Popular summary

The Impacts of Bowtie Effect and View Angle Discontinuity
on MODIS Swath Data Gridding

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The Moderate Resolution Imaging Spectrometers (MODIS) onboard TERRA and AQUA satellites provide global observations of the Earth. It is a whiskbroom sensor that simultaneously scans a swath of the Earth 10 km wide at nadir. Due to the viewing geometry and the curvature of the Earth, the adjacent scans overlap each other. The overlap increases with the scan angle reaching 50% at the edge of scan. This effect, called "bowtie" effect, is present in all whiskbroom sensors. This paper discusses a gridding procedure which places swath measurements into a regular spatial grid.

We consider two effects of the MODIS viewing geometry on the quality of gridded images. First, because MODIS swath is 10 km wide at nadir, the view azimuth angle changes abruptly at the boundary of adjacent scans. This discontinuity appears as striping of the image, which becomes noticeable in certain cases such as sun glint over water or snow. This is a real signature of the surface bi-directional reflectance, which should be preserved in the measurements. Second, due to bowtie effect, the commonly used method of averaging all observations, which cover the grid cell, may cause smearing of the image. Taking the above two effects into account, we revised the current MODIS gridding algorithm using a scan-by-scan processing contrary to the orbit-by-orbit processing used

in the current MODIS gridding algorithm. The new algorithm preserves angular features of the measured surface signals and enhances sharpness of the image.

Abstract

We have analyzed two effects of the MODIS viewing geometry on the quality of gridded imagery. First, the fact that the MODIS scans a swath of the Earth 10 km wide at nadir, causes abrupt change of the view azimuth angle at the boundary of adjacent scans.

This discontinuity appears as striping of the image clearly visible in certain cases with viewing geometry close to principle plane over the snow of the glint area of water. The striping is a true surface Bi-directional Reflectance Factor (BRF) effect and should be preserved during gridding. Second, due to bowtie effect, the observations in adjacent scans overlap each other. Commonly used method of calculating grid cell value by averaging all overlapping observations may result in smearing of the image. This paper describes a refined gridding algorithm that takes the above two effects into account. By calculating the grid cell value by averaging the overlapping observations from a single scan, the new algorithm preserves the measured BRF signal and enhances sharpness of the image.

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I. Introduction

MODIS is a whiskbroom sensor that simultaneously senses ten rows of 1-km detector pixels, 20 rows of 500-m detector pixels and 40 rows of 250-m detector pixels as the scan mirror sweeps across the track. The MODIS observation footprint grows with the scan angle in both along- and across-track direction. As a result, consecutive scans overlap when scan angle is greater than zero. At the edge of scan, the overlap can be as large as 50%. Such a geometrical distortion is called "bowtie effect" which is typical for all "whiskbroom" sensors [1-2].

The MODIS Level 1A (L1A) processing has tagged each observed spatial element in MODIS L1B swath product with location information [1]. However, due to bowtie effect, the observed spatial elements are neither fixed in sizes nor in locations. Observations of consecutive scans from the same orbit overlap each other, and data from different orbits are not aligned. Most of the satellite data users need a uniform representation of the surface, especially in the studies involving spatial pattern, time series analysis and multi-sensor applications [3-7], which requires gridding of the MODIS swath data and removal of geometrical distortions.

Gridding is defined as allocating geolocated satellite observations into an output image in which each grid cell has a fixed size and location. The grid cell value is calculated through resampling of the original observations. Commonly used resample methods include nearest-neighbor, bi-linear interpolation, cubic convolution and others. None of these common methods consider degree of overlap between observations and grid cells. MODIS science team has developed an efficient gridding method (MODIS L2G algorithm) that counts the observation/grid cell overlaps using the concept of

observation coverage [2]. Observation coverage is defined as the observation/grid cell intersection area divided by the area of the observation footprint. It is derived using an efficient polygon intersection algorithm [8]. The MODIS L2G algorithm tags each grid cell with a L2G pointer which contains the location of the overlapped observations in swath format granules, the observation coverage of each overlapped observation and other supplementary information. It also computes the ratio of the observation/grid cell intersection area and the grid cell area (cell coverage). In order to reduce the storage volume, the observation is not stored for given grid cell if the cell coverage is less than certain threshold [2]. The L2G pointer can then be used to grid MODIS swath data. For example, one can select the observation with maximum observation coverage as the grid cell value. This approach is equivalent to the nearest-neighbor method. On the other hand, the MODIS Surface Reflectance Aggregation product (MODAGAGG) uses a weighted average scheme. The MODAGAGG algorithm calculates the grid cell value by averaging all observations from consecutive scans that overlap with given grid cell, using observation coverage as weighting factor. Observations from different orbits are aggregated separately to retain sun-view geometry [9].

The MODAGAGG product has been used in the MODIS level 3 (L3) science products. Performing processing on the orbit per orbit basis, this method, however, does not consider the overlap of observations and the view angle discontinuity between neighboring scans within a single orbit. During the development of a new Multi-Angle Implementation of Atmospheric Correction (MAIAC) algorithm for MODIS, which requires accurate gridding of MODIS measurements [6-7], we found that these effects can be significant in some special cases.

In this paper, we will first discuss the view angle discontinuity and the problem of observation overlaps (section II and III), followed by presenting an amended gridding algorithm for the MODIS swath data (section IV).

II. View Angle Discontinuity in MODIS swath data

The MODIS instrument simultaneously senses ten rows of 1-km detector pixels (20 rows for 500m and 40 rows for 250m detector pixels) producing ten (20 and 40, respectively) scan lines in each scan. The sun-view geometry of two adjacent scans is shown in Figure 1. The leading edge of one scan is adjacent to the tailing edge of the next scan. One can see that at the junction of the two scans, the sensor views the leading edge of first scan in the forward direction and the tailing edge of next scan in the backward direction. The view azimuth angle (VAZ) changes abruptly at the scan edges, even though these pixels are geographically adjacent. The VAZ difference at the scan edge can be close to 180° when the view zenith angle (VZA) is close to nadir. It rapidly decreases with increase of view zenith angle: at VZA=30°, the difference is about 2°, reducing to 1° and less at VZA$\geq 45^{\circ}$, as shown in Figure 2.

This small discontinuity of azimuth is usually not visible in the gridded images over land or ocean, because the surface Bi-Directional Reflection Factor (BRF) is generally a smooth function. However, in some special cases when BRF effect is strong, e.g. near the sun glint direction, it can result in noticeable striping of the image. Two examples are shown in Figures 3 and 4. Figure 3 shows stripes in the sun glint spot in the Red Sea. The top image of Figure 4 shows striping over snow in Greenland with corresponding relative azimuth angle pattern shown on the bottom. At the snow reflectance of 0.85-0.95 in red, green and blue bands, the discussed BRF discontinuity reaches 0.004-0.006.

Shown striping of imagery is not related to observational errors; rather it carries a real BRF signal, which may be important to some applications and should be preserved during gridding.

III. Observation Overlaps

Due to bowtie effect, consecutive scans overlap in 1-km bands when VZA is higher than 25° (17° for 250m bands) [1], resulting in multiple observations of an area within the same orbit. This feature of MODIS should be considered in the gridding. Figure 5 shows the geometric relations between the overlapping observations and grid cell. One can see that a part of the grid cell is covered more than once. This part will have a higher weight if the grid cell value is calculated as a weighted average of all overlapping observations. Besides, weighted averaging will smear the image by adding larger area covered by different footprints. Figure 5 shows the comparison of images with grid cell value calculated by 1) averaging all overlapping observations and 2) averaging overlapping observations within a single scan. It can be seen that the image created by the second method is slightly sharper than that created by the first method. For a relatively homogeneous area, the grid cell value differences are less than 0.001 it the red band with reflectance of 0.07-0.1 and less than 0.002 in the Near-Infrared (NIR) band with reflectance of 0.2-0.3. However, on the sharp boundaries such as cloud boundary and coast line, the differences reach 0.002-0.005 in the red band and 0.007-0.02 it the NIR band, or 1-2.5% relative. Therefore, it may be more appropriate to use observations from only one scan that fully covers the given grid cell or provides the maximum coverage if the grid cell is not fully covered. The latter case is only important for pixels located on the scan boundaries, when VZA is less than 25°. Nominally, the maximum scan coverage

of a grid cell is at least 50 percent because the scan gap at nadir is zero [1]. In fact, for these not fully covered pixels, the final results are similar to the results of the nearest-neighbor method.

IV. The Gridding Algorithm

In order to minimize the impacts of view angle discontinuity and of observation overlaps, we revised the L2G/MODAGAGG processes to develop a new gridding algorithm for MODIS swath data that runs on a scan-by-scan basis. For each scan, the algorithm starts with reading the latitude and longitude of observation centers from MODIS geolocation products (MOD03). The observation footprint is modeled as a convex four-sided polygon with corner locations calculated by bilinear interpolation of the neighboring observation centers. Similar method is also used to find the centers and corners for 250m and 500 bands. Then the intersection areas between observation and grid cell are derived as described in [1-2]. The cell coverage and scan coverage (the total area of the cell covered by all observations in the given scan) are recorded. Figure 7 gives the detailed diagram of the processing. For each grid cell, the algorithm keeps the current cell coverage and scan coverage information in memory so that the value of scan coverage can be compared when a new scan comes. The scan with maximum scan coverage will be reported, with specific geometry of this scan. This choice is the main difference from the MODAGAGG algorithm, which reports a weighted average from all overlapping scans.

It should be noted that we use cell coverage as a weighting factor instead of observation coverage used in MODAGAGG algorithm. Although the difference is not

significant, using cell coverage as weighting factor is logically more consistent because it produces automatic normalization to 100% for fully covered grid cells.

V. Conclusion

This paper presented analysis of two effects of the MODIS viewing geometry on the quality of gridded images. The fact that the MODIS scans a swath of the Earth 10 km wide at nadir, causes abrupt change of the view azimuth angle at the boundary of adjacent scans. This discontinuity appears as striping of the image, which becomes noticeable for certain cases such as sun glint over water or snow. The striping is a true surface BRF effect with the magnitude of discontinuity as high as 0.004-0.006 over snow. The second effect relates to the scan overlaps due to bowtie effect which can be as high as 50 percent at the scan edge. We showed that the commonly used method of averaging all observations, which cover the grid cell, may cause a small smearing of the image.

We described a refined gridding algorithm that takes the above two effects into account. It is based on the scan-by-scan processing contrary to the orbit-by-orbit processing used in the MODAGAGG algorithm. The new algorithm preserves the measured BRF signal and slightly enhances sharpness of the image. This is achieved by calculating the grid cell value by averaging the overlapping observations from a single scan, using cell coverage as weighting factor.

References:

[1] Nishihama, M., Wolfe, R. E., Solomon, D., Patt, F., Blanchette, J., Fleig, A., and Masuoka, E. (1997). MODIS Level 1A Earth Location Algorithm Theoretical Basis Document. Goddard Space Flight Center, Greenbelt, MD, NASA Tech. Memo., SDST-092, Version 3.0.

[2] Wolfe, R. E., Roy, D. P., and Vermote, E. (1998). MODIS Land Data Storage, Gridding, and Compositing Methodology: Level 2 Grid. *IEEE Trans. Geosci. Remote Sens.*, 36, 1324–1338.

[3] Lucht, W., Schaaf C. B., Strahler A. H., 2000: An algorithm for the retrieval of albedo from space using semiempirical BRDF models. *IEEE Trans. Geosci. Remote Sens.*, 38, 977-998.

[4] Tucker, C. J., Pinzon, J. E., Brown, M. E., Slayback, D., Pak, E. W., Mahoney, R., Vermote, E. F., and Saleous, N. E. (2005). An Extended AVHRR 8-km NDVI Data Set Compatible with MODIS and SPOT Vegetation NDVI Data. *International Journal of Remote Sensing*, 26(20), 4485–4498.

[5] Goetz, S. J., Fiske, G. J. and Bunn, A. G., (2006), Using satellite time-series data sets to analyze fire disturbance and forest recovery across Canada. *Rem. Sens. Env.*, 101: 352-365, 2006.

[6] Lyapustin, A., Wang, Y., (2007). MAIAC: Multi-Angle Implementation of Atmospheric Correction for MODIS, Part I: Aerosol Retrievals. (in preparation).

[7] Lyapustin, A., Wang, Y., (2007). MAIAC: Multi-Angle Implementation of Atmospheric Correction for MODIS, Part II: Atmospheric Correction. (in preparation).

[8] Preparata, F. P. and Shamos, M. I., (1988). Computational Geometry: An Introduction. *NewYork, Springer-Verlag.*

[9] Tan, B., Woodcock, C. E., Hu, J., Zhang, P., Ozdogan, M., Huang, D., Yang, W., Knyazikhin, Y., and Myneni, R. B., 2006. The impact of geolocation offsets on the local spatial properties of MODIS data: Implications for validation, compositing, and band-to-band registration. *Rem. Sens. Env.*, 105: 98–114, 2006.
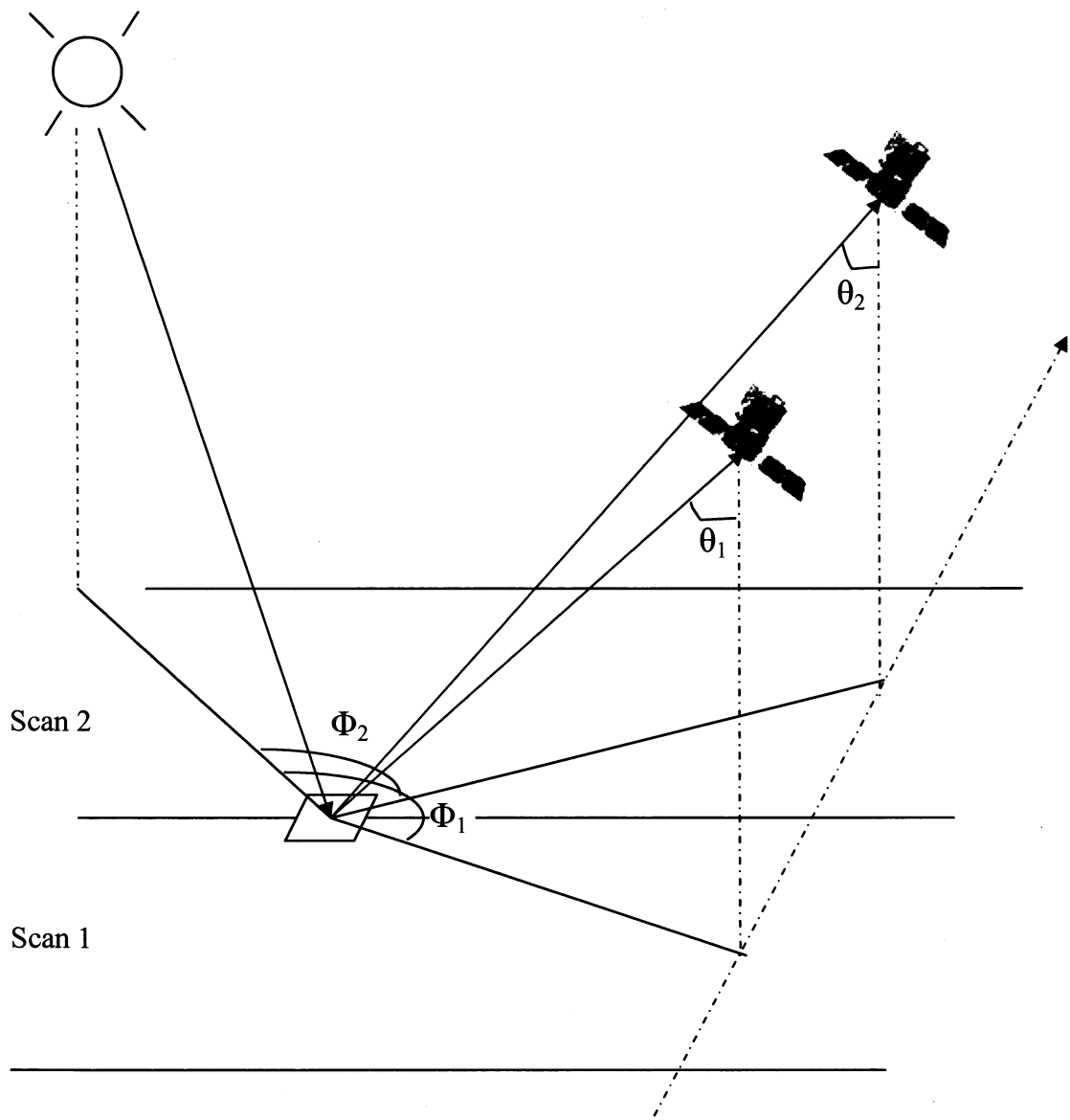
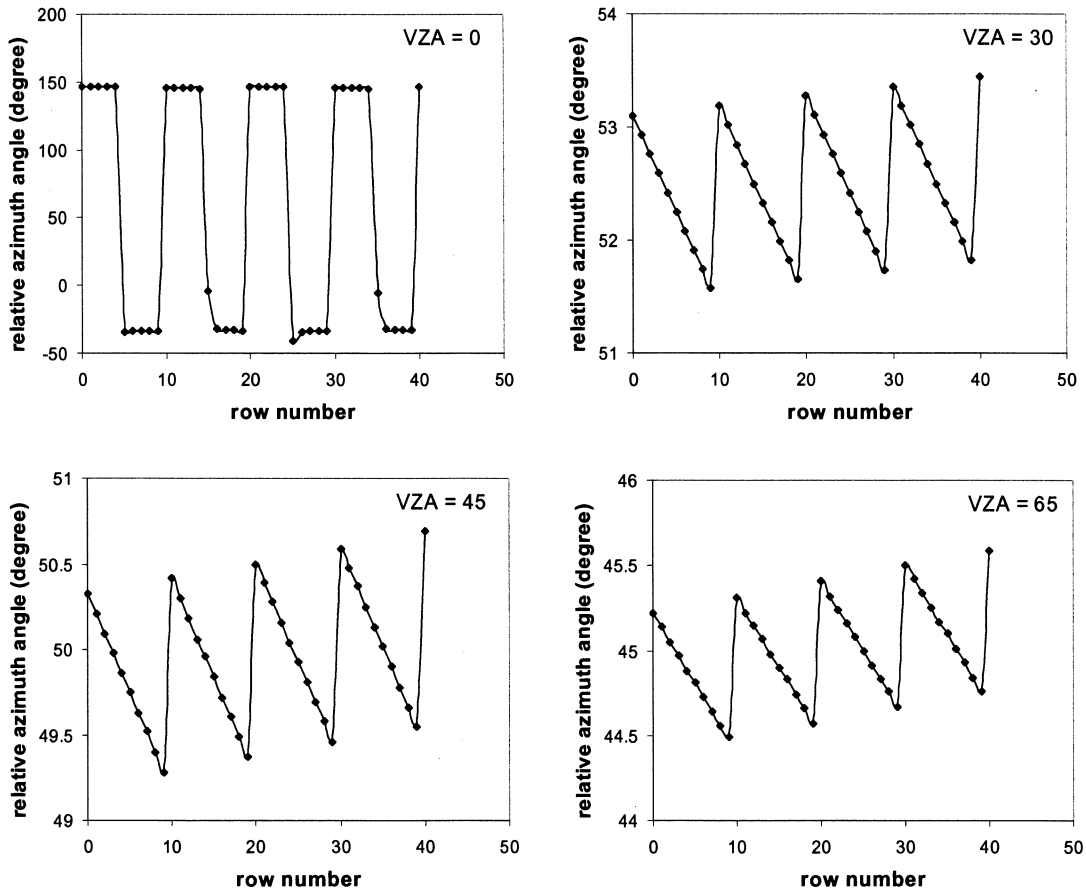Figure 1. The sun-view geometry of two adjacent scans

Figure 2. The relative azimuth as a function of row number in MODIS geolocation and geometry (MOD03) product.

Figure 3. The effect of azimuth discontinuity. This is a zoom-in of a gridded RGB image of MODIS L1B top of the atmosphere reflectance, over Red sea, on day 136, 2005.
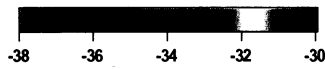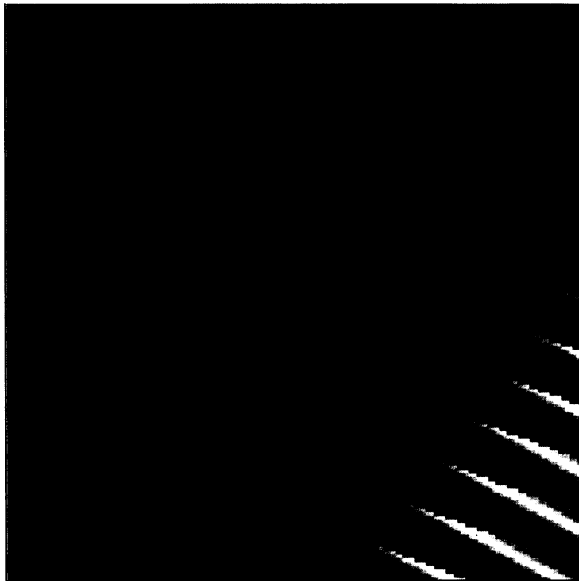
a)

b)

-38   -36   -34   -32   -30

Figure 4. The effect of azimuth discontinuity: a) a zoom-in of a gridded RGB image of MODIS L1B top of atmosphere reflectance over Greenland, on day 184, 2004; b) the relative azimuth angle pattern.
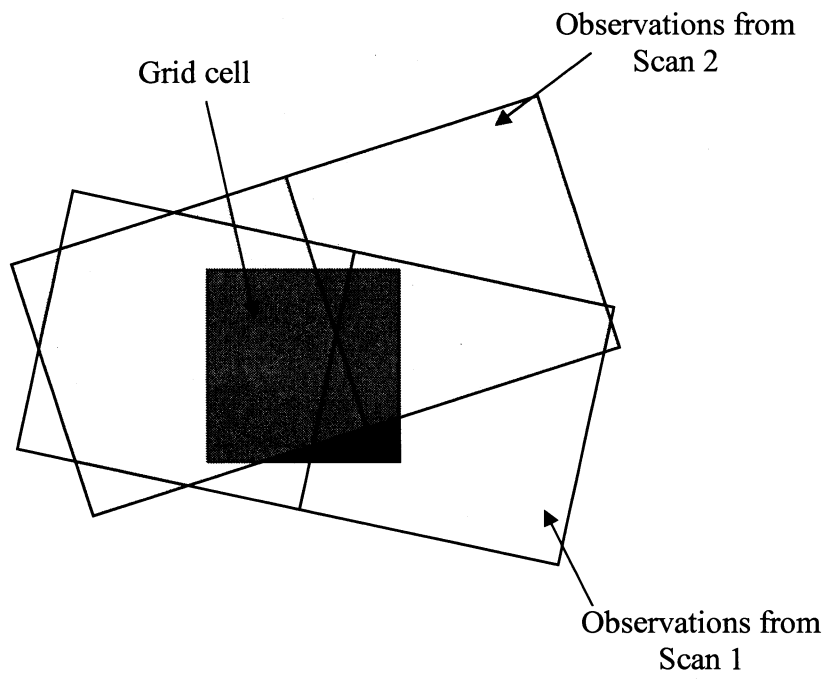
Figure 5. The geometric relations between the overlapping observations and grid cell.

(a) (b)

(c) (d)

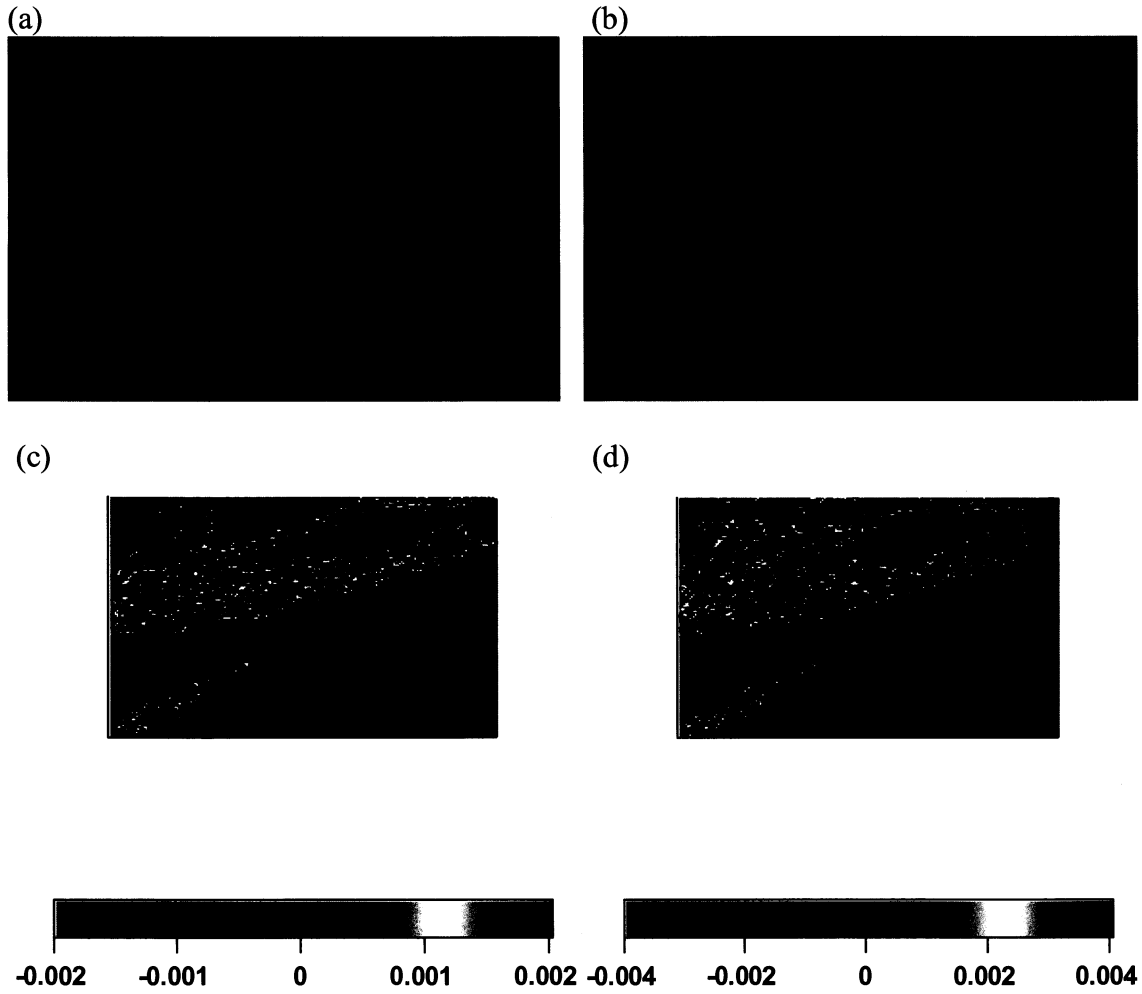-0.002   -0.001   0   0.001   0.002 -0.004   -0.002   0   0.002   0.004

Figure 6.   Comparison of two gridding methods: 1) the grid cell value is calculated by averaging all overlapping observations; and 2) the grid cell value is calculated by averaging overlapping observations within a single scan. a) The RGB image created with method 1); b) the RGB image created with method 2); c) the difference in the red band; and d) the difference in the Near-Infrared band.
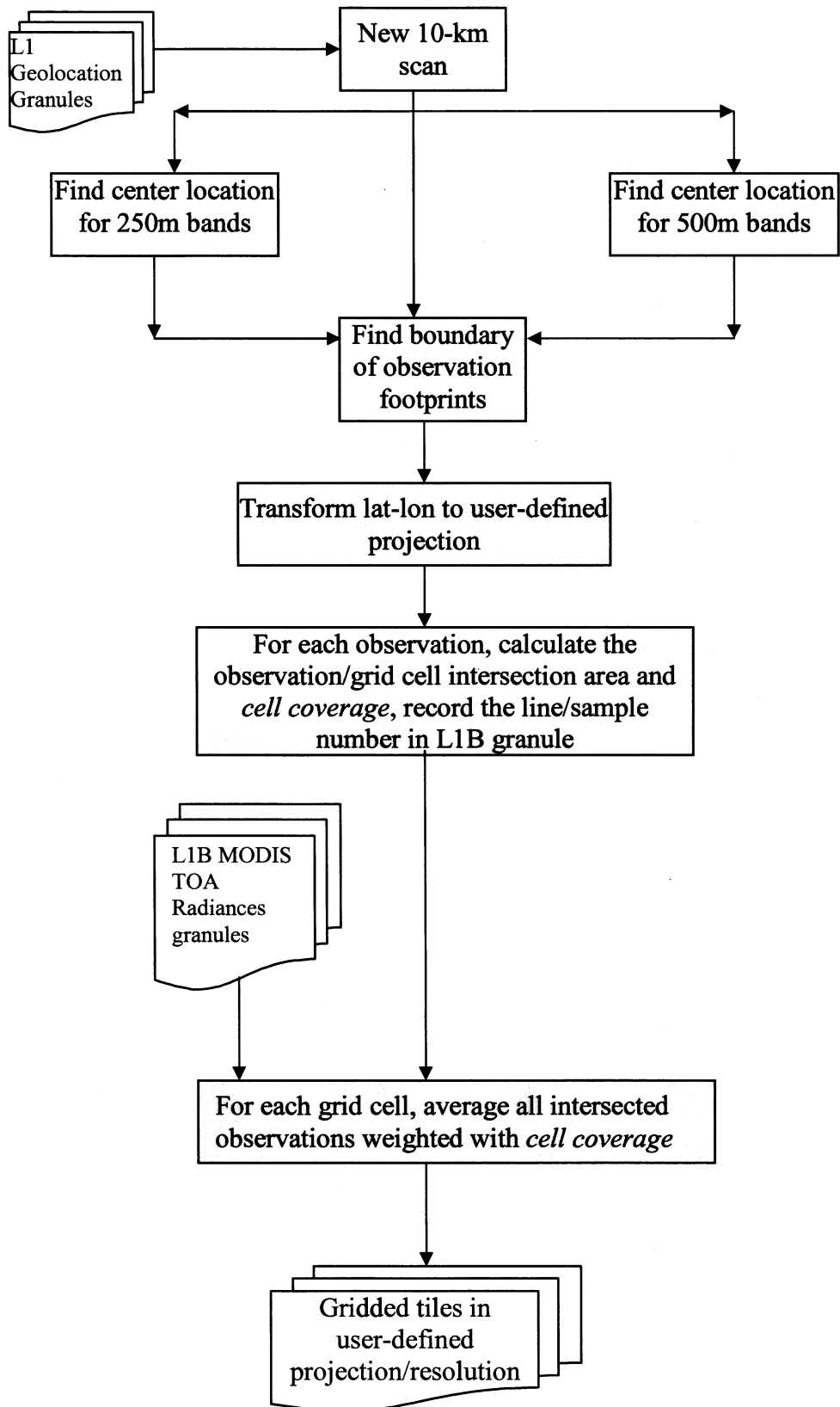
Figure 7. The gridding block-diagram of MODIS L1B data.