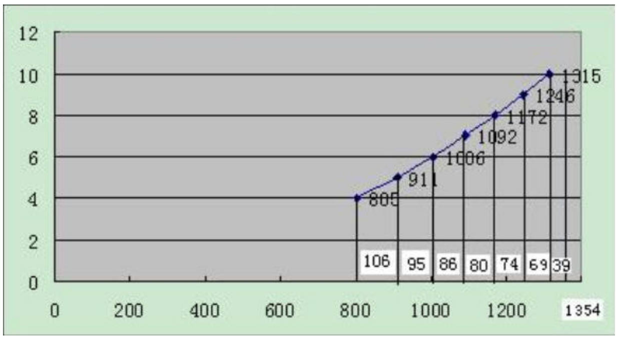

Figure 5. Overlapped lines of different samples away from nadir.

Y	10	9	8	7	6	5	4
X	1315	1246	1172	1092	1006	911	805

Table 2. Relation of the amount of overlapped lines and samples away from nadir sample of MODIS L1B data over China

From Table 2 and Figure 5 the following equation would be found:

$$Y = 0.000005544 * X^2 + 0.3964225 \quad (2)$$

Where Y = the amount of overlapped lines, from 4 to 10,
X = samples away from nadir, ranged from 0 to 1354 and -1354 to 0

Then, equation (2) was applied to calculate the number of overlapped lines for 3、2 and 1 overlapped lines separately. The number of samples with un-overlapped can be calculated by 1354 minus the sum of 10 lines overlapped to 1 line overlapped. which exhibited the general MODIS overlapped orders in China as shown in the Table3 (case 'China'):

The same experiments have been applied to the MODIS L1B data over United States and Australia (case 'United States' and 'Australia' in Table 3), both have approximately 50 images, and the curve functions retrieved from these data for the two regions are:

$$Y = 0.000005594 * X^2 + 0.3605676 \quad (3)$$
$$Y = 0.000005563 * X^2 + 0.4509099 \quad (4)$$

Where Y = the amount of overlapped lines, from 4 to 10,
X = samples away from nadir, ranged from 0 to 1354 and -1354 to 0

Area	China	United States	Australia
10 overlapped lines	39	39	44
9 overlapped lines	69	68	71
8 overlapped lines	74	71	73
7 overlapped lines	80	81	81
6 overlapped lines	86	87	87
5 overlapped lines	95	94	96
4 overlapped lines	106	105	105
3 overlapped lines	121	120	121
2 overlapped lines	148	146	149
1 overlapped lines	207	203	339
Un-overlapped	329	339	314

Table 3. MOIDS overlapped lines Over China, United States and Australia

Comparisons of equations (2) 、(3) 、(4) and statistics information listed in Table 3 demonstrates that the three functions derived from the data of three areas appears to be very similar to each other.

5 COMPARISON AND ANALYSIS

(1) Comparisons by human eyes. Using the same image (the first band of MOD02HKM.A2006196.0430.005.20061961112 34.hdf was selected), Seaspace Terascan Algorithm、ENVI modistool Algorithm and algorithm proposed in this paper were applied separately, the original image and results of bowtie effect removed by different algorithms could be found from Figure 6 to Figure 9. It seems to be very similar for the different results with human eyes.
(2) Comparisons of effectiveness. Algorithm proposed in this paper and the modistool algorithm implemented ENVI were tested on the same computer to remove Bowtie effect for the 5 bands of MOD02HKM.A2006196.0430.005.2006196111234.h df, while the Terascan Algorithm was tested on another computer (shown in Table 4).

	CPU	Memory	OS	Time
Terascan	P4 1.7G	256M	Redhat linux 7.2	13 second
Modistool	P4 1.7G	256M	Windows XP	210 second
Algorithm in this paper	P4 1.7G	256M	Windows XP	15 second

Table 4. Comparisons of effectiveness of three algorithms

The algorithm proposed in this paper is equivalent to that of Terascan system and much more effective than modistool. (Terascan has not been transplanted to Windows platform so no comparison could be made for all the algorithms on the same platform).
(3) Quantitative comparisons. Statistics information were calculated for the result of the three algorithms (Figure 7 for our algorithm, Figure 6 and Figure 8 for other two algorithms) to demonstrate the high efficiency quantitatively (shown in Table 5 and Table 6).

	Figure 8	Figure 7
Minimum	0	0
Maximum	31729	32539
Average	10826.779	10828.375
Standard deviation	6254.132	6310.125
Covariance	39076122.547	
correlation coefficient	0.990162	

Table 5. Comparison between our algorithm and Terascan system

	Figure 8	Figure 9
Minimum	0	0
Maximum	31729	32192
Average	10826.779	10828.2645
Standard deviation	6254.132	6290.143
Covariance	39142058.929	
correlation coefficient	0.994984	

Table 6. Comparison between our algorithm and ENVI modistool algorithm

According to the statistics listed in Table 5 and Table 6, our algorithm has a very well agreement with Terascan and ENVI in removing Bowtie Effect result, the correlation coefficient is 0. 990162 and 0. 994984 separately, which is better than the algorithm published by Enrique Gomez-Landesa (Enrique Gomez Landesa ,2004). So without the utilization of ephemeris, we have a high confidence to remove Bowtie Effect with a high efficiency with no information lost.

Figure 6. Modis L1b data before bowtie effect removed

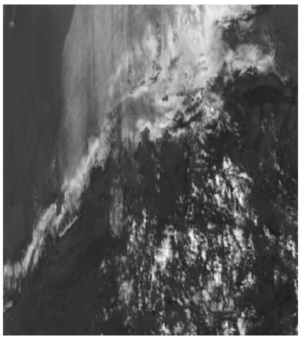

Figure 7. Bowtie effect removed by Seaspace Terascan Algorithm

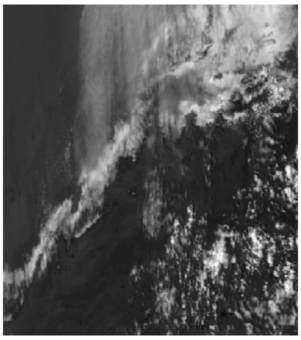

Figure 8. bowtie effect removed by algorithm from this paper

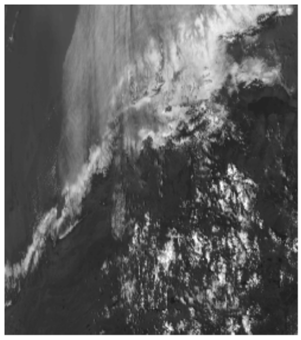

Figure 9. bowtie effect removed by modiotool model in ENVI

6 CONCLUSIONS

This paper has investigated the basic rule of Bowtie Effect based on the special characteristics of MODIS sensor. A new effective algorithm to rapidly remove Bowtie Effect without ephemeris was developed, results were compared with different algorithms, and the efficiency and application were analyzed. On the whole, results led to the following conclusions:

(1) There are some certain rules that MODIS Bowtie Effect follows. The equations (2),(3),(4) show that the rules of “Bowtie effect” over different place is almost the same;
(2) The rules of Bowtie Effect could be described with a symmetric curvaceous foundation, which could be summarized and retrieved by some testing data. MODIS data of the same region in large quantity could be liberated from Bowtie Effect quickly with this foundation applied in our algorithm.
(3) Comparisons and analysis were issued from three aspects to our algorithm and others’, the result indicate that our algorithm is nearly the same in efficiency as TeraScan system (they are implemented on different platform and we believe this may be the main reason for our differences), however, while compared to ENVI modistool, our algorithm is almost 10 times faster with high accuracy and no information lost;
(4) There are no special requirements for hardware and software to our algorithm.

This study mainly focuses on the MODIS L1B data with a spatial resolution of 500m, and it can be extended to process 250m and 1000m bands by adjusting some of the parameters. While comparing different data from the three study region, it is observed that there were apparent difference in both left and right side of the images for 10 overlapped lines, but the two sides remain symmetric for 9、8、7 and other number of overlapped lines. It calls for further and more comprehensive research to reveal the reason of this difference.

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