On the Relationship between Observations from the Lightning Imaging Sensor and Ground-based Lightning Observations at VLF, LF, and VHF Frequencies

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The planned GOES-R Geostationary Lightning Mapper (GLM) will provide unique lightning data, products and information on the location and intensity of thunderstorms over a large, hemispheric spatial domain. Ongoing GOES-R Algorithm Work Group (AWG), GOES-R Risk Reduction (R3) and Proving Ground (PG) activities have already begun demonstrating the capability of GLM proxy lightning data and products for enhancing the situational awareness and forecasting skill of severe convective weather. More recently, GOES-R3 activities for GLM have expanded into other important applications such as aviation weather, quantitative precipitation estimation (QPE), tropical cyclones and fire weather.

To date, GLM total lightning proxy data for AWG, R3 and PG applications have been well served by the Lightning Imaging Sensor (LIS), which is the legacy satellite-based Charged Coupled Device (CCD) optical instrument upon which GLM is based, or by local, ground-based VHF-based systems such as the North Alabama Lightning Mapping Array (Northern Alabama LMA). The LIS is the closest instrument to a true proxy for GLM and provides broad global coverage of the tropics and sub-tropics but it provides no temporal continuity of lightning because of its low earth orbit vantage point. Although not optically based, the LMA (and other similar VHF-based systems in Washington DC, Oklahoma and a few other locations) provide excellent estimates of total flash rate in a spatial domain within about 200 km from network center. Significant AWG research effort has gone into understanding the relationship between these two sources of observations to create more continuous proxy data sets for R3 and PG applications and validation activities.

To continue expanding GLM R3 and PG applications for severe, aviation, QPE, tropical cyclone and fire weather, it will be desirable to develop additional sources of continuous lightning observations that can serve as suitable GLM proxy over large spatial scales (order 1000 km or more), including typically data sparse or denied regions such as the oceans. A number of ground-based observations systems (Lightning Locating Systems, or LLSs) are available for this use, but it is necessary to benchmark the data provided by these systems before they can be used in any quantitative manner.

This work focuses on two related tasks. First, we assess selected LLS datasets produced during the recent CHUVA campaign in Brazil, so that they can be better understood and applied in GOES AWG, R3 and PG (and later VAL) activities. In addition, we are exploring tools to help determine which ground-based observations in various frequency bands (VLF, LF, and VHF) are space-and-time correlated with LIS data. More specifically, we try to identify the lightning parameters that are related to LIS "group" size and radiance, where a "group" is a collection of spatially connected 5-8 km gridded optical detections in a 2 ms period. Conversely, we also try to identify the ground-based observations that do not associate well (within ~50 mS) with LIS observations.

Though not shown here, the workshop presentation will include an analysis of LIS-related observations using data from Vaisala's long-range LLS (GLD360) and the World-wide Lightning Location Network (WWLLN). These "global" LLSs geo-locate significant fractions of CG strokes and some pulses associated with cloud flashes by detecting lightning electromagnetic fields in the VLF frequency range that propagate through the earth-ionosphere waveguide. These long-range datasets will also be inter-compared with CG strokes reported by the LF portion of Vaisala's 5-station TLS200 LLS (TLS-LF), by evaluating the overall stroke relative detection efficiency, location differences, and (where applicable) the differences in peak current estimates.

In the specific analysis shown here, the TLS-LF data were used to identify ground stroke locations, polarity, and peak current. Sensor spacing for this network varied between 50 and 130 km, with a network diameter of ~ 160 km. With all five sensors operating, CG stroke detection efficiency is expected to be in excess of 90% within ~200 km of the network center, with median location accuracy better than 150m (Vaisala personal communication). Data from the 12-station São Paulo LMA (SP-LMA) provided 3-dimensional VHF lightning observations that reflect the progress of breakdown and leader processes in nearly all lightning flashes. Sensor spacing for the SP-LMA was on the order of 15-30 km, with a network diameter on the order of 40-50km. This LLS provides good 3-D lightning mapping out to 150 km from the network center, with 2-D coverage considerably farther. Flash detection efficiency is expected to be nearly 100% within 150 km of the network center, and source location accuracy better than 100m. The SP-LMA has some issues with "outlier" sources due to a high level of VHF noise in the domain. Most of these noise sources had altitudes lower than 3 km. In the figures shown here, all sources below 2.7 km were removed.

In this abstract, we only show example data from one LIS overpass on February 14, 2012, using data from LIS, SP-LMA and TLS-LF CG observations. The LIS observation footprint was within the domain of the LMA system for a 100-second period starting at 16:57:14 GMT. This overpass was selected because it exhibits all the "behaviors" of the three datasets. Data from the complete overpass (space and time limited to only include events within the LIS field-of-view (FOV)) is shown in Figures 1 and 2, and a zoom-in on a small group of flashes is shown in Figures 3 and 4. Figure 1 show observations from the three systems in a plan-view format. The LIS groups are represented as magenta circles with radius defined by the associated group area. A LIS flash is a collection of LIS groups, and appears in this figure as a number of overlapping circles. The SP-LMA sources are color-coded by time using a modified heat scale, shown in the colorbar on the right. The TLS-LF CG strokes are plotted as red "dots".

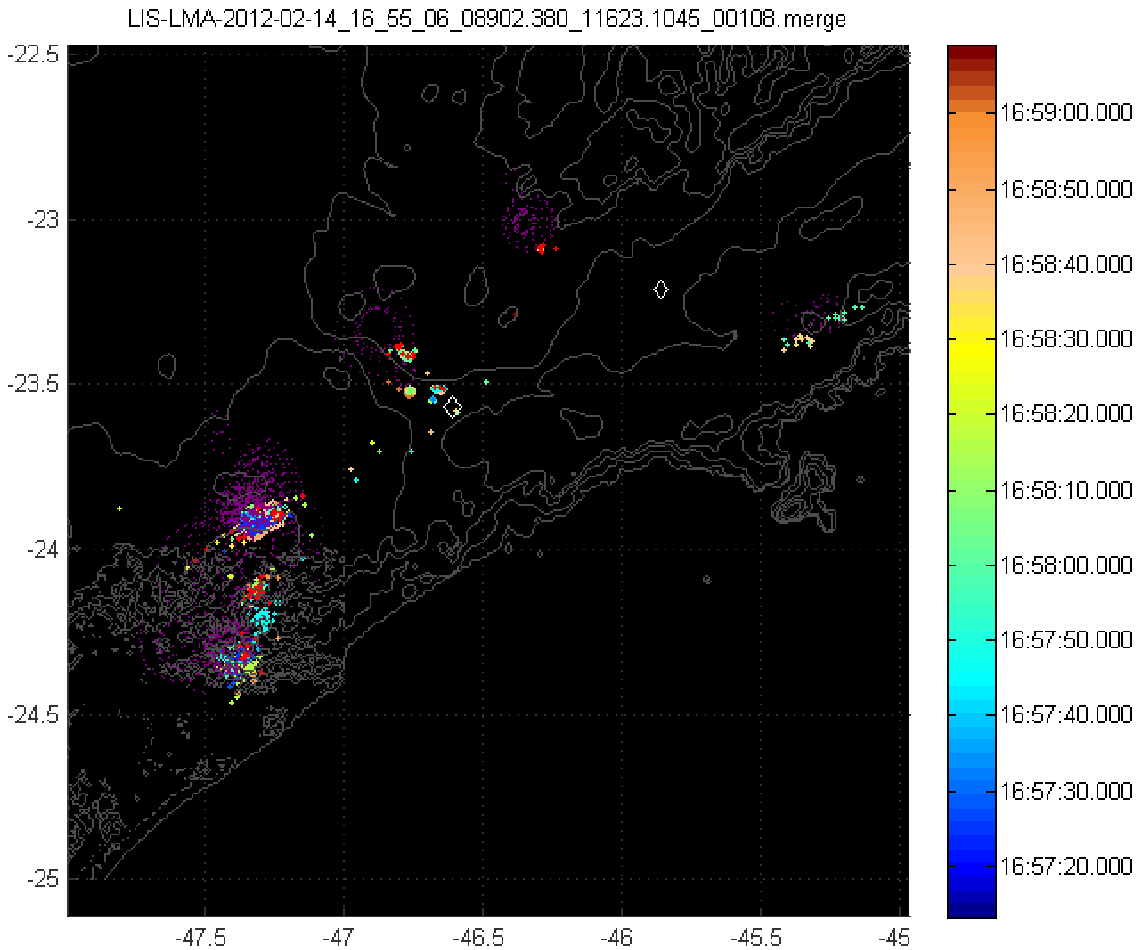

Figure 1. Plan-view representation of lightning data from the February 14, 2012 LIS overpass. See text for details.

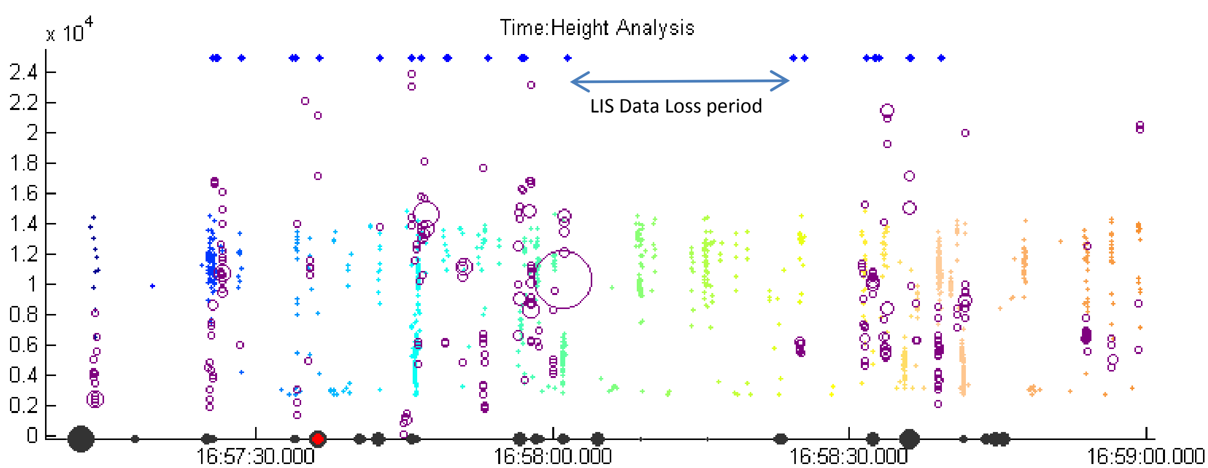

Figure 2. Time:height representation of data from the February 14, 2012 LIS overpass. See text for details.

The center of São Paulo is shown in the white diamond near the center of the plot, and the white diamond in the upper-right shows the location of the INPE headquarters in São José dos Campos. Figure 2 shows these data in a time:height format. The time:Height image uses the same color scale as the plan view, so that one can identify the flashes with the ones in the plan view. Again magenta circles are LIS groups, but now the radius is proportional to LIS Radiance. Their vertical position “overloads” the LMA height scale, and is scaled to meters from the average lat-lon of the closest 7 LMA sources (saturation at 25000m). The TLS-LF CG strokes are the colored circles at zero altitude, where negative strokes are grey and positive strokes are red. The circle area is proportional to peak current, with the smallest ones are near 10 kA and the largest ones are at or above 100 kA.

The combined representations in Figures 1 and 2 provide a fairly complete overview of the space and time relationships between the flash representations of the three datasets. Note in Figure 2 that there is a 20+ second period during this overpass when there were no LIS groups. This is the result of a data buffer overflow. These overflows typically occur under one of two conditions: (1) periods when the FOV is “filled” by high flash-rate storms, such as during large mesoscale convective systems, and (2) FOVs that include the South Atlantic Anomaly, as we have in the CHUVA domain. Other than for this period, almost all of the ~26 well-defined flashes reported by LMA during this overpass have spatially and temporally correlated LIS groups. Of these, roughly half of the LIS flashes have at least one LIS group centroid within 5 km of the centroid of the time-coincident LMA sources.

Figure two show a couple of interesting behaviors. First, there is one moderate-sized positive event reported by the TLS-LF network at about 16:57:36. This +27 kA event is the second report of an 8-stroke negative flash with three negative strokes having estimated peak currents greater than 30 kA. This flash is located in the most south-west storm shown in Figure 1, which is at the limit of the LMA reporting area. LIS and LMA both had two groups/sources for this flash.

A more-interesting set of flashes occurred during the period of 16:57:55 through 16:58:02, ending with a CG flash associated with one of the largest-radiance LIS groups during the whole campaign. The plan-view and time:height images for this period are shown in Figure 3 and 4, respectively. Based on visual spatio-temporal clustering, there appears to be five distinct flashes, three of which are multi-stroke negative flashes. The LIS group centroids are generally more than 4 km from the centroids of the time-coincident LMA sources, and have the appearance of being offset slightly to the north and/or west. Although many moderately-bright LIS groups are associated with the cloud flashes, the brightest one at 15:58:02 is associated with the first return stroke of a CG flash with 6 strokes reported by the TLS-LF LLS. This flash is shown in Figures 5 (plan view) and 6 (time:height). The first stroke had an estimated peak current of -26.5 kA. Based on review of Figures 5 and 6, it seems that the leader preceding this return stroke travelled about 7 km in a northwest direction before striking ground. Based on a review of the individual stroke location sequence (not shown), the second TLS event reported as CG strokes occurred near the initiation point for this flash, and the remaining subsequent strokes occurred near the first stroke. Given the long horizontal propagation of the initial downward leader, and falling-prey to speculation, the very bright LIS group that was simultaneous with the first stroke could have been due to the leader reaching the edge of the cloud before going to ground, resulting in both (1) less attenuation of the direct optical signal and (2) reflection of the indirect light off the cloud edge.

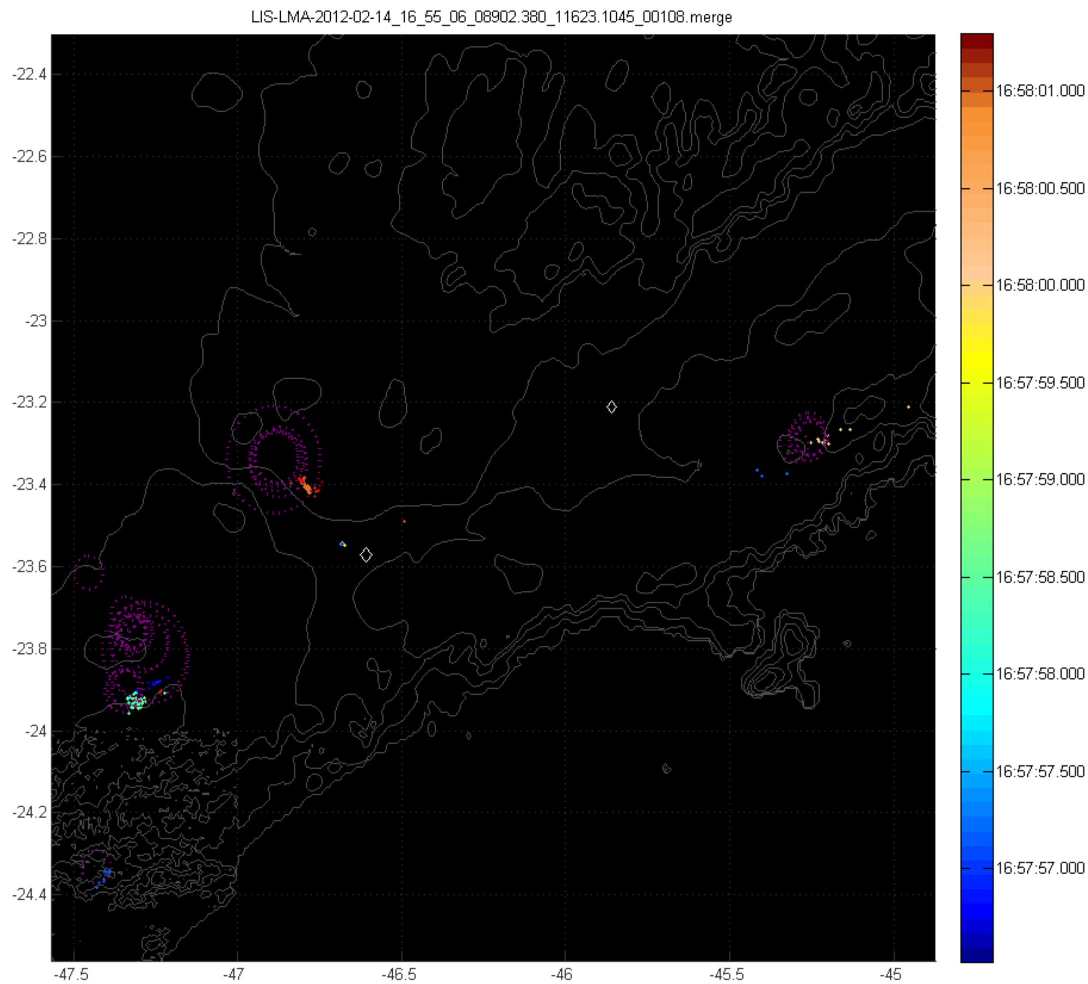

Figure 3. Plan-view representation of 5-flash in a 7-second period shown in Figure 4

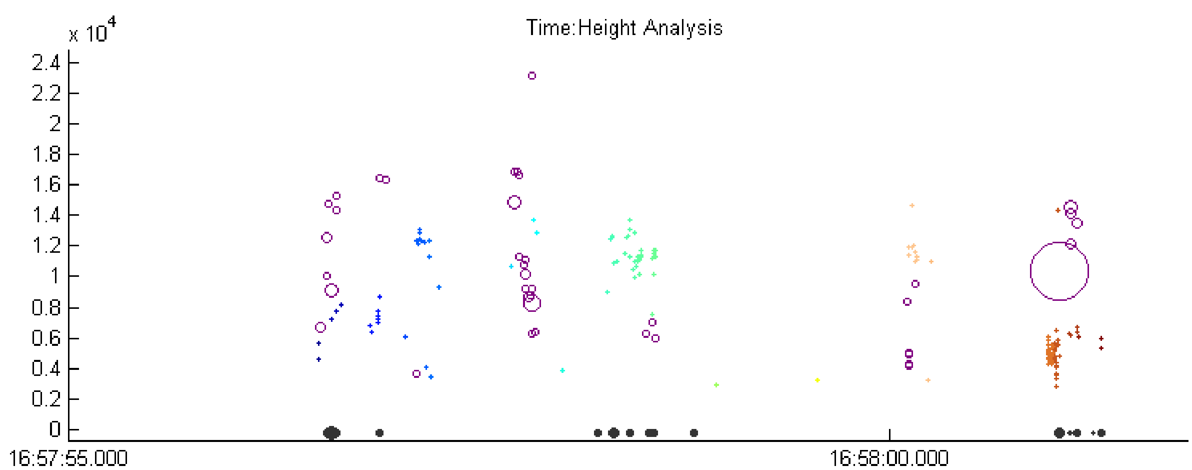

Figure 4. Time:height representation of the 5-flash 7-second period with 3 multi-stroke CG flashes

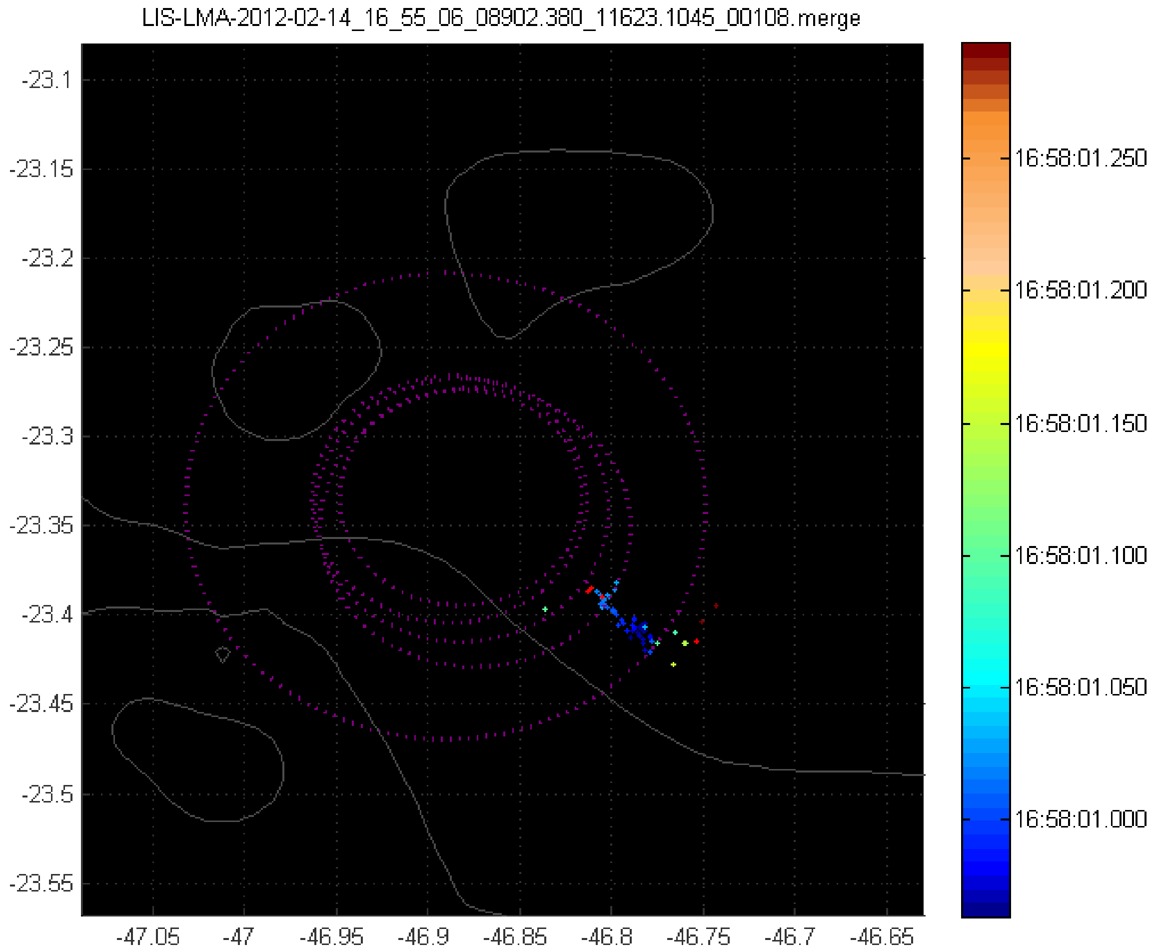

Figure 5. Plan-view representation of a single 6-stroke CG flash shown in Figure 6.

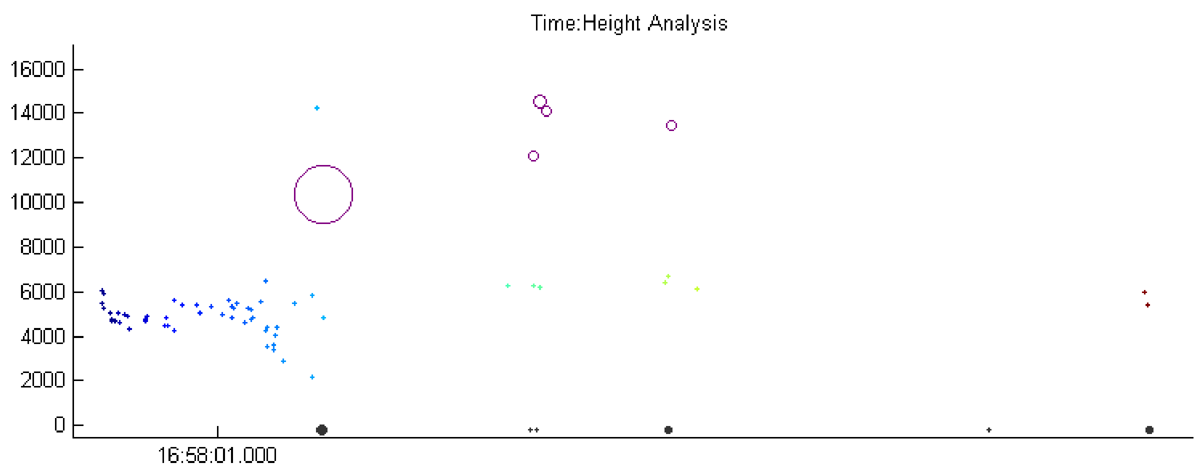

Figure 6. Time:height representation of a single CG flash with 6 return strokes.

The images presented in this abstract show the exploratory tool used to better understand the relationship between LIS observations and the various ground-based datasets. This understanding is being used to develop statistical methods that will quantify the space and time coherence between LIS groups and other lightning datasets. Further results of this analysis, along with direct LLS inter-comparisons, will be shown during the workshop. The long-term objective is to use these results to develop both proxy and validations algorithms that can be used anywhere in the world.