New observation system for disaster monitoring with ground lightning networks and micro-satellite constellation

Yukihiro Takahashi
Space Mission Center (SMC)
Creative Research Institution (CRIS)
Hokkaido University
Torrential rainfall and Typhoon

Flooding paralyse Philippine capital Manila

“The flooding - neck-deep in some areas - forced tens of thousands of people to flee their homes, closing schools, offices and the stock exchange.”

BBC’s Kate McGeown: “Roads have been turned into rivers”
Monitoring and understanding **thunderstorm**
is the key for disaster prevention of torrential rainfall and typhoon

**Torrential rainfall**
flood, inundation

**Typhoon**  energy source = thunderstorm
flood, inundation
violent wind
high tide

**Lightning**
one of the main causes of internet trouble
electrical blackout
human life
wild fire
Thunderstorm is difficult object to observe --- it’s very strong but too tiny scale...

Geostationary Meteorological satellite: 0.5-1.0 km
C band radar: resolution ~1-2 km
How to monitor thunderstorms?

- Lightning observation on the ground
- On demand operation with micro-satellite
Charge distribution inside thunderstorm

Difficult to detect the inner structure of thunderstorm by existing networks
- AMEDAS (10 min., ~17 km)
- C band radar (5 min., ~1km)

(Piepgrass et al., 1982)
Lightning data assimilation for meteorological forecast model

Successful in aspect of rain intensity and distribution in US

[Mansell et al., 2007]
Typhoon predicted by lightning?

1 or 2 days shift  Price et al. [2007]

- Correlation ~0.82 !

We could predict intensity 1-2 days before.
Global ELF Observation network: GEON

![Map of GEON sites](image1)

**GEON sites**

<table>
<thead>
<tr>
<th>Location</th>
<th>Syowa(SYO)</th>
<th>Onagawa(ONG)</th>
<th>Esrange(ESR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>39.506°E, 69.018°S</td>
<td>141.483°E, 38.433°N</td>
<td>21.100°E, 67.833°N</td>
</tr>
<tr>
<td>Declination angle</td>
<td>-48.489°</td>
<td>-7.7°</td>
<td>-</td>
</tr>
<tr>
<td>Sampling frequency</td>
<td>400Hz</td>
<td>100Hz</td>
<td>-</td>
</tr>
<tr>
<td>Low pass filter</td>
<td>1Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High pass filter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data span</td>
<td>2003/08/01～2004/7/31 (Observation day: 300 days)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Global CG distribution (one year) by GEON

Negative
Negative events: 244,332

Positive
Positive events: 364,030

Averaged number of events in each grid [$\times10^{-3}/km^2/day$]

Number of events: Positive CG: 364,030, Negative CG: 244,332

Yamashita, Dr. Thesis, 2011
**Outdoor system**

**Dipole antenna:**
To measure electric field

**Loop antenna:**
To measure magnetic field

**Figure.** Dipole antenna (left panel) and loop antenna (right one) installed at Los Banos, Philippines.

10 K USD / site
Geolocation of lightning by Time-of-Arrival

ΔT₁
Difference of arrival timing between Tainan and Saraburi

ΔT₂
Difference of arrival timing between Saraburi and Pontianak

ΔT₃
Difference of arrival timing between Pontianak and Tainan

Example of geolocation based on 3 stations observation.
100 km-scale
Regional network

1000 km-scale
Asia / Nation-wide network
Lightning and Cloud

Figure. Lightning mapping on cloud data during 2010/12/01 17:00-18:00

117 events

Figure. Lightning mapping on cloud data during 2010/12/01 18:00-19:00

85 events

- Span: 2010/12/01 17:00-19:00
- Analyzed events: 202 events

by Kozo Yamashita
More detail observation with simpler and cheaper sensors

Plate-type sensor

- time constant (RC): 100ms
- sampling interval: 10ms
- height from ground: 15cm

100 USD / site

Weather resistance box

DCDC
GPS
logger
DC12V Battery

antenna

15cm

1m

15cm

amp

POWER
GROUND
SIGNAL
Multi-point observation campaign (2013/08/11-08/23)

- distributed at 4 km distance in 7km×7km range in mountain area
- 7 plate-type sensors and 1 field mill sensor
- lightning and rain drops are recorded on 3 days
estimated locations of discharges
(2013/08/15, 12:00-15:00)
Estimated velocity of rain band motion: 34m/s
spatial resolution is an order of few 100s m.

Negative pulses recorded at 4 sites
~15 sites are enough to cover big city area

Jakarta

Manila
A breakthrough occurred in 2014 in the utilization of very small satellites.

**Micro-satellite**
- Weight: 50kg
- Cost: 3-5M USD
- Quick fabrication (One year)
- On-demand operation based on User’s purposes

**Larger-satellite**
- Weight: 300kg - 6000kg
- Cost: > A few 100M USD
- Long period (>10 years)
- To carry heavy equipments
RISING-2 satellite survived the big earthquake on the table of a building in Tohoku University
RISING-2 (launched May 24, 2014)

Operation at lab. (or at home)
Typhoon 2014-#8 Nogree

Fish-eye camera of RISING-2

from geosynchronous orbit

Thermal Infrared Image by RISING-2
5m resolution color image
one of the best with 50 kg-class satellite
High Precision Telescope with Liquid Tunable Filter (HPT with LCTF)

- 1-m focal length, 10-cm dia. (F10), Case grain telescope
- 5-m resolution (659 x 494 pixels)
- 3-CCD (R,G,B) + Multi spectrum CCD
- Liquid Crystal Tunable Filter (LCTF)
  - range: 650 - 1050nm
  - 1-nm step selection (400 wavelengths)
  - order of 10s-msec switching time
- High sensitive (ISO8000)
- 1/50,000s min. exposure time
- light and strong stiffness CFRP structure
- zero-expansion high stiffness ceramic mirror (ZPF)

- Size:  W380xD161xH124mm
- Weight: < 3.0 kg

the world first super multicolor LCTF imager in space
Liquid Crystal Tunable Filter camera

Airborne Multicolor Imager (AMI)

Multispectral Camera
- Wide FOV lens
- High-sensitive CCD
- Liquid Crystal Tunable Filter (LCTF) for Visible
  - 190 x 100 x 100 mm
  - 1.3 kg

Camera controller
- 100-240 V AC input
- USB 2.0 interface
- 300 x 200 x 60 mm
- 2.0 kg

Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength range</td>
<td>420 - 700 nm</td>
</tr>
<tr>
<td>Band width (FWHM)</td>
<td>8 - 25 nm</td>
</tr>
<tr>
<td>Response time</td>
<td>&lt; 0.3 sec</td>
</tr>
<tr>
<td>Frame rate</td>
<td>&gt; 1 frame /sec</td>
</tr>
<tr>
<td>Number of pixels</td>
<td>659 x 494</td>
</tr>
<tr>
<td>Field of view</td>
<td>92 degree</td>
</tr>
</tbody>
</table>
Aircraft (UAV) campaign with AMI in Java (2012/10/29-31)

UAV developed and owned by BPPT
10/31 ~18:40
forest in the target area

flight direction of UAV
~ 30 m/s

2.5 m/pixel

@420 nm

18h:40m:08s:918ms

~1.2 km

~1.6 km
classification of species or monitoring condition for each tree...
NDVI (vegetation index) = forest and crops based on precise spectral imaging

the detection of detail effects of disaster, such as tsunami, sea water, volcano ... pollution caused by disaster, on crops or environment.
The world’s best resolution of spectral imaging

RISING-2
5 m/pixel

LANDSAT-8
30 m/pixel

(C) Google
Hyperspectral sensor

LCTF camera

185 wavelengths, 30 m/pixel

< 10 wavelengths, 5m/pixel
UNIFORM-1 satellite

by University Union in Japan

launched in May, 2014

HU is in charge of sensor and data analysis

dedicated to forest fire detection + monitoring of volcano

Thermal Infrared Image by UNIFORM-1

Mt. Ontake
28 September, 2014

the earliest satellite report at infrared wavelength
**Target Pointing** by precise attitude control

... most of big satellites make pushbroom scan by orbital motion...\textbf{1 time / 16 days}

- Flexible on-demand operation covering from nadir to horizon (>5000 km in diameter) enables \textbf{frequent visiting (2 times / day in daytime)}

- 3-D reconstruction

\begin{figure}
\centering
\includegraphics[width=\textwidth]{diagram.png}
\caption{Diagram of target pointing by precise attitude control.}
\end{figure}

10m resolution by micro-sat. 0.5-1km res. by meteorological sat.
~50 satellites realize continuous monitoring

- usually used for environmental research or agriculture/fisheries...
- once disaster happened, concentrate on the disaster area under international consortium
Asian Micro-satellite Consortium

sharing technologies, data and application methods

establishing standardization of sensors and BUS operating system

collaboration in making ground validation

being contacted universities, space agency, and government in Asian countries.

To be started with ~10 countries officially soon.
(now under the final correction of MOU)
Asian Micro-satellite Consortium
- to maximize the efficiency of space use
- to realize the super-constellation

**country A**
- BUS design
- payload design
- data utilization with GIS
  - forestry
  - wild fire management
  - agriculture
  - hydrology / marine
  - fishery
  - geography
  - climatology
  - disaster management
  - geospace science

**country B**
- BUS design
- payload design
- data utilization with GIS
  - forestry
  - wild fire management
  - agriculture
  - hydrology / marine
  - fishery
  - geography
  - climatology
  - disaster management
  - geospace science

**country C ...**

- Asian Micro-satellite Consortium
- to maximize the efficiency of space use
- to realize the super-constellation
Space Remote-sensing Alliance
promoted by Asian Micro-satellite Consortium

Philippines
Myanmar
representatives from 6 countries
Space Mission Center (SMC) of H.U.
Facilities for development and testing in microsatellite development lab.

One stop site for micro-satellite development

- Thermal chamber
- Thermal vacuum chamber
- Vibration test facility,
- Shock test facility,
- Radio wave darkroom

Class 100 clean booth and darkroom are available at Hokkaido Research Organization
Next generation disaster monitoring and prediction system

Asia / Nation-wide network

Regional network

City network

order of few km

order of 100 km

order of 1000 km

Public Alert

Data Processing

Internet
Let’s establish the world first disaster prevention system using lightning network and satellite constellation.