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Characteristics of Borneo and Sumatra fire plume heights and smoke clouds and their impact on regional El Niño-induced drought

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During the dry season, anthropogenic fires in tropical forests and peatlands in equatorial Asia produce regionally expansive smoke clouds. We estimated the altitude of smoke clouds from these fires, characterized the sensitivity of these clouds to regional drought and El Niño variability, and investigated their effect on climate. We used the MISR satellite product and MISR INteractive eXplorer (MINX) software to estimate the heights of 382 smoke plumes (smoke with a visible surface source and transport direction) on Borneo and 143 plumes on Sumatra for 2001—2009. In addition, we estimated the altitudes of 10 smoke clouds (opaque regions of smoke with no detectable surface source or transport direction) on Borneo during 2006. Most smoke plumes (84%) were observed during El Niño events (2002, 2004, 2006, and 2009); this is consistent with higher numbers of active fire detections and larger aerosol optical depths observed during El Niño years. Annually averaged plume heights on Borneo were positively correlated to the Oceanic Niño Index (ONI), an indicator of El Niño (r2 = 0.53), and the mean plume height for all El Niño years was 772.5 $\pm$ 15.9m, compared to 711.4 $\pm$ 28.7m for non-El Niño years. The median altitude of the 10 smoke clouds observed on Borneo during 2006 was 1313m, considerably higher than the median of nearby smoke plumes (787m). The difference in height between individual plumes and regional smoke clouds may be related to deeper planetary boundary layers and injection heights later in the afternoon (after the 10:30am MISR overpass) or other atmospheric mixing processes that occur on synoptic timescales.

We investigated the climate response to these expansive smoke clouds using the Community Atmosphere Model (CAM). Climate responses to smoke from two 30 year simulations were compared: one simulation was forced with fire emissions typical of a dry (El Niño) burning year, while the other was forced with emissions typical of a low (La Niña) burning year. Fire aerosols reduced net shortwave radiation at the surface during August–October by an average of 10% in the region encompassing most of Sumatra and Borneo (90°E–120°E, 5° S–5°N). The reductions in net radiation cooled both sea surface temperature (0.5 $\pm$ 0.3°C) and land air temperature (0.4 $\pm$ 0.2°C) during these months. Tropospheric heating from black carbon (BC) absorption increased substantially (20.5 $\pm$ 9.3 W m$-$2) and was balanced by an overall reduction in latent heating in the mid-troposphere. The combination of decreased SSTs and increased atmospheric heating reduced regional precipitation by 0.9 $\pm$ 0.6 mm d^{-1} (10%). The vulnerability of ecosystems to fire was enhanced because the decreases in precipitation exceeded those for evapotranspiration. Together, the satellite and modeling results imply a possible positive feedback loop in which anthropogenic burning in the region intensifies drought stress during El Niño.