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Lightning for Climate (DRAFT)

A Study by the Task Team on Lightning Observation
For Climate Applications (TT-LOCA)
Of the Atmospheric Observation Panel for Climate (AOPC)

TTLOCA

GCOS–XXX

Chair, Publications Board

World Meteorological Organization (WMO)

7 bis, avenue de la Paix Tel.: +41 (0) 22 730 84 03

P.O. Box 2300 Fax: +41 (0) 22 730 80 40

CH-1211 Geneva 2, Switzerland E-mail: Publications@wmo.int

Figure on front page: The road to lightning. Location: Batesville, Texas, USA; photographer: Marko Korosec; credits: World Meteorological Organization.

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1 Introduction

In recent years, measurements of lightning have become more extensive and new satellite instruments have further enhanced measurement coverage. Lightning can be used as a proxy for monitoring severe convection and precipitation, improving estimates of severe storm development, evolution and intensity, and hence provide early warnings for severe weather phenomena. In addition, lightning itself impacts the global climate by producing nitrogen oxides (NOX), a strong greenhouse gas. In regard to climate monitoring, lightning is thought to be a valuable indicator to track and understand trends and extremes in convective events under climate change.

Due to this relevance and potential as climatological variable, lightning has been added to the list of Essential Climate Variables (ECV) in the 2016 GCOS Implementation Plan (IP) (GCOS, 2016), including a first attempt to define the requirements for climate monitoring of lightning measurements. Action 29 of the IP called for defining "the requirement for lightning measurements, including data exchange, for climate monitoring and to encourage space agencies and operators of ground-based systems to strive for global coverage and reprocessing of existing datasets".

In order to follow up on this action, the Atmospheric Observation Panel for Climate (AOPC) agreed during AOPC-22 (Exeter, UK, March 2017, (GCOS, 2017)) on the creation of a dedicated task-team on lightning observations for climate applications (TTLOCA). This task team continues the work related to lightning observations of the Task Team on the Use of Remote Sensing Data for Climate Monitoring of the Commission for Climatology (CCL) as a joint GCOS/CCL task team.

This study summarizes the work done by TTLOCA and covers key aspects of lightning observations for climate applications. It explains the relevance of lightning observations for climate, describes the current status of observations, discusses gaps and open research questions and provides suggestions for monitoring requirements for lightning, including metadata requirements. Recommendations are summarized in the beginning of the document with the intention that these recommendations will be considered for the respective WMO regulations.

In addition, a glossary is added in order to standardize the terminology. The report concludes with recommendations on how to observe lightning and manage data so it can be used for climate monitoring and science.

2 Summary of Recommendations

2.1 Observations

Better accessibility to lightning data and metadata would enable distinctly more applications for lightning observations in a climate context. Therefore we suggest that lightning shall be observed by WMO members for climate applications as explained in section 8.1. The lightning surface observations and also potential satellite observations shall be shared.

Since there is currently no global data repository available for lightning data, we suggest to further explore, if an archive including satellite and in situ data for lightning would be feasible and provide benefits compared to the current system.

2.2 Data Archival

Since lightning data are currently used mainly for nowcasting and warning (see section 3.4), data management policies often do not include the climate perspective. A survey showed that some data providers do even not include permanent data storage for lightning data in their data policies or important metadata are not available (see section 6.1). This hinders current and will hinder future efforts to create climate-relevant time series. Therefore we encourage all data providers to review their data policy in regard to lightning and include permanent data archival.

2.3 Non-governmental Lightning Data

Some of the longest-running lightning data sets, with the highest space and time resolution belong to private organizations or companies. In order to make these data available for climate applications it is important that privacy and intellectual property concerns of these organizations are considered. The survey shows that most of these organisations are generally willing to share their data under certain conditions. This might include a time lag of, for example a month, since the monetary value of the data will be diminished. Other conditions might include a limitation to non-commercial usage of the data or only for research.

We suggest that these considerations should be included in the current discussion of WMO with all private networks to arrive at an agreeable solution which neither adversely impacts the private organizations, nor leaves these relevant lightning data completely out for climate monitoring and science purposes.

2.4 Metadata

General recommendations in regard of metadata are listed in section 9.1 and 9.2. For lightning, one main purpose of the lightning data is absolute lightning detection efficiency at all points covered by the data, and with sufficient time resolution to capture the frequent changes in network configurations. Since absolute detection efficiency is not possible, metadata must include sufficient information to develop the needed detection efficiency variations of a network in order to inter-compare lightning climatology in space and time among different networks and techniques. In view of the fact that private companies are the main data holders and potentially not willing to share station details, this can also be provided by a relative detection efficiency for each pixel at each time (see section 9.1). We recommend to consider this special characteristic of ground-based lightning data in the context of the renewal of the WIGOS Metadata Standard.

2.5 Thunder Day Observations

Operational monitoring of lightning started only late in the 20th century and thus the diagnostic value of lightning time series in regard to thunderstorm activity as a response to long-term climate change is still limited. Thunder day observations, however, have been underway in a systematic fashion since the 19th century and can potentially provide insights into long-term trends. Therefore TTLOCA started an initiative to locate thunder day observations worldwide toward supplementing records of thunder days in existing digital data archives, such as the NOAA Global Surface Summary of the Day (GSOD, ftp://ftp.ncdc.noaa.gov/pub/data/gsod) and the NOAA Global Historical Climatology Network - Daily dataset (GHCNd, ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/daily/). Once the task team has collected all relevant information, we hope that the existing data can be made available. Therefore we encourage WMO members to support efforts to collect thunder day data to supplement the mentioned data archives.

2.6 The Global Circuit

We propose using the GCOS Reference Upper-Air Network (GRUAN) sites for regular ionospheric potential measurements using small E-field sensors attached to regular radiosonde balloons. Only a few

GRUAN sites would be needed to estimate the global atmospheric electrical activity (on a daily basis) and to monitor these changes into the future. This will allow for continuously monitoring of changes in the Earth's global electric circuit which is directly related to thunderstorm and lightning activity (see section 7). The balloon soundings measure the electrical parameters in the free atmosphere, outside the boundary layer, which often hampers other surface electrical measurements. However, a sounding of ionospheric potential involves measurements both in the free atmosphere and in the boundary layer. GRUAN has already agreed to participate in an experiment as proof-of-concept and a more detailed concept for this experiment, including funding, is being developed. We encourage GCOS to further support this initiative in order to promote the new ECV lightning.

2.7 Schumann Resonances

Monitoring extremely low frequency (ELF) electromagnetic radiation at multiple stations seems to be an efficient method for continuous monitoring of global lightning in absolute units, with far fewer stations than are required for very low frequency (VLF) analysis. Therefore the Atmospheric Panel for Climate Observations (AOPC) of GCOS accepted Schumann Resonances as an emerging product for the Essential Climate Variable (ECV) lightning (see section 6.5). In order to become to be established as regular ECV product, we suggest AOPC to review the continuity of data and evaluate the performance of the measurements.

3 Relevance of Lightning Data for Climate Applications

3.1 Casualties and Injuries

Thunderstorms are spectacular weather phenomena and for millennia humanity has been fascinated with the accompanying lightning – one of the most powerful forces in nature. Lightning hazards are well recognised and protection measures are in place to reduce the risk; however, loss of life and damage to infrastructure caused by lightning are still significant.

A number of comprehensive reports present country statistics of lightning-related registered death including reports from Australia (650 fatalities in 1824 - 1991 (Coates et al., 1993)), Canada (999 fatalities in 1921 – 2003 (Mills et al., 2008)), China (5,033 fatalities in 1997 – 2009 (Zhang et al., 2011)), India (5,259 fatalities in 1979-2011 (Singh and Singh, 2015)), USA (20,758 fatalities in 1900 – 1991 (Lopez et al., 1998)), and other countries (Holle, 2016). Global assumptions are highly uncertain and (Cooper and Holle, 2019) estimate after an extensive review of national data more than 24,000 fatalities per year.

In regard of injuries and people suffering from long-lasting neurological disorders, the numbers are even bigger by an order of magnitude. For developed countries a ratio of 10:1 for injuries per death is assumed (Cherington et al., 1999). For developing countries, it is assumed that the number is even higher (Cooper and Holle, 2019).

3.2 Loss and Damage

Assessments of lightning-related impacts and costs demonstrate substantial economic losses for various sectors (Yair, 2018). Estimates of lightning-related damage and disruption costs for Canada including health, property, forestry and electricity indicate annual loss totalling between $0.6 and 1 billion (Mills et al., 2010). For the USA, it is estimated that lightning causes about US$5-6 billion in annual losses due to forest and residential fires, and property damage (Kithil, 2003). Based on a 17-year statistics (2001-2017), more than 10,143 lightning-caused wildland fires are reported and more than 4.2 million acres are burned across the USA annually (National Interagency Fire Center, 2018).

In general, thunderstorm-related losses are large and often cause as much annual property loss in the USA as hurricanes, e.g. US$47 billion in 2011 (Sander et al., 2013). Insurance-related claims arising from thunderstorms (wind, hail and flash flood damage) in Australia from 1967 to 1999 amount to about AU$5 billion (Insurance Council of Australia, 2000). The Sydney hailstorm of 14 April 1999 inflicted over AU$ 1.7 billion of insurance losses (2015 estimated loss value of AU$4.3 billion) (Insurance Council of Australia, 2018) and topped the list of insurance catastrophes of all time in Australia. The storm caused more losses than tropical cyclone Tracy, which destroyed 70% of houses in Darwin in 1974 and the Newcastle earthquake, which damaged 50,000 buildings in the city in 1989.

Significant casualties from lightning strikes and significant thunderstorm-related losses clearly demonstrate that further advancement of thunderstorm and lightning early warning systems is required to reduce risk and improve protection of life and property.

3.3 Lightning as Proxy for Convective Activity and Storms

Lightning is an indicator of developing convective clouds that have matured into thunderstorms. Convective initiation is typically first indicated by radar when reflectivity indicating developing precipitation aloft exceeds 35 dBZ and by lightning when the first lightning discharge occurs. The first lightning produced by a storm is usually an intracloud (IC) discharge occurring 5-10 min on average before the first ground strike, although the first lightning discharge can be a cloud-to-ground (CG) discharge. The sum of IC and CG lightning is referred to as total lightning. As storm updrafts strengthen and the storms continue to develop vertically, the total lightning frequency (dominated by the IC lightning) will also increase (Gatlin and Goodman, 2010; Zipser and Lutz, 1994). Sometimes the cloud turrets will penetrate the tropopause where the overshooting cloud turrets can be detected in satellite imagery (Bedka et al., 2010). For damaging severe storms producing hail and strong surface winds, lightning rates may approach hundreds of flashes per minute. A rapid increase in lightning frequency, referred to as a lightning jump (Schultz et al., 2011, 2009; Williams et al., 1999), often signals the storm intensification before the severe weather is observed at the ground.

3.4 Current and Potential Use of Lightning Data for Climate Applications

There are numerous uses for lightning data by forecasters, commercial enterprises, researchers and the public. These uses can be grouped into (a) Nowcasting and warning, (b) Forensics, (c) Risk assessment, and (d) Research. Warning/nowcasting and forensic use of lightning data are only indirectly linked to climate whereas risk assessment and research are directly climate-related.

(a) Nowcasting and warning are only indirectly linked to climate due to the difference of timescales. Currently the large majority of lightning observations are used for this category of services and is also covered by the private sector.. Since the number and intensity of thunderstorms might increase under climate change, these observations become more relevant in the context of adaptation (see section 3.5). They typically include:

Severe storm detection and warning

Convective (flash flood) rainfall estimation

Storm tracking

Convective aviation hazard

Lightning safety

Warnings to power companies, fuel depots, outdoor activities

Forest fire forecasting

Predicting cyclone intensification

(b) Lightning data are forensically used for example by insurance companies to investigate whether a fire was initiated by lightning or if lightning caused damage to infrastructure.

(c) Risk assessments by national institutions and the private sector are mainly conducted in order to understand risks for lightning damage, and are based on observations. The lightning climatologies for risk assessment are based on long time series and are used to plan infrastructure like power grids and air traffic.

(d) Research about lightning and connectivity depends on lightning observations. The scope of this research is very broad. Particularly relevant for climate is research on trends in lightning activity as a proxy for storms (see section 3.3). Other important research questions related to climate are explained in detail in section 5. Lightning research also includes the following topics:

Climate variability and change

Understanding the physics of the global electric circuit

Understanding the magnetosphere and ionosphere

Studies of NO_x generation

Aerosol effects

Studies of whistler and other wave propagation phenomena

Transient luminous events

Terrestrial gamma-ray flashes.

A survey (see section 6.1) initiated by the task team about lightning observation networks showed that private and national networks currently focus mainly on (a), warning and nowcasting. Still 50% of the networks in the survey responded that their data are used in addition for climate applications and mainly for research (c) and lightning climatologies (d).

3.5 Integration and Improvement of Nowcasting and Forecasting for Early Warning Systems and Adaptation

In conjunction with radar and satellite, the lightning data provide additional insight into the existence and intensity of convective activity that is beneficial in forecasting, nowcasting, and warning decision-making. Lightning parameters of interest include the location, time, intensity, polarity, duration, and areal extent. The lightning data are visualized as individual points or as accumulated grids in space (over several km) and time (several minutes) to match the update rate of radar or satellite imagery. For example, newly available lightning data from operational weather satellites (running five minute moving average trends) are superimposed in the forecaster workstation on top of radar and satellite (visible and infrared) imagery loops, or NWP model fields (Goodman et al., 2012; Gravelle et al., 2016). The integrated display of lightning data enhances forecaster situational awareness and adds confidence in their decision-making.

3.6 Lightning as a Driver of Climate Change

Lightning discharges are a major source of nitrogen oxide gases called NO_x (Koshak, 2014; Lapierre et al., 2018; Price et al., 1997; Schumann and Huntrieser, 2007). The two primary gases (NO and NO_2) are formed during the lightning discharge when the air is heated to 30,000 degrees inside the lightning channel. Since air is made up of approximately 80% N_2 and 20% O_2, these molecules breakup into nitrogen and oxygen atoms. When the channel expands outwards and cools, new compounds form as a result of the nitrogen and oxygen atoms recombining. The amount of NO_x gases formed is related to the rate of cooling of the channel. There is a debate among scientists working in this field as to the relative efficiency of different types of lightning flashes (IC versus CG) to produce NO_x. Besides the hot lightning channel, it is also likely that NOx is produced outside the channel, within the region of high electric fields surrounding the channel (Cooray et al., 2009).

These NO_x gases react with other gases in the atmosphere resulting in the formation of ozone (O_3). Ozone in the lower atmosphere where we live, and where the lightning occurs is toxic to humans and plants, but it absorbs heat from the earth's surface, acting as a greenhouse gas, contributing to the warming of the atmosphere. There is convincing evidence that tropospheric ozone is increasing in concentration over time. Lightning is not the only source of NO_x in the atmosphere. In fact, there are many sources of NO_x, with the anthropogenic burning of fossil fuels being the main contributor to NO_x concentrations in the atmosphere. However, lightning is the largest natural source (~5-1- Tg N/yr), and perhaps the largest source overall in the upper parts of the troposphere where changes in ozone concentrations are very important in the study of future climate change (Grewe, 2004).

4 Thunder Days

Thunder days are defined as days with thunder heard and are a proxy for lightning activity. This activity has been shown to be responsive to two recognized climate variables: surface air temperature and boundary layer aerosol. Evidence for the responsiveness of lightning to temperature has been demonstrated on several natural time scales: the diurnal (Bailey et al., 2007; Blakeslee et al., 2014; Markson, 2007, 2003; Markson and Price, 1999; Price, 1993; Virts et al., 2013; Williams, 1999), the semiannual time scale (Füllekrug and Fraser-Smith, 1996; Williams, 1994), the annual time scale (Adlerman and Williams, 1996; Blakeslee et al., 2014; Christian et al., 2003; Williams, 1994) and the ENSO (El Nino Southern Oscillation) time scale (Chronis et al., 2008; Goodman et al., 2000; Hamid et al., 2001; Sátori et al., 2009b; Williams, 1992; Yoshida et al., 2007). Model calculations also suggest greater lightning in a warmer climate (Romps et al., 2014). In contrast to the large body of evidence for increasing lightning activity under global warming, a recent study projected a decrease of lightning due to a decrease of cloud ice content (Finney et al., 2018). In addition, the evidence for lightning response on the 11-year solar cycle time scale is conflicting (Brooks, 1934; Christian et al., 2003; Fischer and Mühleisen, 1972; Kleymenova, 1967; Pinto Neto et al., 2013) and deserves further attention. An increasing body of evidence has shown that convective vigour and lightning activity are also enhanced by richer concentrations of cloud condensation nuclei (Altaratz et al., 2017; Bell et al., 2009; Fan et al., 2018; Mansell and Ziegler, 2013; Rosenfeld et al., 2008; Stolz et al., 2017, 2015; Thornton et al., 2017).

4.1 Brief History of Thunder Days

The "thunder day" was defined as a standard meteorological unit by the International Meteorological Committee in Vienna in 1873, and was further characterized with a symbol 'T' in Paris in 1896. Measurements of the Earth' electric field over the oceans (Mauchly, 1923) and the emergence of a global signal in universal time, led to C.T.R. Wilson's (1921) hypothesis for the global electrical circuit, maintained by the integrated contribution of electrified weather worldwide. This development motivated Brooks (1925) in turn to make the first assessment of the global thunderstorm activity. A large dataset of 3265 surface stations with thunder day observations became the basis for the cornerstone of atmospheric electricity (Whipple, 1929; Whipple and Scrase, 1936). The recognized value of thunder days to mainstream meteorology led the WMO to assemble data from 3840 stations from 190 countries to produce a global monthly climatology (WMO, 1953, Part I), including global maps (Part II).

A second key WMO contribution toward an organized multi-station time series of thunder day data was facilitated by their collaboration with the United States Air Force in 1972 on the GSOD (Global Surface Observation of the Day) dataset (NOAA, n.d.); This compilation had new applicability to climate studies as it extends the global thunderstorm record back many decades before any lightning network observations are available.

Figure 1 shows the evolution of archived station data in GSOD over the full period of the dataset. In recent years, the number of stations reporting is greater than the station counts used to compute the global mean temperature (e.g. Hansen and Lebedeff, 1987). Evidently GSOD focused on archival going forward from the time of its inception, but little effort was devoted to collecting the station archives on thunder days from the period prior to 1972. Some enhancement of station collection occurred in the decade of the 1953 WMO report, but earlier data are scarce, and no data are in hand prior to 1929, when the existence of archived thunder day data are well documented. We have abundant evidence however that these data (Brooks, 1925) exist in the meteorological archives of individual countries.

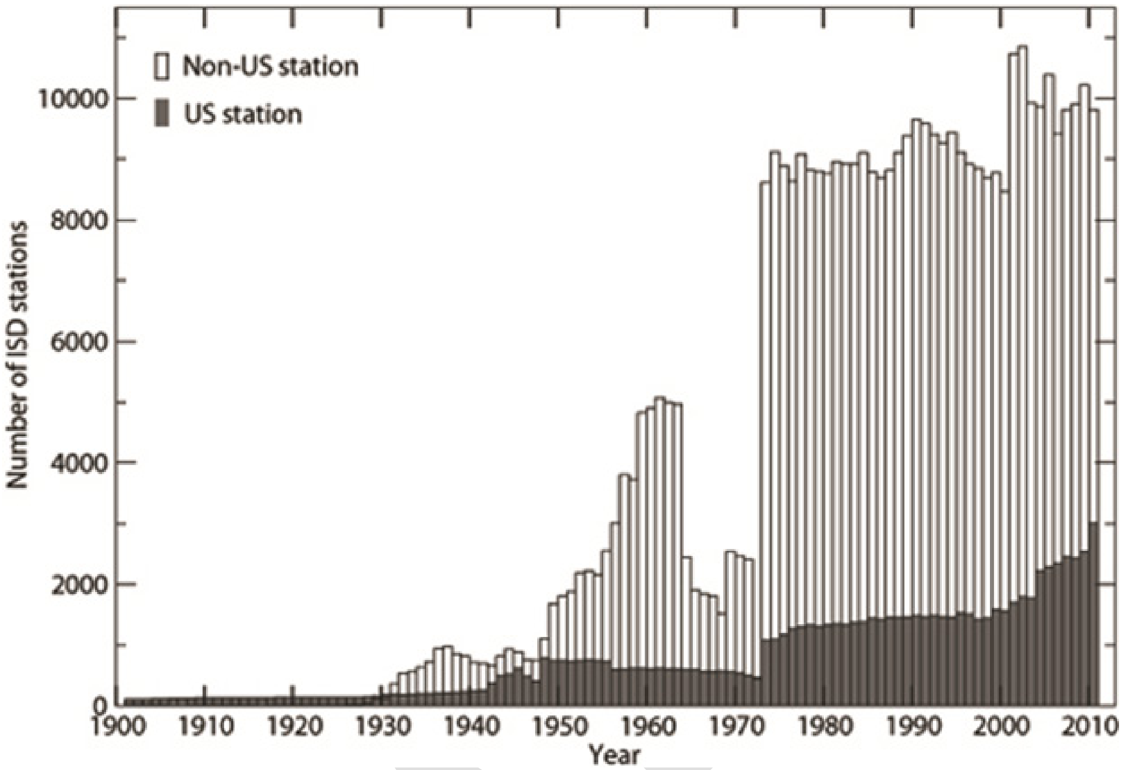

Figure 1 Number of reporting stations versus time for thunder days in the GSOD data set, established in 1972.

Beginning in the late 1990s, automatic weather stations came into widespread use, with a consequent reduction in the number of human observers in national weather services. This situation has led to a reduction in the number of stations reporting thunder days, though all airport stations worldwide continue the original practice.

4.2 Comparisons of Modern Satellite Observations of Global Lightning Activity and Thunder Day data

The continuous observation of global lightning activity is a desirable goal from the climate perspective (Williams, 2005) but has not yet been achieved. The optical observations of lightning from Low Earth Orbit are sufficient however to document the climatological variation of global lightning on the diurnal and seasonal time scales for which systematic global temperature variations are also present (Williams, 1994). The reliability of thunder days as a proxy for worldwide lightning activity can be judged in part by its behaviour on natural time scales. The evidence for agreement on the diurnal time scale comes from the classical work on the global electrical circuit by Brooks (1925), Whipple (1929) and Whipple and Scrase (1936), in comparison with the modern satellite observations of Bailey et al. (2007) and Blakeslee et al. (2014). Comparisons on the seasonal time scale consist of calculations with the gridded WMO (1953) climatology (Williams, 1994) and comparisons with satellite optical observations Christian et al. (2003). The semiannual variation is clearly present in both climatologies, when the near equatorial zone is examined. For the annual variation, the tendency for greater thunder day activity in NH summer is apparent, but the summertime maximum (August) is not evident in the thunder day climatology (Williams, 1994). A possible explanation is that the number of flashes per thunder day in summer is greater in the baroclinic regions at higher latitude than in the quasi-barotropic region of the near equatorial region. This suggestion can be checked with satellite or by ground based global lightning data.

4.3 Scientific Use of Thunder Day Observations

Thunder day observations have been used extensively for the investigation of regional trends, for example in Australia (Davis and Walsh, 2008; Kuleshov et al., 2002), Brazil (Sales, 2014), in the Baltic countries (Enno et al., 2014), in Ontario, Canada (Huryn et al., 2016), in China (Chen et al., 2004; Wei et al., 2011), in Finland (Tuomi and Mäkelä, 2008), in Germany (Kunz et al., 2009), in Iran (Araghi et al., 2016; Ghavidel et al., 2017; Khalesi, 2014) in Nigeria (Ologunorisa and Chinago, 2004), in Poland (Bielec-Bąkowska, 2003; Bielec-Bakowska and Lupikasza, 2009), in Russia (Adzhiev and Adzhieva, 2009; Gorbatenko and Dulzon, 2001), in Alaska (Williams, 2009) and in the continental United States (Changnon, 1985; Changnon and Changnon, 2001; Changnon and Hsu, 1984; Koshak et al., 2015). Correlated trends between thunder days and surface air temperature provide evidence for urban warming (Pinto Jr., 2009; Pinto Neto et al., 2013), as well as possible aerosol effects.

ENSO variations in thunder day records, possibly linked with variations in both temperature and aerosol, have been considered by Pinto et al. (2015) in Brazil and by Kulkarni et al. (2015) in India. Brooks (1934), Kleymenova (1967), Fischer and Mühleisen (1972); and Pinto et al. (2013) have all searched for the 11-year solar cycle in thunder day records of exceptional length, with varying success. Long-term increases in thunder days at stations on the Sea of Japan (Yamamoto et al., 2016) have been shown to accompany long-term increases in sea surface temperature there. Previously published thunder day observations in the USA by Changnon and Hsu (1984) and Changnon (1985) and by Gorbatenko and Dulzon (2001)) overlap with the “big hiatus” in global warming in the period 1940 to 1976, and show flat or declining behaviour, consistent with the behaviour of global temperature (Williams et al., 2016).

The global temperature has been shown to vary by 0.1 °C (peak-to-peak) on the 11-year solar cycle time scale (Camp and Tung, 2007; Tung and Camp, 2008; Zhou and Tung, 2013), substantially smaller than the temperature variations on the other natural time scales discussed previously (all on the order of 1 °C). All these latter studies have clear implications for climate change and global warming. The nature of scientific investigations involving thunder days can expand to global scale once a sufficiently long record at stations as numerous as those used for climatological studies (Brooks, 1925; WMO, 1953) assembled from presently separate archives. This action also speaks to the need raised by Holzworth and Volland (1986) for a global geoelectric index, but for decades gone by. A resolution in such an archive at monthly time scale would fulfil many needs for climate studies (ENSO, 11-year solar cycle time scale, global warming), but a continuation of the practice in the GSOD dataset with daily/hourly resolution is certainly desirable.

5 Open Research Questions

5.1 Drier Climate

There appears to be an apparent paradox when looking at regional time-averaged lightning and precipitation relationships. It is well known for many years that lightning and rainfall are positively correlated in individual storms, and that generally thunderstorms with more lightning will likely produce more rainfall. However, the opposite relationship appears to occur on larger spatial and temporal scales. Observational and modelling evidence shows that in some cases regional lightning activity actually increases as those regions become hotter and drier at the surface (Price, 2009). The tropical continental centers of lightning activity rank in the opposite order when considering lightning and precipitation. While Africa is thought to have the highest lightning activity of the three chimney regions, it may also have the lowest rainfall (Williams, 2005).

5.2 El Niño–Southern Oscillation

When we look at the impact of the ENSO cycle on tropical lightning and rainfall, a similar negative relationship is observed, with drought-stricken Southeast Asia during the El Nino years having more lightning than during the wetter La Nina periods (Hamid et al., 2001; Yoshida et al., 2007). This result is in contrast to the increase in wintertime lightning and severe storms observed in the southeast US attributed to enhanced cyclogenesis and a stronger jet stream (Goodman et al., 2000). Since the rainfall over these islands of the Maritime Continent is mostly due to convective precipitation, the only way to produce more lightning with less precipitation is to produce more intense convective activity in each thunderstorm. This could occur if we had fewer thunderstorms, with each thunderstorm more vigorous, producing more lightning.

5.3 Model Parameterizations

In order to simulate lightning activity in climate models (GCMs) it is necessary to develop lightning parameterizations, since these models cannot resolve the clouds-scale processes that generate lightning. A few parameterizations have been developed (Lopez, 2016; Price and Rind, 1992; Tost et al., 2007). Numerous climate model simulations have suggested that lightning activity will increase in a warmer climate (Grenfell et al., 2003; Price and Rind, 1994; Shindell et al., 2006). Although the parameterizations of lightning in global climate models are quite crude, the models nevertheless manage to capture some aspects of global lightning climatologies (Shindell et al., 2006). Most of these modelling studies indicate an approximate 10% increase in lightning activity globally for every 1 K global warming, with most of the increase occurring in the tropics. A recent paper however claims that tropical lightning may decrease in a warmer climate (Finney et al., 2018).

5.4 Aerosols

The role of aerosols in thunderstorm electrification is still an open question. It is possible that drier climates will result in more suspended aerosols, dust and cloud condensation nuclei, hence influencing cloud microphysics and cloud electrification (Williams et al., 2002). However, it should be pointed out that many climate model simulations of lightning do not include any aerosol effects, and address only thermodynamic changes in their simulations. Whether aerosol effects would enhance these changes is a topic for future studies.

Altaratz et al. (2010) showed that aerosols can have different impacts on lightning activity depending on the concentrations in the background atmosphere. In clean environments, adding aerosols tends to enhance the lightning activity, while in polluted environments, adding more aerosols tends to diminish lightning activity.

In a recent study by Thornton et al. (2017), it was shown that the three month running mean of lightning density was enhanced by a factor of two or more over ocean shipping lanes using high resolution lightning climatology data from 2005 through 2016. Using PM2.5 aerosol data, the authors showed that the enhanced aerosol from the shipping was directly aligned with the enhanced lightning suggesting an important role in the addition of the aerosol.

6 Observing systems and data

6.1 Survey on networks

In order to learn more about existing data and networks as well as their data policy, the task team conducted an online survey (see questions and summary of answers in Annex 1). Invitations to the survey were sent to all national, private sector and scientific lightning detection networks known to the members of the task team and for which contacts were available. Their survey was sent in May 2018 to 36 networks/lightning data providers and we received 24 answers up until it closed in June 2018. Three of 12 contacted space networks responded and 21 of 26 in situ networks.

The survey consisted of ten questions about the network and its data and two additional questions about the reference of the data set. Please note that the summary below is only based on the received answers and other important networks and the answers might not reflect the global picture of lightning observations.

Question 1 asked whether it is an in-situ or satellite observing system.

Question 2 asked how lightning is measured by the respective network.

Most networks (58%) use VLF or LF (38%) frequencies.

Question 3 asked if the data would be archived and if yes, for how long.

21 of the networks store their data permanently, three for a limited time and one does not store it at all. This is discussed in more detail in section 9.3 on data holding and management.

Question 4 asked about the earliest available data.

As shown in Figure 2, in-situ data are available from 1987 onwards and is increasing steadily to present. The first uninterrupted global data set within the survey responses starts in 2004 which indicates the need for proxy data dating back longer in time in order to understand climatic trends in global lightning occurrence (see section 4 on thunder days). Near-global (with varying latitudinal coverage extent) space-based observations began in 1995 and also continue today.

Question 5 asked about the geographic coverage of the networks.

Of the addressed networks, four are global, 10 regional and nine national. Of the four global datasets, two are community based (The World Wide Lightning Location Network (WWLN) and Blitzortung.org) and two are commercial (the Global Lightning Dataset (GLD360), operated by Vaisala and the Earth Networks Total Lightning Network (ENTLN), operated by Earth Networks). This is further discussed in section 10 on the role of the private sector.

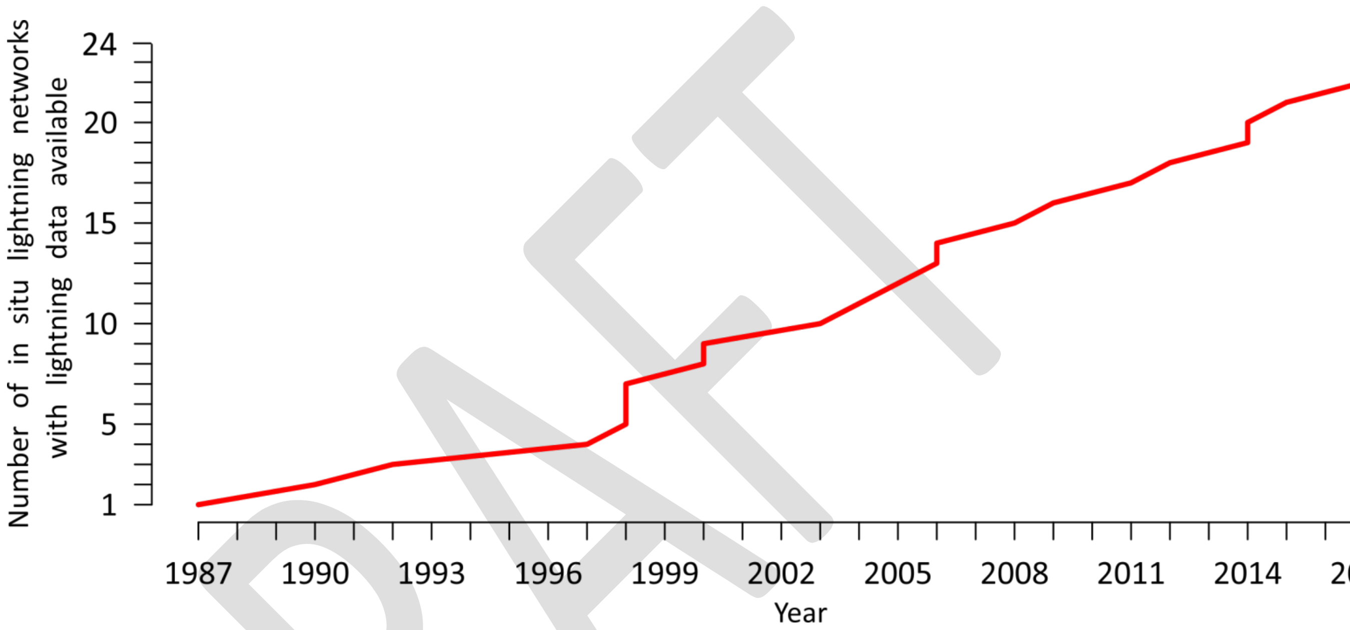

Figure 2 Number of in situ lightning networks with lightning with year of earliest available data.

Question 6 asked what information is stored by the networks.

All networks provide information about the location and the timing of the lightning and most also include the intensity (78%). 52% provide information about whether its IC or CG lightning.

Question 7 asked about availability of metadata.

74% have at least some information and 26% do not provide metadata.

Question 8 asked about the kind of metadata available.

Of the networks with metadata, 90% store the location of the station and 77% the type of the sensor and more detailed information like the processing algorithm or station/sensor operations are stored by fewer networks. This is further discussed in section 9.3 about data holding and management.

Question 9 asked if the data are used for climate applications or if products for climate applications are offered.

50% of the networks state that there data are or have been used for climate applications. The main two applications are lightning climatologies used to calculate risks and climate research. This is further discussed in section 3.4 of lightning data for climate applications.

Question 10 asked, whether the network/institution would potentially be willing to share lightning data for climate purposes.

87.5% of the polled networks are potentially willing to share data and 21% even without a time lag. Asked for specific conditions under which they would share data, mainly time lag and a restriction to research and non-commercial usage was mentioned. This is further discussed in section 10 on the role of the private sector.

Question 11 and 12 were questions about the references and contact information of the networks.

6.2 Complementary Observations by Satellite and Ground-Based Networks

For ground-based lightning networks operating at various radio frequencies from Very Low Frequency (VLF) to Very High Frequency (VHF), variations in ground conductivity, topography, ambient noise, and receiver spacing can all affect the resolution, accuracy and temporal stability of the received signal. The lower frequency networks are best at the detection and discrimination of the CG lightning component with high spatial accuracy, while the VHF ground-based networks excel at mapping the detailed geometry of the lightning channels in the cloud with nearly 100% flash detection efficiency within the boundaries of the network (typically out to a range of 150 km).

The optical satellite-based lightning mappers excel at detecting the total lightning over large areas with near uniform detection efficiency, as well as the horizontal extent or area of the flash, sometimes extending tens to hundreds of kilometres, but the received pixel-based optical signal is of lower spatial resolution than typical regional ground-based networks. Further, the optical signal can be attenuated by a long intervening optical path through very thick clouds, obscured by sun glint, and the performance impacted by energetic particles in the space environment. Ground processing algorithms have been developed to filter erroneous or false lightning events and, as the GLM is a new instrument, will be improved over time. The satellite instruments are also not able to uniquely identify IC vs CG lightning or current polarity on an individual flash basis. The IC or CG characteristics are difficult to identify owing to the extensive channels of CG flashes in the cloud that also produce numerous optical pulses observable at cloud top. Therefore, the satellite and ground-based systems complement each other in fully describing the attributes of a lightning discharge.

Key performance attributes of both the ground-based and space-based lightning detection and mapping systems that are important to users are the Detection Efficiency (DE), Stability, Consistency, and Accuracy (Nag et al., 2015). Attributes of accuracy include the Location (of the ground strike or cloud pulse), initiation and termination of the discharge, its Propagation and Areal extent, Amplitude, Peak current or radiance (optical), Energy, Polarity (positive or negative charge), Multiplicity (number of return strokes), Flash Rate (frequency and tendency/rate of change), and Lightning type (IC or CG). No one type of system is best at measuring all the lightning attributes and therefore efforts are ongoing to determine how best to merge the satellite with the ground-based data.

No lightning location system detects lightning at all points in space and time. Ground bases systems such as LMA (Lightning Mapping Arrays) have been shown to be efficient at locating nearly all the tiny sparks in a stroke with high spatial (horizontally and vertically) and temporal fidelity, but only over a small region (few hundred km at most). Ground based RF networks can cover the world with a relatively few sensors, although with lower and variable detection efficiency, and lower spatial resolution than LMAs.

On the other hand, low altitude orbiting (LEO) satellite based optical systems for locating lightning can approach the LMA detection efficiency for high-altitude cloud strokes, over a small instantaneous areas (with lower spatial accuracy), and they do cover much of the globe (as limited by their orbits and viewing area) but generally cannot detect temporal variations of lightning over the lifetime of thunderstorms due to the LEO satellite orbital motion. Recently high resolution geostationary satellite optical lightning detection capability which approaches the level of absolute detection efficiency for the viewing area have been launched, but they cannot determine stroke altitude, type or polarity nor can they see the whole world (note: lightning occurs regularly north of 55 degrees latitude in the summer over Alaska, Canada, Europe and Asia). Furthermore, both LEO and Geostationary lightning imagers have the intrinsic limitation of only seeing light that comes out of the tops of the clouds, and cannot determine altitude of the light emission. This means neither space-based, nor ground-based lightning location systems so far deployed can see all the lightning, which climate modellers might need.

For the purposes of this study, we suggest that space-based and ground-based lightning location systems are complementary. Climate modellers using, say, NOAA GOES-16/17 GLM lightning data, who want to study climate variations leading to, for example Tropical Cyclone formation, may well benefit from the ground-based lightning data on west African storm development, which is out of the field of view of the GLM instrument. Alternatively, space-based optical lightning data can help calibrate ground-based RF lightning location detection efficiency. Similarly, satellite based systems can use LMA lightning data or total lightning detection using RF sensors to calibrate both detection efficiency as well as spatial fidelity of the satellite measurements.

6.3 Observations from Space

Lightning observations from space date back to the earliest days of research satellites as well as the manned space program when astronauts reported on the spectacular light show as seen from their perspective high above the clouds at night (Goodman and Christian, 1993). The current generation of research and operational lightning instruments in space all use the same or similar approach of spatial, temporal, and spectral filtering for detecting the lightning optical emissions throughout day and night with 5-10 km storm scale resolution and a detection efficiency for total lightning of 70-80% within the viewing area (Goodman et al., 2013; Rudlosky et al., 2018) .

The Optical Transient Detector (1995-2000, Cecil et al., 2014) and Lightning Imaging Sensor (1997-2015, Albrecht et al., 2016) developed by NASA for Mission to Planet Earth as components of the Earth Observing System provide the longest record of space-based lightning observations from low earth orbit. Based on the success of the OTD and LIS, there is now a LIS copy on the International Space Station (ISS-LIS, launched February, 2017) for an expected 2-4-year mission. NOAA operates a Geostationary Lightning Mapper (GLM) on the GOES-R series of Geostationary Operational Environmental Satellites. The first two in the block of four new satellites are in orbit as GOES-16 (launched November, 2016 and operational as the GOES-East satellite at 75.2 W since December, 2017) and GOES-17 (launched March, 2018 and is will replace the aging GOES-15 satellite in January at 137.2 W). The GOES-R series constellation satellite and instruments will be the primary operational lightning mappers for the western hemisphere through 2036. The

Chinese Meteorological Agency launched its new Feng-Yun (FY-4a) second generation geostationary satellite in December, 2016 with a prototype Geostationary Lightning Mapping Imager (LMI) of a similar design and product concept to the LIS and GLM. The FY-4c satellite will also carry an advanced LMI instrument with a much larger area of Asia coverage. EUMETSAT plans four operational Meteosat Third Generation geostationary earth-orbiting satellite Lightning Imagers (MTG-LI) covering nearly the whole of Europe and Africa with the planned launch of the first MTG-I imaging satellite in 2021 made operational in 2022. Other national space agencies in Asia such as the Japanese Meteorological Agency (JMA) are considering possible lightning mappers on their future geostationary satellites.

Various ground-based lightning networks (primarily RF) and the ISS-LIS (optical) provide the primary means for independent performance validation of the new space-based geostationary lightning instruments. Limited-duration airborne science experiments with optical lightning instruments also supported the in-orbit GLM performance assessment. As per the recommendation of the WMO Integrated Global Observing System (WIGOS) and Coordinating Group on Meteorological Satellites (CGMS) Baseline, extensive use of reference instruments and well-characterized calibration sites will be used for performance assessments and long-term trending, cross-validation, and inter-calibration of the various satellite instruments to produce a high-quality climate data set.

6.4 Ground-Based Observations

The workhorse of lightning sensing as used for meteorology and climate studies have been the ground based RF systems. These systems have been around the longest and have the broadest coverage of any lightning sensing system, and therefore are highly useful to be included in any lightning climatology study. Ground based radio frequency (RF) systems detect the electromagnetic radiation pulses from electric currents in lightning processes. LMAs use cross-correlated waveforms at VHF (50-200 MHz) frequencies collected by approximately 10 to 20 stations to locate small-scale current pulses associated with rapid charge movements inside clouds.

These data can be used to follow the leader process of a stroke as it develops. Many large regional networks operate in the Low Frequency (LF)/Middle Frequency (MF)/High Frequency (HF) region of the radio spectrum (0.1 – 20 MHz say) and can cover a continental area with hundreds of stations. These systems typically operate at RF frequencies up to 10s of MHz and locate lightning using multiple electric field time of arrival (TOA) correlations, or use fewer stations with crossed magnetic loops to find the bearing direction and time of arrival for location, and then determine polarity using a vertical electric antenna. LF/Mf/HF systems detect the ground wave from lightning and are generally limited to location of lightning within a few hundred kilometres, beyond which point the sky wave and ground wave overlap complicating the waveform, and making cross correlation difficult. These LF systems therefore have great spatial coverage over well-instrumented continents, but do not reach off shore or across some national boundaries more than a few hundred kilometres (where there are no sensors).

Moving down in frequency to the VLF range (3-30 kHz) it is possible to cover the globe with far fewer stations. This is because the peak energy in RF radiation from lightning cloud to ground-strokes is in the frequency range around 10-15 kHz. These waves travel around the world in the Earth ionosphere wave-guide at nearly the speed of light, and with moderate attenuation. Therefore sensors detect lightning sferics (also known as discrete lightning strokes) out to about 6,000 km in the daytime and nearly 20,000 km at night. These VLF networks do not identify the small-scale strokes in a cloud, and are inefficient at locating in-cloud strokes, and are less efficient at locating weak cloud-to -ground strokes. It is difficult at best for VLF-based RF lightning locating systems to determine polarity or altitude of distant strokes. This difficulty is largely due to the multi-modal nature of VLF waveguide modes.

All of these RF lightning location systems have the intrinsic capability of high, absolute UTC time accuracy (sub-microsecond) and spatial accuracy (down to about 4 km on average) over the globe. These time and space accuracies are better than any demonstrated for any satellite system.

Regional climate studies may benefit greatly from limited regional lightning networks, using either direction finding or time or arrival techniques, for the case of detailed, local climate change studies. Eventually, after sufficient data sets has been collected, data from the geostationary mappers will be useful for studying lightning climatology. On the other hand, global climate modelling may benefit the most from use of the long-range RF network data, using detection efficiency tested with satellite lightning data.

For more information see for instance: Rudlosky, personal communication, 201:5 https://lightning.umd.edu/documents/Basic_Lightning_Detection_Description_V2.pdf.

6.5 Extreme Low Frequency (ELF): Schumann Resonances

At Extreme Low Frequency (ELF) (3 to 1600 Hz) and Very Low Frequencies (VLF) frequencies (1600 Hz to 20 kHz), the electromagnetic radiation from lightning flashes is contained within the Earth-ionosphere cavity—a global waveguide and natural framework for monitoring worldwide lightning activity for climate purposes. However only at ELF frequencies is the attenuation sufficiently small to allow for global reach from a single receiving station. The strong contrast in attenuation between ELF (~0.1 dB/Mm) and VLF (~1 to 10 dB/Mm) dictates the need for entirely different detection methods for ordinary lightning flashes at VLF and ELF. For example, at VLF large numbers of receivers are needed for high global detection efficiency of discrete lightning strokes (e.g., Virts et al., 2013), otherwise known as 'sferics'. For global VLF networks such as WWLLN and GLD360, the strongest strokes originate in CG lightning flashes, though some IC lightning close to receivers are also detected. In contrast, at ELF the attenuation is sufficiently small to enable resonance effects within the global waveguide and the phenomenon known as Schumann resonances. The fundamental resonance mode near 8 Hz involves an electromagnetic wavelength equal to the circumference of the Earth (40 Mm). In this lower ELF frequency range (3-40 Hz) the individual waveforms from lightning strokes overlap in time to form the "background" signal. For a nominal global stroke rate of 100 per second, the mean interstroke interval is 10 ms. This time is small in comparison with the circum-propagation time (~130 ms) for any given stroke, guaranteeing the overlapping of waveforms. This overlapping process prevents the identification of the individual strokes from ordinary convective scale lightning that dominates the worldwide activity.

A notable exception to the common waveform overlap at ELF occurs in the case of exceptional mesoscale (in contrast with convective scale) lightning flashes which can singlehandedly ring the Schumann resonances to intensity levels 10-20 dB greater than the level of the background signal. These exceptional Q-burst events (Ogawa et al., 1967) also produce Transient Luminous Events (TLEs) – haloes, sprites and elves—in the mesosphere, and in so doing modify the global waveguide to some extent. These special events stand out so conspicuously above the background that they can be mapped worldwide from single receiving stations (Greenberg and Price, 2004; Guha-Sapir et al., 2017; Hobara et al., 2006; Huang et al., 1999; Kemp, 1971; Kemp and Jones, 1971; Williams et al., 2010). Multi-station time-of-arrival methods have also been implemented for the geolocation of exceptional flashes (Yamashita et al., 2011). Given that these events lie in the tail of the global energy distribution for lightning flashes, one has come to expectations for a volatile response to global climate change. A preliminary look at this suggestion (Williams, 2005) did not show substantial differences in Q-burst counts between the warm phase (El Nino) and cold phase (La Nina) of the strongest interannual climate variability however.

The overlapping of the individual stroke waveforms for the far more abundant convective scale lightning flashes requires a different method to characterize lightning activity than a stroke rate or flash rate. The method now in place (Clayton and Polk, 1976; Dyrda et al., 2014; Heckman et al., 1998; Mushtak and Williams, 2010; Williams and Mareev, 2014) makes use of a vertical charge moment squared per unit time, with units $coul^2km^2/sec$ to characterize regional or continental scale lightning activity. All lightning strokes with vertical components of charge transfer, whether originating in IC or CG flashes, contribute to this source activity. The evidence that the physical mechanism of charge separation in thunderstorms is gravity-driven provides some assurance that all lightning flashes contribute to this ELF lightning activity. Research efforts are now underway to make use of multi-station spectral observations to obtain the chimney-resolved lightning activity in these absolute units. The inversion calculations are needed because the measured intensities depend on the lightning source-receiver separation and multiple source regions are simultaneously active. A possible shortcut to quantifying Schumann resonance background activity is to make ELF measurements from the South Pole in Antarctica. From this special location, the three major continental lightning sources are all roughly equidistant from the receiver (on the scale of the dominant ELF wavelengths), making possible their evaluation with a single-station measurement (Williams et al., 2018).

Climate-related applications of Schumann resonance observations in the background component may be found in Williams (1992), Nickolaenko et al. (1998); Nickolaenko and Hayakawa (2002); Price (2000), Sekiguchi et al. (2006); Satori et al., (2009a, 2009b) and in the Q-burst transient component in Williams (2005).

6.6 Emerging Technologies (nano-satellites and cube-satellites)

While lightning has been observed from space for many decades, in the last few years a revolution has occurred in the space industry called "New Space". This new philosophy in space observations based on non-governmental, non-military industries, and is focused on academic and commercial entities that intend to develop faster, better and cheaper access to space missions. The main tool in New Space is the use of "cubesats" (cube satellites) made of units of 10x10x10cm cubes that can be attached together to build larger satellites. Today there are a few projects to observe lightning and thunderstorms from space using cubesats, and this emerging technology may allow for higher spatial and temporal resolution observations of lightning from low earth orbit (LEO) in the near future (Selva and Krejci, 2012).

7 Global Circuit

The global Earth system between the surface and the ionosphere can be described as a Global Electric Circuit (GEC) (Markson, 2007; Wilson, 1921) with observable atmospheric currents, electric fields, conductivity, potentials and a capacitance.

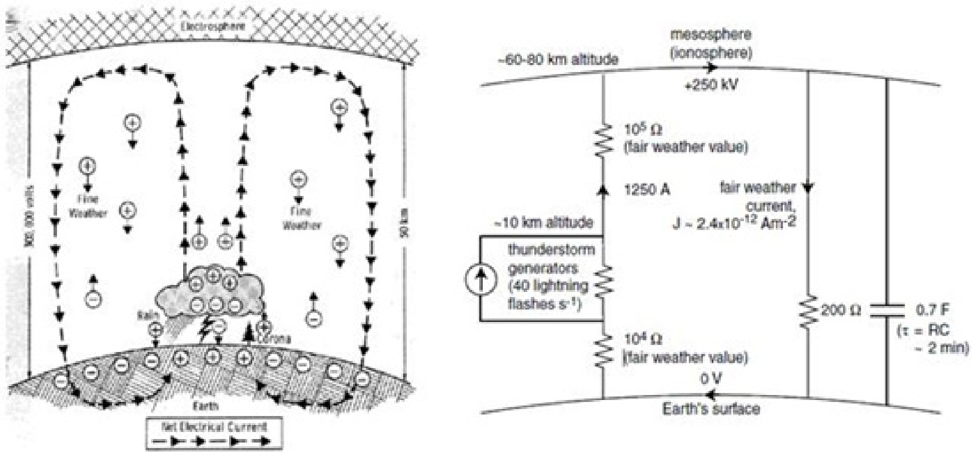

Figure 3 The Global Circuit.

Thunderstorms and electrified shower clouds (~1500 active storms around the planet) drive currents of order 1 Ampere per storm (Mach et al., 2011) upwards to the ionosphere, where the charge is spread around the globe, flowing back to the surface in fair-weather regions. In these regions we continuously measure the conduction currents (~2x10^{-12} Amperes) and vertical electric fields (~130 V/m) produced by worldwide electrified weather (Rycroft et al., 2012). By integrating the E-field with height (using free balloons, tethered balloons or airplanes) we get the Ionospheric Potential of ~250kV. This parameter represents the globally integrated electrical activity in global electrified weather, and hence could provide a global geo-electric index. The validity of the approach with balloon soundings was demonstrated by Mühleisen (1971) in campaign mode, but in the present endeavour we are interested in obtaining measurements over a longer time period.

8 Observation Requirements

To be applicable to current and future climate studies, we recommend these products and related requirements for lightning:

8.1 Total Lightning Stroke Density (gridded)

Data sets at the 1-map-per-month level require limited data storage, and thus should be simply posted on a publically accessible website. The larger data sets reaching down to global resolutions of 0.1 degree with time resolution of a few hours should be maintained by the network managers, and provided to the user community as needed.

Definition: Total number of detected strokes in the corresponding time interval and the space unit. The space unit (grid box) should be equal to the horizontal resolution and the accumulation time to the observing cycle.

Measurement Unit: Dimensionless

Horizontal Resolution:

Levels	Value	Rationale
Threshold	1 x 1 degree pixels	Ideally these data would be provided as both maps as well as digital files, along with the Metadata with adequate time resolution to address both long term and short term detection efficiency variations within these data sets.
Breakthrough	0.25 x 0.25 degree pixels	This is the convection scale and will help identify climate variability at the storm level
Goal	0.1 x 0.1 degree pixels	Thunderstorms are complex, with different dynamics in different parts of the storm, for example the updraft region and the trailing stratosphere region. Therefore the net influence on global currents and climatology is likely to be very different from different sub-storm scales.

Vertical Resolution: N.A.

Temporal Sampling:

Levels	Value	Rationale
Threshold	Monthly (acc.)	Climate Scale
Breakthrough	Daily (acc.)	Weather patterns, weekly and intraseasonal patterns like MJO
Goal	Hourly (acc.)	Lifetime of thunderstorm cell, diurnal cycle. For high resolution climatology, also necessary to validate thunder day data in order to extend time series of lightning activity back in time

Timeliness:

Levels	Value	Rationale
Threshold	Yearly	For lightning climatology studies the provision of yearly data within one year of data collection, and to prepare their data

		back as far as it is available from their network is necessary.
Breakthrough	1 Month	Forecasting and model input
Goal	1 Day	For high resolution climatology. It can be important for special occasions to see direct impacts of events or mitigation immediately in order to react.

Uncertainty:

Levels	**Value**	**Rationale**
Threshold	15 (dimensionless)	For climatologies
Breakthrough		
Goal	1 (dimensionless)	For high resolution climatology, also necessary to validate thunder day data in order to extend time series of lightning activity back in time

Stability:

Levels	**Value**	**Rationale**
Threshold	10% decade	For climatologies
Breakthrough		
Goal	1% decade	For high resolution climatology, also necessary to validate thunder day data in order to extend time series of lightning activity back in time

Standards and References:

- Algorithm Theoretical Basis Document (ATBD) for L2 processing of the MTG Lightning Imager data (Eumetsat, 2014)
- Meteosat Third Generation (MTG) End-User Requirements Document (EURD) (Eumetsat, 2010)
- Nag et al., 2015

8.2 Schumann Resonances (emerging lightning product)

Definition: Extremely Low Frequency (ELF) magnetic and electric field of the three first resonance modes (8 Hz, 14 Hz, 20 Hz).

Measurement Unit: picoTesla2/Hz (magnetic field); volt2/m2/Hz (electric field)

Note: Regular measurements of two horizontal magnetic field components at a location are enough to monitor globally Schumann Resonances. The magnetic field should be monitored at a level of ~0.1 picoTesla2/Hz.

Additionally to the magnetic measurements, one vertical electric measurement would document the full transverse electromagnetic (TEM) waveguide component at any given location. Note the estimate of the electric intensity assumes the wave impedance is half that of free space (377 ohms). In this context, the electric field should be monitored at a level of ~2.3 x 10-9 V2/m2/Hz.). Note also that the electric field should be monitored at 2.3 x 10-9 V2/m2/Hz.

Horizontal Resolution:

N.A.

Vertical Resolution:

N.A.

Temporal Sampling:

Levels	Value	Rationale
Threshold	Monthly	Suitable for investigation of the global seasonal and annual variation, and the interannual ENSO variation
Breakthrough	Daily	Suitable for investigation of intraseasonal variations (5 day wave; MJO)
Goal	Hourly	Suitable for investigation of the strong diurnal variation of tropical "chimney" regions and for use in multi-station inversion methods for global lightning activity

Timeliness:

Levels	Value	Rationale
Threshold	Monthly	For climate-related studies; responsiveness of lightning to long-term temperature changes
Breakthrough		
Goal	Daily	For use in building a representative monthly estimate for climate purposes

Uncertainty:

Levels	Value	Rationale
Threshold	~5 femtoTesla^2/Hz	Absolute coil calibration at the 5% level
Breakthrough		
Goal	~1 femtoTesla^2/Hz	Absolute coil calibration is feasible at the 1% level/ (Calibration of the vertical electric field is difficult, but possible)

Stability:

Levels	Value	Rationale
Threshold	~5 femtoTesla^2/Hz	Coil calibration should be checked and maintained to at least this level
Breakthrough		
Goal	~1 femtoTesla^2/Hz	Given lightning sensitivity to temperature at the 10% per K level, one needs absolute calibration and stability at the 1% level to see fraction of 1K temperature changes

Standards and References:

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9 Data Management

9.1 Metadata for Ground Based Observations

For the lightning location data to be useful to climate studies, it is desirable to know the absolute lightning detection efficiency at all points covered by the data, and with sufficient time resolution to capture the frequent changes in network configurations. Unfortunately, this is not possible (absolute detection efficiency). So therefore, metadata must include sufficient information to develop the needed detection efficiency variations of a network in order to inter-compare lightning climatology in space and time among different networks and techniques.

For lightning climate studies, it is not needed to have access to all individual strokes. Rather (as discussed below) strokes should be accumulated into grids with minimum space and time resolution. For instance, if ground-based systems accumulate strokes into 0.1° x 0.1° grids, with temporal resolution from 10's of minutes up to one month, then the meta data should carry enough information to identify relative detection variations across the entire region, and for the entire time for which those pixels were accumulated. If sensors go off line for significant times, this will affect relative detection efficiency, and should be noted. Location of sensors may be needed in order to determine system performance through time. It is clear that detection efficiency is critical to know, and adjust through an historical data set being used for climate studies. Detection efficiency for RF detection of lightning depends not only on network stations, but also on variable propagation conditions. Day/night changes in the ionosphere can have a dramatic influence on VLF propagation, and therefore on detection efficiency. Also we understand that detection efficiency is not a linear function of the number of stations. Indeed, the NLDN has claimed to locate over 95% of all CG-strokes, so doubling the number of sensors will not double the CG detection efficiency!

We propose that a satisfactory set of metadata for ground-based networks would include:

Spatial grid size and how it may vary over the globe or region of detection, e.g. 0.1° x 0.1° (or ~ 10 x 10 km^2 at equator)

Accumulation time per pixel (say, 10 minutes to one month)

Relative detection efficiency for each grid at each time (or, say, the number of sensors in the network capable of detecting lightning in that grid, at that time). Presumably the detection efficiency varies slowly compared to the changes in strokes per grid, so this detection efficiency metadata information could be accumulated in a separate cross-linked file.

The stroke location information from RF systems would still be useful even without an explicit relative detection efficiency calculation, if the number of station sensors within 'view' of the grid at that time were given. It is not necessary to give exact station coordinates.

For long duration data sets (years and decades) it is very important to identify any and all long-term improvements to a network, both in terms of the number of stations, as well as the detection algorithm improvements so data across the decade can be compared.

Metadata information could usefully include links to published studies about network configuration, and cross correlations with other networks.

9.2 Metadata for Observations from Space

The satellite lightning data archived by NASA and NOAA follow the recommended WIGOS standard template for discovery metadata and description of the observation. The OTD and LIS instrument data as well as the reference validation data are archived and publicly available at the Global Hydrology Resource Center (GHRC), one of the primary NASA Earth Observing System Data and Information System (EOSDIS) Distributed Active Archive Centers (https://lightning.nsstc.nasa.gov). In the near future the GHRC will be moving its lightning data holdings to the cloud. The GOES-R GLM data are archived and publicly available at the Comprehensive Large Array-data Stewardship System (CLASS), NOAA's electronic library of environmental data (http://www.class.noaa.gov). The GLM Level 2 science product and an accompanying ReadMe file containing the validation findings, algorithm updates and refinements, is available at https://www.bou.class.noaa.gov/saa/products/search?datatype_family=GRGLMPROD). Similarly, the CMA has made the LMI data publicly available since March, 2018 at the National Satellite Meteorological Center Fengyun Satellite Data Center (http://satellite.nsmc.org.cn/PortalSite/Data/DataView.aspx?currentculture=en-US&SatelliteType=1&SatelliteCode=FY4A). In Annex 2, metadata for the NOAA GLM and ISS LIS data are exemplary listed in the WIGOS metadata standard form.

9.3 Best practices of data holding and data management

WMO's "Guide to climatological practices" (WMO, 2011) includes relevant information about metadata standards of climatological data that are also relevant for lightning. In general, data management and storage plans should be seen as a critical part of the ultimate value of lightning data to be useful as an ECV. Simply listing all the stroke locations as a function of time, or accumulated stroke densities over a grid as a function of time with no metadata would be insufficient for scientific studies of lightning climatology. For data to be compared within a single data set over time and space, let alone intercomparisons between network data in time and space, it is essential to know the status of the data collection process continuously. We need to be able to show that increases or decreases in stroke density are not caused by network or operational changes resulting in changes in the detection efficiency.

Any climate data set requires verifiable metadata to be useful. This process requires scientists to be as transparent in our reporting as possible. Therefore the guidelines suggested here are aimed at making the lightning data products useful for anyone using the data for research. It will be absolutely critical for independent scientists to intercompare overlapping lightning data sets and identify and diagnose any differences. Simple statements about overall detection efficiency, without the metadata to prove it, will not be useful.

The survey showed that 21 networks store their data permanently, three for a limited time and one does not store it at all. We suggest that in all cases the experimenter should permanently store all the raw data needed to restore the climatology data and related metadata. Therefore it is not absolutely necessary that lightning data for climate is provided as stroke level data. Rather strokes are accumulated as suggested by space and time resolution needed for climate studies, and we recommend that metadata relevant to the time and space scale of the accumulated data should also be stored. All long term multisensory systems are subject to periodic sensor failure, which will affect the relative and absolute detection efficiency of the data set.

We suggest that the raw data mentioned above are likely to contain the time variations of the detection efficiency, so that the network operators can straightforwardly build a reproducible metadata file containing all the information needed to determine how the network was changing over time and space. The raw data files themselves need to be augmented by other more static data such as instrument locations, sensitivity, type, frequency range, noise environment, algorithm assumptions, and any other information needed to validate the variations or stability of the climate data provided by the network.

10 The Role of the Private Sector and Community Based Networks

The task team started the work on lightning observations for climate applications with the clear understanding that some of the longest-running lightning data sets, with the highest space and time resolution belong to private organizations. Therefore, it is important that privacy and intellectual property concerns of these organizations are considered in this process. It is suggested that perhaps by one year after data collection, the commercial, monetary value of the data will be diminished to the point where providing the suggested best-practice data sets will be within the realm of possibility for those organizations.

Indeed a focus of the survey (see section 6.1) was about private sector and community based networks. Regarding global data, the survey identified two community based (The World Wide Lightning Location Network (WWLLN) and Blitzortung.org) and two commercial (Global Lightning Dataset (GLD360), (Vaisala) and Earth Networks Total Lightning Network (ENTLN), Earth Networks) networks participated. Both commercial networks, as well as the community based networks indicated they are generally willing to share the data under certain conditions (non-commercial usage and gridded data).

Publically available lightning climatology maps with 1-month resolution (low end threshold) do not identify the high space and time resolution of the raw location data, and therefore might actually enhance the public desire to go purchase the high resolution data from those organizations. Therefore the authors hope that all privately held lightning climatology data will be made available to the public as their contribution to GCOS Essential Climate Variables (ECV).

GCOS and TTLOCA are interested to discuss these ideas with all private networks to arrive at an agreeable solution which neither adversely impacts the private organizations, nor leaves those data completely out of the ECV available data. This does place a burden on the network providers at some level, since sufficient Metadata, as emphasized above, will need to be supplied so data from different networks can be compared and combined to address climate study needs.

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Glossary

Flash: Partial neutralization process of thundercloud charge that involves many events (leaders, strokes, K-processes, continuing currents, etc.) within a time interval of typically about 1 s; refers to a intracloud flash or a cloud-to-ground flash.

Global electrical circuit: The global atmospheric electrical circuit is the course of continuous movement of atmospheric electricity between the ionosphere and the Earth. Through solar radiation, thunderstorms and electrified shower clouds, and the fair-weather condition, the atmosphere is subject to a continual and substantial electrical current.

Lightning: Transient, high-current (typically tens of kiloamperes) electric discharge in air whose length is typically measured in kilometres.

Lightning channel: A channel of ionized air carrying electrical current between two differing areas of charge. The actual diameter of a lightning channel is 2.5 to 6 cm.

Lightning jump: A rapid increase in lightning flash rate, indicating an intensification of a storm before the severe weather manifestation (hail, wind, tornado) is observed at the ground.

Lightning leaders: Leaders are electrically conductive channels of ionized gas that propagate through, or are otherwise attracted to, regions with a charge opposite of that of the leader tip. The negative end of the bidirectional leader fills a positive charge region inside the cloud while the positive end fills a negative charge region. Leaders often split, forming branches in a tree-like pattern.

Pulse; Intracloud (IC): Lightning discharge that connects regions with opposite polarity (+/-) within one cloud or between multiple clouds.

Return stroke: Lightning process that traverses the previously created leader channel, moving from ground towards the cloud charge source region, and neutralizes the leader charge.

Schumann resonance: A set of spectrum peaks in the extremely low frequency portion of the Earth's electromagnetic field spectrum. They are global electromagnetic resonances, generated and excited by lightning discharges in the cavity formed by the Earth's surface and the ionosphere.

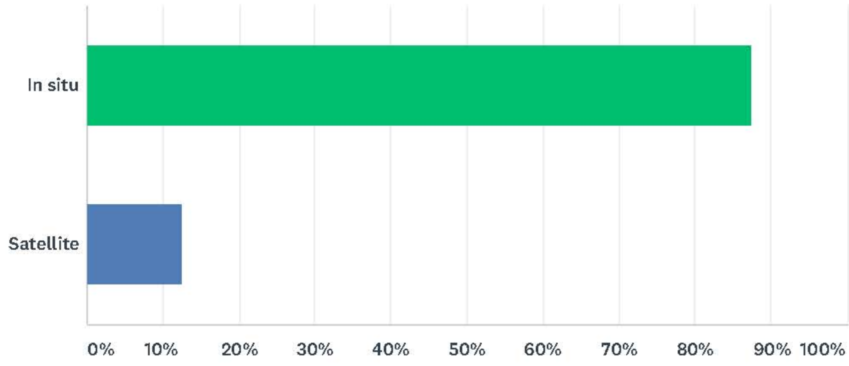
Sferic: Electromagnetic signal from a lightning stroke that travels over long distances.

Sprite: Large-scale electrical discharges that occur high above thunderstorm clouds. They are usually triggered by the discharges of positive lightning between an underlying thundercloud and the ground. Sprites appear as luminous reddish-orange flashes. They usually occur in clusters above the troposphere at an altitude range of 50–90 km.

Stroke; Cloud-to-ground (CG): Lightning discharge that connects a charge region in a cloud with the ground.

Q1 Is your system based on satellite or in situ observations?

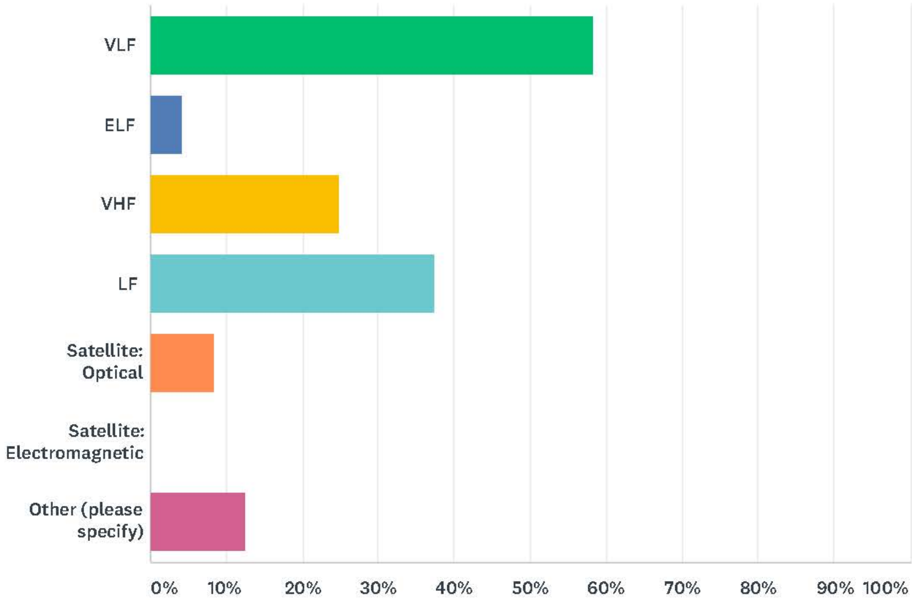
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
In situ	87.50%	21
Satellite	12.50%	3
Total Respondents: 24		

Q2 What is/was the physical parameter used by your institution for lightning location?

Answered: 24 Skipped: 0



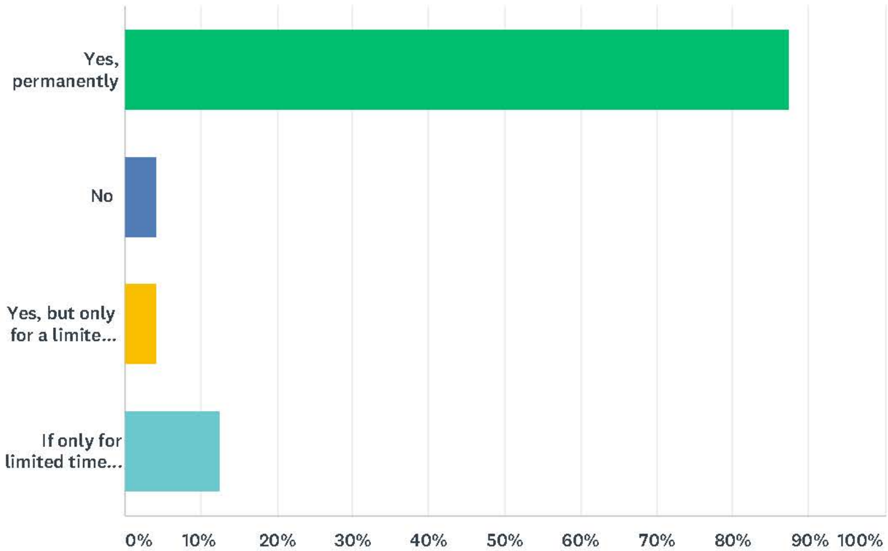
ANSWER CHOICES	RESPONSES	
VLF	58.33%	14
ELF	4.17%	1

VHF	25.00%	6
LF	37.50%	9
Satellite: Optical	8.33%	2
Satellite: Electromagnetic	0.00%	0
Other (please specify)	12.50%	3
Total Respondents: 24		

#	OTHER (PLEASE SPECIFY)	DATE
1	Microwave (UHF)	6/4/2018 11:45 AM
2	optical	5/29/2018 10:57 AM
3	The WeatherZone network sensors utilize a frequency range from 1 Hz to 12 MHz which spans from the ELF to HF bands (the WeatherZone may provide more detailed information if required).	5/21/2018 3:48 AM

Q3 Do you archive your data?

Answered: 24   Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes, permanently	87.50%	21
No	4.17%	1
Yes, but only for a limited time	4.17%	1
If only for limited time, please specify	12.50%	3
Total Respondents: 24		

#	IF ONLY FOR LIMITED TIME, PLEASE SPECIFY	DATE
1	Formally, we hold the last 10 years of data, informally we have data going further back (see Q. 4)	6/14/2018 2:23 PM
2	only for several weeks or months of interest	6/4/2018 11:45 AM
3	10 years	5/29/2018 10:57 AM

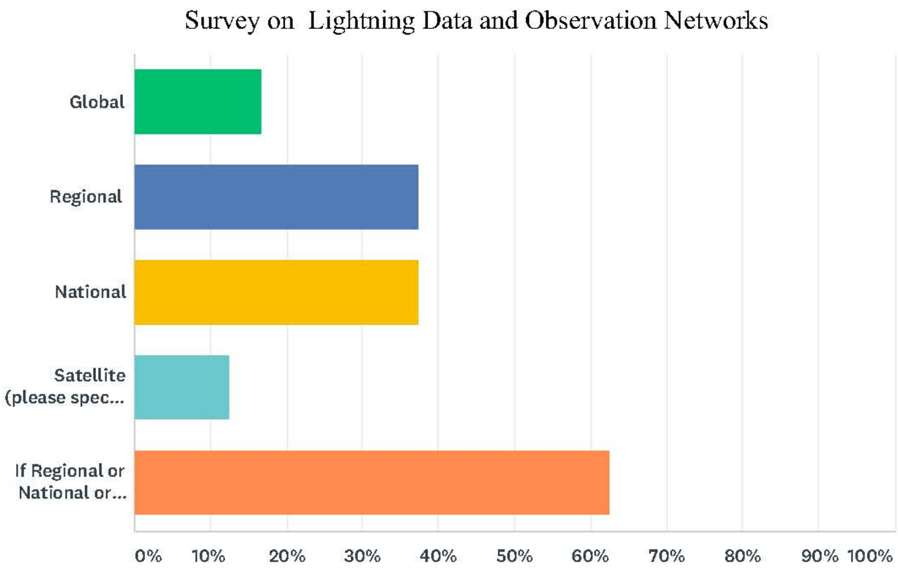
Q4 From which year is the earliest lightning data in your archive?

Answered: 23 Skipped: 1

#	RESPONSES	DATE
1	2003	6/18/2018 1:20 PM
2	Data is available from previous generations of our ATD system, from ~1990, earliest (with gaps) but with lower detection efficiency (DE) and location accuracy than from current system (ATDNET). Better DE and accuracy data from ~Jan 2008 with the advent of latest generation of ATD system, ATDnet.	6/14/2018 2:23 PM
3	2017	6/13/2018 7:38 PM
4	2014	6/6/2018 4:24 AM
5	2018	6/4/2018 6:20 PM
6	1998	6/4/2018 4:43 PM
7	2014	6/4/2018 4:22 PM
8	2009	6/4/2018 1:12 PM
9	2015	6/4/2018 11:45 AM
10	2012	5/31/2018 5:18 PM
11	from 2019	5/31/2018 12:08 PM
12	2006	5/30/2018 10:26 AM
13	May 1997	5/29/2018 5:48 PM
14	April 2018	5/29/2018 10:57 AM
15	2006	5/23/2018 5:14 PM
16	2005	5/22/2018 3:26 PM
17	EUCLID: 2000 ALDIS 1992	5/22/2018 2:19 PM
18	2000	5/21/2018 1:56 PM
19	2008	5/20/2018 12:07 PM
20	2004	5/18/2018 7:12 PM
21	1998	5/18/2018 6:27 PM
22	1998	5/18/2018 5:51 PM
23	1987	5/17/2018 3:07 PM

Q5 What is the coverage of your current systems?

Answered: 24 Skipped: 0

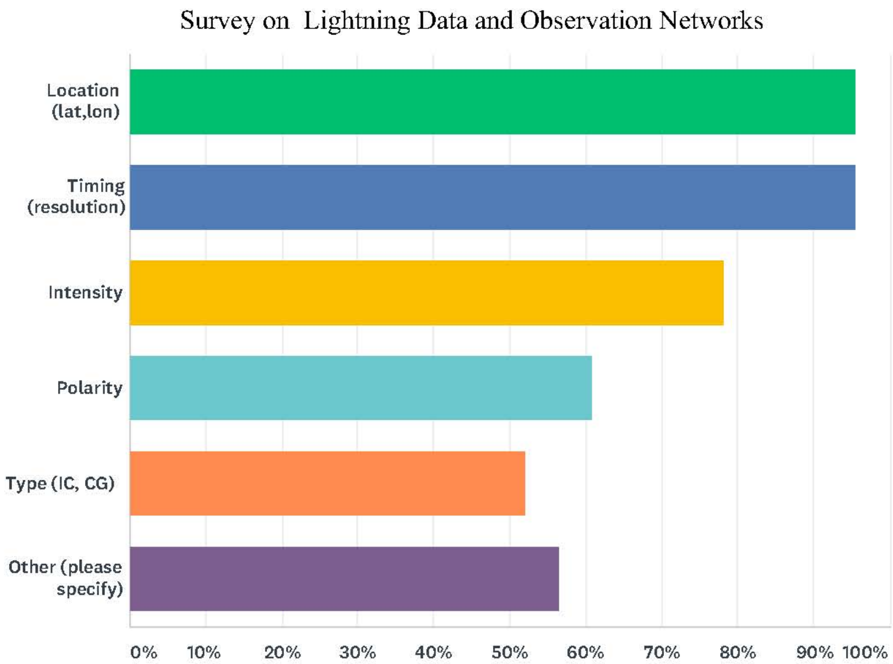


ANSWER CHOICES	RESPONSES	
Global	16.67%	4
Regional	37.50%	9
National	37.50%	9
Satellite (please specify below field of view, orbit and and for non-stationary orbits also revisit time of satellite system)	12.50%	3
If Regional or National or Satellite, please specify	62.50%	15
Total Respondents: 24		

#	IF REGIONAL OR NATIONAL OR SATELLITE, PLEASE SPECIFY	DATE
1	Primary coverage: Europe and N. Atlantic Secondary coverage (with lower detection efficiency and location accuracy): South America and parts of Africa	6/14/2018 2:23 PM
2	Southern Ontario, Canada	6/4/2018 4:22 PM
3	Data is multi-regional to global, with coverage in 90+ countries	6/4/2018 1:12 PM
4	an area less than 200 km from our station in Malacca, Malaysia	6/4/2018 11:45 AM
5	South Africa	5/30/2018 10:26 AM
6	Canada (primarily south of tree line)	5/29/2018 5:48 PM
7	60 deg fov, 400 km alt., 52.6 deg incl. (ISS)	5/29/2018 10:57 AM
8	South america	5/23/2018 5:14 PM
9	Europe, Mediterranean & N. Africa	5/22/2018 3:26 PM
10	Regional: Europe; National: Austria	5/22/2018 2:19 PM
11	Israel	5/21/2018 1:56 PM
12	Austrslia	5/21/2018 3:48 AM
13	Coverage is inhomogeneous.	5/20/2018 12:07 PM
14	Most part of Brazil	5/18/2018 5:51 PM
15	Western Europe	5/17/2018 3:07 PM

Q6 What information do you store?

Answered: 23 Skipped: 1

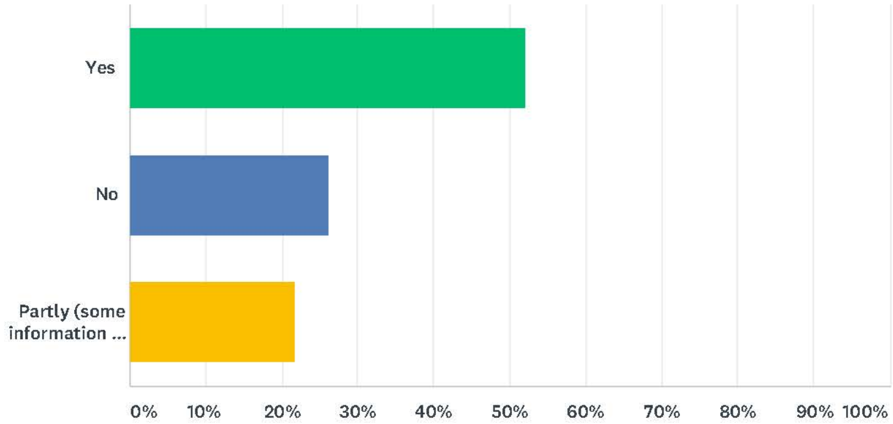


ANSWER CHOICES	RESPONSES	
Location (lat,lon)	95.65%	22
Timing (resolution)	95.65%	22
Intensity	78.26%	18
Polarity	60.87%	14
Type (IC, CG)	52.17%	12
Other (please specify)	56.52%	13
Total Respondents: 23		

#	OTHER (PLEASE SPECIFY)	DATE
1	Calculated location error (in km) of each stroke Indication of the sensor stations contributing to each stroke located	6/14/2018 2:23 PM
2	Prediction	6/4/2018 6:20 PM
3	Can obtain polarity from flash development	6/4/2018 4:43 PM
4	Altitude (3D)	6/4/2018 4:22 PM
5	Waveforms	6/4/2018 1:12 PM
6	Type will be available starting in Aug 2018	5/31/2018 5:18 PM
7	radiance and irradiance (cameras and photometers)	5/31/2018 12:08 PM
8	Semi-major and semi-minor axis of error ellipses, chi-square values, degrees of freedom, number of sensors participated	5/30/2018 10:26 AM
9	Chi-squared value; lengths of semi-major and semi-minor axes of 50% confidence limits; multiplicity (for flash files only). Both stroke and flash files archived.	5/29/2018 5:48 PM
10	spectral bands: 180-240 nm, 337 nm/ bw: 5nm, 777 nm/ bw: 5 mn. 2 cams (337,777) 400 m resolution, 3 photom. 10 microsec resol.	5/29/2018 10:57 AM
11	Flash or Stroke Number of the stroke in a flash Number of sensors detecting	5/22/2018 2:19 PM
12	number of stations participating in each stroke location, standard error for intensity (VLF radiated stroke energy)	5/18/2018 7:12 PM
13	Altitude, i.e. 3D development of individual flashes versus time, with several hundred up to several thousand located events per lightning flash	5/18/2018 6:27 PM

Q7 Have you included metadata inside your archive

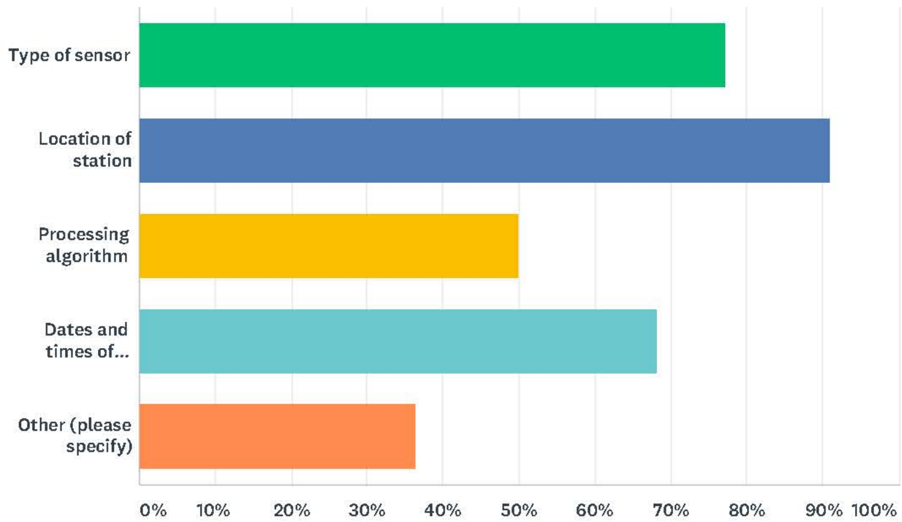
Answered: 23 Skipped: 1



ANSWER CHOICES	RESPONSES	
Yes	52.17%	12
No	26.09%	6
Partly (some information is stored elsewhere)	21.74%	5
TOTAL		23

Q8 What kind of metadata is available

Answered: 22 Skipped: 2



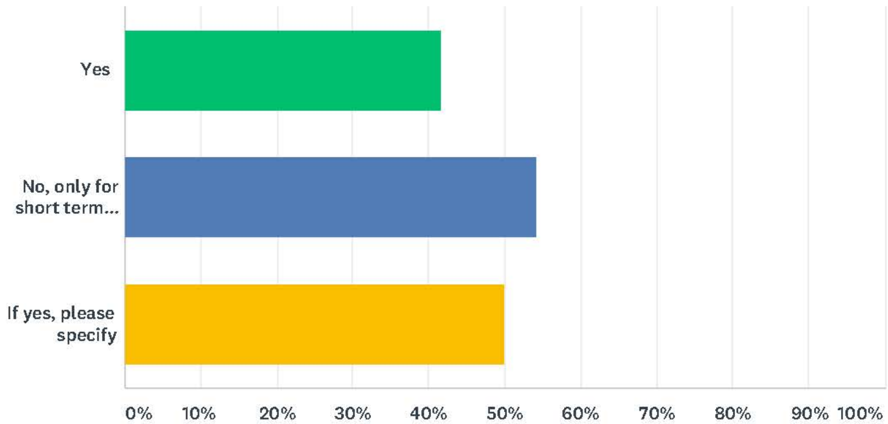
ANSWER CHOICES	RESPONSES	
Type of sensor	77.27%	17
Location of station	90.91%	20
Processing algorithm	50.00%	11

Dates and times of station/sensor operations	68.18%	15
Other (please specify)	36.36%	8
Total Respondents: 22		

#	OTHER (PLEASE SPECIFY)	DATE
1	Variable metadata (encompassing most aspects the above parameters) are available depending on age of data in the record- this is due to gaps/inconsistencies in metadata continuity. Processing algorithim has been essentially the same and is based on Arrival Time Difference location technique.	6/14/2018 2:23 PM
2	Contributing sensors, estimated location accuracy, date of processing, date of storing	6/4/2018 1:12 PM
3	These metadata are not publicly available, but are available	5/31/2018 5:18 PM
4	metadata is stored independently of archive	5/29/2018 5:48 PM
5	TBD	5/29/2018 10:57 AM
6	relative detection efficiency	5/18/2018 7:12 PM
7	Lat, Long, altitude, time microsecond resolution/accuracy, peak VHF power, goodness of fit, etc.	5/18/2018 6:27 PM
8	Do not apply	5/18/2018 5:51 PM

Q9 Do you use the data for climate applications or offer products for climate applications?

Answered: 24 Skipped: 0



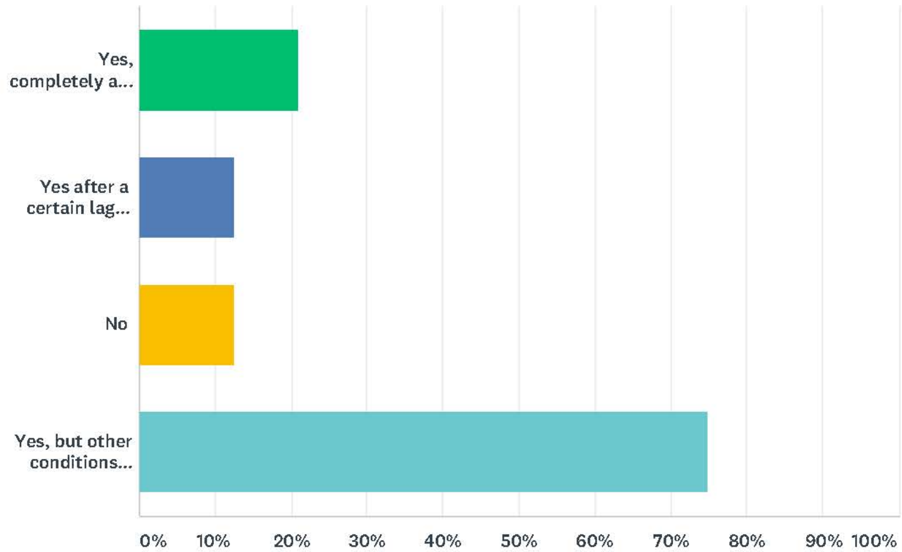
ANSWER CHOICES	RESPONSES	
Yes	41.67%	10
No, only for short term applications like nowcasting	54.17%	13
If yes, please specify	50.00%	12
Total Respondents: 24		

#	IF YES, PLEASE SPECIFY	DATE
1	Mean density anual maps.	6/18/2018 1:20 PM
2	Data used mainly for nowcasting, but some (limited) ad-hoc climatological products have been produced.	6/14/2018 2:23 PM
3	Services to utilities and other companies	6/4/2018 6:20 PM
4	Data is available for any research applications, including climate research.	6/4/2018 1:12 PM

5	Lightning climatology of South Africa	5/30/2018 10:26 AM
6	extreme event and case studies; regional and national climatologies	5/29/2018 5:48 PM
7	used for research, not for monitoring	5/29/2018 10:57 AM
8	Urban effects, thunderstorm severity and intra seasonal coupling	5/23/2018 5:14 PM
9	We have evaluated the average flash densities, average number of lightning days etc for a 10-year period in the area covered by our system	5/22/2018 3:26 PM
10	see wwlln.net/climate	5/18/2018 7:12 PM
11	Data is used for scientific research, nowcasting, and in some instances longer term studies	5/18/2018 6:27 PM
12	To study lightning changes due to climate changes	5/18/2018 5:51 PM

Q10 Without any commitment, do you think that your institution would be willing to share lightning data for climate purposes?

Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes, completely and without lag time	20.83%	5
Yes after a certain lag time (please specify below if possible)	12.50%	3
No	12.50%	3
Yes, but other conditions (please specify)	75.00%	18
Total Respondents: 24		

#	YES, BUT OTHER CONDITIONS (PLEASE SPECIFY)	DATE
1	Cannot specify conditions currently.	6/18/2018 1:20 PM
2	Willing to share data after a certain time lag (likely >24 hours, but to be determined). Data from ATD systems pre-dating present generation ATDNET system may require much longer times to produce. We would not permit data to be used on a commercial basis.	6/14/2018 2:23 PM
3	Yearly	6/4/2018 6:20 PM
4	Not for commercial purposes	6/4/2018 4:43 PM
5	We require a data sharing agreement be signed for academics who use our data for research purposes	6/4/2018 1:12 PM

6	Please email for further info	6/4/2018 11:45 AM
7	We are likely willing to share gridded data (lightning counts accumulated over an agreed lat/lon/time grid)	5/31/2018 5:18 PM
8	data will be available 24 h after observation for guest investigators or fully freely after 18 months	5/31/2018 12:08 PM
9	Lag time, disclaimer, satisfies South African Weather Service data policy.	5/30/2018 10:26 AM
10	not to be made freely available to public beyond the group mandate.	5/29/2018 5:48 PM
11	Conditions and time lag TBD	5/29/2018 10:57 AM
12	we are willing to share data for climate purposes under the condition of knowing the purposes of the studies & participating in relevant analyses	5/22/2018 3:26 PM
13	ALDIS: Yes EUCLID: we have to discuss with all the members	5/22/2018 2:19 PM
14	Payment required	5/21/2018 1:56 PM
15	The data belongs to the members (volunteers) of the network. Coverage and data quality is volatile. Data can not be sold, using for commercial products is unwanted. Usage for research is desirable, but must be permitted by us.	5/20/2018 12:07 PM
16	global, pixelated data with 10 minute or longer time resolution, on 0.1x0.1 degree grid, available after some time (months? a year? - undecided)	5/18/2018 7:12 PM
17	Decimated data is available in real-time, more complete data would be available after post-processing, with a time lag depending on the particular mapping network.	5/18/2018 6:27 PM
18	Météorage has already asked to be a part of TTLOCA. The case of the commercial networks must be addressed still!	5/17/2018 3:07 PM

Q11 If available, please give us a reference that documents your data and network.

Answered: 19 Skipped: 5

#	RESPONSES	DATE
1	https://www.vaisala.com/en/industries-innovation/meteorological-and-hydrological-applications/lightning-detection	6/18/2018 1:20 PM
2	https://journals.ametsoc.org/doi/full/10.1175/2011JTECHA1527.1 https://journals.ametsoc.org/doi/10.1175/JTECH-D-15-0256.1 https://www.nat-hazards-earth-syst-sci.net/14/815/2014/nhess-14-815-2014.pdf See "Lightning flash density in Europe on the basis of 10 years of ATDnet data S_E Enno et al", at (registration required): https://my.vaisala.net/en/events/ildcilmc/archive/Pages/ILDC-ILMC-2018-Archive.aspx?_ga=2.63630831.1767044958.1528894721-825160927.1418311375 See "Lightning flash density in Europe on the basis of 10 years of ATDnet data S_E Enno et al", at (registration required): https://my.vaisala.net/en/events/ildcilmc/archive/Pages/ILDC-ILMC-2018-Archive.aspx?_ga=2.63630831.1767044958.1528894721-825160927.1418311375	6/14/2018 2:23 PM
3	https://www.goes-r.gov/spacesegment/glm.html	6/13/2018 7:38 PM
4	ADTD is operated by Chinses Meteorology Administration. It has not been evaluated scientifically, and may not be suitable for research.	6/6/2018 4:24 AM
5	www.keraunos.co	6/4/2018 6:20 PM
6	Thomas, R. J., P. R. Krehbiel, W. Rison, et al. (2004), Accuracy of the Lightning Mapping Array, J. Geophys. Res., 109, D14207, doi:10.1029/2004JD004549	6/4/2018 4:43 PM
7	Sills, D., H. Yang and P. Joe, 2014: A Lightning Mapping Array in southern Ontario, Canada: uses for severe weather nowcasting. Extended Abstracts, 27th AMS Conference on Severe Local Storms, Madison, WI, Amer. Meteorol. Soc., Paper 83	6/4/2018 4:22 PM
8	Sample conference paper: https://my.vaisala.net/Vaisala%20Documents/Scientific%20papers/2016%20ILDC%20ILMC/Ryan%20Said%20and%20Martin%20Murphy.%20GLD360%20Upgrade%20Performance%20Analysis%20and%20Applications.pdf	5/31/2018 5:18 PM

9	Gijben M. The lightning climatology of South Africa. South African Journal of Science. 2012;108(3/4), Art. #740, 10 pages. http:// dx.doi.org/10.4102/sajs. v108i3/4.740	5/30/2018 10:26 AM
10	CLDN is not static. Technology improvements and available funds allow network to be upgraded in dynamic fashion. Burrows and Kochtubajda (2010) A decade of cloud-to-ground lightning in Canada: 1999-2008. Part 1: Flash Density and Occurrence. Atmosphere-Ocean, 48(3), 177-194. Current network comprises of LS7000-7001-7002 sensors.	5/29/2018 5:48 PM
11	Not available at the moment	5/29/2018 10:57 AM
12	Starnet network. Please visit the following website www.starnet.iag.usp.br	5/23/2018 5:14 PM
13	51. Kotroni V., and K. Lagouvardos, 2008: Lightning occurrence in relation with elevation, terrain slope and vegetation cover over the Mediterranean. JGR-Atmospheres, 113, D21118, doi:10.1029/2008JD010605. 59. Lagouvardos K., V. Kotroni, H-D Betz and K. Schmidt, 2009: A comparison of lightning data provided by ZEUS and LINET networks over Western Europe. Natural Hazards and Earth System Sciences, 9, 1713-1717. 105. Kotroni V. and K. Lagouvardos, 2016: Lightning in the Mediterranean and its relation with sea-surface temperature. Environmental Research Letters, 11, 034006.	5/22/2018 3:26 PM
14	ALDIS: Schulz W., K. Cummins, G. Diendorfer, M. Dorninger: Cloud-to-ground Lightning in Austria: A 10-year Study using Data from a Lightning Location System, Journal of Geophysical Research, Vol. 110, 2005 EUCLID: Schulz W., G. Diendorfer, S. Pedeboy, D.R. Poelman: The European lightning location system EUCLID – Part 1: Performance analysis and validation, Natural Hazards and Earth System Sciences, 16, 595-605, doi:10.5194/nhess-16-595-2016, 2016	5/22/2018 2:19 PM
15	11 Vaisala sensors	5/21/2018 1:56 PM
16	http://business.weatherzone.com.au/products/total-lightning/	5/21/2018 3:48 AM
17	see wwlln.net/publications	5/18/2018 7:12 PM
18	The Accuracy of the Lightning Mapping Array, Thomas et al., J. Geophys. Res. 2004 doi:10.1029/2004JD004549	5/18/2018 6:27 PM
19	Article in ILDC 2018: BrasilDATDataset: COMBINING DATA FROM DIFFERENT LIGHTNING LOCATING SYSTEMS TO OBTAIN MORE PRECISE LIGHTNING INFORMATION	5/18/2018 5:51 PM

Q12 Please provide some more details of your network

Answered: 23 Skipped: 1

ANSWER CHOICES	RESPONSES	
What is the name of the network?	95.65%	22
Please provide the url of the network website	86.96%	20
Please provide contact information	86.96%	20

#	WHAT IS THE NAME OF THE NETWORK?	DATE
1	ATDnet	6/14/2018 2:23 PM
2	Geostationary Lightning Mapper	6/13/2018 7:38 PM
3	ADTD Lightning location network	6/6/2018 4:24 AM
4	Linet Colombia	6/4/2018 6:20 PM
5	Lightning Mapping Array (LMA)	6/4/2018 4:43 PM
6	Southern Ontario Lightning Mapping Array	6/4/2018 4:22 PM
7	ENTLN	6/4/2018 1:12 PM
8	GLD360	5/31/2018 5:18 PM
9	TARANIS satellite (not network)	5/31/2018 12:08 PM
10	Southern African Lightning Detection Network	5/30/2018 10:26 AM
11	Canadian Lightning Detection Netwok (CLDN)	5/29/2018 5:48 PM
12	ATmosphere-Space Interactions Monitor (ASIM)	5/29/2018 10:57 AM

Survey on Lightning Data and Observation Networks

13	Starnet	5/23/2018 5:14 PM
14	ZEUS	5/22/2018 3:26 PM
15	For Europe: EUCLID; for Austria: ALDIS	5/22/2018 2:19 PM
16	Israel Electric Comp. Lightning Location System	5/21/2018 1:56 PM
17	The Weatherzone Total Lightning Detection Network (WZTLN)	5/21/2018 3:48 AM
18	Blitzortung.org	5/20/2018 12:07 PM
19	World Wide Lightning Location Network (WWLLN)	5/18/2018 7:12 PM
20	Lightning Mapping Arrays (LMAs)	5/18/2018 6:27 PM
21	BrasilDAT Dataset	5/18/2018 5:51 PM
22	Météorage	5/17/2018 3:07 PM
#	**PLEASE PROVIDE THE URL OF THE NETWORK WEBSITE**	**DATE**
1	https://www.metoffice.gov.uk/learning/learn-about-the-weather/thunder-and-lightning/lightning AND https://www.metoffice.gov.uk/public/weather/observation/map/#?map=Lightning&fcTime=1527030600&zoom=5&lon=-8.43&lat=59.93	6/14/2018 2:23 PM
2	https://www.goes-r.gov/spacesegment/glm.html	6/13/2018 7:38 PM
3	http://www.cma.gov.cn/en2014/meteorologicalinstruments/Features/201409/t20140918_261651.html	6/6/2018 4:24 AM
4	www.keraunos.co	6/4/2018 6:20 PM
5	http://lightning.nmt.edu/colma/	6/4/2018 4:43 PM
6	solma.ca	6/4/2018 4:22 PM
7	https://www.earthnetworks.com/product/weather-sensors/lightning/	6/4/2018 1:12 PM
8	https://www.vaisala.com/en/products/data-subscriptions-and-reports/data-sets/gld360	5/31/2018 5:18 PM
9	NA	5/30/2018 10:26 AM
10	https://weather.gc.ca/lightning/index_e.html (Lighting Danger Map)	5/29/2018 5:48 PM
11	http://asdc.space.dtu.dk/	5/29/2018 10:57 AM
12	www.starnet.iag.usp.br	5/23/2018 5:14 PM
13	http://www.meteo.gr/meteomaps/obs_zeus_eu.cfm	5/22/2018 3:26 PM
14	www.euclid.org; www.aldis.at	5/22/2018 2:19 PM
15	http://business.weatherzone.com.au/products/total-lightning/	5/21/2018 3:48 AM
16	Blitzortung.org	5/20/2018 12:07 PM
17	wwlln.net	5/18/2018 7:12 PM
18	http://lightning.nmt.edu/colma/ (one example)	5/18/2018 6:27 PM
19	www.inpe.br/elat	5/18/2018 5:51 PM
20	www.meteorage.com	5/17/2018 3:07 PM
#	**PLEASE PROVIDE CONTACT INFORMATION**	**DATE**

Annex 2

International Space Station (ISS) Lightning Imaging Sensor (LIS) WIGOS Metadata

Each element is classified as mandatory (M), conditional (C) or optional (O). An asterisk (*) signifies that the element is required for the WMO Rolling Review of Requirements process. A hash sign (#) means that it is acceptable to record a mandatory element with a value of nilReason (which indicates that the metadata are either unknown, not applicable, or not available) in any circumstances or otherwise according to stated specifications (see nilReason specifications in Chapter 7).

Cat.	*ID*	*Name*	*Definition*	*Example Lightning (in situ and satellite)*	*MCO*
1. Observed variable	1-01	Observed variable – measurand	Variable intended to be measured, observed or derived, including the biogeophysical context	Total Lightning	M*
	1-02	Measurement unit	Real scalar quantity, defined and adopted by convention, with which any other quantity of the same kind can be compared to express the ratio of the two quantities as a number (JCGM, 2012; reference no. 1.9)	Lightning event, group, flash (Lat, Lon, Time, Radiance) with a flash detection efficiency >70% and FAR < 5%	C*
	1-03	Temporal extent	Time period covered by a series of observations inclusive of the specified date/time indications (measurement history)	Event is the smallest temporal resolution made every 2 msec. Storms will be within the instantaneous fov for about 90 sec as the ISS passes overhead.	M*
	1-04	Spatial extent	Typical spatial georeferenced volume covered by the observations	The International Space Station - Lightning Imaging Sensor (ISS-LIS) is an instrument on the International Space Station at an altitude of 400 km. The IFOV Resolution of the ISS-LIS is 5 km at nadir within a global domain extending from 55 deg N/S latitude. The LIS provides continuous coverage of storms within its fov for approximately 90 sec.	M*
	1-05	Representativeness	Spatial extent of the region around the observation of which it is representative	Global coverage between 55 N/S latitude.	O

2. Purpose of observation	2-01	Application area(s)		Lightning is quantitatively coupled to both thunderstorm and related geophysical processes, and therefore provides important science inputs across a wide range of disciplines *(e.g., weather, climate, atmospheric chemistry, lightning physics)*. Lightning frequency, distribution and trends are the long-term climate variables of most interest.	M*
	2-02	Programme/network affiliation	The global, regional or national programme(s)/network(s) that the station/platform is associated with	NASA	M
3. Station/ platform	3-01	Region of origin of data	WMO Region	All WMO Regions RA 1-6	C*
	3-02	Territory of origin of data	Country or territory name of the location of the observation	United States	C*
	3-03	Station/platform name	Official name of the station/platform	International Space Station	M
	3-04	Station/platform type	A categorization of the type of observing facility at which an observation is made	Low earth orbiting	M*
	3-05	Station/platform model	The model of the observing equipment used at the station/platform	N/A? Lightning Imaging Sensor (LIS)	M*#
	3-06	Station/platform unique identifier	A unique and consistent identifier for an observing facility (station/platform), which may be used as an external point of reference	ISS-LIS. Instrument is a copy of the TRMM/LIS which collected tropical lightning data between 38 N/S latitude	M*
	3-07	Geospatial location	Position in space defining the location of the observing station/platform at the time of observation	Low earth orbit	M*
	3-08	Data communication method	Data communication method between the station/platform and some central facility	TDRSS	O
	3-09	Station operating status	Declared reporting status of the station	Operational- Provisional P.02 data since June 2018	M

4. Environment	4-01	Surface cover	The observed (bio)physical cover on the Earth's surface in the vicinity of the observation	Global to 55 N/S latitude	C#
	4-02	Surface cover classification scheme	Name and reference or link to document describing the classification scheme		C#
	4-03	Topography or bathymetry	The shape or configuration of a geographical feature, represented on a map by contour lines		C#
	4-04	Events at observing facility	Description of human action or natural event at the facility or in the vicinity that may influence the observation		O
	4-05	Site information	Non-formalized information about the location and surroundings at which an observation is made and that may influence it		O
	4-06	Surface roughness	Terrain classification in terms of aerodynamic roughness length		O
	4-07	Climate zone	The Köppen climate classification of the region where the observing facility is located. The Köppen-Geiger climate classification scheme divides climates into five main groups (A, B, C, D, E), each having several types and subtypes		O
5. Instruments and methods of observation	5-01	Source of observation	The source of the dataset described by the metadata	ISS-LIS	M
	5-02	Measurement/observing method	The method of measurement/observation used	Optical telescope with 128 x 128 pixel CCD focal plane detects the lightning at a single channel NIR wavelength of 777.4 nm	M#
	5-03	Instrument specifications	Intrinsic capability of the measurement/observing method to measure the designated element, including range, stability, precision, etc.	70% or greater average lightning flash detection the 24-hour diurnal cycle with False Alarm Rate < 5%. Location accuracy is 1 pixel at 3□.	C*#
	5-04	Instrument operating status	The status of an instrument with respect to its operation	Operational	O

	5-05	Vertical distance of sensor	Vertical distance of the sensor from a (specified) reference level, such as local ground, deck of a marine platform at the point where the sensor is located, or sea surface	ISS nominal altitude of 405 km	C*
	5-06	Configuration of instrumentation	Description of any shielding or configuration/setup of the instrumentation or auxiliary equipment needed to make the observation or to reduce the impact of extraneous influences on the observation	Sun shield with a number of ground processing algorithms to filter out non-lightning events (noise, radiation, sun glint, etc.)	C#
	5-07	Instrument control schedule	Description of schedule for calibrations or verification of instrument	Pre-launch laboratory calibration. No in-orbit calibration, however on-orbit calibration and validation activities use well characterized ground-based lightning networks and the GOES-16/17 GLM as cross-platform reference data.	C
	5-08	Instrument control result	The result of an instrument control check, including date, time, location, standard type and period of validity		C#
	5-09	Instrument model and serial number	Details of manufacturer, model number, serial number and firmware version if applicable	Lockheed-Martin, ISS-LIS design same as the Optical Transient Detector (OTD, 1995-2000) and TRMM/LIS (1997-2015)	C#
	5-10	Instrument routine maintenance	A description of maintenance that is routinely performed on an instrument		C#
	5-11	Maintenance party	Identifier of the organization or individual who performed the maintenance activity		O
	5-12	Geospatial location	Geospatial location of instrument/sensor	Low earth orbit	C*#
	5-13	Maintenance activity	Description of maintenance performed on instrument		O
	5-14	Status of observation	Official status of observation	ISS-LIS operational since February 2017.	O

	5-15	Exposure of instruments	The degree to which an instrument is affected by external influences and reflects the value of the observed variable	Radiation, glint, electronic noise all produce false event detections, however ground processing effectively identifies and removes most of these false events.	C#
6. Sampling	6-01	Sampling procedures	Procedures involved in obtaining a sample	ISS-LIS uses a single Real-time Event Processor to select optical transients above a background threshold at each pixel. Details can be found in the LIS Algorithm Theoretical Basis Document (ATBD).	O
	6-02	Sample treatment	Chemical or physical treatment of sample prior to analysis		O
	6-03	Sampling strategy	The strategy used to generate the observed variable		O*
	6-04	Sampling time period	The period of time over which a measurement is taken	128 x 128 CCD focal plane samples each pixel every 2 msec; total time for observation of a given storm within the fov is ~90 sec	M#
	6-05	Spatial sampling resolution	Spatial resolution refers to the size of the smallest observable object. The intrinsic resolution of an imaging system is determined primarily by the instantaneous field of view of the sensor, which is a measure of the ground area viewed by a single detector element in a given instance in time	The ifov (individual pixel) of ~4 km is defined by the top of the cloud using a fixed height to which the lightning is assigned.	M#
	6-06	Temporal sampling interval	Time period between the beginning of consecutive sampling periods	2 msec	M#
	6-07	Diurnal base time	Time to which diurnal statistics are referenced	UTC	C#
	6-08	Schedule of observation	Schedule of observation	continuous	M#

7. Data processing and reporting	7-01	Data-processing methods and algorithms	A description of the processing used to generate the observation and list of algorithms utilized to derive the resultant value	After spatial, temporal, and spectral filtering of the optical signal from lightning at cloud-top, a Real Time Event Processor performs a background subtraction at each pixel to determine if the change in light output at a pixel exceeds a threshold, producing an event. The resulting event is analyzed by Ground Processing algorithms to filter out sources of noise, non-lightning radiation, or other spurious signals leaving events identified as natural lightning.	O
	7-02	Processing/analysis centre	Centre at which the observation is processed	The data are archived and distributed from the NASA Global Hydrology Resource Center (GHRC) Distributed Active Archive Center in Huntsville, AL	O
	7-03	Temporal reporting period	Time period over which the observed variable is reported	Every flash file is created containing the event, group, flash, and area. The NWS also receives gridded products at 1 min and 5 min flash accumulations. Background images, consisting of an instantaneous capture of the focal plane array are produced approximately every 30s.	M*
	7-04	Spatial reporting interval	Spatial interval at which the observed variable is reported	2 msec individual event and group time; flash duration includes multiple events and groups that cluster in time-space over seconds	C*
	7-05	Software/processor and version	Name and version of the software or processor utilized to derive the element value	ISS-LIS PO.02 Provisional Data	O
	7-06	Level of data	Level of data processing	Level 2	O
	7-07	Data format	Description of the format in which the observed variable is being provided	HDF5, netCDF4	M
	7-08	Version of data format	Version of the data format in which the observed variable is being provided		M
	7-09	Aggregation period	Time period over which individual samples/observations are aggregated	variable	M

	7-10	Reference time	Time base to which date and time stamps refer	UTC, including time of flight correction from the source to the optical detection at the ISS	M
	7-11	Reference datum	Reference datum used to convert observed quantity to reported quantity		C
	7-12	Numerical resolution	Measure of the detail in which a numerical quantity is expressed	Time to the millisecond (0.001 sec), Lat/Lon (0.0001 deg), Radiance (.0001 fJ)	O
	7-13	Latency (of reporting)	The typical time between completion of the observation or collection of the datum and when the datum is reported	2 min or less	M
8. Data quality	8-01	Uncertainty of measurement	Non-negative parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the observation/measurand	1 msec	C*#
	8-02	Procedure used to estimate uncertainty	A reference or link pointing to a document describing the procedures/algorithms used to derive the uncertainty statement	GHRC web site http://thunder.msfc.nasa.gov	C*#
	8-03	Quality flag	An ordered list of qualifiers indicating the result of a quality control process applied to the observation		M#
	8-04	Quality flagging system	Reference to the system used to flag the quality of the observation		M#
	8-05	Traceability	Statement defining traceability to a standard, including sequence of measurement standards and calibrations that is used to relate a measurement result to a reference (JCGM, 2012; reference number 2.42)	NIST calibrating sphere reference used for AC and DC Calibration before launch	C*#
9. Ownership and data policy	9-01	Supervising organization	Name of organization who owns the observation	NASA	M
	9-02	Data policy/use constraints	Details relating to the use and limitations surrounding data imposed by the supervising organization	unrestricted	M*
10. Contact	10-01	Contact (nominated focal point)	Principal contact (nominated focal point) for resource	Richard Blakeslee, NASA Principal Investigator (E-mail: rich.blakeslee@nasa.gov, PH: 256-961-7962).	M

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Cat	*ID*	*Name*	*Definition*	*Example Lightning (in situ and satellite)*	*MCO*
1. Observed variable	1-01	Observed variable – measurand	Variable intended to be measured, observed or derived, including the biogeophysical context	Total Lightning	M*
	1-02	Measurement unit	Real scalar quantity, defined and adopted by convention, with which any other quantity of the same kind can be compared to express the ratio of the two quantities as a number (JCGM, 2012; reference no. 1.9)	Lightning event, group, flash (Lat, Lon, Time, Radiance) with a flash detection efficiency >70% and FAR < 5%; Flash Extent Density (FED, km^{-2}), Average Flash Area (AFA, km^2), Total Optical Energy (TOE, fJ)	C*
	1-03	Temporal extent	Time period covered by a series of observations inclusive of the specified date/time indications (measurement history)	Event is the smallest temporal resolution made every 2 msec.	M*
	1-04	Spatial extent	Typical spatial georeferenced volume covered by the observations	GLM is a staring instrument in Geostationary Earth Orbit. IFOV Resolution of the GLM is 8 km at nadir within a domain extending from 54 deg N/S latitude. The GLM on the GOES-E and GOES-W satellites provides continuous coverage from the west coast of Africa to New Zealand.	M*
	1-05	Representative ness	Spatial extent of the region around the observation of which it is representative	Western Hemisphere (GOES-E and GOES-W combined)	O
2. Purpose of observation	2-01	Application area(s)	Context within, or intended application(s) for which the observation is primarily made or which has/have the most stringent requirements	Detects electrically active storms and the areal lightning extent and threat, b) Identifies strengthening and weakening storms, c) Monitors convective mode and storm evolution. The lightning data will be used by NMHS in combination with radar, IR and VIS satellite imagery to improve warning lead time and accuracy.	M*

	2-02	Programme/network affiliation	The global, regional or national programme(s)/network(s) that the station/platform is associated with	The NOAA/NESDIS Geostationary Operational Environmental Satellite (GOES) Program	M
3. Station/platform	3-01	Region of origin of data	WMO Region	WMO Regions RA 3 and RA 4 (primary) with partial coverage for WMO RA 1, RA 5, RA 6	C*
	3-02	Territory of origin of data	Country or territory name of the location of the observation	United States	C*
	3-03	Station/platform name	Official name of the station/platform	GOES-East (GOES-16) and GOES-W (GOES-17) Geostationary Lightning Mapper (GLM)	M
	3-04	Station/platform type	A categorization of the type of observing facility at which an observation is made	Geostationary satellite	M*
	3-05	Station/platform model	The model of the observing equipment used at the station/platform		M*#
	3-06	Station/platform unique identifier	A unique and consistent identifier for an observing facility (station/platform), which may be used as an external point of reference	GOES-E and GOES-W	M*
	3-07	Geospatial location	Position in space defining the location of the observing station/platform at the time of observation	Geostationary orbit, 75.2 W, 137.2 W.	M*
	3-08	Data communication method	Data communication method between the station/platform and some central facility	GOES-R ReBroadcast (GRP)	O
	3-09	Station operating status	Declared reporting status of the station	Operational- GOES-E GLM as of July 2017, GOES-W GLM as of December 2018 (following Provisional Validation reviews)	M
4. Environment	4-01	Surface cover	The observed (bio)physical cover on the Earth's surface in the vicinity of the observation	The Americas and adjacent oceans	C#
	4-02	Surface cover classification scheme	Name and reference or link to document describing the classification scheme		C#

	4-03	Topography or bathymetry	The shape or configuration of a geographical feature, represented on a map by contour lines		C[#]
	4-04	Events at observing facility	Description of human action or natural event at the facility or in the vicinity that may influence the observation		O
	4-05	Site information	Non-formalized information about the location and surroundings at which an observation is made and that may influence it		O
	4-06	Surface roughness	Terrain classification in terms of aerodynamic roughness length		O
	4-07	Climate zone	The Köppen climate classification of the region where the observing facility is located. The Köppen-Geiger climate classification scheme divides climates into five main groups (A, B, C, D, E), each having several types and subtypes		O
5. Instruments and methods of observation	5-01	Source of observation	The source of the dataset described by the metadata	GLM on GOES	M
	5-02	Measurement/observing method	The method of measurement/observation used	Optical telescope with 1372 x 1300 1 megapixel CCD focal plane detects the lightning at a single channel NIR wavelength of 777.4 nm	M[#]
	5-03	Instrument specifications	Intrinsic capability of the measurement/observing method to measure the designated element, including range, stability, precision, etc.	nearly uniform 70% lightning flash detection or greater throughout the 24-hour diurnal cycle with False Alarm Rate < 5%. Location accuracy is 112 □rad at 3□	C*[#]
	5-04	Instrument operating status	The status of an instrument with respect to its operation	Operational	O
	5-05	Vertical distance of sensor	Vertical distance of the sensor from a (specified) reference level, such as local ground, deck of a marine platform at the point where the sensor is located, or sea surface	Geostationary orbit	C*

	5-06	Configuration of instrumentation	Description of any shielding or configuration/setup of the instrumentation or auxiliary equipment needed to make the observation or to reduce the impact of extraneous influences on the observation	Sun shield with a number of ground processing algorithms to filter out non-lightning events (noise, radiation, sun glint, etc)	C#
	5-07	Instrument control schedule	Description of schedule for calibrations or verification of instrument	Pre-launch laboratory calibration. No in-orbit calibration however on-going calibration and validation uses well characterized ground-based lightning networks as reference data and also the International Space Station-Lightning Imaging Sensor (ISS-LIS) used as well to compare with concurrent optical measurements of lightning	C
	5-08	Instrument control result	The result of an instrument control check, including date, time, location, standard type and period of validity		C#
	5-09	Instrument model and serial number	Details of manufacturer, model number, serial number and firmware version if applicable	Lockheed-Martin, GOES-R Series includes GOES-16, 17, T, U.	C#
	5-10	Instrument routine maintenance	A description of maintenance that is routinely performed on an instrument		C#
	5-11	Maintenance party	Identifier of the organization or individual who performed the maintenance activity		O
	5-12	Geospatial location	Geospatial location of instrument/sensor	GOES-16 at 75.2 W, GOES-17 at 137.2W	C*#
	5-13	Maintenance activity	Description of maintenance performed on instrument		O
	5-14	Status of observation	Official status of observation	GOES-16 GLM operational, GOES-17 GLM to be declared operation early December 2018.	O
	5-15	Exposure of instruments	The degree to which an instrument is affected by external influences and reflects the value of the observed variable	Radiation, glint, electronic noise all produce false event detections, however ground processing effectively identifies and removes most of these false events.	C#

6. Sampling	6-01	Sampling procedures	Procedures involved in obtaining a sample	56 Real-time Event Processors sub-divide the full fov comparing optical transients above a background threshold at each pixel. Details can be found in the GOES-R Series Data Book and GOES-R Product Users Guide (PUG)..	O
	6-02	Sample treatment	Chemical or physical treatment of sample prior to analysis		O
	6-03	Sampling strategy	The strategy used to generate the observed variable		O*
	6-04	Sampling time period	The period of time over which a measurement is taken	1372 x 1300 CCD focal plane samples each pixel every 2 msec	M#
	6-05	Spatial sampling resolution	Spatial resolution refers to the size of the smallest observable object. The intrinsic resolution of an imaging system is determined primarily by the instantaneous field of view of the sensor, which is a measure of the ground area viewed by a single detector element in a given instance in time	The ifov of 8 km is defined by the top of the cloud using an ellipsoidal model of the tropopause height that varies from the equator to the poles.	M#
	6-06	Temporal sampling interval	Time period between the beginning of consecutive sampling periods	2 msec	M#
	6-07	Diurnal base time	Time to which diurnal statistics are referenced	UTC	C#
	6-08	Schedule of observation	Schedule of observation	continuous	M#
7. Data processing and reporting	7-01	Data-processing methods and algorithms	A description of the processing used to generate the observation and list of algorithms utilized to derive the resultant value	After spatial, temporal, and spectral filtering of the optical signal from lightning at cloud-top, Real Time Event Processors perform a background subtraction at each pixel to determine if the the change in light output at a pixel, referred to as an event. The resulting event is run through a number of Ground Processing algorithms to filter out sources of noise or non-lightning radiation leaving the remaining pixels to be identified as natural lightning.	O

	7-02	Processing/analysis centre	Centre at which the observation is processed	The GLM L1 and L2 data product is produced at the WCDAS Wallops Island Receiving station. A hot backup is located at Fairmont, West Virginia. Level 0, L1b, L2 data archived and available from the NOAA Comprehensive Large Array Storage System (CLASS). https://www.goes-r.gov/products/docs/PUG-L2+-vol5.pdf	O
	7-03	Temporal reporting period	Time period over which the observed variable is reported	Every 20 sec a flash file is created containing the event, group, flash. The NWS also receives gridded products at 1 min and 5 min flash accumulations.	M*
	7-04	Spatial reporting interval	Spatial interval at which the observed variable is reported	2 msec individual event and group time; flash duration includes multiple events and groups that cluster in time-space over seconds	C*
	7-05	Software/processor and version	Name and version of the software or processor utilized to derive the element value	NESDIS OSPO OE (operational environment) OE.07	O
	7-06	Level of data	Level of data processing	Level 2	O
	7-07	Data format	Description of the format in which the observed variable is being provided	netCDF4.	M
	7-08	Version of data format	Version of the data format in which the observed variable is being provided		M
	7-09	Aggregation period	Time period over which individual samples/observations are aggregated	variable	M
	7-10	Reference time	Time base to which date and time stamps refer	UTC, including time of flight correction from the source to the optical detection at the satellite	M
	7-11	Reference datum	Reference datum used to convert observed quantity to reported quantity		C
	7-12	Numerical resolution	Measure of the detail in which a numerical quantity is expressed	Time to the millisecond (0.001 sec), Lat/Lon (0.0001 deg), Radiance (.0001 fJ)	O

	7-13	Latency (of reporting)	The typical time between completion of the observation or collection of the datum and when the datum is reported	10 sec allocated to generate L1B, 20 sec or less to generate L2+.	M
8. Data quality	8-01	Uncertainty of measurement	Non-negative parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the observation/measurand	1 msec	C*#
	8-02	Procedure used to estimate uncertainty	A reference or link pointing to a document describing the procedures/algorithms used to derive the uncertainty statement	GOES-R Data Book and Product Users Guide (PUG) available from NESDIS operations.	C*#
	8-03	Quality flag	An ordered list of qualifiers indicating the result of a quality control process applied to the observation		M#
	8-04	Quality flagging system	Reference to the system used to flag the quality of the observation		M#
	8-05	Traceability	Statement defining traceability to a standard, including sequence of measurement standards and calibrations that is used to relate a measurement result to a reference (JCGM, 2012; reference number 2.42)	NIST calibrating sphere reference used for AC and DC Calibration before launch	C*#
9. Ownership and data policy	9-01	Supervising organization	Name of organization who owns the observation	NOAA	M
	9-02	Data policy/use constraints	Details relating to the use and limitations surrounding data imposed by the supervising organization	unrestricted	M*
10. Contact	10-01	Contact (nominated focal point)	Principal contact (nominated focal point) for resource	Scott Rudlosky, NESDIS STAR Algorithm Science Team lead (E-mail: scott.rudlosky@noaa.gov, PH: 301-405-4204).	M

GCOS Secretariat

Global Climate Observing System

c/o World Meteorological Organization

7 *bis,* Avenue de la Paix

P.O. Box No. 2300

CH-1211 Geneva 2, Switzerland

Tel: +41 22 730 8275/8067

Fax: +41 22 730 8052

Email: gcos@wmo.int