Lightning Lexicon for the JAG/LDS

Lightning flash: is a total lightning discharge, which usually is composed of many distinct luminous events that often occur in such rapid succession the human eye cannot resolve them. The duration of a flash is typically less than 1 second, but can be several seconds. (Note: In theory, a flash consists of all lightning channels that are physically connected together, though older channels in a flash may have dissipated while newer ones are developing. In practice, delineating flashes with data from a particular type of lightning mapping system can sometimes be ambiguous and may depend on the lightning properties the system detects.)

Lightning channel: The tortuous path of luminous hot ionized air through which the electric current of a lightning flash flows. Near ground, lightning channels typically are a few centimeters in diameter, though a broader sheath of radial current may flow toward or away from the channel. (Note: The processes by which the insulating properties of air break down ionize the air and heat it.)

Flash duration: is normally considered to be the period during which electric current flows through at least some channels in a flash. Once a current no longer flows through it, a channel quickly cools and loses its luminosity and ionization.

Cloud-to-ground lightning: is lightning having a channel spanning from a cloud to the earth. A cloud-to-ground flash can also be called a ground flash.

Negative cloud-to-ground lightning: is cloud-to-ground lightning that lowers negative charge to the ground. A negative cloud-to-ground flash is sometimes called a negative ground flash.

Positive cloud-to-ground lightning: is cloud-to-ground lightning that lowers positive charge to ground. A positive cloud-to-ground flash is sometimes called a positive ground flash.

Cloud flash: is any lightning flash that does not strike ground. In the scientific literature, this is often called an intracloud flash, which, strictly defined, is a flash that stays within a single cloud. Other types of cloud flash include a cloud-to-cloud flash and a cloud-to-air flash. (Note: Determining the subcategory of a cloud flash requires knowledge of cloud boundaries, which no lightning mapping system can provide. Therefore, I suggest that we do not deal with the subcategories of cloud flashes in our requirements and specifications. In terms of impact on assets and personnel, what I think we care most about is where lightning is, not whether it is inside or outside clouds.)

Ground strike point: is the point at which a cloud-to-ground flash strikes ground.

Initiation point or region: is the point or region at which a lightning flash begins. Initiation occurs when the build up of regions of net charge in a storm creates electric forces (typically between the charges) larger than the threshold at which the insulating

properties of air break down. The flash then propagates bi-directionally, one end propagating toward and into positive charge, the other propagating toward and into positive charge. The currents flowing in the lightning channel redistribute charge in the storm to make the electric force smaller than the breakdown threshold. Locating lightning initiation is possible only with systems that map lightning channels that are inside clouds. There is uncertainty in all attempts to determine where a lightning flash originates, because one is never sure whether the mapping system one uses can map a flash's initial leaders. However, most systems that map lightning within clouds can estimate at least the region in which a flash originated.

Leader: the faintly luminous channel which seeks out a path of least resistance into the surrounding air or between a channel and a nearby object during the growth of a lightning channel. Typical leader progression speeds are 10^5 – 10^7 m/s. The channel subsequently becomes bright when a return stroke or another type of current surge travels through it.

Stepped leader: is the initial downward leader of a cloud-to-ground lightning flash. It advances intermittently in steps at intervals of approximately 50-100 microseconds. The length of a channel step typically is 50 m to a few hundred meters. An average propagation speed, including the pauses between steps, is typically 5 x 10^5 m/s. It is possible that stepped leaders also occur in cloud flashes, but they have been identified by images on film or video, which have been available almost exclusively beneath clouds.

Dart or continuous leader: is a leader of a cloud-to-ground flash that propagates smoothly toward ground some period after a return stroke. If too long an interval has occurred, the conductivity of the lower part of the channel can decrease too much to support a dart leader over the remainder of the distance to ground, and further progress to ground occurs by stepped leaders, usually deviating from the previous stroke's path to ground. A leader that has a transition to a stepped leader mode is sometimes called a dart-stepped leader. A dart leader's brightest luminosity is at its tip, which propagates at roughly 10^7 m/s.

Return stroke: refers to part of a cloud-to-ground flash. It is the intense luminosity and electric current pulse that propagates upward from the earth into the cloud after a stepped leader or dart leader connects with earth or with an upward spark from the earth. Typical return stroke ascent speeds are roughly 1 x 10^8 m/s (roughly 1/3 the speed of light).

Stroke or lightning stroke: refers to a specific part of a cloud-to-ground lightning flash. A single stroke consists of a downward propagating leader (either a stepped leader or a dart leader) plus an upward propagating return stroke. A single cloud-to-ground flash may have multiple strokes. The most frequently occurring number of strokes in a cloud-to-ground flash is one, but the mean number of strokes per flash is three. Using "stroke" to refer to part of a cloud flash is incorrect.

Flash multiplicity: is the number of strokes in a cloud-to-ground flash.

Flash polarity: usually (and for our purposes always) refers to the polarity of charge lowered to ground by a cloud-to-ground return stroke. Usually, all strokes in a flash lower the same polarity of charge to ground, but there are exceptions. A positive cloud-to-ground flash has positive polarity and a negative cloud-to-ground flash has negative polarity.

Peak current: can obviously apply to the maximum of any time-varying current. However, in the context of lightning, it usually refers to the peak current during the return stroke of a cloud-to-ground flash. It typically occurs within a few microseconds (sometimes <1 microsecond) of the onset of the return stroke. The mean value has varied over the years as the number and sensitivity of measurements improved. The mean is now usually given as 15-25 kA. The 99th percentile is roughly 100-200 kA. Peak current can be estimated roughly from the peak electromagnetic signal measured by many lightning mapping systems during a return stroke, but to do this, one must make assumptions about the speed at which the return stroke progresses up the channel.

Continuing current: is the reduced current flowing in a channel to ground for at least a few tens of milliseconds following a return stroke. It can last a few hundred milliseconds, with roughly 100 ms being typical. Current magnitudes vary from a few tens of amperes to more than 200 A, with 100-200 A being typical. Continuing current maintains ionization and visible, but reduced, luminosity in the channel to ground. It may occur in half to somewhat less than half of flashes. Because it takes a few tens of milliseconds to heat vegetative fuels to ignition temperature, it is continuing current that is responsible for igniting naturally occurring forest fires and range fires, not the return stroke, which has a much larger, but much briefer, current.

Flash type: is the category of a flash. For our use of flash type, the categories are cloud flash and cloud-to-ground flash.

Triggered lightning: normally refers to lightning that is initiated by an object which enhanced the local electric field (any reasonably good conductor will enhance any electric field in which it is placed, but tall, narrow conducting objects, such as a tall tower, enhance the electric field at the ground the most). Aircraft and rockets in flight may either intercept or trigger a flash. Most, if not all, cloud-to-ground flashes that begin at the ground are thought to be triggered by tall towers or buildings or other tall objects.

A brief discussion of basic concepts involved in mapping in-cloud lightning structure.

Every system that maps a flash maps some part of it, not the whole flash. Compared with the well-defined channel to ground that ground strike mapping systems are supposed to locate, the structural feature located by systems that map channels in a cloud has less specificity. The usual practice, therefore, has been simply to refer to a particular mapped location as a source or an event of the radiation used to map it, such as an optical event or source, a VHF event or source, or an acoustic event or source. Depending on the technology being used, a system may map only one event per flash, a few events per flash, or many events per flash.

Most national or long-range mapping systems operate in the extremely low frequency to medium frequency part of the electromagnetic radiation spectrum. In this band, the strongest radiator is the return stroke of the long channel to ground. Some cloud flash processes also radiate in this band, but the signal magnitude of cloud flash radiation tends to be much smaller than that of the return stroke. Therefore, these systems tend to map the ground strike point, though they also map one to a few events for some cloud flashes. The more sensitive the radio receiver in the system, the more cloud-flash events can be mapped, but the fraction mapped decreases rapidly with distance.

With the sensitivities and station spacings used by the US National networks, I would estimate that they map at least one event of only 10-30% of cloud flashes overall, though there may be small favored regions in which a larger percentage is detected. If one increases the sensitivity of the system to make this kind of cloud-flash detection possible, then it also increases the difficulty in avoiding flash type errors (i.e., in determining reliably which detections are from cloud flashes and which are from ground flashes). Various criteria can be applied to the signal wave forms to do this, but the adequacy of these criteria needs to be demonstrated with independent ground truth data sets. Simply saying one uses waveform criteria says nothing about how well the criteria are able to discriminate flash type.

The presently available systems capable of mapping the in-cloud, three-dimensional structure of flashes tend to operate in the very high frequency (VHF) part of the spectrum. In the VHF band, the signal magnitude of radiation from the shorter channel segments inside the cloud is comparable to that of radiation from the channel to ground. Not all channels inside a cloud are equally likely to be detected, however. Channels that propagate toward or into positive charge tend to produce much larger signals than those that propagate toward or into negative charge, so for each flash, most mapped points usually are for channels that propagated toward or within positive charge. Modern versions of VHF mapping systems are capable of mapping up to thousands of points per flash in real time.

Optical systems such as the satellite mapper locate the light that escapes a cloud. This light has been scattered by cloud particles, so one does not see the channel itself, but sees the region of the cloud illuminated by a flash. For satellite systems, channels in the lower part of the cloud are more difficult to see at cloud top than those in upper regions of the cloud, but some lightning processes such as return strokes tend to be brighter than other processes and so are more likely to be visible.

Note: Almost all studies relating lightning rate changes to storm evolution or severe weather have used flash rates, not stroke or event rates. At least initially, therefore, applications needing to infer storm characteristics or evolution from mapped lightning events or strokes will need to group the events or strokes into flashes.

Terminology and thoughts concerning lightning mapping system specifications:

Geographical coverage: is the region in which data are needed. Indicate first the zone in which the coverage is needed and then whether the whole zone or some part of the zone is needed. Subsets of the zone can be given as range from specified points, states, or latitude and longitude boundaries.

Phenomena: is the specific type of lightning or the specific lightning process for which you need data. If you need all lightning to be detected and do not need flash type discrimination, indicate total lightning. If you need all lightning, but need the flash type (cloud-to-ground flashes and cloud flashes) to be identified, please enter each type on a separate line that lists the specifications applying to mapping that type of flash. If you need cloud-to-ground stroke data instead of or in addition to cloud-to-ground flash data, please list cloud-to-ground stroke on its own line.

Horizontal resolution: is the spatial resolution your application requires. This applies to pixilated data, not to point data, and so would apply mainly to an imaging sensor such as the geosynchronous lightning mapper planned for GOES-R.

Location accuracy: is the standard error (normally expressed in meters or kilometers) in the horizontal location at which a lightning mapping system indicates that a lightning channel segment occurred. Depending on what the mapping system is supposed to report, the reported location may be either the ground strike point of a cloud-to-ground flash or the location of any lightning channel segment above ground. The standard error is the standard deviation in the distance of the mapped location from the actual location. Because the error may be greater in some directions about the actual location than in other directions, the standard error is sometimes expressed as an error ellipse. For our specifications, however, we need to specify only the maximum standard deviation which will be acceptable for our applications.

Location precision: is the least significant digit in the reported location. For example, locations could be reported to the nearest kilometer or nearest 10 meters. Because the required precision should be appropriate to the required location accuracy, a separate column for precision was not included.

Vertical extent: applies only to flashes, not to lightning strikes to ground. If you need to locate lightning channels above ground, how high (in kilometers MSL) do you need to detect them?

Vertical accuracy: is the standard error (expressed in meters or kilometers) in the vertical location at which a lightning mapping system indicates that a lightning channel segment occurred.

Reporting frequency: is the maximum time interval between reports to a user. For example, a user might get the mapped lightning data grouped into one-minute packets of

data. If there is no lightning in the region of coverage, a report is still needed at the reporting frequency to indicate no lightning.

Data latency: is the maximum elapsed time from the occurrence of an event until it is reported to the user.

Detection efficiency: is the fraction of flashes detected by a lightning mapping system. It can apply specifically to cloud flashes (cloud flash detection efficiency), to cloud-to-ground strokes (stroke detection efficiency), to cloud-to-ground flashes (cloud-to-ground flash detection efficiency), or to all flashes (total flash detection efficiency or flash detection efficiency).

Probability of false detection: the fraction (given as a percentage) of mapped events that are not actually produced by the indicated lightning process. Thus, cloud flashes identified as cloud-to-ground flashes would be a false detection of cloud-to-ground flashes. One could also have a false detection of cloud flashes, a false detection of flash polarity (the wrong polarity was indicated), or a false detection of flashes (something other than lightning was identified as a lightning flash. False detection of flashes needs to be a very small percentage. For some applications, false detection of polarity or of flash type may be of no concern, but for others, they may be critical. If correct identification of polarity is of concern to you, please specify the probability of false detection for both cloud-to-ground flashes or strokes (depending on what you specified on this line under phenomena) and for polarity.

Reliability: is the fraction of time in which the data provided by the contract meet the specified operational standards. This should be fairly close to 100%, though some periods for maintenance and repair should be allowed. We probably also would want a specification of how long the vendor has to correct a problem with the network and perhaps another specification of how long to correct a problem with communication of data to the government points of contact.

Timing accuracy: is the standard error in the reported time at which a mapped lightning process occurred. For example, one might require the reported time of a ground strike to be accurate to within a second or to within a millisecond. The accuracy a user needs will depend on the application. To associate a particular mapped lightning process with other events or other lightning data, millisecond accuracy is needed.

Timing precision: is the least significant digit in the reported time. The needed precision will depend on the application, but millisecond precision should be adequate for most, if not all, government applications of lightning mapping data.

Polarity: is the polarity of charge lowered toward ground in a vertical lightning channel during the mapped flash. For most applications, this will apply only to the return stroke of a cloud-to-ground stroke or to the first return stroke of a flash or to the return stroke with the largest peak current in a flash. A positive cloud-to-ground stroke lowers positive charge to ground and a negative cloud-to-ground stroke lowers negative charge to

ground. Use this column only on a spreadsheet line for cloud-to-ground strokes or cloud-to-ground flashes, and indicate whether you need to know the polarity (yes or no). If knowing the polarity is important for your application, please also indicate a probability of false detection for polarity in the false detection column.

Peak current: under this column, indicate whether you want an estimate of the peak current of each cloud-to-ground flash or return stroke. This parameter does not apply to cloud flashes, as there is not yet a good way to estimate the peak current of a cloud flash..

Peak current accuracy: is the standard error in the reported peak current of a return stroke. This parameter, along with multiplicity, does not apply to cloud flashes. Note that peak current is not measured directly, but is estimated from the received signal by a theoretical model which uses some typical values of lightning return stroke parameters that will not be measured (it would take high speed, stereo video recordings of every return stroke to measure one of the required parameters). Thus, errors in peak current estimates will be relatively large by necessity, and the accuracy will be almost impossible to verify, except in a few cases of lightning triggered to instrumented towers.

Flash multiplicity: is the number of strokes in a cloud-to-ground flash. Under this column, please enter "yes," if you want an estimate of the number of strokes in a flash, or "no," if you do not need an estimate of the number of strokes. It would be difficult to specify a level of performance for multiplicity, because many subsequent strokes produce very weak signals and accurate multiplicity also is affected by how accurately strokes are grouped into flashes. If detecting as many strokes as possible is important for your application, I suggest that you include specifications for strokes, instead of or in addition to specifications for cloud-to-ground flashes. Keep in mind that stroke detection efficiency is generally lower than flash detection efficiency. For systems such as the NLDN or USPLN, stroke detection efficiency is very sensitive to the spacing between stations, and a high stroke detection efficiency will require closely spaced stations (which are more expensive).

Archive: is the permanent archive of the lightning data collected by the vendor under the contract. Under this column indicate whether you need archive data (yes or no), whether you want to be able to maintain your own copy of the archive or are willing to rely on the vendor's archive, and what level of archive data you need (e.g., products made by the user from the vendor's data essentially in real time, products made by the vendor, or the time and location and other parameters for each mapped point.)

Parameters needed in the archive: is self explanatory. What parameters will you need in the archive: mapped lightning location, time, measures of error, peak current, multiplicity, polarity, etc. or just images of mapped locations or something else?

For ground-based systems, location accuracy and detection efficiency in a given region of coverage are a function of the number and arrangement of the stations providing the coverage. If one or more stations are missing temporarily, it may degrade network

performance below the specified standards. One would like to know when network performance has been degraded.