Analysing Linkages of Palm Oil, Deforestation and Local Climate through Modelling

Alizan Mahadi[1]

Abstract

The impact of oil palm plantations to the environment and livelihoods at local, regional and global levels has been a contested area. As the world aims to achieve the Sustainable Development Goals (SDGs), understanding the impact of anthropogenic land use and land cover change (LULCC) due to conversions of forests into oil palm plantation is critical. This paper utilised a modelling study as a numerical experiment to assess the linkages across palm oil, deforestation and local climate. By downscaling a global climate model to the context of Sabah, Malaysia, three scenarios of different levels of conversion of forests to palm oil were analysed. The results demonstrated that within the numerical experiment, the changes in temperature can be attributed to land use change, where the temperature within each land use strongly correlates with the type of land use cover. The findings have implications for land use management where land use change could lead to perturbations in the local climate.

Keyword: Oil palm, SDGs, linkages, modelling, deforestation, climate change

Introduction

Palm oil is one of the most controversial crops on the planet. Its critics cite the link between palm oil and deforestation, being one of the key drivers in global deforestation (Gaveau et al., 2016, 2014). Defenders of the crop, mainly importing countries, see palm oil as an important contributor to the economy as well as strategy for social inclusiveness, being a success story in bringing millions out of poverty (Nambiappan et al., 2018). As a crop that is only grown within the tropical belt and in competition with other fuels and oils in the world, there is still little consensus and scientific understanding on the effects of palm oil to society at large and towards other development goals. This is due to the fact that the linkages between cause and effect are often mired in complexity. As the Sustainable Development Goals (SDGs) aims to address interlinkages as one of its main principles, this research aims to contribute towards this challenge by proposing a method to analyse the linkages across palm oil, deforestation and the local climate.

This proposition is investigated by understanding the impact of anthropogenic land use and land cover change (LULCC) to the local climate. Towards this end, the paper looked at the conversion of tropical forests to oil palm plantation in Sabah, a state located in Malaysia and part of Borneo. With the conversion of forests to plantations, especially to produce palm oil, the main driver behind deforestation, the project aimed at understanding its impact on the local climate. In many cases, the impacts of deforestation and land use change often is linked to biodiversity loss (i.e. loss to flora and fauna) (Koh & Wilcove, 2008), but less on the impacts across other fields, such as the climate.

Nonetheless, the impact of deforestation to

---

[1] Graduate School of Media and Governance, Keio University, Kanagawa, Japan

climate has been studied both from observation and modelling studies. These impacts are often divided into either biogeochemical or biophysical. Many previous integrated assessment models (IAM) has focused on the biogeochemical impacts through modification of the atmospheric composition. For example, the Intergovernmental Panel on Climate Change (IPCC) reports focus mainly on the carbon sinks (CO2) that forests provide. This focus denotes the important of forests for mitigating climate change.

Less attention has been provided to the biogeophysical impacts – the direct influence of human activity on the climate of the earth surface through land use and land cover change (LULCC) until recently (Avissar & Werth, 2005; Boisier et al., 2012; Bonan, 2008; Davin & de Noblet-Ducoudre, 2010; Pielke et al., 2011; Pitman et al., 2012). Deforestation, in particular, has been highlighted as having various interactions with the atmosphere and in particular, with the regional and local climate.

Observational and modelling studies broadly demonstrate that there are three mechanistic reasons behind this interaction (Bright, Zhao, Jackson, & Cherubini, 2015; Hardwick, 2015). Firstly, is through radiation, where the density of canopies (i.e. Leaf Area Index) determines how much energy penetrates through to the ground, soil and below-canopy air (Hardwick, 2015). Secondly, is through aerodynamic resistance, where the turbulent mixing of air affects the fluxes of momentum, heat, water vapor (Pielke et al 2011, Bright et al 2015). And thirdly, and very closely related to the previous two is evaporation intensity where evapotranspiration is affected through the vapour pressure deficit whereby the amount of water vapour in the air is dependent upon the air temperature. While these three mechanisms are closely interrelated, this paper focused on identifying which mechanism has the highest dependence on perturbations to the local climate.

METHOD

The method consists of descriptions on three areas that are vital components and inputs into the analysis: (1) Model, (2) Downscaling, and (3) Classification. These components are described below.

A. Model

An original model developed by the Japanese Agency for Marine-Earth Science and Technology (JAMSTEC) was used in the simulation. The model is primarily based on the Weather Research Forecasting (WRF), a mesoscale modeling system. In order to understand the land-atmosphere interaction, it needs to be coupled with land surface processes such as the Noah Land Surface model (LSM). For this project, a custom model was used.

B. Downscaling

In order to address the regional and local effects of deforestation downscaling of the model was utilised. One of the reasons that the biophysical impacts were previously not focused on for global assessments is due to its relative lesser importance as a climate forcing at the global level (Pielke et al., 2011). Efforts on climate change mitigation often focuses on the global impacts of carbon sinks and fluxes that have the same impact either on a global or local level. However, more recent studies have demonstrated the importance of biophysical impacts at the regional and local levels (as well as teleconnections of which are not covered in this study) (Avila, Pitman, Donat, Alexander, & Abramowitz, 2012; da Silva, Werth, & Avissar, 2008; Davin & de Noblet-Ducoudre, 2010; Pielke et al., 2011; Pitman et al., 2012). Furthermore, many of the decisions are made at the local level and therefore this paper took the approach of downscaling the model to a decision-making scale by selecting Sabah as the case study, where forestry issues are under the jurisdiction of the state in Malaysia.

C. Land Use Classification

For climate modelling studies, many of the Land Surface Models (LSM) adopt the land use classification of the International Global Biosphere Programme (IGBP) such as used in the USGS land classification data in the Weather Research Forecasting Model (WRF) (Anderson, Hardy, Roach, & Witmer, 1976; Running, Loveland, Pierce, Nemani, & Hunt, 1995). While the classification is useful, with the interest of this paper to understand how policymakers can utilize the results of modelling studies better, a more detailed classification was used, one tier below the existing classification. The rationale of this study is to understand the impact of the conversion of forests into oil palm plantations. As will be made obvious later, the characteristics of oil palm are very different than generic assumptions made for cropland and therefore, requires a parameterization and classification that is more accurate and specific to the characteristics of the type of plantation. This requires another tier of classification that identifies not only type of land use (i.e. plantation), but also the type of plantation (i.e. oil palm plantation).

IMPLEMENTATION

A.The study area and site selection

Sabah is a state in the country of Malaysia and is located in Borneo, the third largest island in the world. It is part of East Malaysia and shares the island of Borneo with Sarawak (Malaysia) and Kalimantan (Indonesia). Located in the tropics (coordinates 5°15’N 117°0’E), Sabah climate is equatorial with tropical rainforests covering the state, signifying it as a major biodiversity hotspot.

The rationale of selecting Sabah is due to its location in Borneo, where the largest deforestation due to palm oil occurred (Gaveau et al., 2016).

Variable	Areas (in Hectare)	%
Total land area	7,396,621	
Forest area in 1973	5,833,479	78.87%
Non forest area in 1973	1,233,951	16.68%
Total deforestation (1973–2015)	1,862,375	25.18%
Intact forest area in 2015	1,647,149	22.27%
Logged forest area in 2015	2,322,139	31.39%
Total Forest Area In 2015	3,969,288	53.66%
Area Of Plantations In 1973	128,047	1.73%
Total Area Of Plantations In 2015	1,778,508	24.04%

Table 1. Forest Area in Sabah 1973 – 2015 (adapted from Gaveau et al., 2016).

B.Data preparation

The parametrization of initial conditions are provided in the tables below. Other parameters are based on the WRF model prescribed parameters. The surface roughness (Z0) was the biggest change in initial conditions. While the method for calculating surface roughness is not the most accurate, for the purpose of this experiment, a factor of 0.1 is applied to the canopy height (Raupach, 1994; Verhoef, McNaughton, & Jacobs, 1997). The results are comparable to previous modelling study in the region (Ashworth, Folberth, Hewitt, & Wild, 2012) and provides the a scale of difference based on observation studies. Albedo is also reflected from observational studies (Sabajo et al., 2017). It is worth noting that the initial conditions of stomatal conductance and soil moisture also used default parameters and therefore is not part of the numerical experiment despite that it will likely have impacts in real world land use perturbations.

Land Use	Canopy Height observation in (m)	Surface roughness (Z0)	Source
Oil Palm Plantation	5.3	0.53	Hardwick et al 2014
Logged Forest	19.4	1.94	Hardwick et al 2014
Old growth	33.7	3.37	Hardwick et al 2014

Table 2. Parameterization for surface roughness

C.Simulation Performed (numerical experiment)

It is important to note that the simulation performed is not undertaken to determine realistic land surface perturbations or the future local climate. The purpose of the paper is to understand the potential impact and the mechanistic reasons for any changes in temperature.

Land Use	USGS Classification	Albedo Data from USGS	Albedo revised Data used	Source
Oil Palm Plantation	Irrigated Cropland	0.18	0.15	Sabajo et al 2017
Logged Forest	Evergreen Broadleaf Forest	0.12	0.12	USGS (WRF)
Old growth	Evergreen Broadleaf Forest	0.12	0.12	USGS (WRF)

Table 3. Parameterization for albedo

The simulation was performed for a period of 30 days using climate data in December 2014. The weather was not affected by strong inter-annual variability linked to the El Niño-Southern Oscillation (ENSO) during this period. The climate in Sabah is largely aseasonal with only minor changes in rainfall patterns throughout the year (Hardwick, 2015).

A grid spacing of 2km x 2km was used. Due to the fact that the United States Geological Survey (USGS) maps only provide for the IGBP classifications, data from (Gaveau et al., 2016) was based on remote sensing imagery on a more realistic land cover estimate for 1973 and 2016 land use maps. The maps, provided on ArcGIS, was converted to gridded file into 2km x 2km grids. A further third scenario was created where all class II commercial forests (Reynolds, Payne, Sinun, Mosigil, & Walsh, 2011) were converted to oil palm plantations.

Result

The impacts of conversion of forests into oil palm plantation in Sabah is investigated through looking at three scenarios, (1) S1 Afforest – reforest to 1973 levels; S2 Maintain – maintain current (2016) levels of forest and; S3 Deforest – convert all forests classified as commercial forests (Class II) to oil palm plantation.

Air temperature at 2m height was measured based on extrapolation used in the model from a height of 28 meters. The results demonstrate that in average, there is generally a trend of a small increase in temperature of up to 1.5 degrees though this is is heavily dependent on location and land use. The figures below demonstrate the difference in average temperature of S2 Maintain and S3 Deforest with S1 Afforest. The air temperature increases or decrease varies due to both land use and location. For example, there is an obvious reduction in temperature in the area of forest regrowth (5.3N 117.E). But the climate is not only dependent on land use as at the coast, there is a slight decrease despite the area being mainly urban. This is likely due to the fact that it is sheltered from the mountain range, reducing the effects of any warming due to land use change on the other side of the mountain.

To investigate the impact of conversion of forests into oil palm plantation further, the three scenarios are broken down further into the impact at three areas and elevation: (1) Low lying coastal areas (0-100m elevation); (2) Mid-level inland areas (500-100m elevation) and; High level inland areas (500-1000m elevation)

Generally, the results demonstrated that while there are clear differences between the elevations, there is not a major difference between the three scenarios. Nonetheless, there is generally a warming trend with temperature changes ranging from -0.1 – +1.1 degrees Celsius between S2 and S3 with S1. Between S2 and S3, despite the larger oil palm plantation area, there is almost no change in overall temperature. In terms of areas, the strongest variance across the scenarios is at the mid-level inland areas (100-500m elevation) where an overall rise of 1.1 degree temperature from S2 and S1 and 1 degree rise from S3 and S1 occurred (see Table 4).

Scenario	Highest Frequency in Celsius					
	Intact Forest	Plantation	Logged Forest	Urban	Cropland	ALL
S1 (1973) at 0-100m	29	N/A	N/A	29.1	30	29
S1 (1973) at 100-500m	27.5	N/A	N/A	28.9	29.7	27.6
S1 (1973) at 500-1000m	26.3	N/A	N/A	25.5	28.1	26.3
S2 (2016) at 0-100m	29.2	29.9	29.7	29.5	29.9	29.5
S2 (2016) at 100-500m	27.2	28.9	27.9	29.3	29.5	28.7
S2 (2016) at 500-1000m	26.3	27.2	27	24.6	27.5	26.8
S3 (2050) at 0-100m	29.2	29.8	29.7	29.6	30	29.5
S3 (2050) at 100-500m	27.4	28.6	28.7	29.2	29.4	28.6
S3 (2050) at 500-1000m	26	27.3	26.9	25.3	27.6	26.8

Table 4. Parameterization for surface roughness

To attribute the cause of the changes, a look at the variation within each land use also shows minimal changes. Within intact forest only a range of -0.3 - + 0.2 is found while -0.3 - +0.1 in plantations, -0.1 - + 0.8 in Logged Forest, -0.9 - + 0.7 in Urban areas and -0.6 - +0.1 in Cropland areas.

Difference	Intact Forest	Plantation	Logged	Urban	Cropland	ALL
Difference with Scenario 1						
S2 - S1 at 0-100m	0.2	N/A	N/A	0.4	-0.1	0.5
S3 - S1 at 0-100m	0.2	N/A	N/A	0.5	0	0.5
S2 - S1 at 100-500m	-0.3	N/A	N/A	0.4	-0.2	1.1
S3 - S1 at 100-500m	-0.1	N/A	N/A	0.3	-0.3	1
S2 - S1 at 500-1000m	0	N/A	N/A	-0.9	-0.6	0.5
S3 - S1 at 500-1000m	-0.1	N/A	N/A	0.3	-0.3	1
Difference with Scenario 2						
S3 - S2 at 0-100m	0	-0.1	0	0.1	0.1	0
S3 - S2 at 100-500m	0.2	-0.3	0.8	-0.1	-0.1	-0.1
S3 - S2 at 500-1000m	-0.3	0.1	-0.1	0.7	0.1	0

Table 5 Difference with scenario 1

What this suggests is that due to strong locality with distribution patterns similar within each land use classification, the changes in temperature is likely influenced by the change of size in the land use itself. This can be viewed in the figure below which demonstrates that, where the different scenarios show a different overall frequency due to the change in size. Where S1 was predominantly forest in 1973, by reducing the amount of land of forests in conversion to oil palm plantation, the temperature rises can be attributed to the change in land area of the warmer oil palm plantation, rather than the interaction between the oil palm plantation and other land uses including forests. Nonetheless, it is worth noting that this may also be due to the fact that the grid spacing of 2km x 2km may not be able to capture those interactions.

The attribution to the different size of land area can be seen in the comparison between the air temperatures in the different land use areas. This can be seen by looking at the difference in temperature between the land use cover. In S2 and S3, the difference in the temperatures are compared (see table below). In S2 the difference is clear where plantation and Cropland are warmer than intact forest by up to 0.7 degrees at 0-110m, up to 2.3 degrees. Cropland in particular, is the warmest land use cover, especially at 100-500m with up to 0.5 degrees higher than plantation and 0.2 degrees higher than urban areas. In S3, similarly, Cropland is higher at 100-500m by 2 degrees in comparison with intact forests, and 0.8 degrees higher than plantations (which is surprisingly cooler in S3 by -0.3 degrees).

Land Use in S2	0-100m	100-500m	500-1000m
Plantation	0.7	1.7	0.9
Logged Forest	0.5	0.7	0.7
Urban	0.3	2.1	-1.7
Cropland	0.7	2.3	1.2
ALL	0.3	1.5	0.5

Table 6. Difference with of S3 and S2 with S1

Land Use in S3	0-100m	100-500m	500-1000m
Plantation	0.6	1.2	1.3
Logged Forest	0.5	1.3	0.9
Urban	0.4	1.8	-0.7
Cropland	0.8	2	1.6
ALL	0.3	1.2	0.8

Table 6. (Continue)

Discussion

The results in the previous section, demonstrated that the temperature increased due to land use change. Understanding the mechanisms will enlighten policymakers as to what is the cause, or the mechanistic reasons behind the results. As described in the first section, previous modelling and observation studies have demonstrated that there are three main mechanisms that land use can change the local climate in the context of the tropics. These are investigated in more detail below.

A. Radiative Forcing

A visual of the net surface radiation (Figure 1) does show a correlation with the land use type in S2 but less in S3. This is probably due to the fact that the lower surface roughness allows for a higher penetration of radiation in oil palm plantation areas. However, in the study, the Leaf Area Index is not utilized in the model.

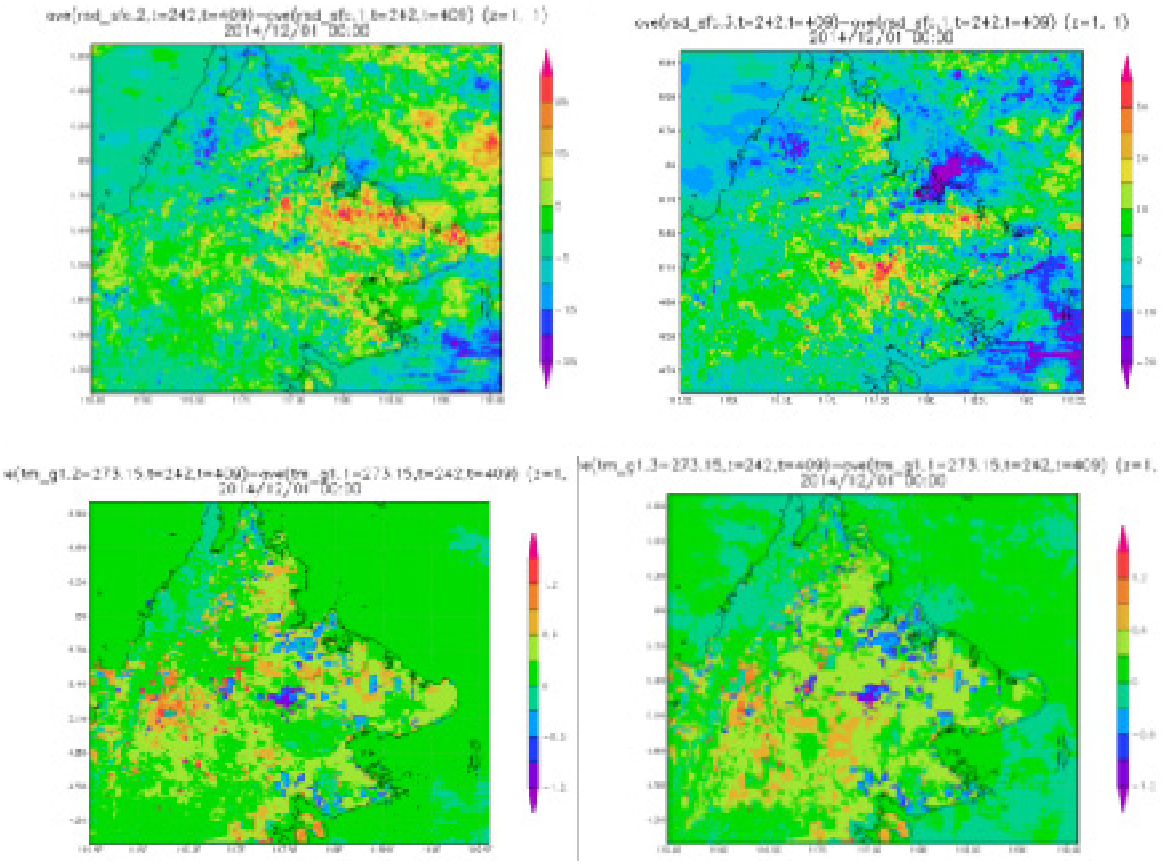

Figure 1. Difference in surface radiation between S2 and S1 (top left) and S3 and S1 (top right) and ground temperature equivalent (bottom right and left)

As for surface albedo, previous studies have suggested that change in radiation is primarily due to the albedo effect at mid to high latitudes (Davin & de Noblet-Ducoudre, 2010). However, as demonstrated earlier, due to the absence of snow cover throughout the year and the small differences in albedo rates for forest and oil palm plantations, it is unlikely that it is a major mechanism in tropical Sabah. This demonstrates that while the density plays a role in the radiative forcing in Sabah, the changes to radiation due to albedo is likely to be small, and therefore, the radiative forcing is also likely to not dominate the reasons behind temperature change.

As for surface albedo, previous studies have suggested that change in radiation is primarily due to the albedo effect at mid to high latitudes (Davin & de Noblet-Ducoudre, 2010). However, as demonstrated earlier, due to the absence of snow cover throughout the year and the small differences in albedo rates for forest and oil palm plantations, it is unlikely that it is a major mechanism in tropical Sabah. This demonstrates that while the density plays a role in the radiative forcing in Sabah, the changes to radiation due to albedo is likely to be small, and therefore, the radiative forcing is also likely to not dominate the reasons behind temperature change.

B. Aerodynamic resistance

In dense forests, turbulent mixing of air is suppressed by the canopies where a denser canopy should result in cooler air beneath the canopy (Hardwick, 2015). It was hypothesized that the aerodynamic resistance is more dependent at the coastal areas than inland areas.

The major change in initial conditions was the surface roughness (Z0) which would change the magnitude of wind within the land use covers. While it is hypothesized that the wind will be stronger in low lying coastal areas, due to the high surface roughness of the forests and to a lesser extent, plantations, the wind speed remains consistent. There is a considerable difference, however between plantation and intact and log forests. Nonetheless, the wind speed peaks to about only 1.5 m/s (Figure 2). This demonstrated that the aerodynamic resistance did not play a dominant role in the air temperature.

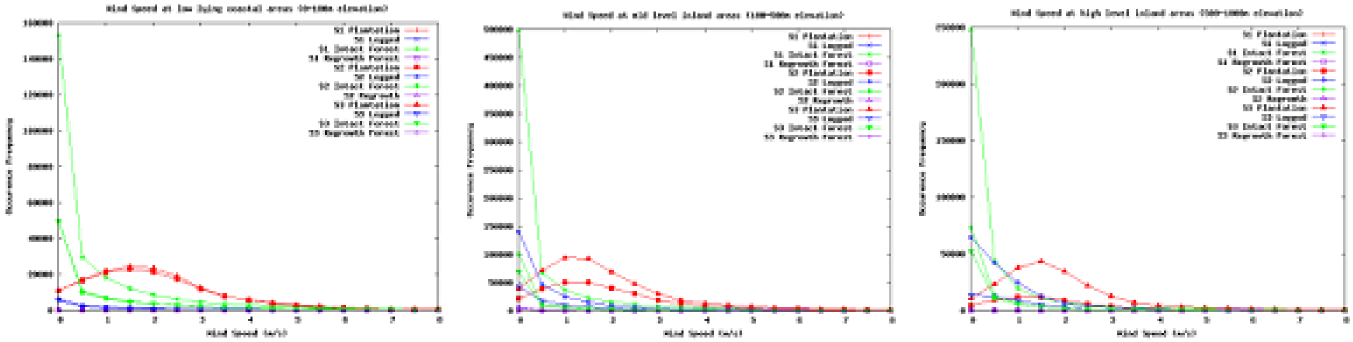

Figure 2. Aerodynamic Resistance difference

C. Evaporation intensity

It is hypothesized that evaporation intensity is the most dependent parameter and the main mechanism in the context of climate change in Sabah due to LULCC. Previous studies at the tropics suggest evaporation and evapotranspiration plays a prominent role. In Figure 3, you can see the impact of evaporation as the strongest difference between the different scenarios. Due to the heating of ground temperature, the more sparse oil palm plantation has lower evaporation rate and therefore increasing the sensible heat (air temperature). If compared to the land use, there is a clear relationship between the oil palm plantation areas and a decrease in latent heat flux both for S2 and S3 differences with S1. This can especially be seen clearly in S3-1.

It is worth noting that stomatal conductance is not included within the model. The inclusion of stomatal conductance would possibly decrease the latent heat flux further due to the higher conductance in forests in comparison with oil palm plantation. This means that the impacts may be stronger if it is included.

When looking at the range of factors and mechanisms, it is clear that evaporation efficiency is the most predominant mechanism in changing the temperature (Figure 4.)

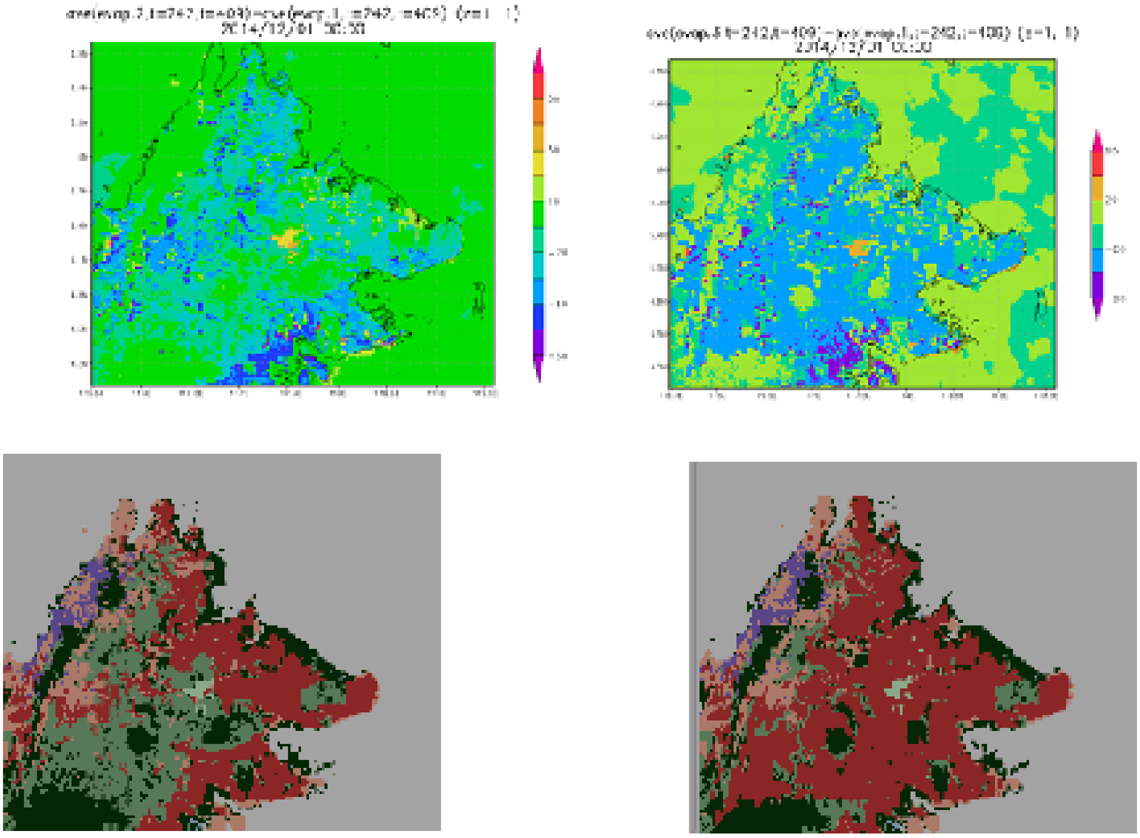

Figure 3. Difference in surface radiation between S2 and S1 (top left) and S3 and S1 (top right) followed by land use change (bottom left and right)

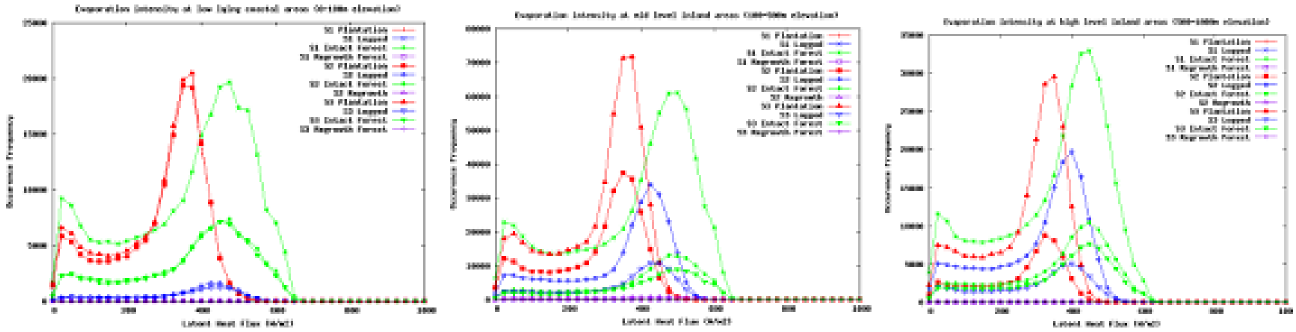

Figure 4. Evapotranspiration difference in occurrences across three scenarios

Conclusion

The results demonstrated that within the numerical experiment, the changes in temperature can be attributed to land use change, where the temperature within each land use strongly correlates with the type of land use cover. Enlarging a specific land use cover type, such as the warmer oil palm plantation, with the cooler intact forests will make the overall area warmer. This has implications for land use management, whereby, disregarding other socio, economic, political and food security issues that may play a larger role, as well as the practicalities in doing so, for adaptation against global warming, it would be better to convert from existing cropland. More pertinently, the analysis demonstrated that there is a need for land use planning to take into consideration the impact of converting land use cover types. While the results of this numerical experiment do not necessarily mirror the reality of future land use change or the future climate, it shows the correlation of temperature and land use change. While reforestation has been spoken about more in the context of mitigation (Davin & de Noblet-Ducoudre, 2010), however future climate change adaptation policies should also take into consideration this change to regulate local temperature.

In conclusion, the results demonstrate modelling studies can be an important tool for identifying both causes and mechanisms of linkages across issue areas. This would provide important inputs towards sustainable development generally, and in addressing the United Nation’s Sustainable Development Goals (SDGs) agenda on interlinkages.

References

Anderson, J. R., Hardy, E. E., Roach, J. T., & Witmer, R. E. (1976). A Land Use and Land Cover Classification System for Use with Remote Sensor Data. United States Geological Survey Professional Paper, 964.

Ashworth, K., Folberth, G., Hewitt, C. N., & Wild, O. (2012). Impacts of near-future cultivation of biofuel feedstocks on atmospheric composition and local air quality. Atmospheric Chemistry and Physics, 12(2), 919–939. https://doi.org/10.5194/acp-12-919-2012

Avila, F. B., Pitman, A. J., Donat, M. G., Alexander, L. V., & Abramowitz, G. (2012). Climate model simulated changes in temperature extremes due to land cover change. Journal of Geophysical Research Atmospheres, 117(4), 1–19. https://doi.org/10.1029/2011JD016382

Avissar, R., & Werth, D. (2005). Global Hydroclimatological Teleconnections Resulting from Tropical Deforestation. Journal of Hydrometeorology, 6(2), 134–145. https://doi.org/10.1175/JHM406.1

Boisier, J. P., De Noblet-Ducoudré, N., Pitman, A. J., Cruz, F. T., Delire, C., Van Den Hurk, B. J. J. M., … Voldoire, A. (2012). Attributing the impacts of land-cover changes in temperate regions on surface temperature and heat fluxes to specific causes: Results from the first LUCID set of simulations. Journal of Geophysical Research Atmospheres, 117(12), 1–16. https://doi.org/10.1029/2011JD017106

Bonan, G. B. (2008). Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Fiorests. Science, 320(5882), 1444–1449. https://doi.org/10.1126/science.1155121

da Silva, R. R., Werth, D., & Avissar, R. (2008). Regional impacts of future land-cover changes on the Amazon basin wet-season climate. Journal of Climate, 21(6), 1153–1170. https://doi.org/10.1175/2007JCLI1304.1

Davin, E. L., & de Noblet-Ducoudre, N. (2010). Climatic impact of global-scale Deforestation: Radiative versus nonradiative processes. Journal of Climate, 23(1), 97–112. https://doi.org/10.1175/2009JCLI3102.1

Gaveau, D. L. A., Sheil, D., Husnayaen, Salim, M. A., Arjasakusuma, S., Ancrenaz, M., … Meijaard, E. (2016). Rapid conversions and avoided deforestation: Examining four decades of industrial plantation expansion in Borneo. Scientific Reports, 6(June), 1–13. https://doi.org/10.1038/srep32017

Gaveau, D. L. A., Sloan, S., Molidena, E., Yaen, H., Sheil, D., Abram, N. K., … Meijaard, E. (2014). Four decades of forest persistence, clearance and logging on Borneo. PLoS ONE, 9(7), 1–11. https://doi.org/10.1371/journal.pone.0101654 Hardwick, S. R. (2015). Interactions between vegetation and microclimate in a heterogeneous tropical landscape.

Koh, L. P., & Wilcove, D. S. (2008). Is oil palm agriculture really destroying tropical biodiversity? Conservation Letters, 1(2), 60–64. https://doi.org/10.1111/j.1755-263X.2008.00011.x

Nambiappan, B., Ismail, A., Hashim, N., Ismail, N., Shahari, D. N., Idris, N. A. N., … Kushairi, A. (2018). Malaysia: 100 years of resilient palm oil economic performance. Journal of Oil Palm Research, 30(1), 13–25. https://doi.org/10.21894/jopr.2018.0014

Pielke, R. A., Pitman, A., Niyogi, D., Mahmood, R., McAlpine, C., Hossain, F., … de Noblet, N. (2011). Land use/land cover changes and climate: Modeling analysis and observational evidence. Wiley Interdisciplinary Reviews: Climate Change, 2(6), 828–850. https://doi.org/10.1002/wcc.144

Pitman, A. J., De Noblet-Ducoudré, N., Avila, F. B., Alexander, L. V., Boisier, J. P., Brovkin, V., ... Voldoire, A. (2012). Effects of land cover change on temperature and rainfall extremes in multi-model ensemble simulations. Earth System Dynamics, 3(2), 213–231. https://doi.org/10.5194/esd-3-213-2012

Raupach, M. R. (1994). Simplified expressions for vegetation roughness length and zero-plane displacement as functions of canopy height and area index. Boundary-Layer Meteorology, 71(1–2), 211–216. https://doi.org/10.1007/BF00709229

Reynolds, G., Payne, J., Sinun, W., Mosigil, G., & Walsh, R. P. D. (2011). Changes in forest land use and management in Sabah, Malaysian Borneo, 1990-2010, with a focus on the Danum Valley region. Philosophical Transactions of the Royal Society B: Biological Sciences, 366(1582), 3168–3176. https://doi.org/10.1098/rstb.2011.0154

Running, S. W., Loveland, T. R., Pierce, L. L., Nemani, R., & Hunt, E. R. (1995). A remote sensing based vegetation classification logic for global land cover analysis. Remote Sensing of Environment, 51(1), 39–48. https://doi.org/10.1016/0034-4257(94)00063-S

Sabajo, C. R., Le Maire, G., June, T., Meijide, A., Roupsard, O., & Knohl, A. (2017). Expansion of oil palm and other cash crops causes an increase of the land surface temperature in the Jambi province in Indonesia. Biogeosciences, 14(20), 4619–4635. https://doi.org/10.5194/bg-14-4619-2017

Verhoef, A., McNaughton, K. G., & Jacobs, A. F. G. (1997). A parameterization of momentum roughness length and displacement height for a wide range of canopy densities. Hydrology and Earth System Sciences, 1(1), 81–91. https://doi.org/10.5194/hess-1-81-1997