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Determining critical groundwater level to prevent degraded peatland from severe peat fire

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Abstract. Peat fires have been a severe recurrent problem for Indonesia, but droughts due to prolonged dry season aggravate burning conditions. To get a better understanding of this issue, we studied fire conditions in a portion of the ex-Mega Rice Project (MRP) area, Central Kalimantan. To examine fire season and hydrology factors affecting peat fires we analyzed daily TRMM data, Nino 3.4 SST Anomalies, and changing groundwater levels (GWL) from 300 dipwells. Our results quantify time-lags between the period of lowest precipitation and the lowest GWL; providing some ability to predict fire risk in advance of the lowest GWL. The rise of Nino 3.4 SST anomalies is significant risk factors for peat fire as they signify dry months which may yield large fire occurrences. GWL in 2011 was lower than in 2012, but fires were more frequent in 2012, indicating that low precipitation amounts in the wet season of 2011/2012 left the peat in a dry condition early in 2012. Most of the fires occurred in areas with GWL less than -30 cm, powerfully illustrating the importance of maintaining GWL at more than -10 cm, to prevent degraded peatlands from experiencing surface and deep peat fires.

1. Introduction

Peat fire have been a severe recurrent problem in Indonesia, but our prolonged observations indicate that recent Indonesian peat fires tend to occur every year in the dry season, even in non-El Nino years. The country then suffered from severe peat fires episode when it experienced droughts due to long dry season, where burning conditions provoke. To get a better understanding of this critical issue, we studied the recent fire situation and hydrology factors affecting peat fires in a portion of the Mega Rice Project (MRP) area, Central Kalimantan. A giant tropical peat swamp-forest conversion [1] has converted 9,191 km^2 of peatland in the area to the fields for rice cultivation and promote transmigration [2], but it just left huge drained peatland area mainly due to the built of over 4,600 km of channels to open-up the area and make it suitable for cultivation. Without sufficient consideration of peatland hydrology and the area topography [3], this project just exacerbated the problem when the over drained peatland became more vulnerable to fire. Fires commonly occur in this area annually during the dry season (July-September), but burning conditions aggravated during pronounced El Niño years when the peatlands there are subjected to extremely severe dry conditions.

Groundwater level (GWL) has used widely as a critical indicator for predicting fire occurrences [4,5,6]. Our previous study [4] revealed that the fires in the MRP area were mostly, over 99%, occurred when the GWL was below the soil surface with the peak fire period started in the middle of August when daily precipitation reached the minimum and GWL tent to decreased steeply. Recurrent fires in the Ex-MRP area may result to the decreasing of peatland capacity for retaining and absorbing water from precipitation, lowering groundwater levels further and making the area more susceptible to fire, particularly in the dry season. Here, we examine the situation by linking the GWL, precipitation and fire tendency in the area.

2. Methods

In this study, we are using monthly GWL data from 300 dipwells in the northern part of Block A and southern part of Block E of the MRP area (figure 1). These dipwells established in 2010 within the Kalimantan Forest and Climate REDD+ demonstration project (KFCP). The GWL were monitored monthly during January 2010-January 2013 using the blow-straw method [7]. We conducted static DGPS Survey to provide exact peat surface elevation for these 300 dipwells [8].

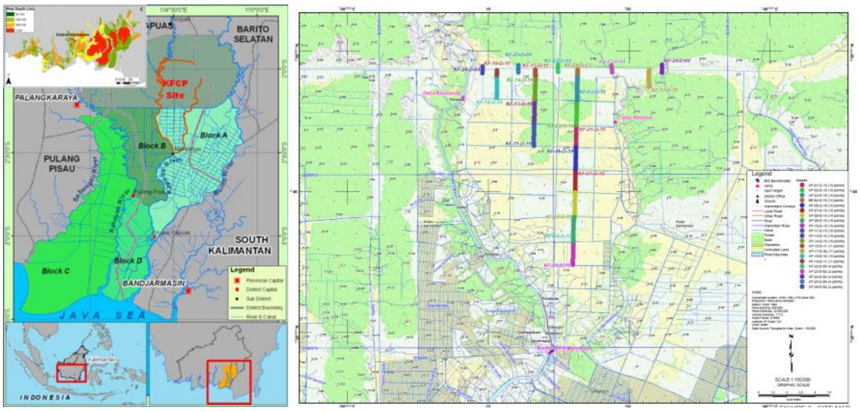

Figure 1. Map of study area [7] (left) and location of dipwells [8] (right)

We examine the relationship between groundwater level, a rate of precipitation and fire occurrences during 2010-2012. IDW (Inverse Distance Weighting) multivariate interpolation technique is used to figure the groundwater level surrounding each deep well point. Monthly TRMM (Tropical Rainfall Measuring Mission) data derived from GES-DISC NOAA (http://mirador.gsfc.nasa.gov/) is used to illustrate precipitation patterns in the study area. As the study area covers four TRMM pixels, we have four different precipitation regions for the study area (figure 2). We used Terra/Aqua MODIS active fire data from NASA-EOSDIS (https://earthdata.nasa.gov/) to explain fire occurrences and tendency in the area.

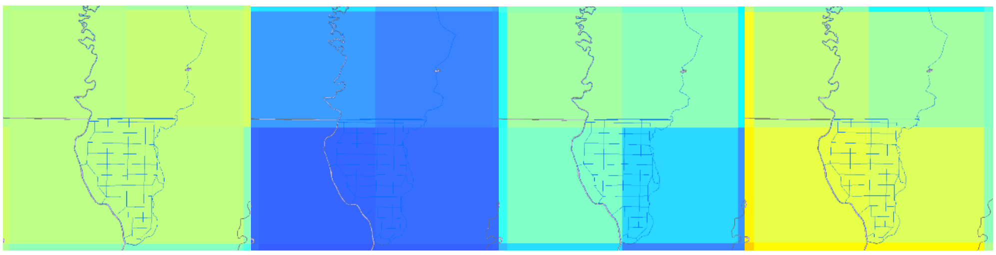

Figure 2. Monthly precipitation surrounding area, July – October 2012. The graduated color indicates precipitation rates; dark blue for lowest precipitation (0-10 mm), yellow to moderate rain (30-40 mm); light blue and green indicates precipitation rate between the lowest and moderate.

3. Results and Discussion

Monthly precipitation is commonly used to define the dry and wet season in Central Kalimantan [3,4,8]. A dry month is determined by Mackinnon et al. [9] as a month with less than 100 mm mean monthly rainfall, and a wet month when the mean monthly rainfall exceeds 200 mm. All regions experienced similar U-shaped monthly precipitation patterns with peak dry season between July and September and a trough reaching a minimum in August (figure 3). As the same findings revealed in the previous study [10], then we can point June-October as the dry season and November-May as the wet season in the MRP area; provides some ability to predict fire risk in advance. Low precipitation in the dry season dries the degraded peatland in the MRP area, increasing its susceptibility to fire, and creating suitable conditions for peat fires to ignite.

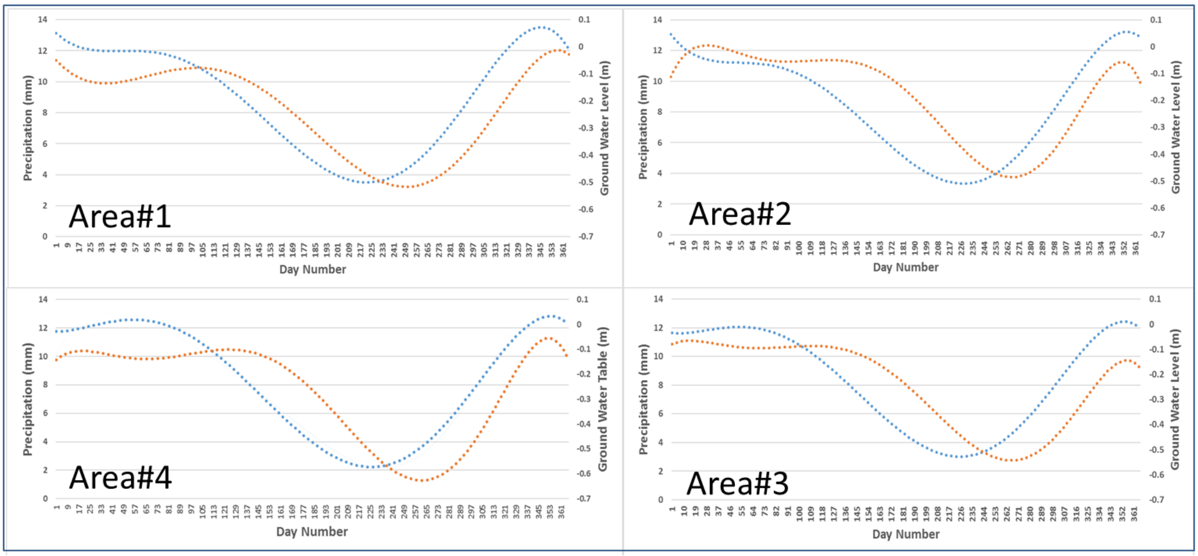

Figure 3. Daily groundwater level and precipitation tendency at four TRMM pixels in the study area

In its natural condition, peat swamp forest always inundated with water [11]. The peat acts as a natural sponge and normally waterlogged already (UNDP, 2006). GWL in MRP area peatlands previously remained positive above the peat surface in wet season [10]. However, GWL in the study area now remains in deficit for the whole of the year (figure 3), which can reflect the severe dry condition of peat in the area. This situation may also be considered unnatural for the system and can explain the degraded status of the peatland in the study area where the peat has lost its ability for absorbing and storing water, brings the high risk of future fires in the area. Peatland in the study area experienced severe dry conditions during the dry periods of July – October, as shown by the red and orange colors in figure 4, resulting in the frequent peat fire occurrences here. The study area has suffered from almost yearly peat fire occurrences since 2001, except 2008 (figure 5).

We observed a time-lag between the lowest precipitation and the lowest GWL for a month in 2011 and two-month in 2012 (figure 6). Lowest precipitation is found in August for both 2011 and 2012, while the lowest GWL occurred in September (2011) and October (2012). GWL starts to increase after having continuous high precipitation. These time-lags strongly indicates that peatlands here have lost the capacity to effectively absorb and retain water from rainwater droplets, suggesting that groundwater levels in the study area will recover only after having plenty water supplies from continuous precipitation. Less precipitation rate in 2012 compared to 2011 brings longer time-lag in 2012 compared to 2011.

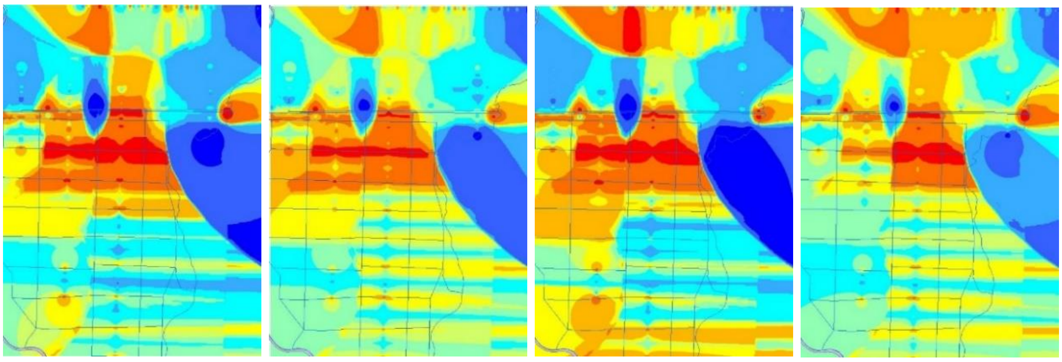

Figure 4. Change of groundwater level from July – October 2012. Red colour indicates deep GWL (more than 30 cm below peat surface); dark blue colour for positive GWL; light blue, yellow and orange represent GWL between 0 (peat surface) and -30 cm (30 cm below peat surface).

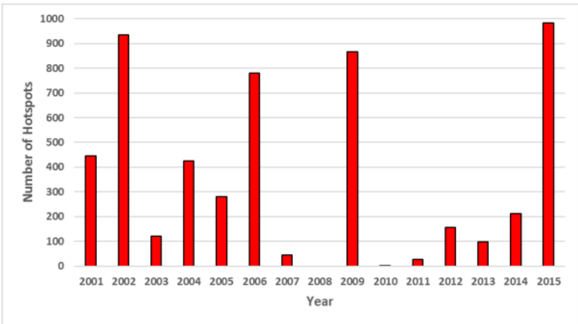

Figure 5. Number of hotspots detected by Terra/Aqua MODIS Satellite in study area, 2001 - 2015

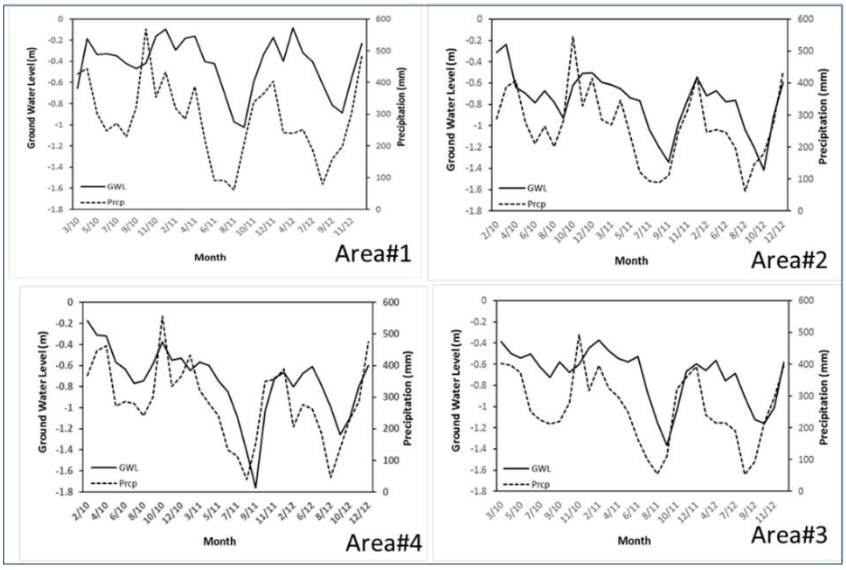

Figure 6. Groundwater level and precipitation patterns at four TRMM pixels in the study area, 2011 – 2012. Solid lines represent the GWL and dot lines represent precipitation.

Figure 7 (left) shows the coincidence of peat fire occurrences with the precipitation curve. Fires usually occur following precipitation patterns with little or no rainfall during the dry period. Large number of peat fires tends to start three months after the start of the decreased of precipitation. However, GWL in 2011 is lower than 2012 (figures 7 and 8), but fires were more frequent in 2012.

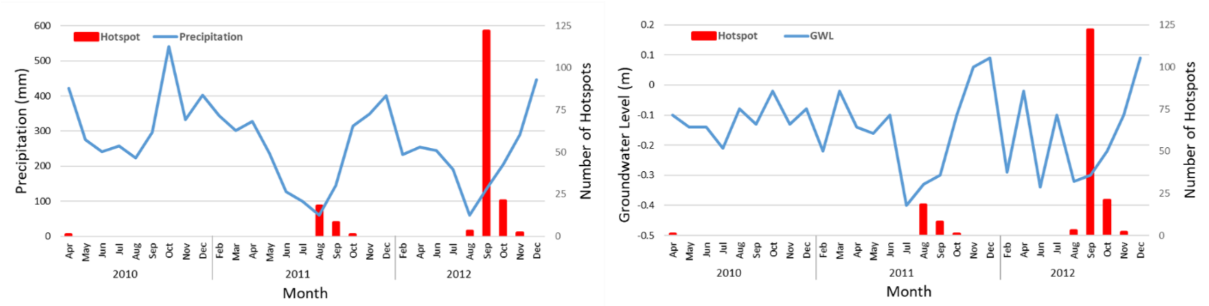

Figure 7. Relationship between hotspot occurrences in study area with monthly precipitation (left) and groundwater level (right), 2010-2012

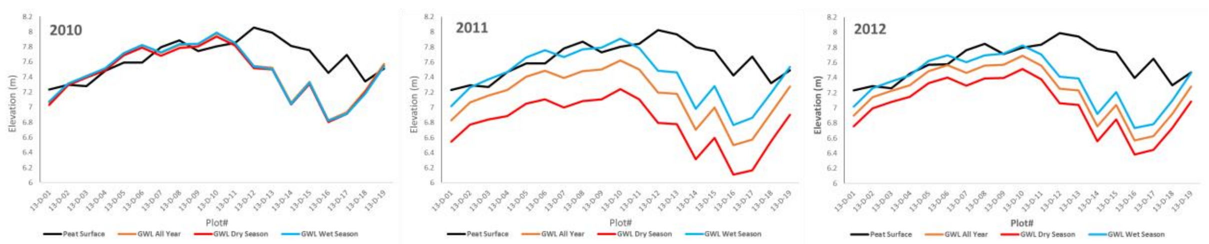

Figure 8. Comparison between groundwater level in dry season and wet season at some dipwells, 2010-2012. The red lines represent GWL in the dry season, blue lines represent GWL in the wet season, black lines represent peat surface, and the orange lines represent the average of GWL.

In 2011, precipitation reached the lowest point in August after experiencing a gradually decreased from May. This condition creating the necessary dry conditions for fires to ignite. Equally, large number of fires occurred in August and September. In 2012, large numbers of fires started during August, three months after the commencement of decreasing precipitation patterns during June 2012. This phenomenon may indicate that wet season precipitation (November 2011-May 2012) was not sufficient to raise the water table high enough to rewet the degraded peat in the study area, leaving the peat in a dry condition early in 2012 and effectively extending the fire season when peat burning was possible. Wet season usually started from November, but the fires occurrences in November 2012 explain the dry condition of the peat was still existing in the beginning of the wet period after suffering from severe dry conditions for prolonged dry periods, maintaining the appropriate conditions where ignition may readily occur [14].

Sea surface temperature (SST) anomalies is found greatly responsible for severe drought occurrences in years coinciding with intense El Nino events [13,15], but our previous work [16] suggested SST Anomalies as a useful index to determine drought in Palangka Raya instead of the El-Nino event. This study notices a significant decrease of precipitation in dry season is following the rise of SST anomalies (figure 9), bring the dry condition in the area, and thus allowing the fire to ignite in ease.

Fires in 2011 and 2012 started when the area suffer from lack accumulated precipitation for less than 5 mm in a week. However, the rising of SST Anomalies in 2012' dry season to high positive value may bring less precipitation and more prolonged drought to the area. Thus, fires in 2012 were much higher compared to 2011. Fires in 2012 began in early August when the SST Anomalies was +0.6^{0}C and there was no rainfall during a week. Numbers of fires in 2012 significantly expanded to more than 100 in September and October when the area subjected the low accumulated weekly precipitation of less than

25 mm and the increasing of SST Anomalies to +0.8^{0}C. Therefore, we strongly suggest considering the rising of Nino 3.4 STT Anomalies to any positive value for a significant risk factor for fire prevention efforts as it may initiate the driest months, likely to yield large fire occurrences.

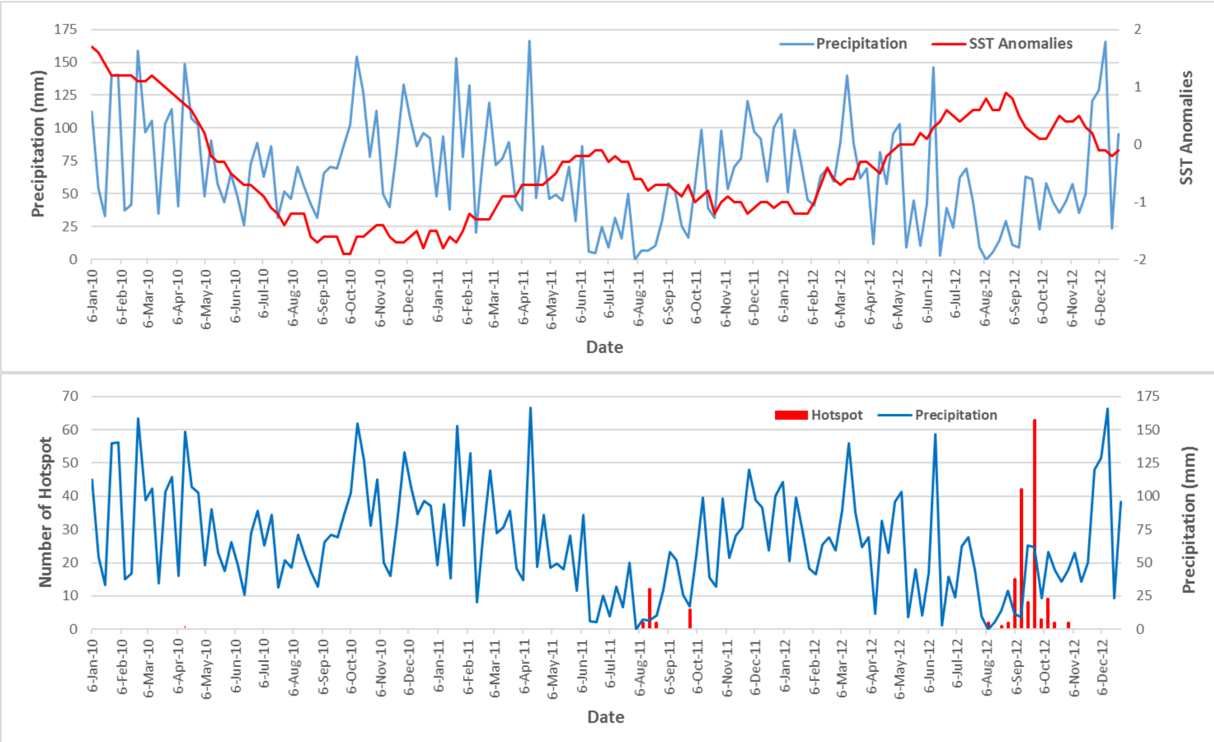

Figure 9. SST Anomalies, weekly precipitation and hotspot occurrences in study area, 2010-2012

Relationships between fire occurrences and GWL (figures 7 and 10) may suggest that the low GWL accelerated conditions where fires ignite with ease. In 2011, large number of fires started occurring in August following the drop of the mean GWL to – 33 cm, while in August 2012 fires began with a mean GWL of -34 cm (Fig. 7). Usup et al. [5], Wosten et al. [6], Putra and Hayasaka [12], Susilo *et al.* [15] and DeVries [17] suggested critical groundwater level of 40 cm below peat surface to prevent fire. However, our findings suggest that shallower GWL below peat surface should be maintained to prevent peat fire occurrences in dry-degraded peatlands.

Most of the fires in the study area occurred with GWL conditions of 30 – 39 cm below the peat surface (figure 10), but fire occurrences with GWL of less than 10 cm below peat surface may strongly suggest that degraded peatlands are very vulnerable to fires even under relatively moist conditions. Therefore, degraded peatlands should be maintained in wet conditions with critical GWL of less than 10 cm below peat surface, to prevent the area from experiencing surface peat fires. Dry conditions of degraded peatland create a suitable condition for the fire to burn downward into deeper peat layers and ignite deep peat fires, resulting in devastating peat fires in the area.

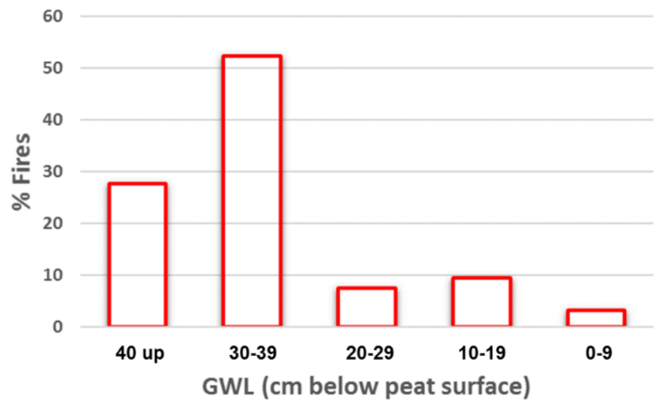

Figure 10. Percentage of peat fires occurrences on each GWL depth, September 2012

4. Conclusions

This study reveals that the degraded peatlands in the northern part of Block A and southern part of Block E of Ex-MRP have lost its capacity in absorbing and retaining water from rainwater droplets, keeping them in drier conditions than natural for most of the year, and therefore are very vulnerable to fire. The rising of Nino 3.4 STT Anomalies should be considered to predict significant fire risk as it may yield large fire occurrences. Time-lags between lowest precipitation and lowest GWL may provide some abilities to predict fire risk in advance of the lowest GWL. We propose the critical GWL of less than 10 cm below peat surface to prevent the degraded peatland from experiencing surface peat fires that may escalate to devastating deep peat fires.

Acknowledgements

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