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⁶Spatial Correlation between Land Surface Properties and Cloud Characteristics in Indonesia

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Abstract. The change of surface vegetation also links to the evapotranspiration pattern so that the moisture flux might be affected by the atmospheric stratiform or convective clouds, meant to be important in balancing hydrological cycle and the more analysing is necessary to explain this phenomenon. The aim of this paper to analyze the complex phenomenon that link in spatial correlation of cloud response towards land surface change that ensued from cloud microphysical components. Fourteen years from 2003 to 2016 over Indonesia was applied that issued by Moderate-Resolution Imaging Spectroradiometer (MODIS) level-3 (L3) provides both cloud and land surface products. Cloud microphysical features consist of cloud fraction, cloud top pressure, cloud optical thickness, and cloud effective radius, whereas Normalized Difference Vegetation Index (NDVI) was applied to identify the land surface change. The distribution of spatial correlation and probability distribution function are used as the method to determine each cloud microphysical components response to land surface change. Concerning annual result, desirable connections among correlation between NDVI and cloud parameters is rather widely. Probabilistic approach from statistical analysis in the wet season forms palpably pattern (parabolic pattern) rather than a dry season pattern. Correlation values based on spatial analysis between NDVI anomalies and cloud parameter anomalies have a range of values around -0.8 to 0.8. Throughout Indonesia, every correlation between NDVI anomalies and cloud parameter anomalies has a negative correlation. Sumatra, Kalimantan and Papua have a major role to inject negative correlations. This causes this area to be covered with oil palm plantations.

1. Introduction

Approximately, 1.2 percent of total world's landmass is categorized as the land surface in Indonesia as a pattern to shelter [1]. It also exists for all types of landforms that include mountains, forests, urban areas, deserts, etc. [2]. ¹² type has different qualities depending on their particular type of land. Indonesia was located in maritime continent region with sensitivity respect to rainfall, net radiation, latent and sensible heat fluxes, and evapotranspiration over the land surface. In a tropical region such as Indonesia, the higher the altitude of the region (mountains), the more frequent the presence of clouds. Mountains in Indonesia, one type of land surface, are mostly covered by forest trees that actually produce more water droplets for evapotranspiration. When a forest tree oxidizes, it will produce tiny particles that float into air and become cloud shape ¹ and even more will grow from new particles formed into the beginning of the flow of the convective system [3].



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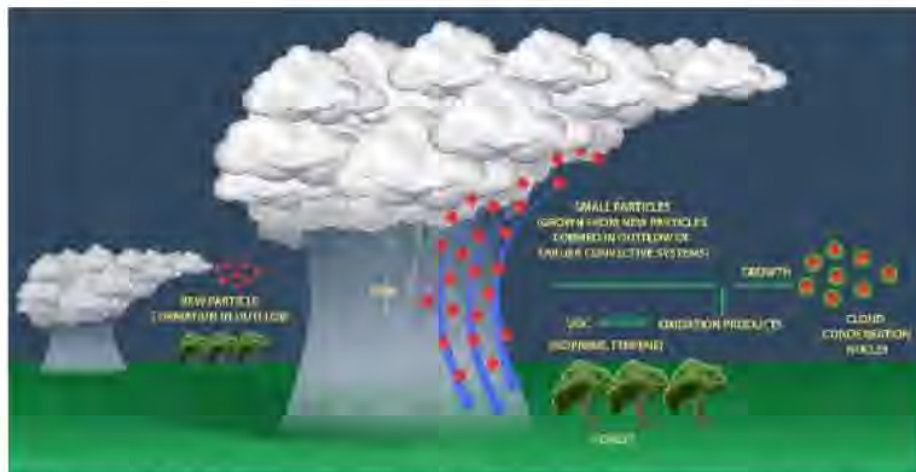


Figure 1. Volatile organic compounds (VOCs) emitted by trees react with oxidants.
Source: Machado, 2016 [4]

This cycle is indirect system describing the mutual relationship between Earth's surface and the atmospheric component, as a consequence, small changes to one part of the system can accrue to have larger effects on the other system as a whole [5]. This statement shows any possibility of the interrelation between land surface and local climate may affect other atmospheric phenomena such as clouds and their formation and properties. Fluctuation of forest plants exerts subtle effects on the stability of surface phenomenon. A recent study that estimated Indonesia to be one of the higher rates of tropical deforestation, is in the permanent transition from the forest and may even breakthrough from 2001 to 2012 in an estimated 6.02 million hectares of forest reconstruct to make the other land uses [6].

In recent decades, some research focuses on land plants transpiration which dominates terrestrial water fluxes and releases the larger amount of aerosol particles that affect cloud properties, concern on cloud condensation nuclei [7], surface properties finds the influence in land surface properties altering the surface energy balance in large scale afforestation in the sub-Saharan area toward climate [8], dominating in evapotranspiration on Earth's climate [9], functioning on future of evapotranspiration depend on ecosystem, climate, carbon, agriculture, and water resources [10], impacting on sea breeze extent and aerosol [11]. Hofer et al. in 2017 observed that the increasing cloud cover drives the recent mass loss on the Greenland Ice Sheet [12]. Teuling et al. in 2017 applied the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on board the MSG series of satellites to observe the cloud cover enhancement over western European forests for the period 2004–2013 at a 15 min resolution [13]. However, due to the high temporal resolution, they have the larger probability of false detection to get the coherence of spatial and temporal resolution. Therefore, here we propose an approach to complement those issues by comparing monthly as the time period of both parameters and construct the relationship between them.

2. Study Area

Indonesia as an area of interest which is geographically located in Southeast Asia stretches line from 95°45'E to 141°05'E about 5,120 kilometers (3,181 mi) and from 11°15'S to 6°08'N around 1,760 kilometers (1,094 mi). Around 1.9 million square kilometers identified as total land area of Indonesia and 7.9 million square kilometers of sea area [14; 15]. More than 13,466 Islands spread across the Indonesian archipelago is mostly unspoiled and boasts [16]. Top five of Indonesia's islands are Java, Sumatra, Kalimantan, Sulawesi, and Papua. Four from five major islands consist of Sumatra, Kalimantan, Sulawesi, Papua lie on equator (0° latitude) line which influences on the climate between

North hemisphere or South hemisphere direct (see Figure 2). Indonesia has total forest area around 88,495,000 ha or 48,8 percent of land area [17; 18]. The climate of Indonesia is tropical, with a monsoonal wet season, and a dry season. The rainy or wet season implies high rainfall intensity occurrence starts in November till lasts May and dry season occurs from June to October. In most of the city, rainfall is comparatively heavy throughout the year, with a pronounced rainy season roughly between December and March [19].



Figure 2. Indonesia geographical map.
Source : Anonym, 2018 [57]

3. Data and Methods

3.1. Data and Parameters

This study was collected by the MODIS (or Moderate Resolution Imaging Spectroradiometer), i.e. Terra MODIS and Aqua MODIS on NASA's satellite, datasets from 2003 to 2016 to investigate the land surface properties and cloud characteristics. MOD08 and MYD08 were applied for cloud characteristics with spatial resolution $1^\circ \times 1^\circ$ equal-angle global grid and monthly product as temporal resolution (Platnick, 2015). Four parameters from MOD08 and MYD08 which apply consist of: (1) Cloud coverage, also called cloud fraction, or cloud cover describes the amount of cloud in the sky. It can be measured as a percentage (0-100) or as a fraction (0-1.0) (2) Cloud top pressure is Atmospheric pressure at the level of the cloud top. (3) Cloud optical thickness a measure of how much sunlight passes through the cloud to reach Earth's surface. (4) Cloud effective radius is a weighted mean of the size distribution of cloud droplets. The MODIS vegetation products were obtained from MOD13C2 and MYD13C2 indices are designed product contains atmospherically corrected bi-directional surface reflectances masked for water, clouds, and cloud shadows.

3.2. Methods

In this study, cloud characteristics refer to cloud fraction, cloud top pressure, cloud optical thickness and cloud effective radius from MOD08 and MYD08 which collect from 2003 to 2016. On the other hands, MOD13C2 and MYD13C2 were using to NDVI analysis. Several methods were applied statistical by combining MOD and MYD, and then binning for 168 data to obtain the diurnal value, summing the binning result, calculating the anomaly for each parameter and finally climatology mean to investigate NDVI with each cloud characteristics. Additionally, each parameter is further divided into the dry and wet season to define how the particular relation between NDVI and cloud characteristics. Finally, the profile of cloud characteristics over land surface change can be determined.

4. Result and Discussion

The results of the standard deviation of each cloud parameter variable and surface properties from January 2003 to December 2016 presented in Figure 26. NDVI values range from 0.73 to 0.82, which fluctuate from the average value of each parameter for 14 years. This shows that the land surface is constantly changing by long-term land type transformation as a whole over Indonesia, tropical forests are relatively easy for deforestation, forest degradation, and loss of biodiversity. It might be caused by any factor combination of leading to intervention, climate - driven land-cover modifications interact with land-use changes [20]. Cloud fraction values ranging over 0.6, which means this value is close to one indicating cloudy confidence at fluctuates in morning and afternoon from the average value of each parameter for 14 years. A distinct yearly cloud cover can characterize cloud cover over Indonesia in land areas [21]. The depth analysis of cloud characteristics depends on cloud top pressure, cloud optical thickness and cloud droplet effective radius. Cloud top pressure has the values ranging from 600 to 200 hPa show clouds over Indonesia categorized by level from low to high clouds. Cloud optical thickness has values in the range 7 to 12 correlated to extinction of radiation. The effective radius of cloud droplet has a value of 14 to 20 micron, which indicates the longer size.

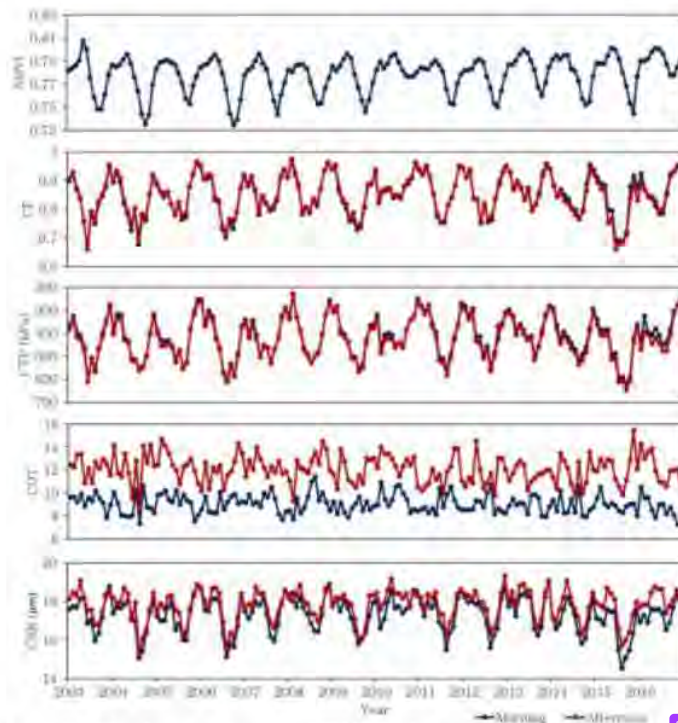


Figure 3. The graph of land properties (i.e., NDVI) and cloud characteristics (i.e., cloud fraction, cloud top pressure, cloud optical thickness, and cloud effective radius) from MODIS Terra (Morning) and MODIS Aqua (Afternoon) start from January 2003 to December 2016. Blue line depicts MODIS Terra and Redline depict MODIS Aqua.

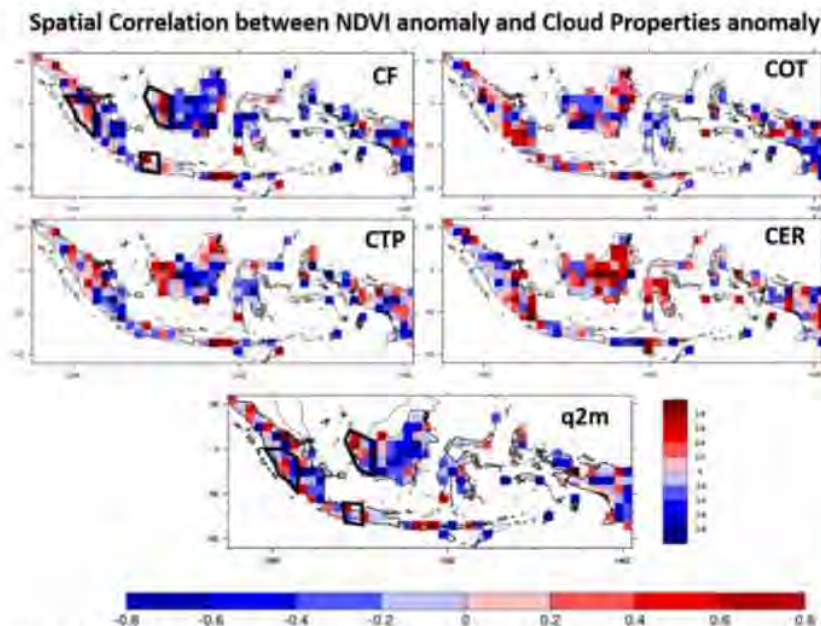


Figure 4. Spatial correlation between NDVI anomaly versus anomaly of cloud properties: (a) anomaly of cloud fraction, (b) anomaly of cloud top pressure, (c) anomaly of cloud optical thickness, (d) anomaly of cloud effective radius, and specific humidity anomaly of Terra (Morning) MODIS data in Wet season from January 2003 until December 2016. Colour bar represent the changes from negative to positive.

By considering the spatial relation between cloud characteristics and land surface properties, further analysis to depict the potential suspicious area shown in Figure 4. The top panel represents the spatial correlation between cloud fraction and NDVI during the wet season from 2003 to 2016. From negative correlation until positive correlation appears over Indonesia. Positive correlation area was detected as a forest area and negative correlation area was detected as a deformation from forest to an oil palm tree. Positive correlation (increase in NDVI accompanied by an increase in cloud cover) is detected in the forests of the west coast of Sumatra (average annual rain: 400 cm). The same was observed for northwest Kalimantan, West Java, Papua and some parts of Sulawesi [22]. Other islands such as Sumba and Timor receive relatively small amounts of rain. Negative correlation (increase in NDVI accompanied by a decrease in cloud cover) is detected in oil plantation area. Replacement of forest by annual biofuel crops (palm oil plantation) causes a decrease in evaporation and cloud cover. Humidity seems to be tightly correlated with cloud properties, so, humidity is high, much water is available for cloud formation. with mean decrease cloud cover exponentially as humidity falls below 100%, and relative to other layers in the troposphere, the layers 2.5–5 km above the surface contain the highest cloud amounts at the lowest relative humidities, with mean cloud amounts of 30% near 50% humidity at 650 mb. Oil palm trees can develop growth in the tropics with humidity reaching 80% [23; 24; 25].

5. Conclusion

Overall analysis realizes the goal of the research purpose to investigate land surface properties and cloud characteristics over Indonesia from 2003 to 2014. Highlight data period in the wet season (start from December to May) seems obviously represent to correlate between cloud parameter (cloud

fraction, cloud top pressure, cloud effective radius and cloud optical thickness) with land surface variable (NDVI). Land properties (i.e., NDVI) and cloud characteristics (i.e., cloud fraction, cloud top pressure, cloud optical thickness and cloud effective radius) from MODIS Terra (Morning) and MODIS Aqua (Afternoon) start from January 2003 to December 2017 are fluctuates over period.

To account for periodical changes in land surface properties toward cloud parameters, relationship of annual and seasonal be consider to expected that the rainy season plays a portion of the time the main role of observation. Concerning annual result, desirable connections among correlation between NDVI and cloud parameters is rather widely. Probabilistic approach from statistical analysis in the wet season forms palpably pattern (parabolic pattern) rather than a dry season pattern. Comparison between morning and afternoon result either in annual or seasonal show identically each other, exclude cloud optical thickness. As radiative concept, morning clouds are more common and lower reflectivity than afternoon. From the general result, it would lead to observe in wet season in morning time.

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