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Land cover, lightning frequency, and turbulent fluxes over Southern Louisiana

Nicholas J. Sokol*, Robert V. Rohli

Department of Geography and Anthropology, Louisiana State University, Baton Rouge, LA 70803-4105, USA

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ABSTRACT

Lightning is one of the most impactful weather phenomena but little precise and accurate information is known about how its frequency is impacted by changes in land use/land cover (LULC). Similarly, little is known about the spatial and temporal variability of the convective (i.e., turbulent) fluxes of sensible and latent heat that fuel the updrafts associated with lightning under changing LULC. This research applies NOAA's gridded annual lightning data from the National Lightning Detection Network (NLDN), gridded annual mean convective flux data from the North American Regional Reanalysis database (NARR), and LULC classification data from the NOAA Coastal Change Analysis Program (C-CAP) to analyze frequency changes in lightning and the turbulent fluxes across a swath of Louisiana, U.S.A., over the years 1996–2011. Results suggest that urban areas have the highest means of CG lightning with a consistent mean of approximately 152 flashes per km^{-2}. However, urban areas support less convective flux of sensible (latent) heat than five (four) of six other generalized land classes tested. Lightning frequency tends to be positively related to latent heat fluctuations but less directly related to sensible heat, at least at the annual time scale, as we see positive relationships in all land classes except unconsolidated shore ($p < 0.05$). Collectively, these results suggest that land use change should be considered carefully in models of future projections of severe weather events and climate.

1. Introduction

Lightning claims dozens of lives every year in the United States (Curran, Holle, & López, 2000; Holle, 2016), in part due to increasing population (Gomes & Ab Kadir, 2011). Louisiana is ranked ninth among all states in lightning-induced deaths per year (Holle, 2017), despite having a population that ranks 25th. Although it lacks the persistent convective enhancement of peninsular Florida, the state has a frequently large supply of warm, moist air from the Gulf of Mexico that fuels atmospheric instability for a substantial number of days throughout the year (Lericos, Fuelberg, Watson, & Holle, 2002; Orville & Huffines, 1999). In addition, increased development and industrial activity along the Gulf Coast has spurred ecosystem and boundary layer changes for southern Louisiana (Couvillion et al., 2011, p. 12; Mahmood et al., 2010), which could modify spatio-temporal lightning trends.

Several researchers have presented evidence of urban modification of thunderstorm activity. Urban areas have been found to increase the frequency and intensity of thunderstorms (Ashley, Bentley, & Stallins, 2012; Haberlie, Ashley, & Pingel, 2015). Urban influences on lightning flash frequency could occur due to increases in atmospheric particulates, enhanced convection, or a greater availability of attractive objects (Steiger & Orville, 2003). In an analysis of lightning patterns around 16 major U.S. cities from 1989 to 1992, Westcott (1995) found that areas downwind and over cities experienced a 40–80% increase in lightning activity over adjacent environs. Watson and Holle (1996) found that in the southeastern U.S., the cloud-to-ground (CG) strike frequency is often increased over urban areas. Naccarato, Pinto, and Pinto (2003) found a 60–100% enhancement in CG lightning over urban areas in Brazil, with this increase attributed to additional heat output from urban surfaces. Bentley and Stallins (2005) found that in Atlanta, Georgia, each season has its own predominant synoptic conditions for producing lightning when coupled with urban enhancement. In a follow-up study by Stallins and Bentley (2006), the northeastern quadrant of Atlanta was found to support the most lightning, with the enhancement attributed to increased urban-induced instability.

Although links between land use/land cover (LULC) and lightning most often have emphasized urban areas, a few studies have analyzed the relationship between other LULC types and CG lightning strike frequencies. For example, García, Martín, Soriano, and Dávila (2015) found that mining and industrial areas, along with forest and shrub land, are struck more frequently, while non-agricultural vegetated areas

* Corresponding author. Present address: Department of Geography, University of South Carolina, Columbia, SC 29208, USA.
E-mail addresses: Nsokol44@gmail.com (N.J. Sokol), rohli@lsu.edu (R.V. Rohli).

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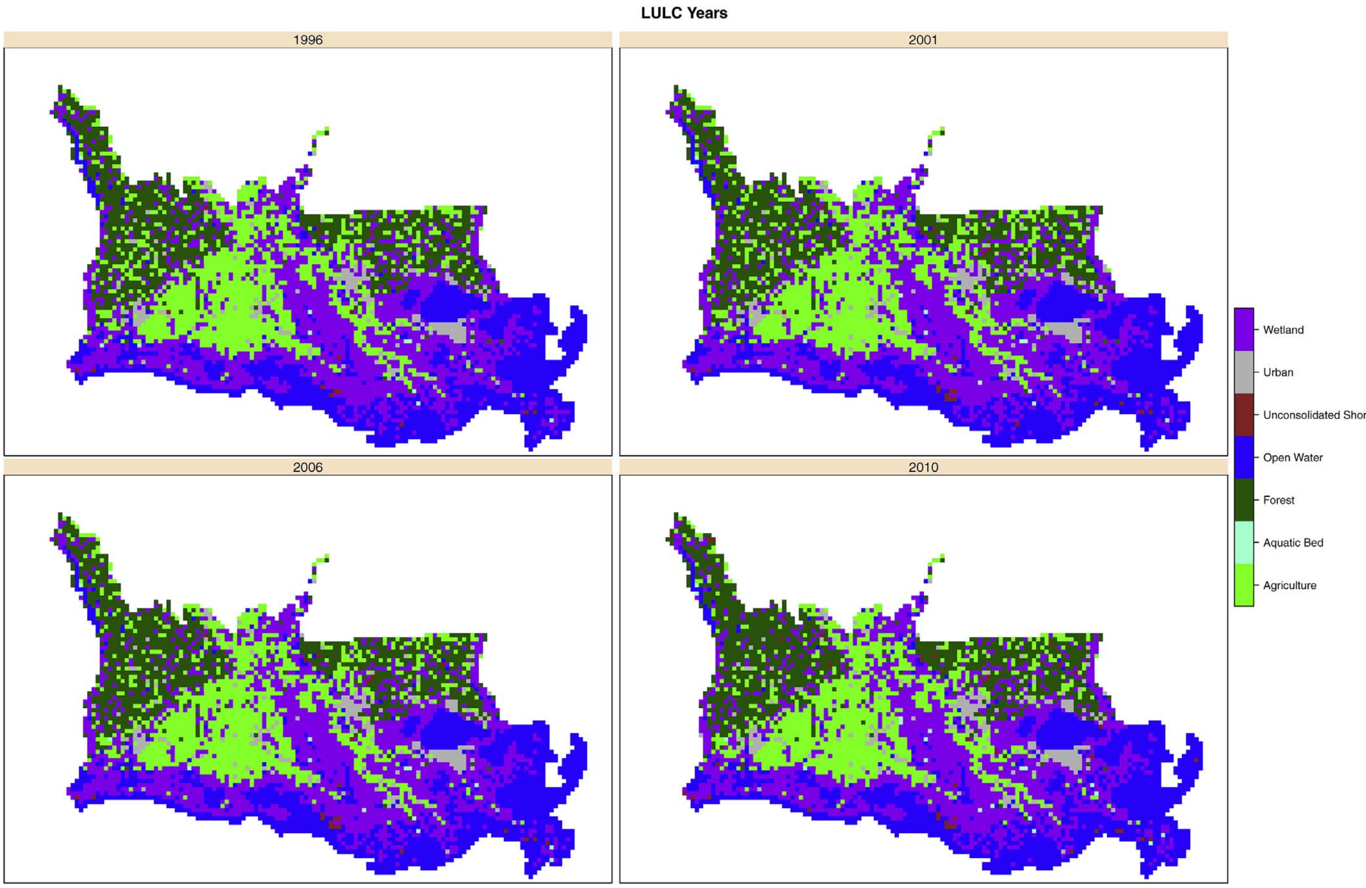

Fig. 1. Distribution of the seven land classes across southern Louisiana for each of the LULC years studied.

and pastures have lower frequencies. García et al. (2015) also detected slight variations in CG lightning frequencies by soil type. By contrast, Brown, Reuter, and Flesch (2011) found no evidence of spatial discontinuities in lightning strikes around the Athabasca oil sands of northeastern Alberta, Canada, despite the substantial disturbance represented by the sands amid near-continuous boreal forest. While the literature has addressed some facets of LULC and lightning frequency, more analysis is required for a more complete understanding of this relationship.

Lightning occurs in conjunction with vertical cloud development to such an extent that the base of the cloud and top of the cloud contain abundant liquid water and ice, respectively. The vertical cloud development requires vigorous lifting of air from the surface. In the subtropical United States, the lifting often takes the form of free convection in a convectively unstable atmosphere, driven by the turbulent vertical transfer of energy in the form of the sensible and latent heat fluxes (Q_H and Q_E, respectively). The total atmospheric heat flux ($Q_H + Q_E$, which summed together comprise the enthalpy) has been found to correlate strongly with lightning flash count in the tropics and subtropics (Chate, Tinmaker, Aslam, & Ghude, 2017). Moreover, recent model-based research (Boone et al., 2016) suggests that LULC changes are linked to substantial changes in Q_E in subtropical West Africa. Thus, an analysis of the relationship between LULC, lightning, and Q_H and Q_E in the subtropical United States is warranted.

This study aims to further expound upon associations of local changes in LULC to lightning frequency, Q_H, and Q_E. This will be done by: 1) investigating the spatio-temporal distribution of lightning across southern Louisiana by satellite-derived land class, and 2) analyzing spatio-temporal changes in Q_H and Q_E by land class, and their association to lightning. We analyze these turbulent fluxes separately to advance the work of Chate et al. (2017) in assessing their relative association as energy sources for lightning development, and because they are easily modified by changes to topography (Pielke et al., 2002). Moreover, the applied importance of Q_H and Q_E calls for a better understanding of their changes under changing LULC. Q_H represents the surface-atmosphere heat exchange that could be expected to change by LULC, across space and time, due to different thermal properties of the surface. Q_E represents the surface-atmosphere flow of water, in the form of evaporation, and is therefore expected to change through space and time with LULC; it can be used to derive evapotranspiration rate (ET, in units of meters of precipitation equivalent per second, which is easily convertible to mm day^{-1} of precipitation equivalent) through the simple equation

$$ET = \frac{Q_E}{L_v \rho_l} \quad \frac{Wm^{-2}}{Jkg^{-1}kgm^{-3}} \quad \frac{Js^{-1}m^{-2}}{Jm^{-3}} \quad \frac{m}{s}$$

where Q_E is the observed net latent heat flux (Wm^{-2}), L_v is the latent heat of vaporization (2.5008×10^6 J kg^{-1}) and ρ_l represents the density of liquid water (1000 kg m^{-3}). In a broader sense, this research represents a call for application of the increasingly available LULC data sets for deducing changes in other geophysical phenomena that are hypothesized to be related to LULC.

2. Material and methods

This study utilizes LULC data from the National Oceanic and Atmospheric Administration's Coastal Change Analysis Program (NOAA, 2017; C-CAP), lightning data from NOAA's severe weather data inventory, and Q_H and Q_E data from the North American Regional Reanalysis database (NARR). These data are chosen because of their high resolution and temporal coverage. The C-CAP data are 30-m Landsat 4–5 derived images of Louisiana (https://coast.noaa.gov/