

Detect and Locate Lightning Events from Geostationary Satellite Observations

Report Part II

Feasibility of Lightning Location
from a Geostationary Orbit

EUM/CO/02/1016/SAT

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October 2002

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1 Introduction

This is the second of two reports for the study 'Detect and Locate Lightning Events from Geostationary Satellite Observations'. The first report entitled "Review of existing lightning location systems" reviewed the current status of ground based lightning and also surveyed the applications of lightning data. This second report on the 'Feasibility of lightning location from a geostationary orbit' discusses the value of geostationary lightning detection for the various applications with emphasis on the value added to conventional surface-based lightning detection networks. Furthermore, the requirements to the design and operation of a satellite based lightning location sensor are discussed but also limiting factors for such a system are presented.

The report is organized as follows: Section 2 summarizes the main findings from Report I with focus on the main deficiencies of ground based systems, the principal suitability of the geostationary lightning location and on the value added. This also includes an examination of the applications which benefit from the data provided by the geostationary lightning location. Section 3 examines the basic demands to the design and operation of the sensor system, which have to be satisfied in order to meet the user requirements. Here we consider mainly the basic components of the system and the data processing methods. It follows in section 4 a discussion of the limiting factors of geostationary lightning location. The synergies arising from the combination of the geostationary lightning data with other satellite and ground based observables are discussed in section 5. Section 6 deals in short with other concepts for space based lightning location.

2 Value of Lightning Location from Geostationary Orbit

2.1 Deficiencies of Ground Based Systems

Ground based lightning location systems (LLS) are in successful operation for more than 10 years. These systems provide reliable lightning location data with quite satisfying detection efficiency and accuracy. Despite the acknowledged data quality and the ongoing sensor improvements, the ground based systems still suffer from several drawbacks and deficiencies:

- No lightning detection over wide parts of the earth including the tropics and oceans.
Large scale ground based lightning detection is potentially able to detect lightning globally, but the detection efficiency of such systems is generally low and changes with daytime. Moreover, the location uncertainty is very large and not comparable with the one of conventional systems.
- Predominantly cloud-to-ground (CG) flashes are detected. Only SAFIR systems provide total lightning location information.
- The networks have non-uniform detection characteristics due to heterogeneous distribution of detection stations and the use of different types of sensors.

It should be emphasized, that the above limitations are of principal nature and will persist in the next years despite the prospective evolution of ground based systems (see Report Part I). Moreover, many countries, especially developing ones, may even in the far future not be able to finance and operate surface based systems. For many applications, especially global ones, these deficiencies limit the

use of lightning data in general. Lightning detection and location from a geostationary satellite may overcome some of these limitations and may represent, eventually, the only realistic solutions for global applications.

2.2 Suitability of Geostationary Lightning Observation

It has been shown, that lightning can in principal be detected and located from space. As described in Part I of the report, several location techniques were applied in the past. The most developed method is the lightning detection and location with an optical sensor. This instrument consists of a telescope pointing towards the earth and a photosensitive matrix for the detection of the transient lightning signals. Despite the large background optical signal from clouds and ground surface, the lightning signal can be extracted reliably by appropriate filtering and data processing techniques.

Prototypes on low orbiters have demonstrated in the past years the suitability of satellite based optical lightning location sensors.

The NASA space born lightning detection program at the Marshall Space Flight Center (MSFC) in Huntsville, Alabama resulted in an optical lightning detection sensor. A prototype (OTD, Optical Transient Detector) was launched in 1995 and an improved successor LIS (Lightning Imaging Sensor) was then on board of the Tropical Rainfall Measurement Mission (TRMM) in 1997. It is planned to launch a further developed version of the system (LMS, Lightning Mapping Sensor) on board of the new GOES-East and GOES-West satellites, for geostationary detection of lightning over the American continent.

Another lightning detection sensor package (FORTE) was launched in 1997 by Los Alamos National Laboratory (LANL). An optical lightning sensor (OLS, another improved version of the OTD) was complemented by a broad band photo diode (PDD) and a VHF receiver both with high time resolution for the observation of optical and radio wave forms.

All these instruments are mounted on low orbit satellites, OTD and FORTE at altitudes of ≈ 800 km and LIS at 350 km respectively. The corresponding short sampling time permits only 'snapshots' of few minutes of the lightning activity within a given area of interest.

Data from these systems is freely available for the scientific community. Extensive validation studies were performed which compared the space born data against ground based data. They confirmed the applied detection principle and also the data processing methods.

Lightning data from these systems was widely used for a broad range of scientific applications, including storm research and climatological analyses. For a more detailed review of the scientific output emerging from these instruments, see Report Part I and the references therein.

2.3 Expected Value Added by Geostationary Location

One basic question concerns the transfer of the now well-proven optical lightning detection from a low orbiter to a geostationary orbit. Table 1 lists the critical parameters to be considered here and how they change by the transition from low to geostationary orbit, respectively what the user requirements are.

In section 3 the requirements for the envisaged transfer to a geostationary orbit for the instrument design to achieve these parameters are examined.

Parameter	low orbit (OTD)	geostationary orbit
satellite altitude above ground	740 km	35'800 km
orbit period	90 min	24 h
field of view of the sensor	1300 km × 1300 km	hemisphere (expected)
observation time at given location	4 min	permanent
location accuracy	10 km	8 km (expected)
detection efficiency	50%	90% (expected)

Table 1: Orbit and lightning location parameters for space based lightning location sensors on low orbit and geostationary orbit.

The deployed prototypes together with some theoretical considerations permit an estimation of the expected advantageous capabilities of geostationary lightning location. The value added with respect to existing and also future operational ground based systems may be summarized as follows:

- A total hemisphere can be observed permanently with location accuracy of about 8-10 km and estimated detection efficiency of 60-90%.
This enables the detection of lightning over areas not covered by ground based LLS.
- In contrast to lightning detection from low orbits and as the main applications for National Weather Services storms can be observed over their whole life cycle.
- Total lightning including cloud-to-ground and intracloud lightning is detected.
The intracloud lightning is by about one magnitude more frequent than cloud-to-ground lightning. The total lightning data thus provides a much more complete information on electrical activity than ground flash data alone.

This additional information, which cannot be provided by ground based systems with the same quality, will give benefit for a number of applications and will be discussed in the following.

2.4 Benefit from Geostationary Lightning Data for Applications

The benefit of lightning data from geostationary observation in operational applications has been assessed by Weber et al. (1998). The authors estimated the possible reduction of casualties and damage costs. This study was dedicated to the planned installation of the NASA lightning mapper LMS on board of the GOES. Hence the focus was put on the United States. Since the US are more exposed to convective storms than Europe as a whole, the cost estimations will differ between both regions. However, the most part of the argumentation and discussion holds as well for Europe. The following list from this study shows the operational application which would most benefit from the additional value of geostationary lightning data.

1. "Improvements to the lead time and/or reliability of warning for tornados, damaging thunderstorm winds and hail;
2. Augmented warning capability for thunderstorm flash floods in mountainous areas where the NEXRAD weather radar networks's coverage is incomplete owing to beam blockage;

3. Improvements in information provided to commercial airlines on hazardous convective weather, particularly over oceanic regions where current sensor coverage is limited; and
4. More reliable warnings of lightning strike hazard." (Weber et al., 1998)

A estimate of the annual benefits in these four application fields yield a reduction in lightning caused property damage costs of about 40 Million Dollars per year. This estimated monetary benefit is large compared with the costs of the sensor. The authors also emphasized the necessity of additional research and algorithm development in order to make full advantage of the cost reduction potential.

Considering the situation in Europe we have first to note that the spatial coverage with surface based systems is dense and, probably, will cover whole Europe at the eventual advent of a geostationary system. Thus we have to focus on the value added to surface based systems by the latter.

Applications with the expected main benefit from geostationary lightning data are:

Nowcasting and warning of severe convective weather including the hazards of hail, flooding, wind gust.

Improved warning of lightning strike risk for both ground strikes and aircraft lightning strikes.

Climate observation and monitoring of global lightning distribution.

Atmospheric chemistry impact from lightning produced NOx.

Values added to European surface based systems reside in:

1. Integration and enhancement of the use of surface based systems. This concerns mainly the heterogeneous nature of the European systems with many operators, different sensor and error characteristics etc. A geostationary system will serve as a reference platform for the various surface based sensors and will thus enable to adjust all to the same standard.
2. Areas outside the coverage of surface based systems but of general of interest for Europe. This concerns mainly the adjacent areas as the Atlantic ocean, the Black Sea, and parts of Asia with a potential impact on the weather in Europe.
3. Hemispheric coverage as a service for the international community. There are substantial commercial interests for support in aviation and ship routing. It can be foreseen that for at least decades some if not many countries in Africa cannot afford surface based systems and thus both the international community and the respective national weather services would gain much support from a geostationary lightning system.
4. Climate monitoring. This is necessarily based on constant operation conditions and is not provided by surface based systems. It is assumed that the number of thunderstorms will change with the expected global warming. Especially an increase in severe weather is hypothesized. Worldwide monitoring of the thunderstorm activity is, therefore, considered as absolute necessary and requires a European geostationary system, for hemisphere viewed from a Europe satellite.

3 Requirements to Sensor Design and Operation

The known high level user requirements for a lightning detection sensor are: (i) high detection efficiency, (ii) low false alarm rate, (iii) un-interrupted coverage in space and time, (iv) fast data dissemination to the user, (v) high position accuracy, (vi) discrimination between CG and IC lightning.

critereion	requirement	determined by
detection efficiency	$\geq 90\%$	detector sensitivity, pixel size, observation time fraction
false alarm rate	$\leq 10\%$	data processing
location accuracy	8-10 km	cloud scattering, pixel size
geographical coverage	hemisphere (up to 61° latitude)	detector matrix size
timeliness	≤ 1 min	data processing and transmission

Table 2: High level user requirements which can be met by a lightning location sensor on a geostationary platform (Christian, 1998)

An assessment of the capabilities of a geostationary lightning mapper was given by Christian et al. (1989). The authors also discussed the demands to sensor design and data processing necessary to approach the theoretically possible best quality. One should note, that despite of the several improvements and refinements during the years, the basic concept of OTD and LIS prototypes was not changed. Simply, because it was proven to be successful. The follow-on LMS is scheduled now for launch on board of the geostationary GOES. The state of the art as it is manifested in the soon available optical lightning location instrument is documented in a number of publications (e.g. Christian et al., 1989; Christian, 1998; Boccippio et al., 2000).

The LMS predecessors were successfully implemented in operation. Much experience has been gained with these systems in validation studies and scientific applications. These facts and the upcoming installation of the LMS on GOES provide strong arguments for further, eventually planned geostationary lightning location systems to follow the same basic instrument concept. Modifications will arise from improvements due to technological development and possibly also from slightly different user demands.

Two important statements have to be made here and in this context. The existence of lightning mappers on GOES satellites will exert a lot of pressure from both the political side and the scientific community. The already existing applications of lightning data will be further extended and cost-benefit studies will then reveal the expected substantial benefit from geostationary systems. A European development of a geostationary lightning detection system will profit from the experiences with the systems developed by NASA. The inherent risk of the first positioning of a lightning sensor on a geostationary orbit can be critically monitored and eventual shortcomings may be overcome. A great benefit can be expected from simultaneous operation of LLS on both GOES and METEOSAT platforms. The geographical coverage will be substantially enhanced and the large overlap area (Atlantic and Brazil) will enable a synergistic use of both data sets.

The basic components of the LMS system are: the optical telescope, a narrow-band interference filter, the detection elements in the focal plane, real time data processing, data transmission. The performance criteria to these components are in brief described and critically examined in the following

and mainly from a principal point of view. A more detailed and quantified specification is beyond the scope of this study and is left to future studies.

3.1 Optical Signal Propagation from Lightning

Lightning occurs predominantly in or below thunderstorm clouds, some also above. Viewed from above the lightning channel in most cases is obscured by the cloud, respectively some cloud layers. A direct view of the lightning channel may be only possible for sprites and other discharges towards the ionosphere or for discharges between clouds. Due to multiple scattering, however, the cloud top surfaces radiates brightly. Thus, lightning appears to an observer in space as emerging from the illuminated cloud surface.

The peak optical power emitted from a lightning flash is about 10^9 W, the optical energy yield is about 10^4 J. This energy is radiated from the luminous part of the lightning channel and becomes then subjected of multiple scattering within the cloud. The scattering is conservative, i.e. absorption is low, so that the emitted optical energy is transferred from a line source to a surface source, the illuminated cloud surface. Monte Carlo simulations (Light et al., 2001) and observations from aircraft (Christian and Goodman, 1987) and space shuttle (Vonnegut et al., 1983) showed a distribution of the optical energy over an area of approximately 10 km in diameter. Thus not all of the cloud body is illuminated, depending, of course, on strength and orientation of the lightning channel. Further consequences of the scattering is a time delay due to the increased photon path and a stretching of the optical pulse.

The fraction of energy which is scattered from cloud top into space, i.e. which is available for detection varies with cloud type and shape (Light et al., 2001). For horizontally large clouds about 50% of the optical energy is released in the upward directions. Moreover, CG and IC lightning differ with respect to scattering. IC lightning is almost entirely inside the cloud, while the CG flashes have a strong radiating part of the channel below the cloud.

The optical emission is concentrated at specific spectral lines. The strongest is the one of ionized Oxygen at 777.4 nm, which contains about 5-10% of the optical energy (Orville and Henderson, 1984). For the majority (about 90%) of the lightning discharges the peak radiances were larger than $4.7 \mu\text{J m}^{-2} \text{sr}^{-1}$ (Christian et al., 1989). This value gives a rationale for the detection threshold of an optical detection sensor ($4.0 \mu\text{J m}^{-2} \text{sr}^{-1}$ in LMS).

3.2 Geometrical Characteristics of the Geostationary Orbit

The prototype optical lightning detection sensors were carried by satellites on low, near solar-synchronous orbits at altitudes of about 800 km. The transition to geosynchronous orbits at a 50 times larger distance from the ground leads to the corresponding changes in the geometrical parameters Table 3).

Additionally, the signal attenuation increases due to the larger distance.

Parallax causes bias in projection of lightning position to ground coordinates due to the elevated lightning source of unknown height. This bias increases with angular distances from nadir. For instance, a point at 0° longitude, 46° latitude and 12 km height above ground appears to be at 46.14° latitude, which corresponds to a bias of 15.5 km. With the knowledge of the cloud top height provided by a other instrument, e.g. the cloud imager, this error can be corrected.

parameter	
altitude above ground	35,800 km
diameter of the Earth disk	17.4° (0.072 sr)
viewing angle of 10 km distance at nadir	0.015°
total visible sector on earth	162.6°
highest visible latitude	81.3°
highest latitude with satellite elevation 20°	61.8°

Table 3: Geometrical parameters of the geostationary orbit around the Earth

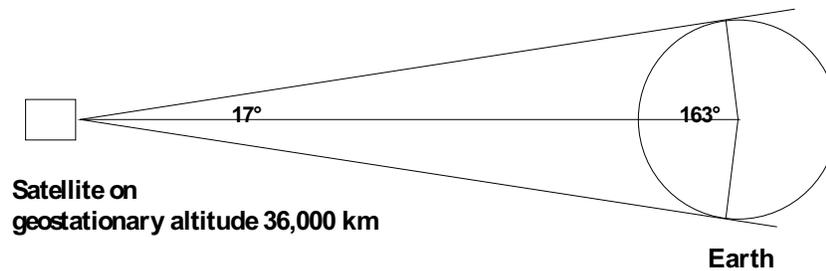


Figure 1: Schema of earth and satellite position for geostationary orbit

3.3 Optical System and Detection Elements

The optical system consist of the telescope and an interference filter concentrated at the wavelength of a strong emission line of lightning (777.4 nm). The actual detection and location is accomplished by a photosensitive matrix. In the LMS instrument a $f/1.2$ telescope is used with 10 cm aperture.

One constraint arises from the applied interference filter. The incident angle must not be too large in order to avoid a significant shift of the filter frequency. This problem is circumvented by the use of additional lenses in an advanced optical system.

3.3.1 Detection CCD – Matrix

The detecting and locating element is a CCD array in the focal plane of the optical system. The optical system parameters and the pixel size determine the angular pixel size (steradian from which the given pixel receives energy) which then defines both resolution and detection efficiency of the instrument. The total size, respectively the number of pixels of the CCD matrix determines the geographical coverage.

The choice of the pixel size is a trade off between energy per pixel and spatial resolution. Since the cloud scattering diffuses the lightning location to a spatial scale of approximately 10 km, a lower limit exist for the pixel size. A smaller pixel size does not enhance location accuracy but would lower the detection efficiency, since the radiance of one lightning event is shared by more pixels.

In order to realize the potential capabilities of lightning location from geostationary orbit a full hemispheric coverage including land and oceanic areas is requested from the users.

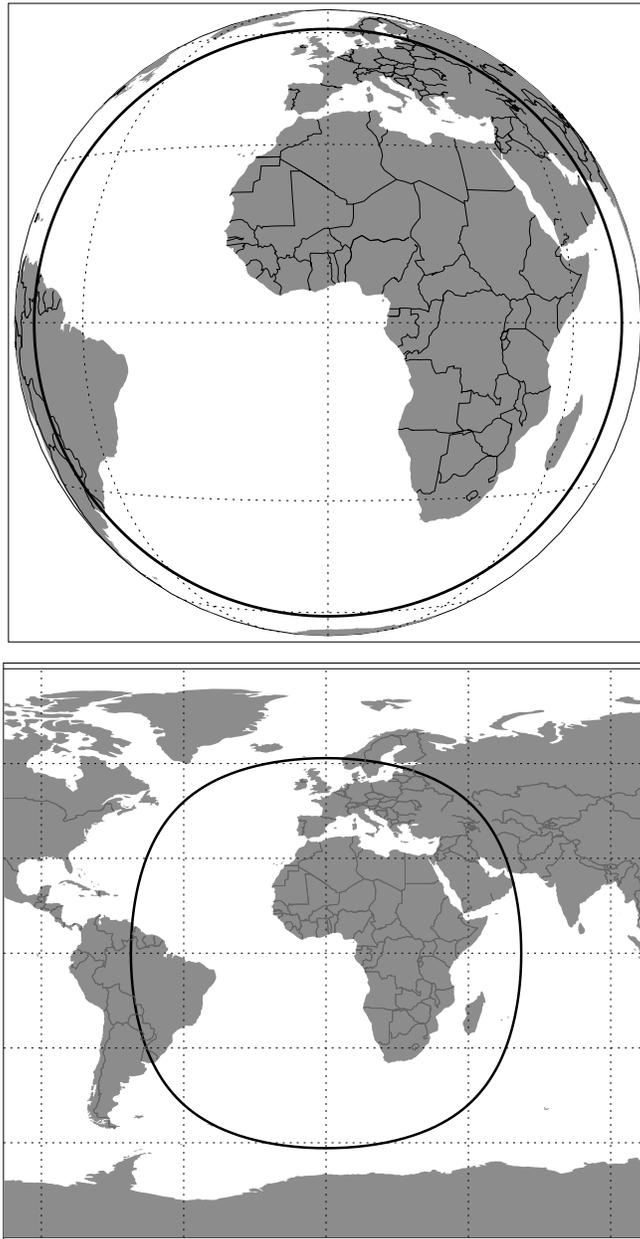


Figure 2: Field of view from a geostationary satellite in satellite (top) and cylindrical projection (bottom). The thick circle includes the area where the satellite is visible with an elevation angle exceeding 20° .

A resolution of 10 km at nadir corresponds to a viewing angle of 0.015° ($5.4 \cdot 10^{-8}$ sr). Thus, to cover the full range of the 16.4° field of view (Fig. 2), a number of $\approx 1100 \times 1100$ pixels is necessary. This is two orders of magnitude larger than the now used pixel arrays in the LMS prototypes (OTD: 128×128). Christian (1998) proposed for the LMS on GOES a matrix of 700×560 pixels corresponding to 8 km ground size per pixel at nadir. It can be expected, that technological progress makes it possible to handle these large arrays.

In order to reach a resolution of 10 km over central Europe (50°), the resolution at nadir must be increased to 6 km.

3.4 Data Processing

Corresponding to the short duration of the lightning events (a few $100 \mu\text{s}$), the complete CCD array is read out at a high sampling rate of 2 ms. The resulting huge amount of data requires on-orbit real time data processing.

The key function of the detection sensor is the discrimination of lightning from other light sources ensuring a low false alarm rate. Slow and fast varying sources have to be considered. Slowly changing light sources are mainly caused by reflected solar radiation from clouds and also from the earth surface. In the present realisations the lightning events are extracted by subtraction of the slowly changing background signal from the actual sample.

Fast changing light signals are produced by reflecting surfaces with strong directional dependence, mainly water surfaces. These 'glints' can, therefore, produce false events. They fortunately, however, can be eliminated since they are produced in cloudless areas only.

An elaborated real time data processing scheme was developed and implemented in the optical detector prototypes Christian et al. (1989); Christian (1998). It consists of four filter steps.

- 1. Spatial filtering:** pixel size corresponds to lightning footprint size
- 2. Temporal filtering:** short integration time (1 ms) adapted to the short time of lightning event ($\sim 500 \mu\text{s}$).
- 3. Wavelength filter:** interference filter with 1 nm width around a strong emission line 777.4 nm .
- 4. Background subtraction:** Background illumination varies more slowly, hence the actual frame is subtracted by a mean background signal for every pixel.

With the increase in processor power, more sophisticated data processing methods can be implemented in the real time processing.

3.4.1 High event rates

The requirements to the detection capacity on CCD level and the real time data processing rise with the transition to geostationary orbit. Nearly 50% of the global lightning is in the field of view. According to recent estimates the global ground lightning flash rate amounts to approx. 50 s^{-1} . To this flash rate one has to add the contribution from the intracloud lightning which occurs about one order magnitude more frequent. Hence, a number of approx. 500 events per second can be expected on average. Thus a high number of events must be processed. This, however, can be seen as a transient problem due to the expected technological development.

3.5 Sensor Operation

The lightning detecting instrument as a part of the satellite's sensor package has to be integrated smoothly in the overall system design. This requires an appropriate design of the instrument hardware interfaces including power supply, data transmission link to earth. Thermal stabilisation must be guaranteed. An interactive control and commanding mode of the instrument must be implemented. Further details of the lightning sensor specification should be the subject of implementation studies.

3.5.1 Pointing of the instrument

Lightning signals are transient and extremely short, hence the observation time of a given location on earth determines directly the detection efficiency of lightning. This requirement for the sensor operation can be met by appropriate stabilization methods of the satellite. On board of a three-axis stabilized platform, as it is e.g. the case for the new generation of GOES, a permanent pointing of the sensor telescope can be realized. For the accurate calculation of the lightning position the exact satellite orientation data are necessary.

On a spin-stabilized platform (such as MSG) the satellite rotation will generally complicate an uninterrupted observation of the earth. If the spinning platform reduces the observation time the lightning detection efficiency will decrease proportionally, i.e. is determined by the ratio of the observation time to the rotation period.

3.5.2 Protection from high energetic particles

High energetic particles from solar and galactic sources can damage the electronics and generate false events. For the low sun-synchronous orbits this has led to detection problems in the region of the Southern Atlantic Anomaly (SAA), where the geomagnetic field bundles solar protons. Due to the high altitude of the geostationary orbit and being inside the earth's magnetopause, however, much less particles are to be expected.

Appropriate shielding can suppress the interference from high energetic particles to a certain amount. The remaining false locations can be identified by data processing and eliminated from the data.

3.6 Required Additional Data

The primary output of the optical lightning sensor is the angular position of the event relative to the telescope axis and its radiance. Several additional data, however, are required to transform these data into accurate lightning position data.

Data on the satellite's orbit and orientation are necessary for exact geolocation of the detected lightning events. The accuracy and the knowledge of the sensor pointing direction must be within certain limits.

The information on cloud top height is necessary to eliminate the parallax bias in lightning position. These data can be obtained from the cloud imager.

For several applications the discrimination between IC and CG lightning is important. This is difficult to accomplish using only the optical lightning sensor data. For areas, where the information on CG

flashes is desired, the additional use of data from ground based lightning detection systems may be necessary.

Data on cloud coverage and additional ground data (surface albedo, ocean wave parameters) will be utilized to eliminate false events produced by glint on reflecting surfaces. One must be aware, however, that these data are provided with lower sampling rates than lightning data. Furthermore, information on cloud type, particle shape and density can be utilized for inverse scattering calculations.

Other supplementary data about environment and noise conditions will be useful for data interpretation. This includes solar activity data, status information on the satellite etc.

4 Limiting Factors

The capabilities of lightning detection from geostationary orbit are limited by several factors which are listed below.

Visible area of the globe is limited by the geostationary orbit to a nominal field of view (FOV) extending to a maximum geographical latitude of 82° . In practice this FOV will be limited further, since at more slanting angles close to the earth's horizon the uncertainty grows to large values.

Resolution depends on geographical position and drops with distance from nadir.

Spinning satellite If a spinning type of satellite is chosen, the earth observation is interrupted due the spinning and the detection efficiency reduces according to the observation time fraction.

Light scattering in clouds limits the location to 8 – 10 km.

Discrimination of lightning types The discrimination of the detected total lightning in CG and IC flashes is difficult using solely the optical observation. Additional data from ground based lightning location systems may be required to solve this.

Other limitations, which are due to limits in the applied system components (e.g. sensitivity, storage capacity, processor power), can be expected to become obsolete due to the technological progress.

5 Synergistic Value from Combination with other Data

Many applications will profit from the value added by geostationary lightning data. This value results both from the exclusive provision of lightning data and from the combination with other observation data.

5.1 Combination with Cloud Observing Systems

As evident from section 2, in application to storm nowcasting the added value from lightning data actually arises from their synergistic use in combination with other data from weather radar and cloud observing satellites. Due to their high resolution in time (quasi-continuous) lightning data can be

advantageously combined with these scanning systems, since the lightning data preserve continuity and fill the gap between successive scans. Additionally lightning indicates the most active parts in convective clouds. Also rising or cease of storm is associated with changes in the lightning flash rate.

As shown in case studies the discharge activity in clouds is linked to other storm hazards, such as hail, tornados or microbursts. Particularly sudden changes in total lightning rate are highly correlated with the occurrence of these phenomena. The availability of permanent total lightning data will make it possible to take advantage of this. Lightning data can serve as proxy for convective precipitation. As demonstrated by the TRMM project synergy arises from the combination with cloud radar and microwave radiometers.

In turn, the quality of the satellite lightning data can be improved by involving other data. The elimination of false events, caused by glints can be accomplished using the cloud data from satellite.

A sample application (LISDAD) for support of nowcasting in aviation was installed at the US National Weather Service at Melbourne (Florida). This system combines lightning data from several sources: the low orbit LIS instrument, the total lightning detection network of the Kennedy Space Center and the US-wide National Lightning Detection Network. The lightning information is integrated in the display of the NEXRAD weather radar and supports the tracking of storms taking advantage of the rapid sampling cycle.

Global lightning distribution data are of importance in atmospheric chemistry due to the production of NO_x by lightning. The permanent observation of lightning in combination with other satellites observing nitrogen compounds and ozone (GOME, TOMS) can be input in chemical transport models for climatologic research and chemical weather forecast.

5.2 Combination with other Lightning Data

The combination of the satellite lightning date with data from ground based systems can be used for cross validation. For the geostationary lightning data this combination gives the possibility to extract the CG lightning from the total lightning data.

The combination of the lightning data from several geostationary platforms can provide a global lightning data set. The large overlap of the fields of view result in a redundancy, which can be used for validation and improvements in detection efficiency and accuracy.

6 Further Concepts for Satellite Based Lightning Location

Following the NASA optical sensor development other concepts basing on optical or RF detection from low or high orbits were developed. These concepts are at different stages of realisation. A few of them are listed in the following.

6.1 VHF Location by Direction Finding

Lightning location using VHF detection and interferometry from a single satellite is being developed by the ORAGES project (Bondiou-Clergerie et al., 1999). The proposed method is similar to the lightning location used in ground based SAFIR location systems. This project is planned to operate

on a low orbit satellite. The transformation of this technique to geostationary orbit would require a very large antenna size of several metres (Laroche, pers. communication).

Another location technique for low orbits was proposed by Jacobson and Shao (2002). This 'power-ratio geolocation technique' analyses the polarization components and takes advantage of the motion along orbit for larger synthetic aperture. The estimated accuracy is in the order of 100-500 km.

6.2 Time of Arrival for Several Orbits

Suszcynsky et al. (2000) presented the idea of global lightning detection by a multi-satellite system on GPS orbits equipped with a FORTE sensor package which is able to detect VHF. Lightning location can be performed by a time of arrival (TOA) method employing the data from several satellites. A minimum of 3 satellites is required and several ground stations for real time data transmission. The method also needs high time resolution of the detected signals in the order of few microseconds. Preliminary studies on data from low orbits showed that a combined analysis of optical and RF measurements enables the discrimination between the CG and IC lightning.

7 Conclusions

A optical sensor on a geostationary orbit is able to detect and locate lightning over a full hemisphere. An appropriate sensor construction provided, such an instrument will be able to detect total lightning with a high detection efficiency (app. 90%) and location accuracy (8-10 km). The data can be available in quasi-real time with time resolution of few milliseconds.

The main advantage of such a sensor comes from the hemispheric coverage with uniform, homogeneous observation of lightning over land and ocean. In contrast to many ground based systems, this instrument detects both intracloud and cloud-to-ground lightning thus permitting a more complete recording of the electrical activity in convective clouds.

Very likely, the expected benefit is high compared with the estimated costs for this type of sensor. Many application fields in the weather services, industries and science will definitely benefit from the new data.

The total lightning data from this instrument can be advantageously used for nowcasting of storms in combination with other weather observing techniques. For climate observation and monitoring it enables first time the contiguous detection of tropical and oceanic lightning with high geographical resolution.

A geostationary lightning sensor will not replace the ground based systems. It will rather fill a gap, since it provides data, where ground based data do not exist at all, and will very likely not be available in the prospected future. In regions with existing ground data it gives additional total lightning information not detected currently from the most ground based systems.

Great benefits would arise from simultaneous operation of several geostationary lightning sensors. If the same technique is applied, the data can be easily integrated into a complete global data set. Large redundancy from overlap areas have the potential for quality enhancement.

8 Acknowledgements

We acknowledge gracefully the provision of information and helpfully discussion which were given in interviews and email communication by S. Senesi (Meteo-France), H. Christian (NASA), S. Thern (Siemens AG, BLIDS), P. Richard (Vaisala), P. Laroche (ONERA), G. Diendorfer (ALDIS), F. Montariol (Meteo-France), T. Kratzsch (DWD).

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Appendices

A Abbreviations

ALDF	Advanced Lightning Direction Finder
ALDIS	Austrian Lightning Detection and Information System
DE	Detection Efficiency
EUCLID	European cooperation on Lightning Detection
FORTE	Fast On-orbit Recording of Transient Events
FOV	Field of View
GAI	Global Atmospheric Inc. (now Vaisala-GAI)
GOES	Geostationary Operational Environmental Satellite
IMPACT	IMProved Accuracy from Combined Technology
LANL	Los Alamos National Laboratory
LF	Low Frequency (30 kHz – 300 kHz)
LIS	Lightning Imaging Sensor
LISDAD	Lightning Imaging Sensor Data Application Display
LLP	Lightning Location and Protection
LLS	Lightning Location System
LMS	Lightning Mapping Sensor
LPATS	Lightning Positioning and Tracking System
MSG	Meteosat Second Generation
NASA	National Aeronautic and Space Administration
NLDN	National Lightning Detection Network (USA)
ONERA	Office National d'Etudes et de Recherches Aérospatiale
OTD	Optical Transient Detector
OLS	Optical Lightning Sensor (on FORTE)
RF	Radio Frequency
SAA	Southern Atlantic Anomaly
SAFIR	Surveillance et Alerte Foudre par Interférométrie Radioélectrique
TOA	Time of Arrival
VHF	Very High Frequency (30 MHz – 300 MHz)