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REGIONAL CLOUD-FREE COMPOSITE OF MODIS DATA

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ABSTRACT: CRISP started to receive MODIS data in March 2001. A fully operational processing of the received MODIS data to level 1b has been successfully implemented. An algorithm for generating cloud-free composite of MODIS data are developed. The algorithm combines several passes of georectified MODIS reflectance onto a map of S.E. Asia. The algorithm uses several conditions to determine a cloud-free pixel from the original passes of image. The conditions are based on the MODIS cloud mask algorithm to determine whether a pixel is Cloud, Thin Cirrus Cloud or Shadow. In additions, we also use the Normalized Vegetation Index as an indicator to determine how clear is the pixel from the cloud. With all these conditions, a composite of map is generated by selecting the most cloud free pixel from the corresponding passes.

1. INTRODUCTION

South East Asia region is often covered by cloud. Therefore, a cloud-free satellite image of the region is valuable for many scientists to study the spatial and temporal distribution of vegetation, land cover types and geophysical phenomena. The compositing processes can be performed automatically once the MODIS data are processed to level 1b. Therefore, an 8-daily or monthly composite of MODIS data can be generated operationally.

2. ALGORITHM DESCRIPTION

The entire process of generating a cloud-free MODIS data composite consists of the several steps, namely Solar Angle Correction, Computation of NDVI, Cloud Mask Generation, Georectification of bands and MODIS Composite data Generation. The Composite of MODIS data is done on the Short-Wave InfraRed band (SWIR), Near InfraRed (NIR) and the RED band which are the Band 6, Band 2 and Band 1 of the MODIS earth view data. The SWIR band (band 6) is at 500m resolution and both the NIR and RED bands (band 1 and 2) are in 250m resolution.

2.1. Solar Angle Correction

The MODIS Level 1B data products are Top of the Atmosphere (TOA) radiance and reflectance. The data are radiometrically corrected and fully calibrated in physical units at the instrument spatial and temporal resolutions. Both the TOA radiance and reflectance are stored in a *Scientific Data Set* (SDS) Object, *Scaled Integer* (SI). The scaled integer is a 16-bit unsigned integer which can be converted into radiance or reflectance by the following equations

$$radiance = radiance\_scale[B](SI - radiance\_offsets[B]) \tag{1}$$

$$reflectance = reflectance\_scale[B](SI - reflectance\_offsets[B]). \tag{2}$$

where B is the index of the desired band within the set of bands for this SDS. Both the $scale$ and the $offsets$ are attributes of the corresponding SDS.

This reflectance, $\rho*$, is actually the product of TOP reflectance (ρ) and cosine the solar zenith angle ($\cos\theta$), i.e. $\rho* = \rho\cos(\theta)$. Therefore, the reflectance varies with the solar zenith angle. The descending node for the TERRA orbit is 10:30am in which the sun is always on the eastern side of the pass. The zenith angle always decreases along scan line. Therefore, the effects on the reflectance is that the eastern side of the pass is brighten by the solar zenith angle. To correct for this effect, we just need to divide the reflectance of each pixels by the cosine of solar zenith angle of that pixel

$$\rho = \frac{\rho*}{\cos(\theta)}. \tag{3}$$

The reflectance obtained is independent of the solar zenith angle and the solar flux. However, it is still not independent of the atmospheric effects. In SWIR, NIR and RED bands, the atmospheric effects is not very strong. Therefore, we can safely ignore the atmospheric effects in these bands.

2.2. Computation of NDVI

The Normalized Difference Vegatation Index (NDVI) is defined as

$$NDVI = \frac{\rho_{nir} + \rho_{red}}{\rho_{nir} - \rho_{red}} \tag{4}$$

where ρ_{nir} is the reflectance for NIR band and ρ_{red} is the reflectance for RED band. The NDVI is a good indicator of the vegetation density. Its value range from -1 to 1 with the higher value the denser the vegetation. When the pixel is covered by cloud, the values of the two bands become closer and resulting a smaller NDVI. Threfore, NDVI serve as a good determining factor of cloud-free pixels.

2.3. Cloud Mask Generation

MODIS have 16 thermal bands which are very sensitive to temperature. Some of these bands are specifically designed to detect the cloud. When a pixel is covered by cloud, the thermal band is measuring the radiance emitted from the top of the cloud which has a much lower temperature. Therefore the brightness temperature of cloud is always much lowerer than the surrounding non-cloud area. The brightness temperature for a certain band can be computed by the inversion of Planck equation

$$BT = \frac{hc/\lambda k}{\log(1 + 2hc^2/L)}. \tag{5}$$

Two emissive bands were used in cloud detection, band 20 and band 31. The corresponding wavelengths are 3.750μm and 11.03μm. Band 20 is used for determine thick cloud and band 31 is to be used together with band 20 to detect thin cirrus cloud. The criteria that we used are as followed:

- When it is over the land,
  - $BT_{20} - BT31 > 6$ implies thin cirrus cloud. A score of 1 is given to the mask.
  - $BT_{20} < 270$ implies thick cloud. A score of 2 is given to the mask.
  - Non of the above implies cloud free. A score of 0 is given to the mask.
- When it is over the sea,
  - $BT_{20} < 273$ implies thick cloud. A score of 12 is given to the mask.
  - $BT_{20} - BT_{31} > 10$ implies thin cirrus cloud. A score of 11 is given to the mask.
  - Non of the above implies cloud free. A score of 10 is given to the mask.

The score is given in such a way that the higher the value, it is more likely that the pixel is cloud. When the score is more than 10, it indicates that it is over the sea.

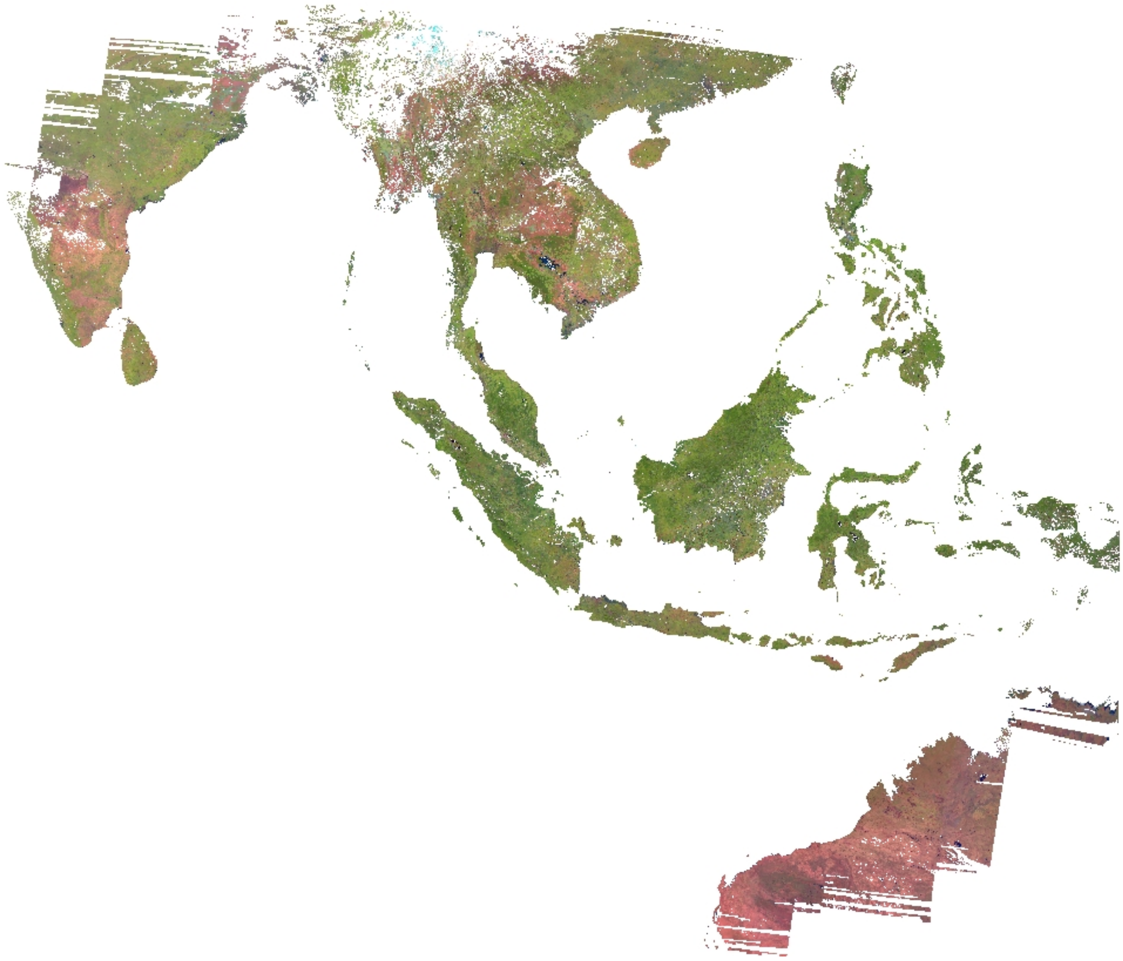

Figure 1: A Regional Cloud-free Composite of MODIS data from 7 May to 14 May. The bands combination is (SWIR,NIR,RED) in RGB display. The Myanmar and southern part of China are still cloudy.

2.4. MODIS Composite data Generation

The reflectance and NDVI for each bands together with the cloud-mask are georefereced onto a map. The composite of reflectance for each bands (SWIR, NIR and RED) are obtained by the following algorithm:

- If it is on the land, find the minimum scores among the N passes
  - If the minimum score is equal to 0, take the average of the reflectance of all those passes which have the score of 0.
  - If the minimum score is equal to 1, find the maximum NDVI among all the N passes and assign the composited reflectance to the reflectance of the pass which have the maximum NDVI.
  - If the minimum score is greater than 1, leave the composited reflectance as zero. The composite pixel is undetermined.
- If it is on the sea, find the minimum scores among the N passes
  - If the minimum score is less than 12, take the average of the reflectance of all those passes which have the score less than 12.
  - If the minimum score is equal to 12, leave the composited reflectance as zero. The composite pixel is undetermined.

3. DISCUSSIONS AND CONCLUSION

Figure 1 is an 8-day composite of MODIS data. The image is composited from MODIS data received in CRISP dated from 7 May to 14 May 2001. The image is displayed with SWIR band in Red channel, NIR band in Green channel and RED band in Blue band. In this display, vegetation appears in green colour and built-up area or non-vegetated land appears in pinkish colour. In this composite, most of the cloud has been taken away except those in the upper part of the image. This area are cloudy throughout the week and there are less data available, therefore they are remain undertermined.

Figure 2 is the zoom-in of Sumatra and Peninsula Malaysia area which has a resolution of 1km. There are a lot of undetermined pixels surrounding the mountain ranges in Sumatra. Mountain ranges in this region are always covered by cloud. Therefore, they are filled with zeroes. In high urbanised area such as Kuala Lumpur and Jakarta, the entire city appears pink in colour. Burned scars in Riau Province of Sumatra can be seen clearly.

The quality of cloud-free MODIS composite shows that MODIS is indeed well calibrated. There is virtually no distinctive line between different sets of MODIS data. However, this may not be true when it is applied to MODIS GREEN and BLUE bands in which atmospheric effects are relatively stronger.

The cloud-free MODIS composite reveals a lot of geographical features such as urban area, burned scars, deep forest, secondary forest, plantations and so on. It is particularly useful for environmental monitoring if 8-daily or monthly MODIS composite is generated on operational basis. CRISP are ready to generate 8-daily and montly MODIS cloud-free data operationally. It will certainly enhance our capabilities in monitoring the regional environments.

We will further improve the composite algorithm by applying Rayleigh Scattering correction to the visible bands such RED, GREEN and BLUE bands. In this ways, we can generate cloud-free composite of True colour MODIS image. We would also like to extend to NDVI composite so that we can study the temporal and spatial variation of vegetations in the region. Delineation of burned scars can be applied to the cloud-free MODIS composite as well. With this, we can map out the forest or plantation fires in the region more easily.

REFERENCES

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Figure 2: A zoom-in of Sumatra and Peninsula Malaysia area. Urbanised area like Kuala Lumpur and Jakarta appear clearly in pink colour. Burned Scars can be identified in Riau Province of Sumatra.