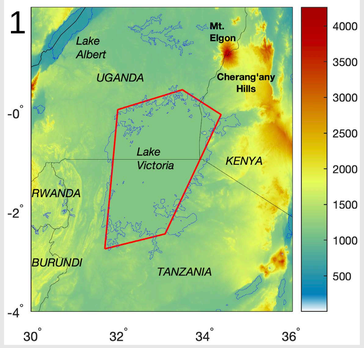
Lightning Density and Thunderstorm Initiation in the Lake Victoria Region in East Africa

Katrina Virts (University of Alabama in Huntsville, katrina.virts@uah.edu) and Steven Goodman (Thunderbolt Global Analytics)

1. Motivation



The Lake Victoria basin in eastern Africa is home to over 30 million people, over 200,000 of whom work in the fishing or transportation industries on the lake.

The Red Cross estimates that **3,000 to 5,000 people are killed every year** on the lake because of thunderstorms.

We want to understand:
- How often and where do thunderstorms occur?
- Where do the strongest thunderstorms initiate, and under what conditions?

Figure 1: Elevation (m) of Lake Victoria basin.

2. Lightning Climatology of Lake Victoria Basin

- Starting in 2014, Earth Networks Global Lightning Network (ENGLN) placed 15+ low frequency-high frequency sensors around Lake Victoria → first continuous total lightning observations in this region.
- We studied lightning occurrence from September 2014 – August 2018.

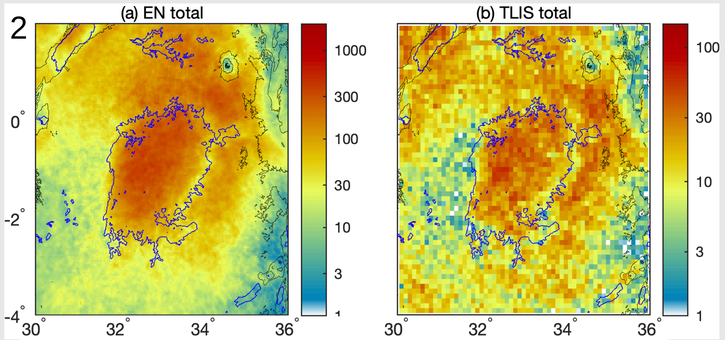


Figure 2: Annual-mean lightning density (flashes km^{-2} yr^{-1}) measured by (a) ENGLN and (b) TRMM-LIS. Note the different color scales.

- **Thunderstorms occur on an almost daily basis over Lake Victoria**: >100 flashes over the lake on 89% of days.
- ENGLN and the Lightning Imaging Sensor (LIS) aboard the TRMM satellite report similar climatological lightning patterns.
- Lightning is most frequent over the lake, over the plains to the north, and between the lake and highlands to the east.
- Lake Victoria is on the equator → lightning occurrence shifts latitudinally with the equatorial trough during the year.
- Lightning is most frequent during the equinox seasons (March-May, September-November) and least frequent during the solstice seasons (December-February, June-August).

Season	*Mean lightning density over LV*
DJF	164 flashes km^{-2} yr^{-1}
MAM	212 flashes km^{-2} yr^{-1}
JJA	126 flashes km^{-2} yr^{-1}
SON	215 flashes km^{-2} yr^{-1}

- Solar heating, lake breezes, and valley breezes produce afternoon lightning maxima over land, especially north and east of Lake Victoria.
- At night, land cools more rapidly than water, and land breezes and mountain breezes lead to convergence over the lake that may be enhanced by outflow boundaries from daytime convection over land.
- A nocturnal lightning maximum propagates from northeast to southwest over the lake.

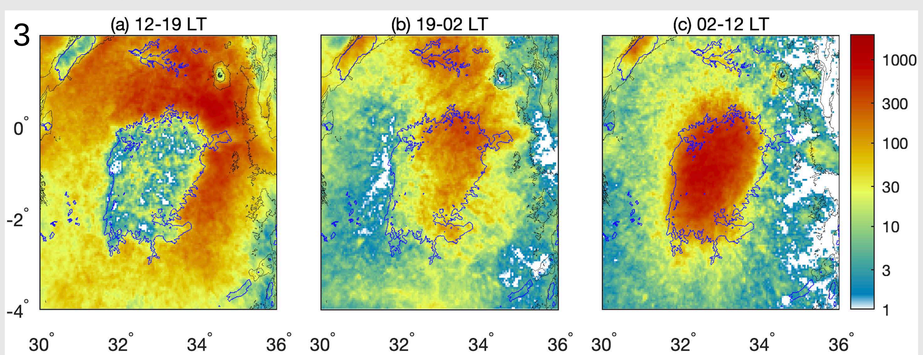
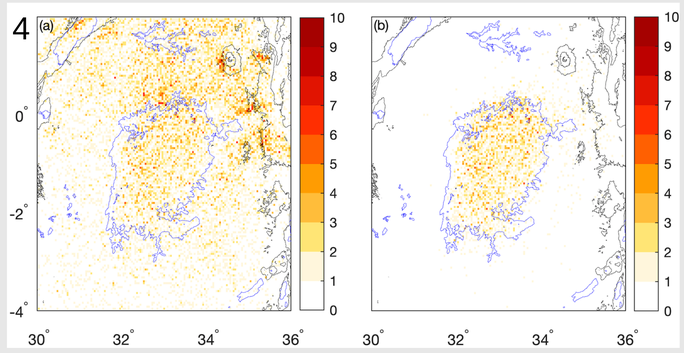


Figure 3: ENGLN lightning density (flashes km^{-2} yr^{-1}) during (a) daytime, (b) evening and early night, and (c) night and morning.

3. Initiation of Prolific Thunderstorms over Lake Victoria Basin



In order to examine the initiation of individual thunderstorms, ENGLN flashes were clustered using a weighted Euclidean distance method: WED^2 = (D/10)^2 + (T/600)^2, where D is the distance between two flashes in kilometers and T is the time between them in seconds. Two flashes are assigned to the same thunderstorm cluster if WED < 1.

Figure 4: Location of first flash of lightning clusters producing (a) more than 1,000 flashes during their lifetime and (b) more than 1,000 flashes over Lake Victoria (i.e., within the red polygon in Fig. 1).

- **The vast majority (~85%) of prolific Lake Victoria clusters initiate in situ over the lake.**
- Terrain-related maxima over the steep western slopes of Mt. Elgon and other topographical features in Fig. 4a are absent in Fig. 4b → while they often propagate toward the lake, these clusters generally dissipate before reaching it.

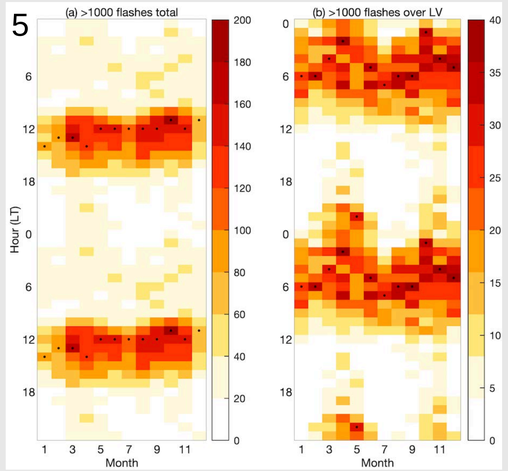
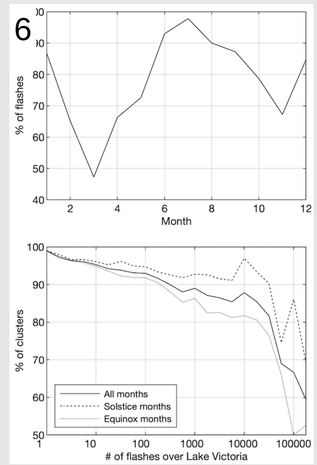


Figure 5: Histograms of the month (abscissa) and local time (ordinate) of the first flash of lightning clusters producing (a) more than 1,000 flashes during their lifetime and (b) more than 1,000 flashes over Lake Victoria. The diurnal cycle is repeated for clarity.

- Clusters producing >1,000 flashes initiate around 11-14 LT, just before the lake and valley breezes reach their maximum amplitude, and 1-2 hours earlier than the average cluster.
- **The initiation times of clusters producing >1,000 flashes over Lake Victoria exhibit a bimodal seasonal cycle:**
  - During solstice seasons, clusters primarily initiate between midnight and noon, peaking at 05-08 LT, about 12 hours after the afternoon convective peak.
  - During equinox seasons when lightning is most frequent over the lake, initiation times range from early evening through the night and morning. The hour of peak initiation ranges from 22-04 LT.
- **Earlier initiation times during equinox seasons suggest that clusters may be triggered by outflow boundaries or gravity waves propagating away from decaying convection over land, or that land-originating convection undergoing a lull in lightning production may be reinvigorated by the warm lake waters and land breezes.**

Figure 6: (a) Monthly percentage of flashes over Lake Victoria that were produced by clusters initiating over the lake. (b) For bins based on the number of flashes that clusters produced over Lake Victoria (abscissa), the percentage of clusters in each bin that initiated over Lake Victoria (ordinate).



- During solstice seasons, 80-95% of flashes over Lake Victoria were produced by clusters initiating in situ over the lake.
- During February-April fewer than 70% of flashes over the lake were produced by clusters initiating there. During March, over half of Lake Victoria lightning was produced by thunderstorms initiating over land.
- Clusters producing <10 flashes over the lake initiate almost exclusively in situ. **As flash count increases, the likelihood of initiation over land increases.** This trend occurs in all seasons but is more marked during equinox months.
- Of the 100 most extreme Lake Victoria clusters (>85,000 flashes over the lake), 64 initiated over the lake and 36 over land, primarily north and east of the lake.

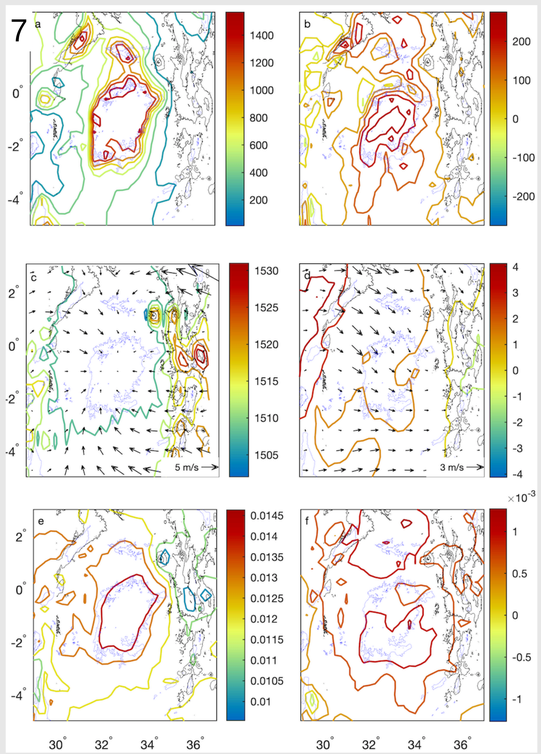


Figure 7: (left) Composite and (right) anomalous ERA5 (top) CAPE, (middle) 850-hPa geopotential height and winds, and (bottom) 850-hPa specific humidity 3h prior to initiation of the 100 most extreme Lake Victoria clusters. Anomalies were obtained by subtracting the climatological monthly-mean for that hour.

- **Extreme Lake Victoria clusters initiate in an environment of enhanced CAPE and low-level moisture, supporting vigorous convection. A broad trough extends from the lake northward, with low-level convergence over the lake. Low-level winds over the lake are anomalously westerly.**
- Mid-level winds are easterly over the basin and do not statistically differ from the climatological-mean, and deep layer shear anomalies over the lake are small (not shown).

4. Conclusions

We have examined climatological lightning occurrence and the initiation of high-impact, prolific thunderstorms in the Lake Victoria basin using new, continuous observations of total lightning from ENGLN. We find that:
- Lightning is an almost daily occurrence over Lake Victoria.
- Strong seasonal and diurnal cycles, with most frequent lightning over the lake at night during equinox seasons.
- Afternoon, terrain-related thunderstorm initiation hotspots northeast of the lake.
- **The vast majority (85%) of storms producing over 1,000 flashes over the lake initiate in situ during the night. However, the more prolific the storm, the more likely that it initiated over land and then propagated over the lake. This trend is especially prevalent during the equinox seasons.**
- The initiation times of prolific LV storms have a bimodal seasonal cycle:
  - Solstice seasons: storms initiate in early morning (05-08 LT), ~12 hours after the peak afternoon lightning.
  - Equinox seasons: thunderstorms initiate from late evening through the night (22-04 LT), or about 5-6 hours earlier than during solstice season. **These storms are more likely than solstice-season storms to initiate over land and then propagate over the lake.**
- Our results suggest that during equinox seasons, afternoon thunderstorms over land have more direct and indirect influence on the intense nocturnal storms over Lake Victoria, compared to solstice seasons.
- The most extreme Lake Victoria clusters are associated with enhanced instability and low-level moisture, and converging low-level winds over the lake. Mid-level wind and deep layer shear anomalies are small.

Acknowledgments: The authors thank ENGLN for providing the lightning data, the Met Office for collaboration in the HIGHWAY project, and the NASA Postdoctoral Program for support.