ON THE RELEVANCE OF LIGHTNING IMAGERY FROM GEOSTATIONARY SATELLITE OBSERVATION FOR OPERATIONAL METEOROLOGICAL APPLICATIONS

Convective activity  
(covered areas, cloud tops, precipitation, ice content, updraught speed…)

Cloud electrification  
(microphysical processes, dynamics, initiation processes…)

Lightning

Present lightning detection

Ground based networks  
large continental surfaces (developed countries)

Detection from space  
mostly optical detection from orbiting satellites

WHAT SHOULD BE THE DETECTION FROM GEOSTATIONARY PLATFORMS?
WHAT DOES "LIGHTNING DETECTION" MEAN?

- time of flash occurrence
- flash "location"
- flash type
- some flash characteristics (current, multiplicity …)
- ………

Determine

MAIN CHARACTERISTICS OF A LIGHTNING FLASH

Intra-Cloud flashes (IC) stay within cloud – from 70 to 80 %

Cloud-to-Ground flashes (CG) connect to ground – from 20 to 30 %

Conceptual model of lightning initiation and development

Phases:

Bi-leader
  weak currents, low velocities
Recoil streamer (IC)
  high currents, high velocities
Return stroke (CG)
  high currents, high velocities

Effects:

Temperature up to 30000 K
Thunder
Luminosity
Electromagnetic radiation
GEOMETRICAL EXTENSION OF A FLASH

Vertical extension

IC and CG flashes can extend from ground up over the tropopause

Horizontal extension

The intracloud trajectory of a flash (IC or CG) can reach considerable distances.

CONCLUSION

Most flashes develop over distances exceeding the horizontal resolution of detection systems.

Only a CG ground impact can be determined with a high resolution.
TIME SCALE AND SPATIAL DETECTION

Lightning activity → Transient event (from ms to 2 s)

Time scale different from other meteorological observables (temperature, humidité, clouds, vegetation)

GROUND DETECTION

Constant observation of a given area → monitoring of lightning activity

SPACE DETECTION

Present systems (orbiting satellites) → sampling of activity

Future geostationary systems:
- Constant observation
- Image Scanning
LIGHTNING CLIMATOLOGY
Available from OTD optical data

Detection from orbiting satellite adapted to climatological study
RELATIONSHIP BETWEEN LIGHTNING ACTIVITY AND OTHER METEOROLOGICAL CHARACTERISTICS

PRECIPITATION OF CONVECTIVE SYSTEMS
August, 17th, 1997, Ile de France Area (Soula and Chauzy, 2001)

Radar cumulative rainfall estimation (mm)

Rainfall volume per flash:
CG+ : $657 \times 10^3$ m$^3$
CG- : $38 \times 10^3$ m$^3$
Flash : $9.7 \times 10^3$ m$^3$

CG flash-estimation (mm)

Total flash-estimation (mm)
CLOUD ICE CONTENT

Ice crystal in the anvils of thunderstorms ➔ climatological importance

TRMM Platform
LIS Lightning Imaging Sensor
TMI Microwave Imager
several microwave radiometers: (10.7; 19.4; 22.2; 37; 85.5GHz)

Brightness temperature $T_B$/ lightning frequency $G$

85 GHz
Ice crystal
Relationship with lightning frequency

37 GHz
Ice Precipitation
Relationship with lightning frequency

From Blyth et al., 2001
Close correlation between climate change and lightning activity

Lightning activity from tropics

Schumann resonance =
global tropical thermometer
(Williams, 1992)

+ 3°C in coastal zone of Pacific Ocean near the equator

+ 100–150 % in lightning days
+ 200 % in lightning hours
in Gulf of Mexico (LIS data; Goodman et al., 2000)
## Comparing Performances and Limitations

<table>
<thead>
<tr>
<th>Systems Parameters</th>
<th>IMPACT (TOA-DF)</th>
<th>IMPACT ESP (TOA-DF)</th>
<th>LDAR (TOA)</th>
<th>ATD (TOA-DF)</th>
<th>SAFIR Interferometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection efficiency</td>
<td>80-90 %</td>
<td>&gt; 90 %</td>
<td>&lt; 50 %</td>
<td>&lt; 50 %</td>
<td>90 %</td>
</tr>
<tr>
<td>Horizontal resolution</td>
<td>0.5 – 1 km</td>
<td>&lt; 0.5 km</td>
<td>1 km</td>
<td>2 km - 100 km</td>
<td>1 km</td>
</tr>
<tr>
<td>Time sampling level 1</td>
<td>1 ms</td>
<td>&lt; 1 ms</td>
<td>0.1 ms</td>
<td>0.45 s</td>
<td>0.1 ms</td>
</tr>
<tr>
<td>Detected events</td>
<td>CG</td>
<td>CG and IC</td>
<td>VHF Sources</td>
<td>CG</td>
<td>VHF Sources</td>
</tr>
<tr>
<td>Ocean detection</td>
<td>Possible</td>
<td>Possible</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
## Operational and Research Applications

Lightning detection aids at

<table>
<thead>
<tr>
<th>Research</th>
<th>Operational</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climatology studies</td>
<td>Forest or building fire</td>
</tr>
<tr>
<td>Lightning phenomenology</td>
<td>Flash flood and hail nowcasting</td>
</tr>
<tr>
<td>Electrification mechanisms</td>
<td>Accident identification (persons, cattle, aircrafts…)</td>
</tr>
<tr>
<td>Correlations with meteorological parameters</td>
<td>Risk prevention for outside activities</td>
</tr>
<tr>
<td>Discrimination of flash types</td>
<td>Special care for airport activities</td>
</tr>
</tbody>
</table>
DETECTION FROM SPACE

EARLY WORKS

Radio frequency detection started in the mid-sixties
Optical detection in the mid-seventies
First films and pictures of TLE’s (Sprites and Jets), late eighties
Maps of global lightning activity (Optical Linescan System)

Weak localization accuracy (100 km)

RECENT OR PRESENT WORKS

All systems are installed on orbiting satellites
Two general detection procedures

Optical (OTD, LIS, partial FORTE)
Electromagnetic (Partial FORTE)

PRINCIPAL PROJECTS

Optical detection

Lightning Mapper Sensor (LMS) – Geostationary platform

Electromagnetic detection

ORAGES (Interferometry) – Orbiting satellite

Global Lightning and Severe Storm Monitor (Difference Of Time of Arrival) – Satellites constellation (GPS)
OPTICAL TRANSIENT DETECTOR
NASA

Satellite

Period : 100 minutes
Altitude : 740 km
Pictures 400 separate 3-minute observations/year

Sensor

Field of view : 1300 km x 1300 km (128 x 128 pixels)
Spatial and temporal resolutions : 10 km, 2 ms
Detection efficiency : from 40 % to 65 %

Products

Events → Groups → Flashes → Areas

<table>
<thead>
<tr>
<th>Orbits</th>
<th>3039</th>
</tr>
</thead>
<tbody>
<tr>
<td>Areas</td>
<td>152156</td>
</tr>
<tr>
<td>Flashes</td>
<td>845857</td>
</tr>
<tr>
<td>Groups</td>
<td>4105432</td>
</tr>
<tr>
<td>Events</td>
<td>8574078</td>
</tr>
</tbody>
</table>

Flash scale

January 1, 1999 – December 31, 1999
## LIGHTNING IMAGING SENSOR
### NASA

### PERFORMANCE CRITERIA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel IFOV</td>
<td>5 km</td>
</tr>
<tr>
<td>Total FOV</td>
<td>$80^\circ \times 80^\circ$ (600 km x 600 km)</td>
</tr>
<tr>
<td>Wavelength</td>
<td>774.4 nm</td>
</tr>
<tr>
<td>Radiant energy threshold</td>
<td>$4.7 , \mu$J m$^{-2}$ sr$^{-1}$</td>
</tr>
<tr>
<td>SNR</td>
<td>6</td>
</tr>
<tr>
<td>Array size</td>
<td>$128 \times 128$ pixels</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>$&gt; 100$</td>
</tr>
<tr>
<td>Detection efficiency</td>
<td>$&gt; 90 %$ of all events</td>
</tr>
<tr>
<td>False alarm rate</td>
<td>$&lt; 10 %$ of total events</td>
</tr>
<tr>
<td>Measurement accuracy</td>
<td>Location: 1 pixel</td>
</tr>
<tr>
<td></td>
<td>Intensity: 10 %</td>
</tr>
<tr>
<td>Weight</td>
<td>20 kg</td>
</tr>
<tr>
<td>Power</td>
<td>25 W</td>
</tr>
<tr>
<td>Telemetry</td>
<td>Data rate: 6 kb/s</td>
</tr>
<tr>
<td></td>
<td>Format PCM</td>
</tr>
<tr>
<td></td>
<td>Sample size: 12 bits</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>-25°C to +40°C</td>
</tr>
</tbody>
</table>

### Diagram

The diagram shows a map with various lightning strike locations and intensity levels. The scale is indicated with a color-coded legend and a flash count for the year 2000.
ELECTROMAGNETIC DETECTION

FORTE
(Fast Onboard Recording of Transient Events)

LOS ALAMOS NATIONAL LABORATORIES

Satellite 800 km altitude – 100-minute revolution period

THREE SENSORS:

OPTICAL

1. Fast-time response photodiode detector (PDD) – Footprint 1200 km – 0.4 to 1.1 μm

2. 128 x 128 pixel CCD array imager, same f-o-v as PDD – 0.77 μm

ELECTROMAGNETIC

3. Two broadband receivers: use sub-bands 26 – 48 MHz, 118 – 140 Mhz
Log-periodic antenna, nadir directed.
“Field-of-view” ≈ 1200 km
Time resolution: 20 ns

BASIC FUNCTION

1. CCD array provides localization of lightning EM sources
2. VHF instrumentation analyses its characteristics

Trans-ionospheric pulse pairs (TIPPs)
PROJECTS

ORAGES
(Observation Radioélectrique et Analyse Goniométrique des Eclairs par Satellite)
(CNES ONERA LA)

Principle: Electromagnetic Interferometry

Installed on an orbiting satellite

Function: detection, localization, and time sampling of VHF emission

F-o-v: 1000 km x 1000 km

Horizontal resolution: 15 km

Retrieved parameters:

- Lightning channel reconstruction
- Evaluation of total lightning length
- Discrimination between ICs and CGs
- Determination of flash phase from the type of emission

Example of lightning activity retrieved from ground interferometer (Florida thunderstorm 08/14/1992)
LIGHTNING MAPPER SENSOR

NASA

OBJECTIVE: Fly an optical lightning sensor on a GOES spacecraft, in order to:

1. Measure total lightning activity on a continuous basis over the continental United States, Central and South America and portions of the adjoining oceans.
2. Develop an extensive lightning climatology to be used for global change research.
3. Deliver, on a real time basis, lightning measurements for operational storm monitoring and severe weather warning.

LMS Performance Criteria

- **pixel IFOV**: 8 km (at nadir)
- **FOV**: 8 degree x 5 degree FOV
- **Wavelength**: 777.4 nm
- **Threshold**: < 4.0 J m⁻² sr⁻¹
- **SNR**: 6
- **array size**: 700 x 560 pixels
- **dynamic range**: > 100
- **detection efficiency**: > 90% of all events
- **false alarm rate**: < 5% of total events
- **measurement accuracy**
  - **location**: 1 pixel
  - **intensity**: 10%
  - **time**: tag at frame rate
- **weight**: 35 kg
- **power**: 100 watts
- **telemetry**
  - **data rate**: 80 kb/s
  - **format**: PCM
  - **sample size**: 12 bits
- **operating temperature**: -10 to +40 °C
<table>
<thead>
<tr>
<th>SCIENCE REQUIREMENT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Large Area Coverage</strong></td>
<td>Monitor lightning in the tropics, extra tropics to 50° latitude over both land and water</td>
</tr>
<tr>
<td></td>
<td>Provide data sets from as many areas of the globe that will assure unbiased performance statistics; assure operations over calibration/validation sites.</td>
</tr>
<tr>
<td><strong>High Detection Efficiency</strong></td>
<td>Estimate the total lightning activity of each storm.</td>
</tr>
<tr>
<td></td>
<td>Used for inferring convective activity, mixed phase precipitation, etc.</td>
</tr>
<tr>
<td><strong>Low False Event Rates.</strong></td>
<td>Accurately detect only lightning events.</td>
</tr>
<tr>
<td></td>
<td>Less than 5% of total events Minimize ground based processing</td>
</tr>
<tr>
<td><strong>Measurement Sensitivity.</strong></td>
<td>$3.8 \times 10^{-6} \text{ J m}^{-2} \text{ um}^{-1} \text{ sr}^{-1}$ (preferred) $4.7 \times 10^{-6} \text{ J m}^{-2} \text{ um}^{-1} \text{ sr}^{-1}$ (acceptable).</td>
</tr>
<tr>
<td></td>
<td>The sensitivity numbers include 6 dB of SNR margin.</td>
</tr>
<tr>
<td><strong>Dynamic Range</strong></td>
<td>&gt; 2 orders of magnitude.</td>
</tr>
<tr>
<td></td>
<td>After background subtraction, the system must maintain greater than 2 orders of magnitude dynamic range for lightning detection.</td>
</tr>
<tr>
<td><strong>Spatial Resolution</strong></td>
<td>Identify individual convective cell</td>
</tr>
<tr>
<td></td>
<td>8 km at nadir</td>
</tr>
<tr>
<td><strong>Contiguous Observations</strong></td>
<td>Continuous observation of the monitored area.</td>
</tr>
<tr>
<td><strong>Single Wavelength Operation</strong></td>
<td>Daytime lightning detection.</td>
</tr>
<tr>
<td></td>
<td>7774 Å</td>
</tr>
<tr>
<td><strong>Radiometric Measurement</strong></td>
<td>Determine lightning intensity</td>
</tr>
<tr>
<td></td>
<td>Measure to 10% accuracy</td>
</tr>
<tr>
<td><strong>Continuing current</strong></td>
<td>Detect and quantize continuing current</td>
</tr>
<tr>
<td></td>
<td>Do not update background during active pixel periods</td>
</tr>
<tr>
<td><strong>Data compression</strong></td>
<td>High event rate throughput</td>
</tr>
<tr>
<td></td>
<td>Multiple dimension, adjacent pixel compression</td>
</tr>
<tr>
<td><strong>Platform Attitude</strong></td>
<td>Earth viewing</td>
</tr>
<tr>
<td><strong>Command and Control</strong></td>
<td>Must be able to: select subarray(s), adjust threshold, select image area</td>
</tr>
<tr>
<td></td>
<td>Map 20 subregions to 16 RTEPs preferred RTEP readout.</td>
</tr>
<tr>
<td><strong>Pointing Accuracy</strong></td>
<td>Locate lightning to specific cell</td>
</tr>
<tr>
<td></td>
<td>110 microradians</td>
</tr>
<tr>
<td><strong>Pointing Knowledge</strong></td>
<td>Locate lightning to specific cell</td>
</tr>
<tr>
<td></td>
<td>40 microradians</td>
</tr>
</tbody>
</table>
## Comparing Performances

<table>
<thead>
<tr>
<th>System Parameters</th>
<th>C-G ground detection</th>
<th>Total lightning ground detection</th>
<th>OTD</th>
<th>LIS</th>
<th>FORTE</th>
<th>ORAGES</th>
<th>LMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection efficiency</td>
<td>&gt; 90 %</td>
<td>&gt; 90 %</td>
<td>40 % to 65 %</td>
<td>&gt; 90 %</td>
<td>&gt; 90 %</td>
<td>&gt; 90 %</td>
<td>&gt; 90 %</td>
</tr>
<tr>
<td>False alarm rate</td>
<td>10 %</td>
<td>10 %</td>
<td>5 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal resolution</td>
<td>0.5 km to 1 km</td>
<td>10 km</td>
<td>3 km to 6 km</td>
<td>10 km</td>
<td>15 km</td>
<td>8 km</td>
<td></td>
</tr>
<tr>
<td>Time sampling level 1</td>
<td>1 ms</td>
<td>0.1 ms</td>
<td>2 ms</td>
<td>2 ms</td>
<td>RF: 1.3 ms Opt.: 2 ms</td>
<td>?</td>
<td>2 ms</td>
</tr>
<tr>
<td>Time sampling level 2 (average)</td>
<td>Not relevant</td>
<td>Not relevant</td>
<td>24 h</td>
<td>24 h</td>
<td>24 h</td>
<td>24 h</td>
<td></td>
</tr>
<tr>
<td>Detected events</td>
<td>CG</td>
<td>CG / IC</td>
<td>CG / IC</td>
<td>CG / IC</td>
<td>CG / IC</td>
<td>CG / IC</td>
<td>CG / IC</td>
</tr>
<tr>
<td>CG / IC discrimin.</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>Ocean detection</td>
<td>Limited</td>
<td>Limited</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
</tbody>
</table>

### Remark about time sampling

There are two levels of time sampling:

1. The first one corresponds to the inhibition period during which the sensor detects and processes a flash signature and cannot record a new event occurring during this period within its detection area;

2. The second one relates to space detection from orbiting or spinning satellites and corresponds to the period of time between two passages of the sensor field-of-view over a given region.
FEASIBILITY OF LIGHTNING DETECTION FROM GEOSTATIONARY PLATFORM

VALUE ADDED

1. DETECTION OVER OCEANIC AND LAND MASSES

Ground networks cover limited oceanic areas (with lower detection efficiencies and lower resolution)

Geostationary detection should provide for land and ocean areas:
- equal detection efficiency
- equal horizontal resolution

2. LARGE GLOBAL AREA HOMOGENEOUSLY COVERED

Ground networks have different characteristics.

Geostationary detection provides homogeneous measurements over large areas.
- Optical detection allows limited areas selections
- Electromagnetic detection does not select from the Earth disc.

3. THEORETICAL POSSIBILITY TO FOLLOW A GIVEN THUNDERSTORM EVENT

Like ground detection networks and unlike orbiting satellite observation

- Geostationary detection can follow a given event

To do so, the sensor must constantly observe the same area

- Electromagnetic detection can not undergo any spin-up.
- Optical sensor: a spin-up (100 rpm) would produce a sampling of lightning activity (Under MSG conditions, an area 9 km x 9 km would be observed 21 μs during one line scan.)
THEORETICAL POSSIBILITY OF FOLLOWING A GIVEN THUNDERSTORM

NECESSARY TIME SAMPLING CHARACTERISTICS:

**SAMPLING DURATION**

- > 90 s for flash rate measurement

**SAMPLING PERIOD**

- < 250 s for limiting the horizontal motion of the storm between 2 samples

TOTAL SAMPLING TIME PER DAY FOR A GIVEN AREA

About 8 hours and 40 minutes

MSG (spinning geostationary platform): 6 ms/day
OTD (orbiting platform): 180 s/day
LIS (orbiting platform): 90 s/day
VARIOUS POSSIBLE SYSTEMS:

**OPTICAL DETECTION**

One system is planned to be used in space:

- LMS on a geostationary platform (NASA)

ADVANTAGES

1. **Tested and reliable technology for operational task**
   Successful observations with OTD and LIS on orbiting satellites
   Operational detection efficiency of 90%

2. **Simplicity and compactness**
   No large antenna to deploy

3. **Flash luminous intensity**
   Possible relationship between flash luminous intensity and lightning current
OPTICAL DETECTION

DISADVANTAGES AND UNCERTAINTIES

1. Lightning location uncertainty:
   Strong scattering of light from thunderclouds
   Horizontal resolution limited by cloud tops illumination

2. Lightning characteristics unknown:
   No discrimination between IC and CG lightning
   No discrimination between CG+ and CG- lightning
   Peak current intensity and channel length undetectable

POSSIBILITY TO MEET USERS REQUIREMENTS

1. Accuracy:
   90% of HR and lower than 5% of FAR (LMS)
   Users requirements more than fully achieved

2. Horizontal resolution:
   Light scattering prevents from reaching horizontal
   resolution better than 8-10 km

3. Time sampling:
   Largely met with a staring imager (time processing of 2 ms
   after each event)
   15 min is too long for warning procedure
ELECTROMAGNETIC DETECTION

Two systems based on EM detection are planned to be used in space:

- DTOA for constellation of satellites (Los Alamos)
- VHF Interferometry (ORAGES)

Unique geostationary platform compatible only with VHF Interferometry
(DTOA needs long baseline)

ADVANTAGES-

1. Cloud transparency to VHF signals
   No limitation of resolution from cloud scattering
   No signal alteration

2. Possibility to discriminate flash types
   EM signature provides IC or CG (+ or -) characteristics

3. Possibility to determine lightning channel length
   Important for possible NOx estimation

4. Constant and uniform detection efficiency (day/night)
   No influence of background light
ELECTROMAGNETIC DETECTION

DISADVANTAGES AND UNCERTAINTIES

1. Received power
   Needs to be estimated in order not to limit detection to strong flashes.

2. Antennas deployment
   ORAGES dimension about 3 m

3. Possible influence of background EM noise
   Needs preliminary study – Choice of frequency range depends on background noise

POSSIBILITY TO MEET USERS REQUIREMENTS

1. Accuracy:
   90 % of HR and 10 % of FAR are required.
   If satisfactory power received and pattern recognition procedure can be met.

2. Horizontal resolution:
   Very difficult to meet 1 or 5 km from geostationary distance.
   May be not really useful (dimension of the flash event)

3. Time sampling: Largely met (level 1, better than 2 ms), but 15 min is too long for warning procedure.
**LIMITING FACTORS OF PLATFORM**

**Related to accuracy positioning**

<table>
<thead>
<tr>
<th>Horizontal resolution required</th>
<th>Necessary positioning accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 km</td>
<td>30 μrd</td>
</tr>
<tr>
<td>5 km</td>
<td>140 μrd</td>
</tr>
<tr>
<td>10 km</td>
<td>300 μrd</td>
</tr>
</tbody>
</table>

**NO SCANNING POSSIBLE**
SYNERGIES WITH OTHER SPACE OBSERVATION SYSTEMS

Lightning detection

+ 

Infrared observations
(temperature and height of cloud tops)

+ 

Diagnostic of convective areas with infrared and water vapour observations
(Global Convective Diagnostic, NOAA)

= 

Operational reduction of False Alarm Rate
Enhanced quality of warning message
POSSIBLE SYNERGIES WITH OTHER SPACE OBSERVATION SYSTEMS

Enhancement of the storm monitoring and prevision:

Precipitation radar (TRMM, Ushio et al., 2002)

Ground temperature and water vapour by radiometer (SEVIRI on MSG)

Cloud updraft velocity by Doppler radar

NO\textsubscript{x} production by lightning, impact on global climate change:

Gases detection with space sensors (like SCIAMACHY, MOPPIT)

Impact of pollution on lightning activity:

Aerosols detection with space sensors (like SCIAMACHY)
CONCLUSION

THE OPERATIONAL APPLICATIONS

Basic Relevance

- Detection on a global basis
- Simultaneous real time observation
- Detection of total lightning activity

1. Electrical discharges for fuel/explosive handling

   Warning benefits from
   - Total lightning detection
   - Short sampling period

2. Convection monitoring indicator of intensity and hail

   Nowcasting benefits from
   - Simultaneous real time observation
   - Flash type discrimination

3. Chemistry (NOx) and Climate change

   Sensor choice
   - Accuracy
   - Time sampling

   Not so critical for global estimation

   Benefits from channel length estimation by electromagnetic sensing of each thunderstorm event.
CONCLUSION

RECOMMENDATIONS

1. Lightning detection from geostationary satellite needs a non-rotating platform.
   Necessary for lightning rate determination

2. Users requirements are not really adapted to lightning detection from geostationary distance:
   Horizontal extensions of flashes usually exceed required resolution (1 to 5 km).
   Time sampling is not relevant to warning criteria (15 min is too long) and does not correspond to a still platform.
   Optical detection – light scattering from cloud keeps from reaching resolutions better than 10 km.
   Electromagnetic detection – resolution better than 10 km should be difficult to obtain from geostationary distance.

3. Choice between optical and electromagnetic detection
   | Optical | Operational efficiency |
   |         | Simplicity              |
   |         | Compactness             |
   | Electromagnetic | Provides more information: |
   |         | flash type – IC, CG + and – |
   |         | channel length,          |