

# Interannual variability in water and biogeochemical inputs to a coastal Bornean peatland

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## Background

- Forested Bornean peatlands are ombrogenous, or rainfed, ecosystems that derive water exclusively from precipitation.
- In addition, rainwater delivers nutrients and pollutants from the atmosphere and the canopy to the forest floor and is critical to maintain water tables that mitigate vulnerability to fire and soil carbon loss.
- Bornean peatlands experience substantial rainfall variability associated with warm (El Niño) and cool (La Niña) phases of the El Niño Southern Oscillation (ENSO).
- Due to extensive burning for agriculture, atmospheric concentrations of sulfur (S), chloride (Cl<sup>-</sup>), nitrogen (N), and phosphorus (P) may also be increasing.
- Together, burning and ENSO-driven precipitation variability may fundamentally alter biogeochemical inputs to ombrogenous Bornean peatlands.

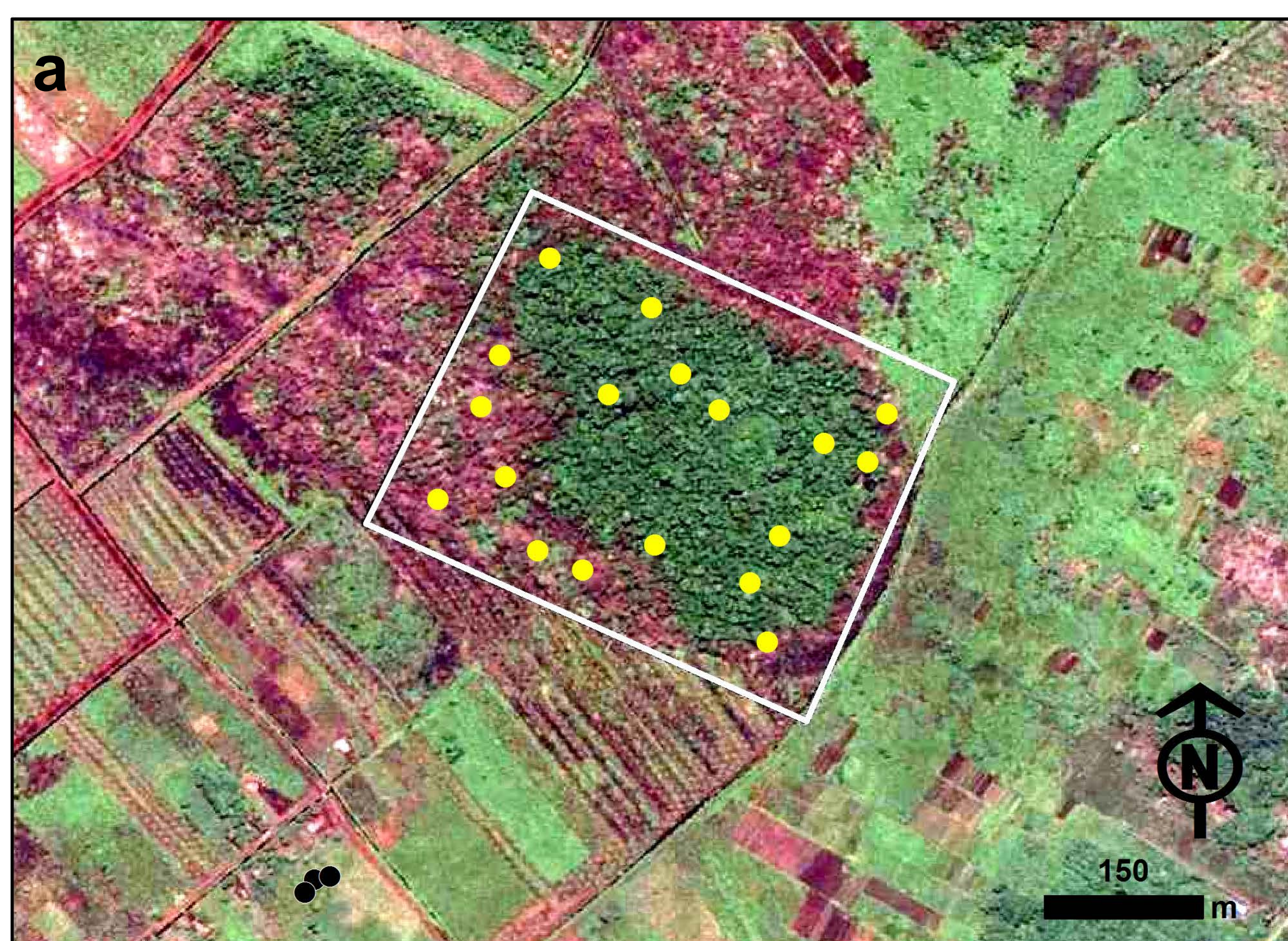
## Questions

- How do seasonal and annual rainfall and throughfall water fluxes to a forested peatland vary with changing ENSO conditions?
- What is the magnitude of wet deposition and throughfall S, Cl<sup>-</sup>, N, and P fluxes to the forest floor?
- What is the influence of local fire events on biogeochemical inputs?

## Methods

- In a 12 ha forested peatland in West Kalimantan, Indonesia, bulk rainfall and throughfall water flux to soil were measured weekly to monthly during four water years (WY, months September-August) dominated by El Niño (WY1, 2009-2010), La Niña (WY2, 2010-2011), and neutral (WY3/4, 2012-2014) conditions.
- Rainfall data (1980-2014) from the nearest meteorological station were used to assess ENSO effects on rainfall variability.
- Sulfate-S in throughfall was used as a tracer of total (wet + dry + fog) atmospheric deposition, and net S flux as an index of dry/fog deposition. Sulfate-S fluxes in bulk rainfall and throughfall were measured during WY1 (*n*=8 mos), WY3 (*n*=10 mos) and WY4 (*n*=11 mos), while Cl<sup>-</sup>, N, and P fluxes were measured in WY3 and WY4.
- The MODIS Active Fire Product (MCD14ML) was used to determine the number of fire locations within 20 km of the site.

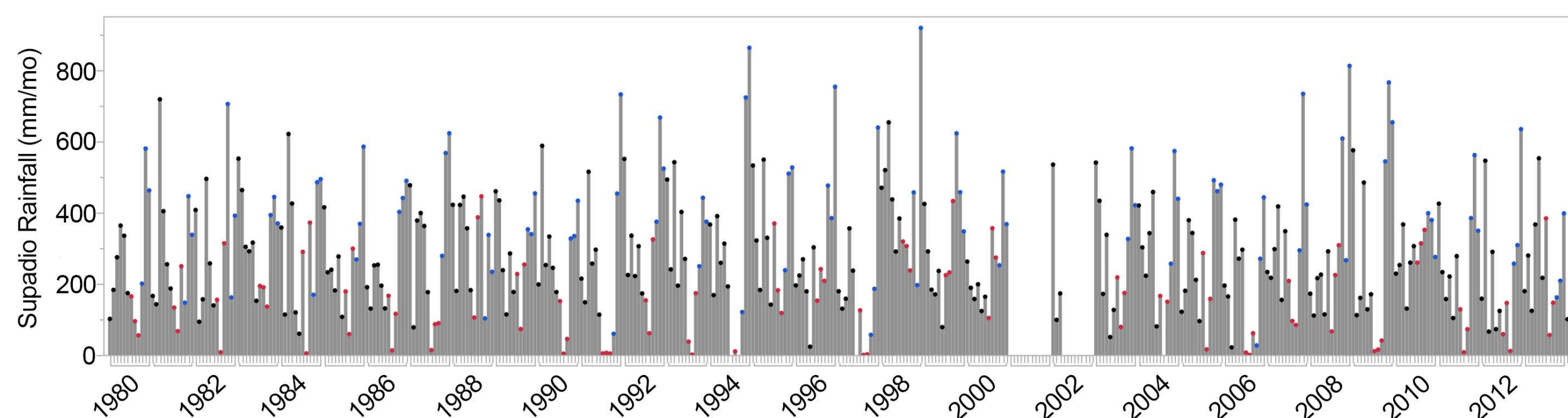
## Plot Location and Description



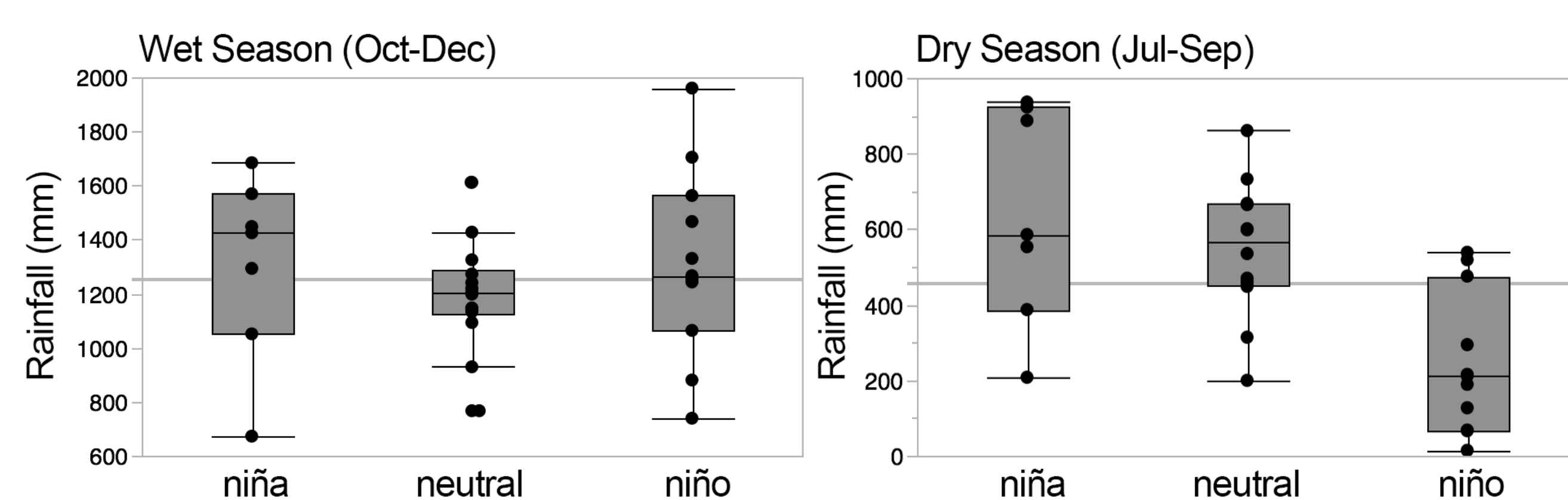
**Fig. 1.** (a) A DigitalGlobe image (June 1, 2014, accessed via Google Earth) shows the 12 ha forested peatland plot (bounded in white) and the surrounding matrix of burned peatlands, oil palm plantations and small-scale agriculture. Nine and eighteen throughfall collectors (yellow dots) were monitored from 2009-2011 and 2012-2014, respectively. In an adjacent clearing, three bulk rainfall collectors (black dots) were established. (b) Plot location (red dot) within West Kalimantan, Indonesia, on the island of Borneo.

## Long-Term Rainfall (1980-2014)

**Fig. 2.** (a) Long-term rainfall data indicate considerable inter- and intra-annual rainfall variability. Red and blue dots indicate dry (July-September) and wet (October-December) season months, respectively.

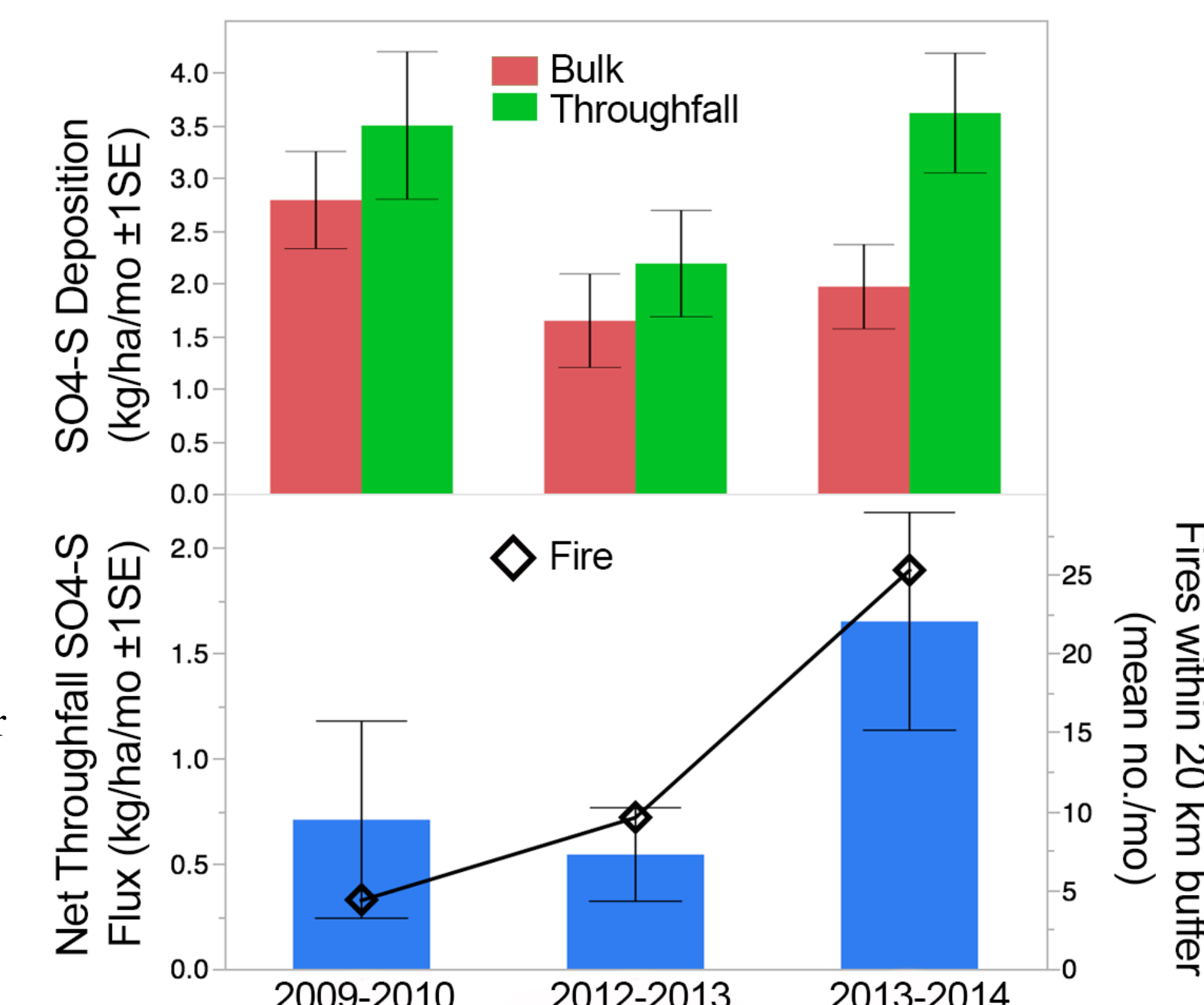


(b) Wet season rainfall does not differ among La Niña, neutral, and El Niño conditions. However, during dry season months (July-September), when fire activity increases, rainfall is significantly (~63%, on average) lower during El Niño compared to neutral (*p* = 0.0117) and La Niña (*p* = 0.0235) conditions.

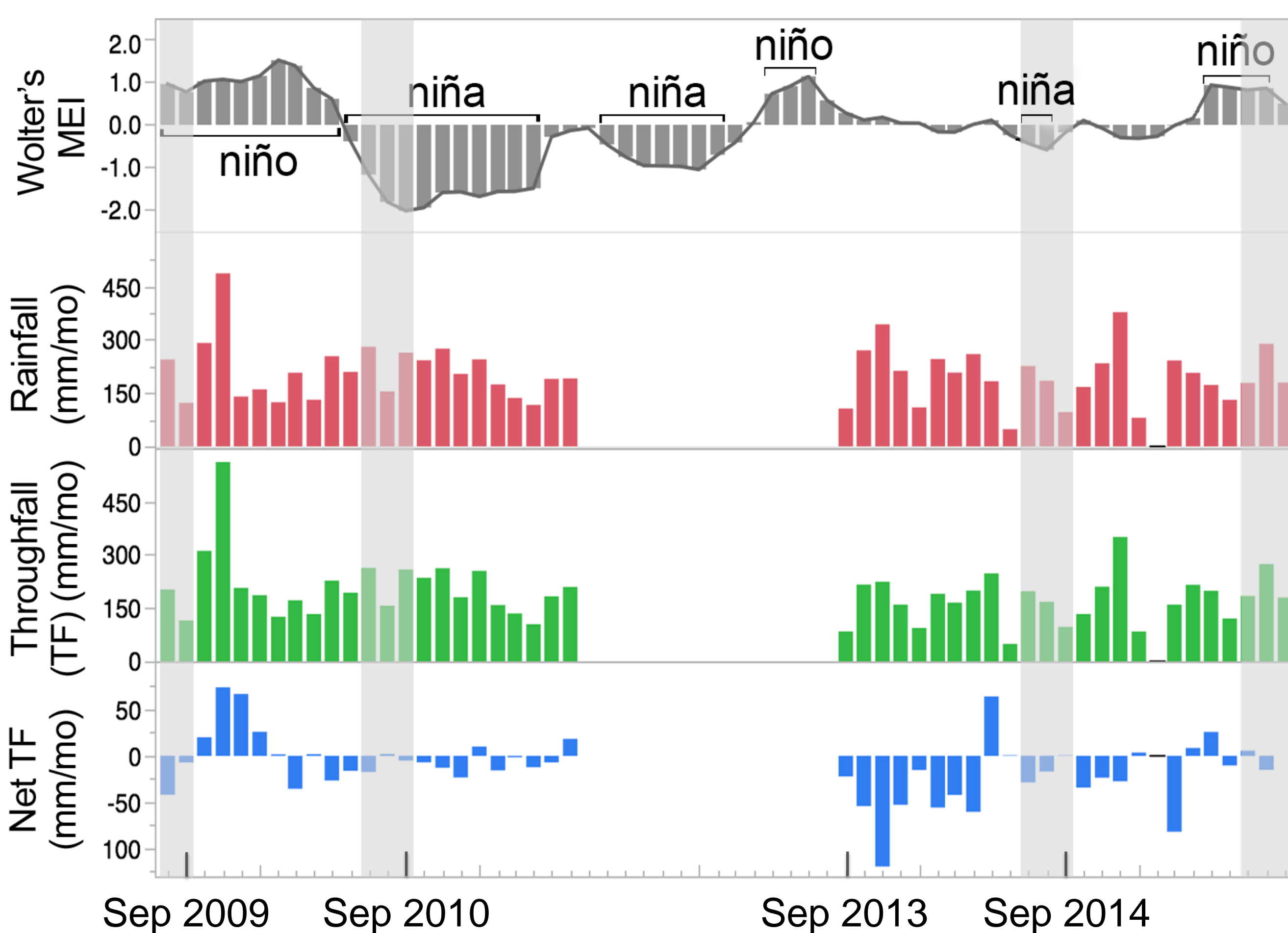


## Fire Effects on Sulfate-S Deposition (2009-2010, 2012-2014)

**Fig. 4.** Bulk rain S fluxes ranged from 1.6-2.8 kg/ha/mo. During all years sampled, fluxes in throughfall were higher than in rainfall, and these were 1.5-fold greater in WY4 (3.6 kg/ha/mo) and WY1 (3.5 kg/ha/mo) compared to WY3 (2.2 kg/ha/mo). Net throughfall flux was threefold greater during WY4 than the other water years, indicating enhanced dry/fog deposition. Burning around the sample plot likely contributed to elevated dry S deposition in WY4. In total, there were more fires in WY4 (303 fires, mean = 25/mo) than in WY3 (115 fires, mean = 10/mo) and WY1 (52 fires, mean = 4/mo). Monthly fire totals and sulfate concentrations were not correlated, however, suggesting that S sources other than biomass burning, such as volcanoes, also contributed to elevated S inputs.



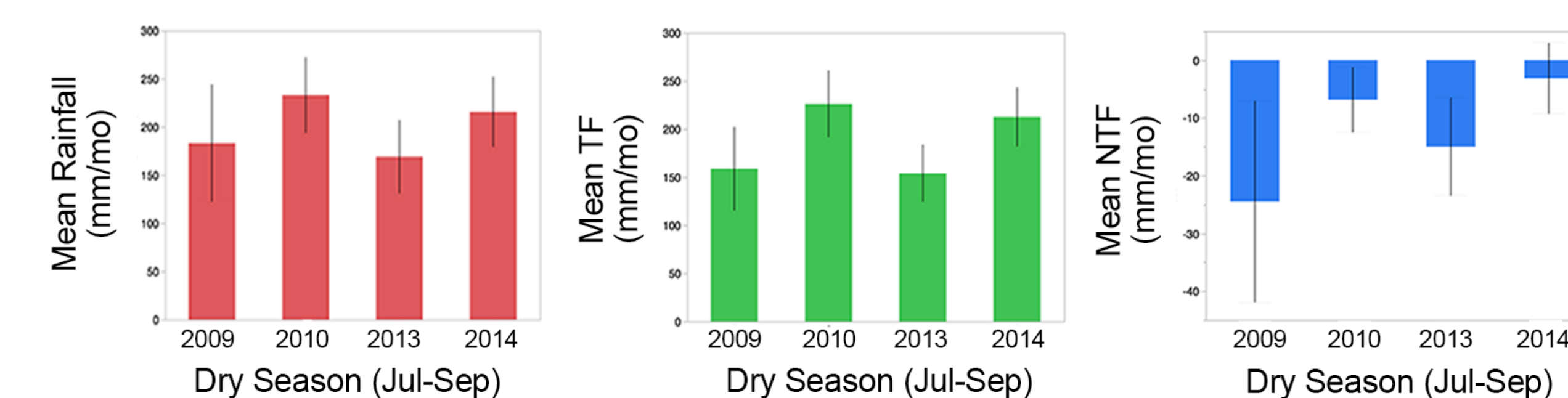
## Peatland Water Fluxes (2009-2011, 2012-2014)



**Fig. 3.** Wolter's Multivariate ENSO Index (MEI, top) for the period August 2009-September 2014 showing months classified as El Niño or La Niña (otherwise neutral). Sampled dry seasons (light grey shading) were dominated by moderate El Niño, strong La Niña, weak La Niña, and weak El Niño conditions. Water fluxes over the four water years (September-August) were characterized by substantial monthly variability. On average, November was the wettest month (339 mm), receiving 2.5-fold times more rain than February (135 mm), the driest month. Overall, there was less intra-annual variability in both rainfall and canopy throughfall fluxes when strong La Niña conditions prevailed.

| Water Year    | Total P <sub>g</sub> (mm) | Min P <sub>g</sub> (mm/mo) | Max P <sub>g</sub> (mm/mo) | Total TF (mm)     | TF < 100 mm (mos) | Net TF (mm)         | TF (%)           | TF (IQR) |
|---------------|---------------------------|----------------------------|----------------------------|-------------------|-------------------|---------------------|------------------|----------|
| 9/2009-8/2010 | 2562 <sup>a</sup>         | 1202                       | 487                        | 2652 <sup>a</sup> | 0                 | -89.4 <sup>a</sup>  | 104 <sup>a</sup> | 21       |
| 9/2010-6/2011 | 2038 <sup>a</sup>         | 117                        | 285                        | 1982 <sup>a</sup> | 0                 | -56.2 <sup>ab</sup> | 97 <sup>a</sup>  | 10       |
| 9/2012-8/2013 | 2398 <sup>a</sup>         | 49                         | 344                        | 1995 <sup>a</sup> | 2                 | -403 <sup>b</sup>   | 86 <sup>b</sup>  | 13       |
| 9/2013-8/2014 | 2176 <sup>a</sup>         | 0                          | 378                        | 2028 <sup>a</sup> | 3                 | -148 <sup>ab</sup>  | 94 <sup>ab</sup> | 14       |

**Table 1.** Over the sampling period, annual rainfall (P<sub>g</sub>) input to this forested peatland ranged from 2038-2562 mm. Surprisingly, neither bulk rainfall nor throughfall (TF) differed significantly among water years. However, percent throughfall did differ significantly among water years (*p* < 0.010); eighty-six to 104% of incoming rainwater was delivered to the forest floor. Net throughfall (Net TF, throughfall - bulk rainfall), or the total amount of water retained and/or lost to evaporation, varied sevenfold (-56 to -403 mm) among water years, and these differences were significant (*p* = 0.0210). Different letters indicate significant differences among water years (*p* < 0.05).



**Fig. 4.** No differences in any water fluxes were detected among dry seasons (July-September). However, dry season rainfall and throughfall water fluxes were 15-25% lower during a moderate (2009) versus a weak El Niño dry season (2014) and 38-47% higher during a strong (2010) compared to a weak La Niña (2013) dry season.

## Acknowledgements

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## Conclusions

- Water fluxes to a forested peatland in West Kalimantan, Indonesia, were characterized by considerable inter- and intra-annual variability.
- Year-to-year differences in water input and atmospheric S concentrations resulted in pronounced differences in total atmospheric deposition of S to this forested peatland.
- Rates of sulfur deposition were exceptionally high, ranging from ~26-43 kg/S/ha/yr.
- Net S fluxes, an index of dry deposition, were as much as threefold greater during 2013-2014, when fire frequency surrounding the plot was highest, than during the other water years.
- Ongoing analyses will evaluate how shifts in water fluxes, fires, and other emissions sources alter chemical fluxes to this Bornean peatland.