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RESEARCH ARTICLE

VALIDATION OF MODIS ATMOSPHERIC AEROSOL RETRIEVALS USING AERONET DATA AT REGIONAL SCALE IN WEST AFRICA

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ABSTRACT

This study is based on the validation of MODIS (MODerate resolution Imaging Spectroradiometer) products of atmospheric aerosols in West Africa using data from the global network AERONET (AErosol RObotic NETwork) of six photometric stations in West Africa. It aims to characterise atmospheric aerosols at the regional or sub-regional scale of West Africa. The optical thickness and the Angstrom coefficient or size coefficient of atmospheric aerosols are validated at six photometric stations in West Africa, which are the stations of: Banizoumbou, Cape Verde, Dakar, IER Cinzana, Ilorin and Zinder. The results obtained show a correlation coefficient of 0.90 (Zinder station) to 0.94 (Banizoumbou station) for the optical thickness, of 0.90 (Ilorin station) to 0.93 (Dakar station) for the particle size coefficient. This indicates a good correlation between the measurements reported by MODIS and the AERONET network at the locations considered. These results indicate a good correlation between MODIS recoveries of optical thickness and size coefficient with local AERONET data for all six stations considered during the period 2010 - 2019.

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INTRODUCTION

Atmospheric aerosols, although minor constituents of the atmosphere, are known to be major players in the climate system and the hydrological cycle (1). However, large uncertainties remain in the quantification of their effects. Indeed, there is great variability in the shape, size, optical and chemical properties of aerosols, and moreover, the short lifetime of these particles and their diverse origins lead to a very inhomogeneous distribution within the atmosphere. The ground-based sunphotometers of the global AERONET network are well suited to continuously observe the atmosphere in key locations, but not on a global scale (1). Only satellite observations can provide daily and global measurements. The application of satellite data to derive global aerosol properties has progressed considerably in recent years (2). A wide range of instruments dedicated to aerosol monitoring has been successfully launched, such as POLDER (3) on the ADEOS spacecraft or MODIS (4) on the Aqua or Terra spacecraft and MISR on Terra (3). These new capabilities have already improved our knowledge of aerosol properties (1); (2); (4); (5); (6); (7). Nevertheless, each instrument has its own characteristics leading to different ways of retrieving aerosol properties and different accuracies in these retrievals. Launched aboard NASA's Terra and Aqua satellites in December 1999 and May 2002, the MODIS (MODerate resolution Imaging Spectroradiometer) spaceborne radiometer has 36 channels covering the spectral range from 0.41 to 15 µm representing three spatial resolutions: 250 m (2 channels), 500 m (5 channels) and 1 km (29 channels) (8). Aerosol retrieval uses seven of these channels (0.47 to 2.13 µm) to retrieve aerosol features and uses additional wavelengths in other parts of the spectrum to identify clouds and river sediments (8); (9); (10). Unlike previous satellite sensors, which lacked sufficient spectral diversity, the MODIS sensor has the unique ability to retrieve the optical thickness of aerosols with greater accuracy and to retrieve parameters characterising aerosol size (8); (11). Aerosol products available on land include aerosol optical thickness at three wavelengths, a measure of the fraction of fine mode aerosol optical thickness, and several derived parameters, including the spectral solar flux reflected at the top of the atmosphere (12). Over the ocean, aerosol optical thickness is provided in seven wavelengths from 0.47 to 2.13 µm. In addition, information on aerosol size including the effective radius of the aerosol particles and the quantitative fraction of the optical thickness attributed to the fine mode. The spectral irradiance contributed by the aerosol particles, the mass concentration and the number of cloud condensation nuclei complete the list of aerosol products available over the ocean (12); (13). The daily Level 2 data are produced at the spatial resolution of a 10x10 pixel array of 1 km (at nadir) (1); (3); (12). MODIS was chosen for several reasons: it is free of charge, the size of the scenes is adapted to the geographical extent of the phenomenon studied and its high temporal resolution (an image of 1 to 2 days) compensates for its low spatial resolution (pixel size of 250 m to 500 m for the spectral data used).

METHODOLOGY

The data used in this study are the archival data from the AERONET network and the MODIS sensor. We selected more than 2500 MODIS and AERONET co-located optical thickness and size parameter retrievals from six sites of the global AERONET network in West Africa during the period 2010 - 2019. The six photometric stations considered are Banizoumbou station (Niger), Capt-Vert station (Cape Verde), Dakar station (Senegal), IER Cinzana station (Mali), Ilorin station (Nigeria) and Zinder station (Niger). The AERONET products used are the aerosol optical parameters, which are the aerosol optical depth (AOD) at 440 nm, denoted τ440, and the Angström coefficient at 440-870 nm or size coefficient, denoted α440-870. These spectral ranges are the most sensitive to atmospheric aerosols with the AERONET measurements. The MODIS retrievals are the MOD04_L2 and MYD04_L2 products, which are digital data of daily aerosol optical thickness and size coefficient measurements from the Terra and Aqua platforms, respectively; and the MYD08_L3 products, which are image data of monthly averages from the Aqua platform. The MOD08_L3 products are the same type of data reported by the Terra platform. These data contain the same information and their simultaneous use with the MYD08_L3 products (retrieved from the Aqua platform) is not necessary in our study. The AERONET data is free of charge and can be accessed on the AERONET website at the following link: http://aeronet.gsfc.nasa.gov MODIS data, also free of charge, can be accessed at the following link: http://ladsweb.modaps.eodis.nasa.gov/

RESULTS AND DISCUSSION

Validation of daily averages of the optical thickness of atmospheric aerosols retrieved from MODIS by photometric measurements of the AERONET network: The results obtained on the validation of the values of the optical thickness of atmospheric aerosols provided by the MODIS radiometer and by the ground-based photometric measurements of the AERONET network, during the considered study period, 2010 - 2019, for all six photometric stations are shown in Figure 2. The results of the recoveries are discussed using an evaluation index, which is the correlation coefficient or multiple determination coefficient or regression coefficient R2. For the Banizoumbou station, according to the results, there is a good correlation between the MODIS and AERONET AOD data with a correlation coefficient $R^2 = 0.93$. At the Cape Verde station, the results indicate a good correlation between the AOD measurements collected from MODIS and the AERONET measurements. The regression coefficient $R^2 = 0.91$. At the Dakar station, the figure shows a good correlation between MODIS and AERONET data of aerosol optical thickness. The regression coefficient R^2 is 0.91. At the IER Cinzana photometric station, the results also show a good correlation between MODIS and AERONET AOD data with a correlation coefficient $R^2 = 0.92$. At the Ilorin station, the AOD reported by MODIS correlates well with the AOD of the AERONET network with a correlation coefficient $R^2 = 0.91$. At the Zinder station, the correlation coefficient between the optical thickness reported by the MODIS sensor and the AERONET network is $R^2 = 0.90$.

This indicates a good correlation between the MODIS and AERONET AOD measurements. D. A. Chu *et al*, 2002, found a correlation coefficient of 0.85 to 0.98 between MODIS AOD recoveries and AERONET measurements at more than 30 AERONET sites during July to September 2000. Their results showed a good correlation between MODIS recoveries and AERONET measurements but the study period is not large enough to confirm the persistence of this correlation. Cheng Chen *et al*, 2018 performed validation of the global AOD data recovered on PARASOL/GRASP at several lengths, from 440nm to 1020 nm with AERONET measurements over a period of one year. Their study based on desert dust aerosols and carbonate aerosols, showed a good correlation between the global data and AERONET with a regression coefficient $R^2 = 0.85$ obtained with the 440 nm wavelength. The results obtained for all six stations during the period 2010 - 2019, indicate a good correlation between MODIS retrievals and AERONET measurements of AOD, and suggest that the MODIS AOD product can be used to characterise atmospheric aerosols at the global scale.

Validations of the daily averages of the size coefficient of atmospheric aerosols retrieved from MODIS by the photometric measurements of the AERONET network: The validation of the Angstrom or size coefficient is shown in Figure 3 below. The size coefficient considered for the MODIS data is the Angström coefficient in the 470-660 nm spectral band, denoted α470-660. This range, for MODIS measurements, is more sensitive to fine and coarse mode aerosols. For the AERONET array the array size coefficient is that in the 440-870 nm spectral band, denoted α440-870, where both fine and coarse mode aerosols are most sensitive. For the Zinder station, the results indicate a good correlation of the MODIS size coefficient measurements with those of the global AERONET network. The obtained correlation coefficient R2 = 0.92. For the station of Ilorin, the correlation coefficient R2 is 0.90, which indicates a good correlation of the size coefficient reported by MODIS with the AERONET measurements. At the Banizoumbou station, the results indicate a considerable correlation between the size coefficient data with a correlation coefficient R2 = 0.90. At the IER Cinzana station, the correlation coefficient R2 = 0.92 indicates a good correlation between the MODIS and AERONET measurements reported on the size coefficient of atmospheric aerosols in the atmospheric column above the locality. At the Dakar station, the results indicate a good correlation between the MODIS and AERONET measurements of the locality with a regression coefficient R2 = 0.92. For the Cape Verde station, the R2 correlation coefficient is equal to 0.92, as for the Dakar, Zinder and Cinzana IER stations. This indicates a good correlation between the aerosol size coefficient measurements retrieved from MODIS and the global AERONET network in the atmospheric column above the locality. For all photometric stations considered, the regression coefficient between MODIS and AERONET data is 0.90 ≤ R2 ≤ 0.92. These results indicate that the size coefficient of atmospheric aerosols retrieved on MODIS correlates well with the AERONET measurements for all six photometric stations during the period 2010 - 2019.

Validation of monthly averages of MODIS atmospheric aerosol optical thickness at 440 nm from AERONET photometric measurements: The monthly averages of aerosol optical thickness at 440 nm (AOD_440), denoted τ_{440} from AERONET and the West African sub-regional recoveries of AOD at 470 nm from MODIS are shown in Figure 4 below. At the Zinder station, the histograms of monthly mean AOD from MODIS and AERONET evolve in almost the same way for all twelve months, although they show slight deviations due to an over- or underestimation of AOD by MODIS in some months. These observations indicate, however, a good correlation between the monthly AOD averages retrieved by MODIS and those of the global AERONET network. The monthly AOD averages of the global AERONET network and those recovered by MODIS are above 0.50 from February to June. The months of April, May and June are the most marked with monthly averages above 0.60. The two radiometers, ground and space, show simultaneously low values of AOD in August and September, then in November,

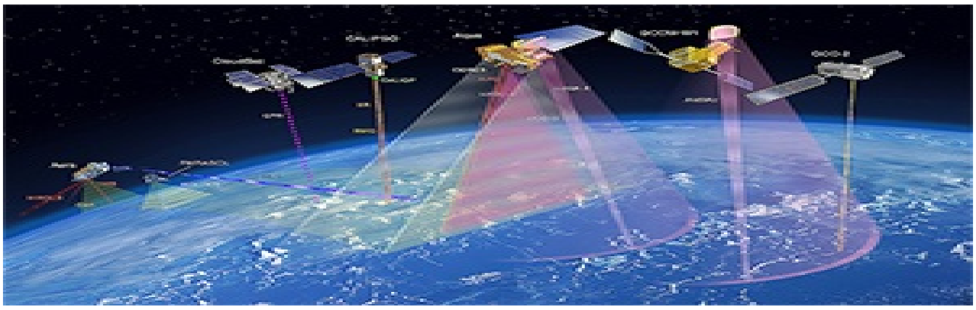

Figure 1. A-Train constellation including Terra and Aqua with MODIS sensor

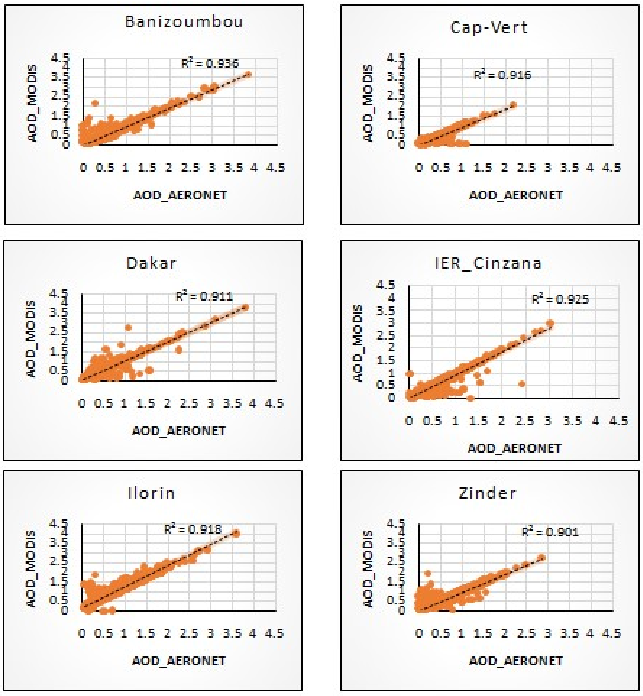

Figure 2. Validation of daily averages of aerosols optical thickness the retrieved by MODIS from the AERONET photometric measurements

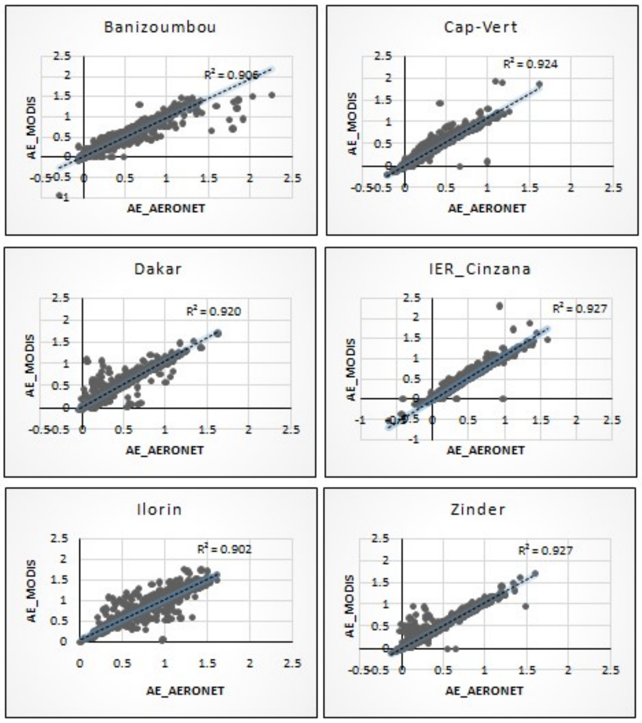

Figure 3: Validation of daily means of aerosol size coefficient retrieved by MODIS from AERONET photometric measurements in West Africa

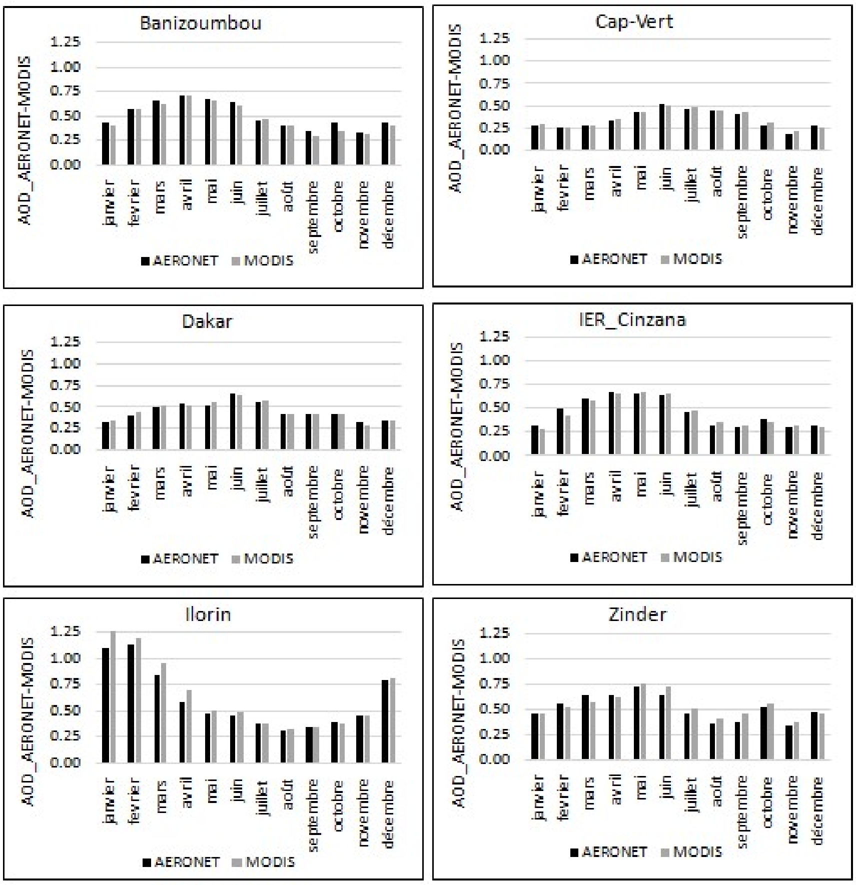

Figure 4. Validation of monthly averages of the atmospheric aerosols optical thickness retrieved by MODIS from AERONET photometric measurements in West Africa

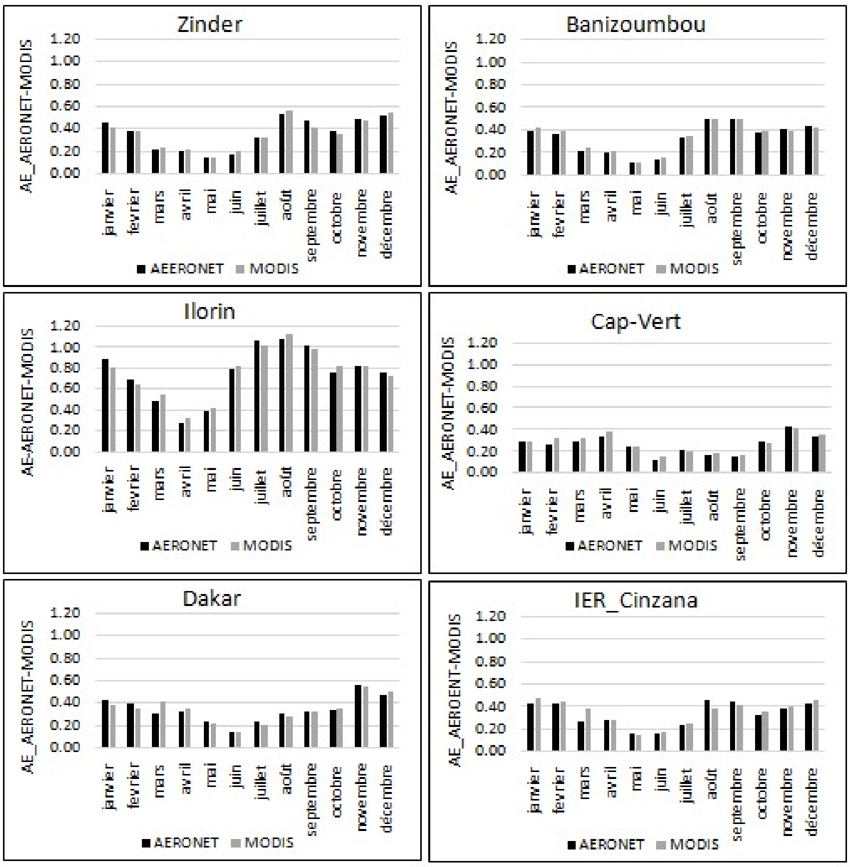

Figure 5. Validation of monthly means of the atmospheric aerosol size coefficient retrieved by MODIS from AERONET photometric measurements in West Africa

December and January. At the Banizoumbou station, the monthly averages recovered from the two radiometers correlate well due to the almost identical evolution of the representative histograms for both types of data (ground and space). Slight discrepancies are observed, particularly in July, August, September, and December and January. The observations suggest an overestimation of the ADO recovered by MODIS in July and August and an underestimation of these products in December and January, and in July and September. The monthly averages, for both recoveries together, are between 0.38 and 0.70. Note that the months of March, April, May and June are the most marked with monthly averages $\tau440 > 0.60$. For the Ilorin station, the histograms of the monthly means of the MODIS AOD and the AOD of the global AERONET network have an almost identical evolution over the twelve months. The MODIS retrievals seem to indicate an overestimation of the AOD by the space radiometer in January, February, March and April. The monthly averages for both measurements together are between 0.30 and 1.15. The months of December, January, February and March are very marked due to their monthly average being significantly higher than 0.60, while for the months of April to November the AOD is below this value. At the IER station in Cinzana, MODIS recoveries of monthly average AOD correlate well with the ground measurements of the global AERONET network, despite the small deviations in values in January, February and March. The monthly mean values of the AOD for both measurements together are between 0.29 and 0.68. The highest values of the monthly averages are recorded in the months of March, April, May and June with values of the optical thickness above 0.60. For the Dakar station, the evolution of the histograms representing the MODIS recoveries and the AERONET measurements into monthly averages of AOD shows a good correlation between the two measurements. The monthly AOD averages for both data types together are lower compared to the previous stations. The values of the monthly average AOD are between 0.32 and 0.68. The month of June is the most marked with a value of $\tau_{440} > 0.60$; followed by July with a monthly average AOD equal to 0.58. At the Cape Verde station, the uniformity between the histograms suggests a good correlation between the monthly AOD averages recovered by MODIS and measured by AERONET. For both types of data, the lowest monthly average AOD values are recorded compared to the other photometric stations. The AOD values are between 0.20 and 0.50. The months of June and July are in fact the most marked with monthly averages almost equal to 0.50. These results suggest that the months of March, April, May and June are overall marked by the most intense aerosol episodes for all six photometric stations during the 2010 - 2019 study period.

Validation of monthly MODIS atmospheric aerosol size coefficient means from AERONET photometric measurements: The monthly averages of the aerosol size coefficient $\alpha_{440-870}$ measured from the AERONET network and those recovered by MODIS are shown in Figure 5 below. For the Zinder station the monthly averages of the size coefficient retrieved by MODIS and those measured from the global AERONET network evolve in a nearly identical way. This indicates a good correlation between the two types of data. The monthly averages of the size coefficient from both MODIS and AERONET radiometers vary from 0.12 to 0.52 over the twelve months. For the Banizoumbou station, the identical evolution of the histograms representing the monthly averages of the aerosol size coefficient recovered by MODIS and those obtained by AERONET indicates a good correlation between the two types of data for the twelve months. The monthly means of the size coefficient for both types of radiometers, MODIS space radiometer and AERONET ground radiometers, are between 0.10 and 0.50. Slight overestimations of the size coefficient recovered by MODIS are observed in the months of January to April. For the Ilorin station, the histograms representing the monthly averages of the size coefficient from the MODIS recoveries and the AERONET measurements show a good correlation between the types of data. However, there are slight underestimations of the size coefficient by MODIS in January, February, July and December and slight overestimations in August and October. The monthly averages of the two types of data are between 0.28 and 1.15. At the IER station in Cinzana, overestimates of the size coefficient by MODIS are observed in January, February, then December, especially in March where this overestimate is considerable. The histograms also indicate an underestimation of the size coefficient by MODIS in August. Nevertheless, these observations do not indicate a significant difference in the evolution of the histograms representing these monthly averages. Indeed, there is a good correlation between the monthly means reported by the two radiometers. The monthly averages of the size coefficient are between 0.18 and 0.48. At the Dakar station, the histograms show a good correlation between the monthly means of the two types of data despite overestimations of the size coefficient by MODIS in March and April and underestimations in January and February. The monthly averages of the two types of data are between 0.12 and 0.58 with the lowest value recorded in June. For the Cape Verde station, the histograms show small overestimates of the size coefficient by MODIS in the months of February through June. However, they do not show a significant difference in the variation of the monthly mean recoveries by MODIS and the AERONET measurements. These observations suggest a good correlation between the data from the two radiometers. The monthly averages of the size coefficient are between 0.11 and 0.45. The month of June also has the lowest value for this station. These results indicate a good correlation between the MODIS space radiometer data and the AERONET measurements for all six photometric stations considered.

CONCLUSION

This study validated with good correlation the optical thickness and size coefficient of atmospheric aerosols retrieved from the MODIS space radiometer using AERONET data in West Africa during the period 2010 - 2019. The results indicate a correlation coefficient ranging from $R^2 = 0.90$ (Zinder station) to $R^2 = 0.94$ (Banizoumbou station) for the daily means of the optical thickness and a correlation coefficient ranging from $R^2 = 0.90$ (Dakar station) to $R^2 = 0.93$ (IER Cinzana station) for the daily means of the size coefficient. The monthly averages of these parameters also indicate a good approximation for all six stations. The results obtained are in good agreement with the work of D. A. Chu al., 2002 and Shikuan Jin *et al.*, 2019. MODIS data products, in three different resolutions 250 m, 500 m and 1 km, help to improve our understanding of global environmental processes and dynamics occurring on land, in the oceans and in the lower atmosphere. MODIS-derived data products continue to play a vital role in helping to develop and validate models to inform and assist policy makers in addressing global environmental change.

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