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Review: land, cloud, and climate change (in focus: Borneo)

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ABSTRACT

This article discusses the salient findings of the Intergovernmental Panel on Climate Change Special Report on Climate Change and Land (2019). Local impacts of global warming in Borneo are discussed in terms of changes in temperature and precipitation. A drier and warmer climate is expected with the continued deforestation of Borneo. Changes in land surface characteristics of Borneo also affect the properties of cloud that forms over it. Deforested areas are generally associated with diffused clouds, small cloud particles, and thin and high clouds. Low vegetative areas are associated with a low evapotranspiration rate and low amount of latent heat release, which discourages the formation of convective clouds. The weak updraft associated with a non-convective cloud cannot support the formation of large cloud droplets. Moreover, the deforestation of primary forests of Borneo and replacing them with palm trees may cause larger cloud properties' variability over the area.

Keywords: Borneo; capital; climate change; land use

1 Introduction

Main drivers of energy and water budgets of the Earth are mostly embedded in land-atmosphere interactions. Processes within the atmospheric planetary boundary layer (PBL) and the land surface regulate the PBL climate. Cloud, precipitation, and persistence of drought and flood are influenced by the land-atmosphere interaction [1]. Thus, any alterations of the land surface properties may directly and indirectly affect the formation and properties of cloud, the spatio-temporal distribution of rainfall, and the frequency and period of drought and flood.

Land use and land cover (LULC) can influence the near surface fluxes through modification of surface albedo and roughness. Surface albedo is ability of earth to reflect back the incoming short-wave solar radiation that reaches the surface. A change in land cover from forest to bare soil increases the surface albedo, cooling the earth. However, a forested area may also achieve this by balancing the sensible and latent heat fluxes. Moreover, high surface roughness due to forested vegetation increases the intensity of mixing of momentum, heat, water vapor, scalars in the PBL, which provides an efficient way of cooling the surface temperature. Surface roughness and albedo then directly influence the near-surface climate [2].

The potential ability of forest to regulate climate is underscored on it vastness. In 2008, it is reported that 30% of the total land surface of the Earth (~42 x 106 km2) is covered with forest [3]. However, we are losing this forest cover fast in recent years due to natural phenomena and anthropogenic activities [4, 5]. The latter is found to be the most active agent of change of forest cover [3, 6, 7]. Forests in tropical region are at greater risk with warmer and drier climate [8]. This positive feedback mechanism - forest lost, decreasing evaporative cooling and increasing atmospheric carbon dioxide, and increasing temperature-poses greater threat with the acceleration of human-induced deforestation [2]. At the heart of this issue in deforestation and climate change is the forest of Borneo. The impending capital transfer of Indonesia from Jakarta to Nusantara gives us an opportune time to discuss the effect of land cover change and climate especially over Borneo.

This article addresses the current knowledge of land and climate change, as well as the direction we are heading based on these conditions. It will discuss the possible mechanisms between changes in land

surface characteristics and cloud. Finally, implications of land cover change and climate for the impending capital transfer of Indonesia from Jakarta to Nusantara, East Kalimantan, will also be addressed.

2 Methods

The first part of this article utilized the Intergovernmental Panel on Climate Change (IPCC) 2019 special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL). The article provides the major findings as reflected in the technical summary of the IPCC SRCCL. The second part made use of the several studies to discuss the local impacts of climate change and LULC to Borneo's temperature, rainfall, and other atmospheric parameters. Finally, the article employed the results from [9] and [10] to provide insights of the possible mechanisms between land surface and cloud properties over Borneo, and Indonesia in general.

3 Discussion

Among the greenhouse gasses, other anthropogenic forcings, and natural forcings, the highest positive climate forcing comes from carbon dioxide. Therefore, we will begin by introducing the global carbon cycle. The natural flux of carbon (source and sink) can be found in vegetation, soil, and ocean. With the changing LULC, fossil fuel combustion, and industrial processes, new carbon sources are introduced into this cycle. These led to an increased concentration of carbon dioxide in the atmosphere, which in turn causes the increase in global (land-ocean) mean surface temperature. Not surprisingly, a more drastic increase in temperature is found in surface air temperature over land. This means that forests, pastures, irrigated cropland, urban areas, ice-covered regions, etc. are more likely to experience changes than the maritime regions. The spatio-temporal availability of water (in the soil, rivers, lakes, etc.) is of prime concern especially for agricultural land and pastures, where we obtain most of our food. Water is one of the most important greenhouse gases and its concentration in the atmosphere varies considerably in time and space. With the rising global temperature, the water vapor holding capacity of the atmosphere is also affected as predicted by the Clausius-Clapeyron equation.

In August 2019, the Intergovernmental Panel on Climate Change (IPCC) published a special report on the status quo of climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL). The special report also presents shared socio-economic pathways. These pathways lay out the magnitude of adjustment and intervention needed to mitigate the impacts of and to adapt with the changing climate towards development.

According to the IPCC SRCCL [11], more than 70% of the global land surface (ice-free) is directly affected by human activities, with infrastructure and irrigated cropland being most intensely used. Of the total anthropogenic greenhouse gas emissions, 23% is produced from agriculture, forestry and other land use. Slash-and burn agriculture is largely used to add vast swaths of land for growing food. Also, the use of inorganic nitrogen fertilizer for agriculture has dramatically increased in the past two decades. With increasing global population and calorie intake per person, land use intensification and land use change rapidly increased to meet the demand for increased food production. As a result, inland wetland is trimmed down by around 30% along with the loss of habitat and the crucial ecosystems, dry land areas in drought increased by approximately 50%, and population exposed to desertification increased by 200%.

The IPCC SRCCL [11] presented five shared socio-economic pathways (SSP), which are scenarios of projected socioeconomic global changes up to 2100. These are the SSPs and their corresponding descriptions: SSP1: Sustainability or taking the green road (more sustainable pathway, human wellbeing over economic growth, reduced inequality, less intensive consumption); SSP2: Middle of the road (social and economic trend continue, inequality not alleviated, some efficiency improvements, high vulnerability to environmental changes); SSP3: Regional rivalry or a rocky road (nationalism, focus on regional issues, less investment in education and technology, material intensive consumption, degradation continues in some countries); SSP4: Inequality or a road divided (unequal investments in human capital, high challenges to adaptation, social cohesion degrades, high technological development); and SSP5: Fossil fueled development or taking the highway (market driven, fossil fuel dependent world, integrated global society, high investment in human capital, faith in technological solutions). Among these, SSP1 has the lowest challenges in mitigation and adaptation. This means that if we will be able to implement a sustainable land management, agricultural intensification, production and consumption patterns, there will be a reduced need for agricultural land, in spite of the increase in per capita food consumption. This land, which is supposed to be an addition for food production, may then be used for reforestation, afforestation, and bioenergy. On the other hand, SSP3 requires the most adjustments and interventions. Given the same level of global mean surface temperature increase, risks are lower in SSP1 as compared to SSP3. Thus, it is encouraged to take the SSP1 in which the global population growth is low, the income is high while the inequalities are reduced, food production is done with low greenhouse gas emission, land use regulation is effective and adaptive capacity is high.

Now that the current global conditions of land and climate change, and the projected scenarios are laid out, why do these matter to an Indonesian? Substantial studies had been done in the Island of Borneo, which in recent 50 years underwent one of the fastest changes in land use and land cover, in the world. It is reported that the total forest cover percentage of Borneo went from ~76% in 1973 to ~28% in 2015 [12]. That is an approximately 187,000 km^2 of cleared or degraded forest, mainly in coastal lowlands, where agriculture and industrial plantations are most suitable and accessible. This deforestation has been associated with the increased in temperature as well as reduced in precipitation [13]. Accordingly, the daily mean temperature increased significantly and the daily mean rainfall reduced drastically after 1973. Watersheds that were intensely deforested experienced the most pronounced reduction in rainfall. Also, deforested areas were found to have higher increase in temperature and more frequent hot temperature extremes as compared to forest areas [13]. A recent study found that the forest cover of Borneo declined by as much as 37% between 1980 and 2015 [14]. The conversion of Borneo's native forests to oil palm and a mosaic of timber plantations and regrowth vegetation, compounds the impacts of El Niño events, resulting in a hotter and drier climate. The impacts on climate is most pronounced in the most heavily deforested areas and stronger during El Niño years as compared to neutral years. Moreover, the authors also found that the latent heat flux, relative humidity, and cloud covered are lesser, and the aridity index is higher during El Niño than during neutral conditions. But what are the mechanisms of these interactions between the changes in land cover and the above-mentioned atmospheric parameters?

The IPCC SRCCL [11] offers an extensive explanation as to how land cover change affects surface climate through morphology (albedo, surface roughness) and physiology (evapotranspiration, sensible and latent heat fluxes) (Figure 1). The albedo of land dictates how much of the incoming shortwave solar radiation will be absorbed by land or ocean or reflected back. On the other hand, the emissivity of land determines how much radiation will be emitted to the atmosphere. The roughness of the land surface, which may be changed by changing the land cover, is one of the main drivers of turbulent mixing of momentum, heat, water, and scalars within the atmospheric boundary layer (lowest part of the troposphere). Land ecosystems also modulate the composition of the atmosphere by emitting, and removing greenhouse gases and precursors of gases and particles that affect the climate. Aerosols formed form these precursors modify rainfall rate and cloud properties, thereby affecting the amount of radiation that reaches the earth's surface.

Now that we have established the physical science bases of how changes in land cover could lead to changes in cloud properties, let us look more closely on the case of Borneo. Studies of the cloud properties over Indonesia by [9] and over Borneo Island by [10] provide observational evidences on how the changes in vegetation affect the formation and properties of clouds. For most part of Indonesia, the wet season is more sensitive to cloud and vegetation changes [9]. Areas with low vegetation areas are associated with diffused clouds, small cloud particles, and thin and high clouds (Figure 2). On the other hand, over areas

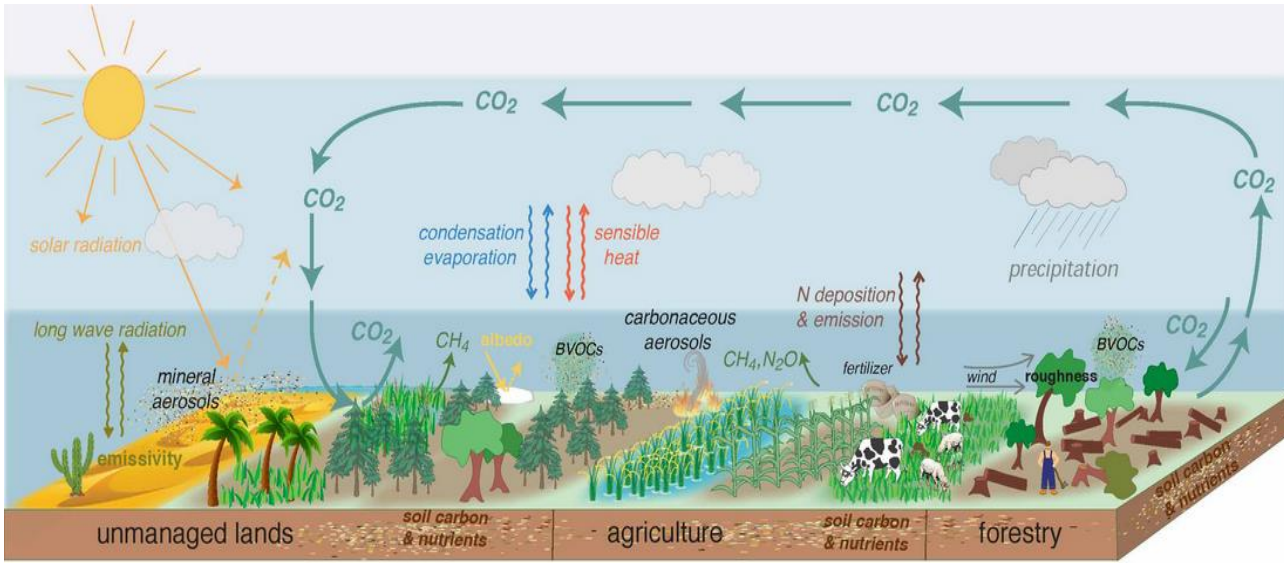

Figure 1. The structure and functioning of managed and unmanaged ecosystems that affect local, regional and global climate (adapted from [11]).

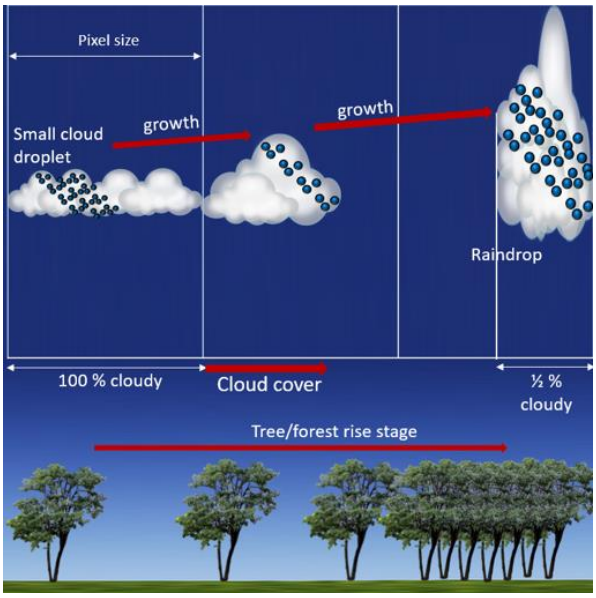

Figure 2. Cloud properties (cloud fraction, optical thickness, and effective radius) over low and high vegetation areas in Indonesia (adapted from [9]).

with high vegetation, clouds are compact, convective (thick) and made up of large particles. These results were mainly attributed to the effects of vegetation on the dynamics and thermodynamics of the surrounding air. Highly vegetative areas generally have high moisture which translate to high evapotranspiration. This moisture is carried to higher elevation. The accompanying release of latent heat encourages the formation of convective clouds. The strong updraft

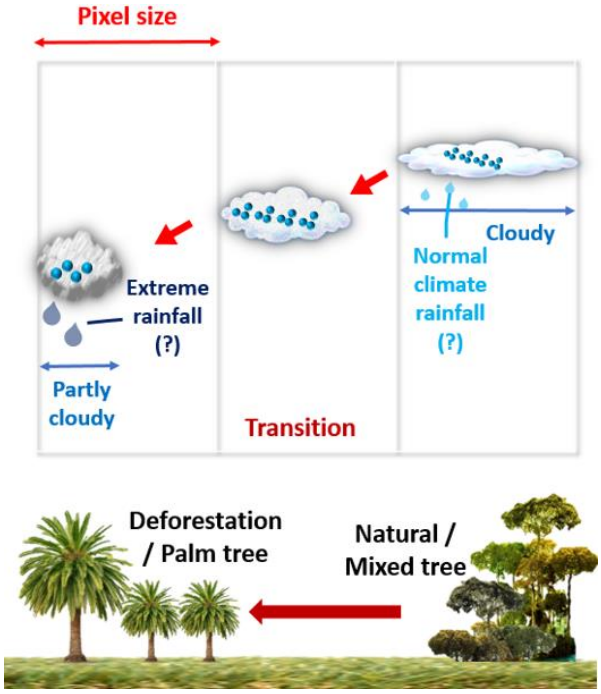

Figure 3. Cloud properties (cloud fraction, optical thickness, and effective radius) over natural/mixed forest and palm tree areas in Borneo (adapted from [10]).

associated with convection then supports the formation of larger cloud droplets. A further study revealed the impacts of changing the forest areas to palm tree areas on the cloud properties over Borneo Island [10]. Palm tree dominant areas with low normalize difference vegetation index (NDVI) are generally covered with convective (thick) clouds with large particle sizes as depicted in Figure 3. The study hypothesized that deforestation of natural primary forests and replacing them with single tree species (palm tree) may cause larger variability from the normal cloud and climate states over the area. Higher probability and/or frequency of local extreme rainfall is one of the possible consequences of such.

The forthcoming transfer of Indonesia's capital from Jakarta to Nusantara, East Kalimantan will directly or indirectly impact Borneo's climate. Although this article cannot provide a holistic approach to such issue, it provides some scientific bases on how the changes in land cover affects the properties of clouds that form aloft. The land cover change that comes with the transfer of capital should be taken seriously by the urban planner. With careful planning and science-based decision, these vegetation and other surface alterations may lead to a negative climate forcing [11]. That is, a sustainable land management of the new capital not only may overcome the environmental issues but could potentially help reverse the adverse impacts of Borneo's deforestation on climate.

4 Conclusion

The change in land use and development led to the increase of CO_2 concentration in the atmosphere, which in turn increase the global mean surface temperature. Drastic increase in temperature is found in land, affecting agricultural regions and pastures. The IPCC SRCCL (2019) presented five SSPs, one of which underlines a more sustainable approach toward land use and development in order to mitigate further consequences of global mean surface temperature increase.

Borneo has experienced one of the fastest changes in land use and land cover in the world. These changes significantly increase daily mean temperature and reduce daily mean rainfall. Vegetation change to palm tree in the deforested areas in Borneo may cause larger variability from the normal cloud and climate states over the area. Higher probability and/or frequency of local extreme rainfall is one of the possible consequences of such. Hence, the transfer of capital to Nusantara, East Borneo, faces some environmental issues and land cover change that comes with the transfer of capital should be taken into account by the urban planner

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