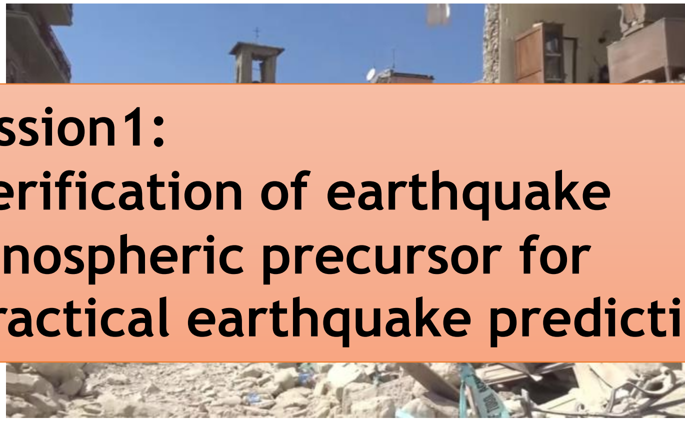
Microsatellites observing atmospheric and space electricity for the science of serious natural disasters: Challenge to their mitigations

Shoho Togo, Kikuko Miyata*, Hidetoshi Nitta, Shusaku Takahashi, Kohei Tanaka†, Tomohiro Okada, Yuko Suzuki, Yoshiaki Orihara, Masashi Kamogawa

Tokyo Gakugei University, * Nagoya University, †Sokendai (Japan)

Introduction

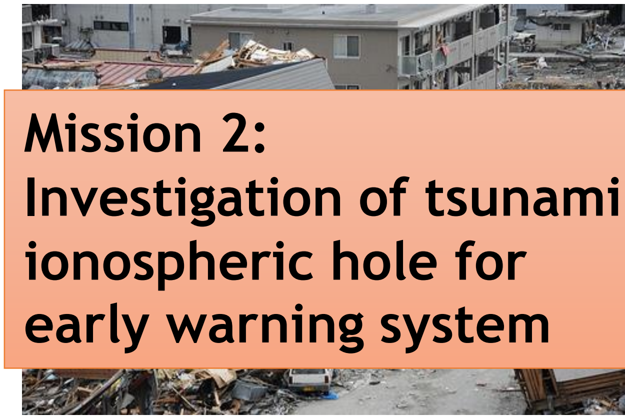
Earthquake



Mssion1:
Verification of earthquake ionospheric precursor for practical earthquake prediction

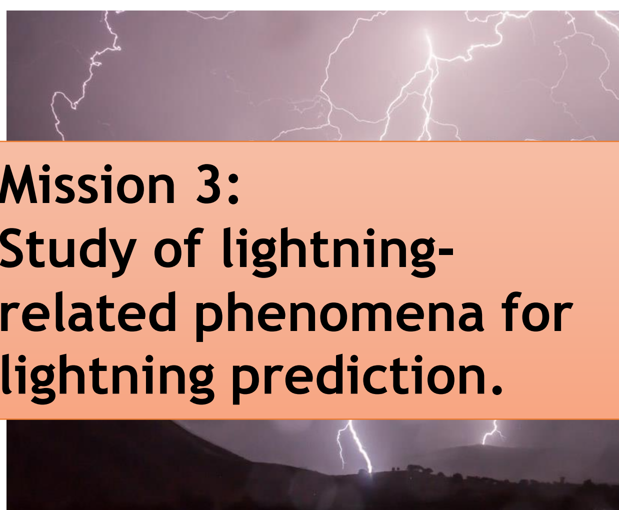
This photo is taken by Leggi il Firenzepost

Tsunami



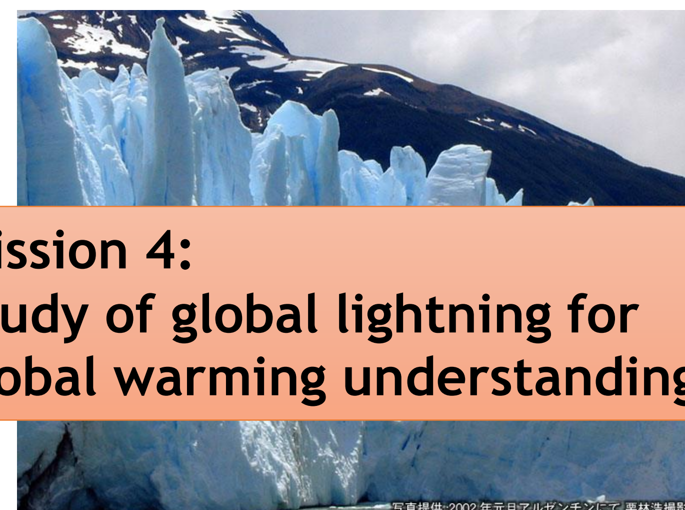
Mission 2:
Investigation of tsunami ionospheric hole for early warning system

Lightning



Mission 3:
Study of lightning-related phenomena for lightning prediction.

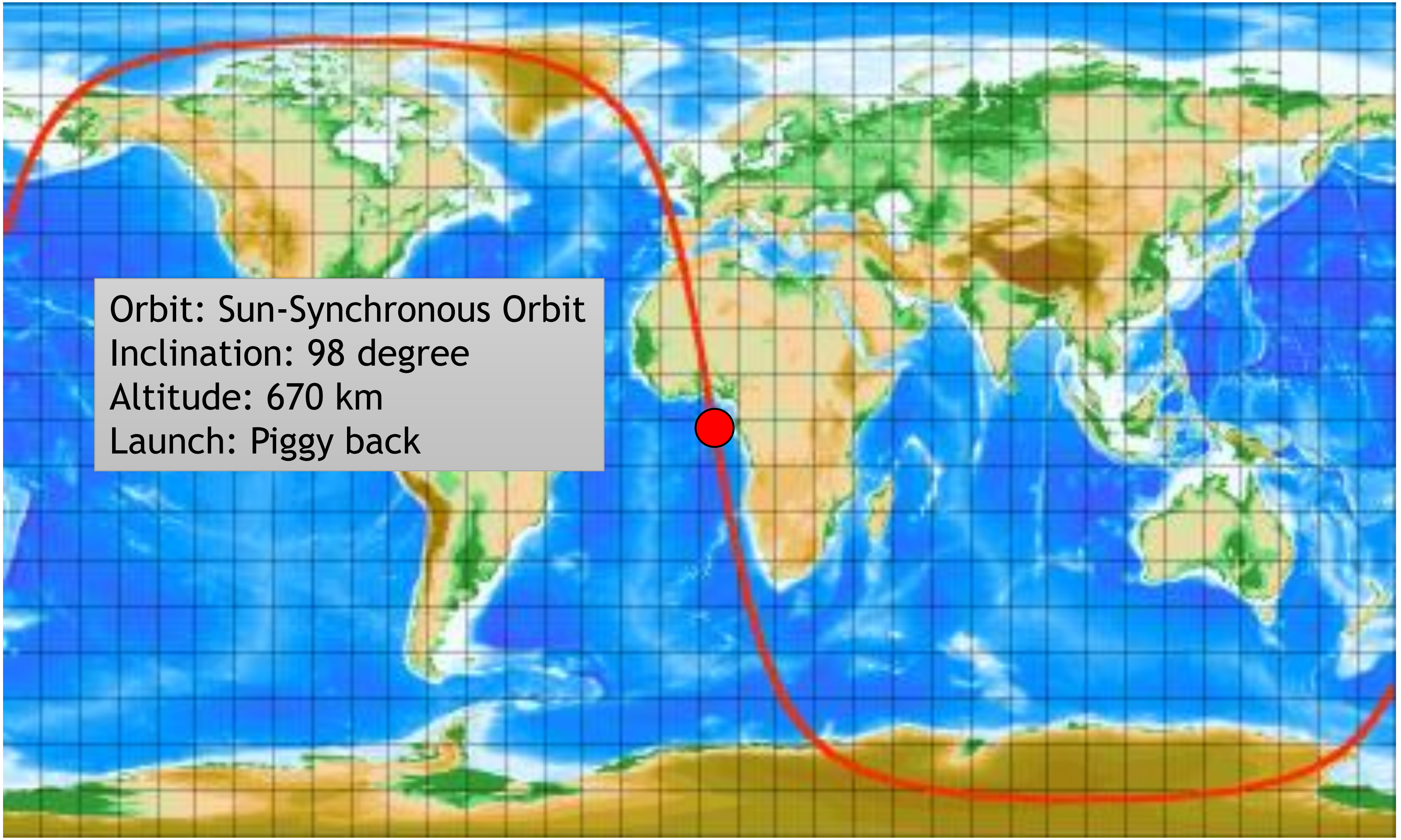
Global warming



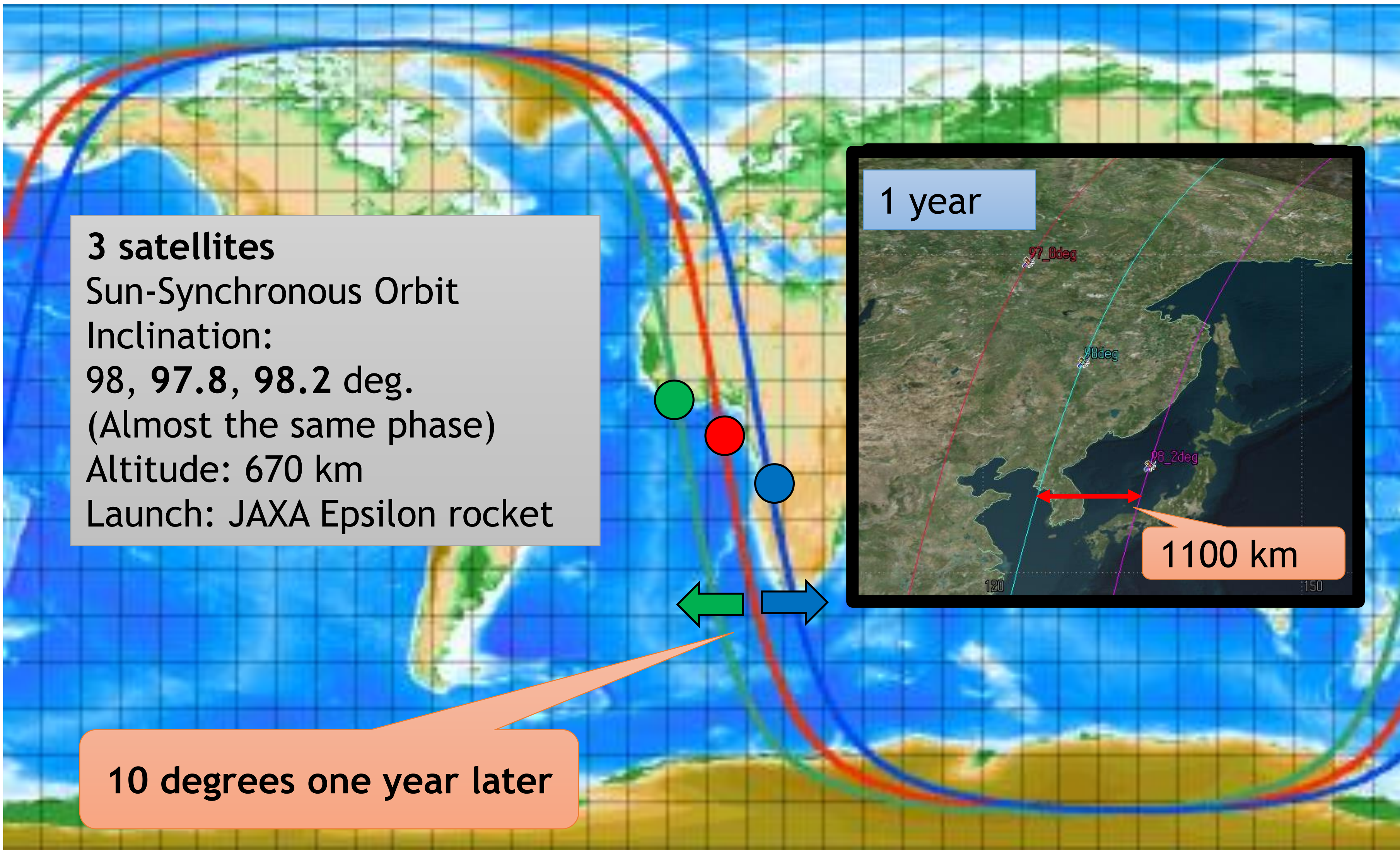
Mission 4:
Study of global lightning for global warming understanding

「全国地球温暖化防止活動推進センターホームページより （http://www.jccca.org/)」

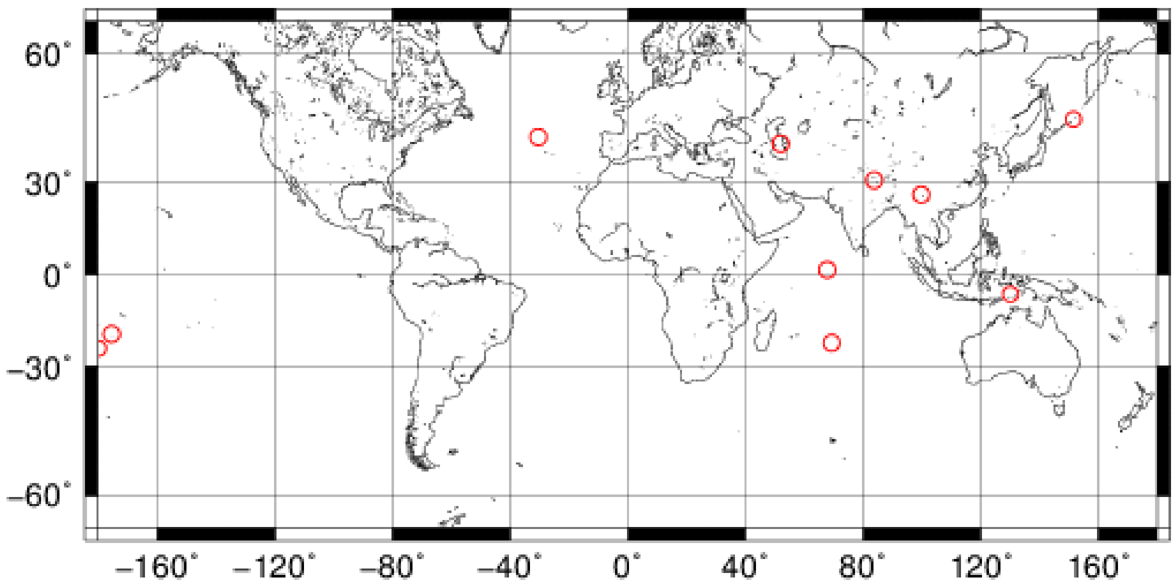
Plan A: Single satellite operation (Low cost plan)



Plan B: 3 satellites constellation (Integrated plan)



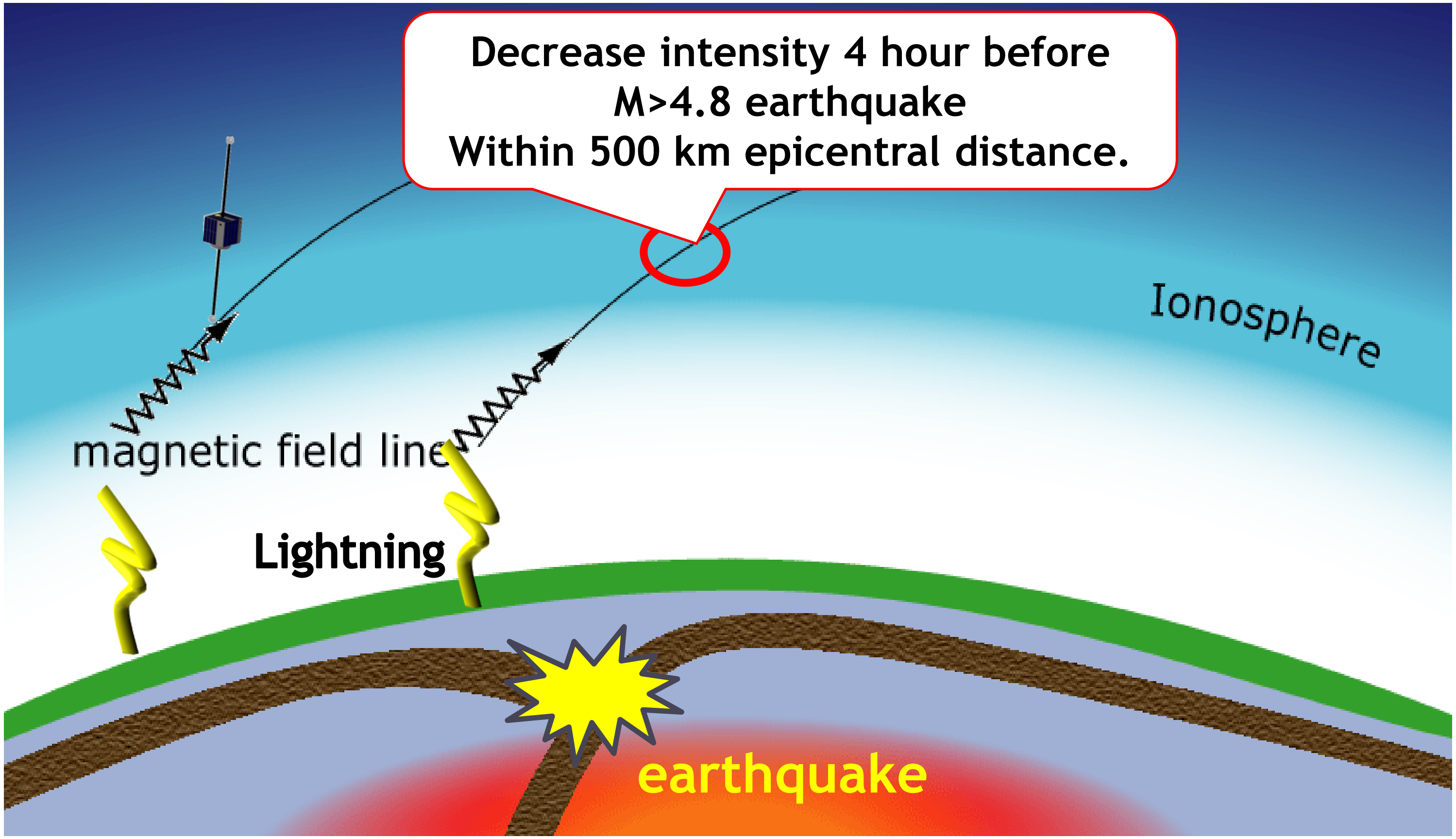
Mission 1 :
Verification of earthquake ionospheric precursor for practical earthquake prediction (EQ mission)



No reliable and frequently repeatable precursor for a long time.

Pre-seismic decrease of VLF wave intensity at nighttime

Nemec et al., Geophs. Res. Lett. (2008)
Kamogawa et al. (in preparation)



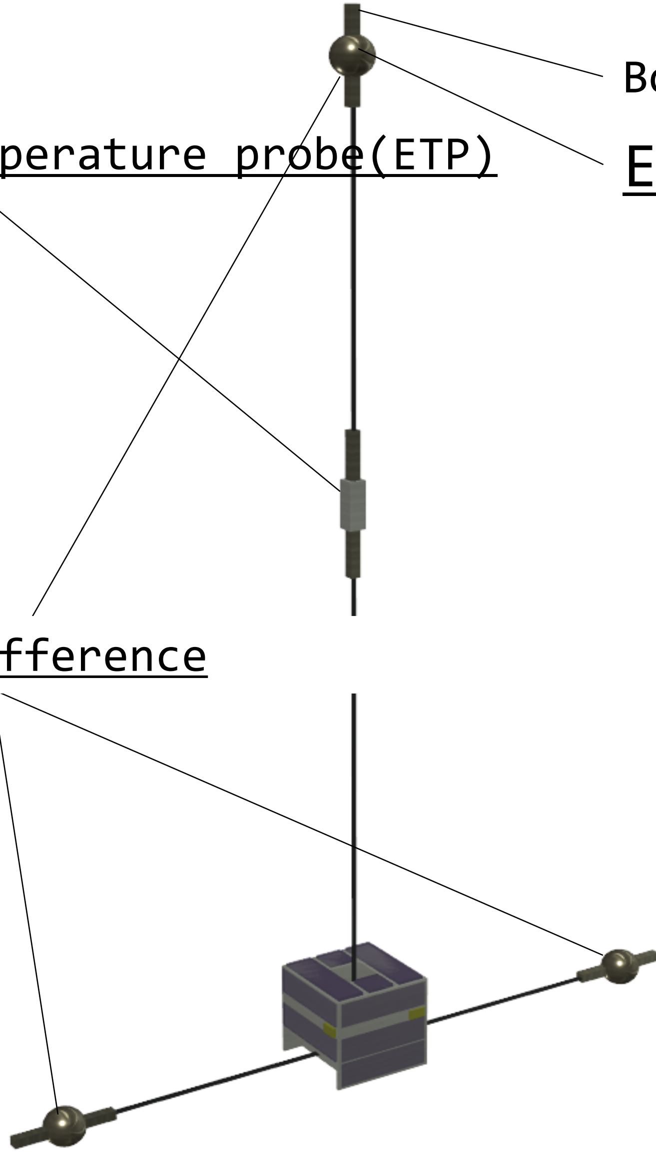
Mission system

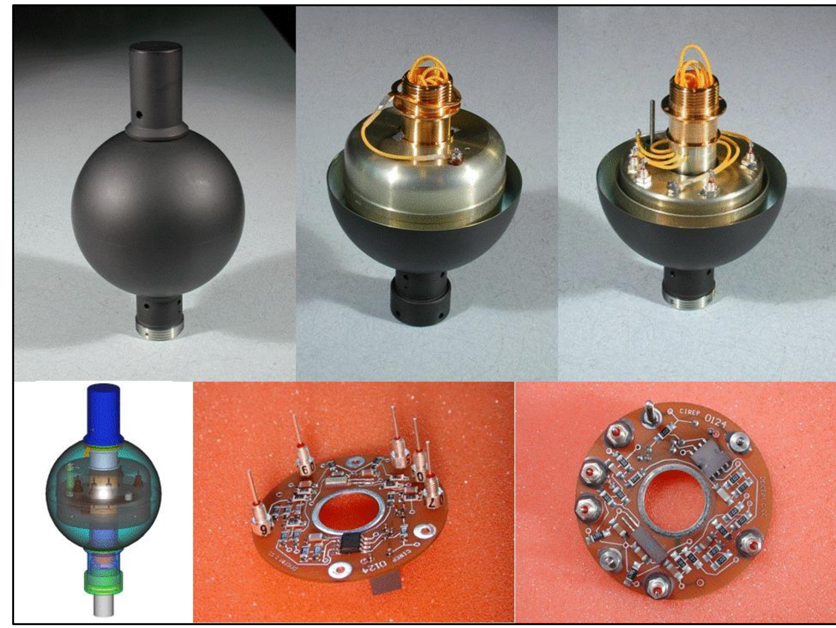
Bootstrap

Electric temperature probe(ETP)

Electric Field Probe (EFP)

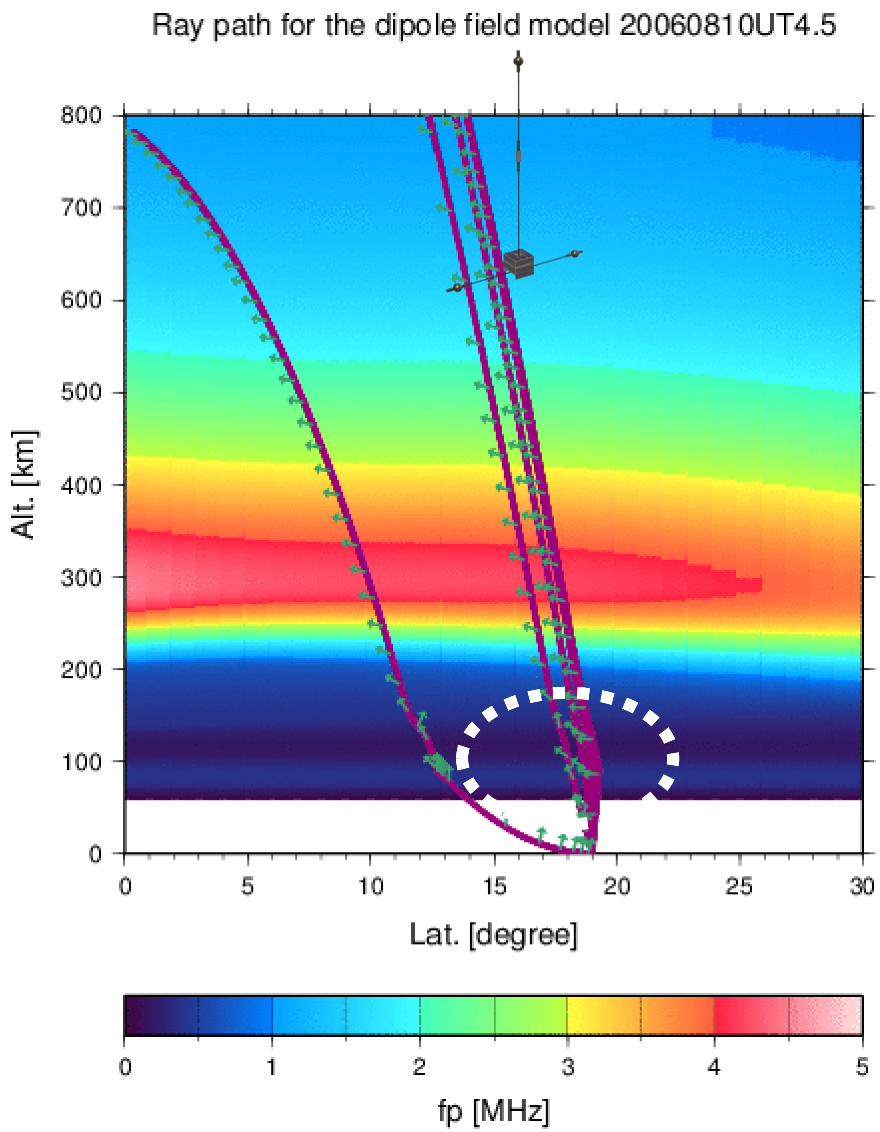
Potential difference measurement

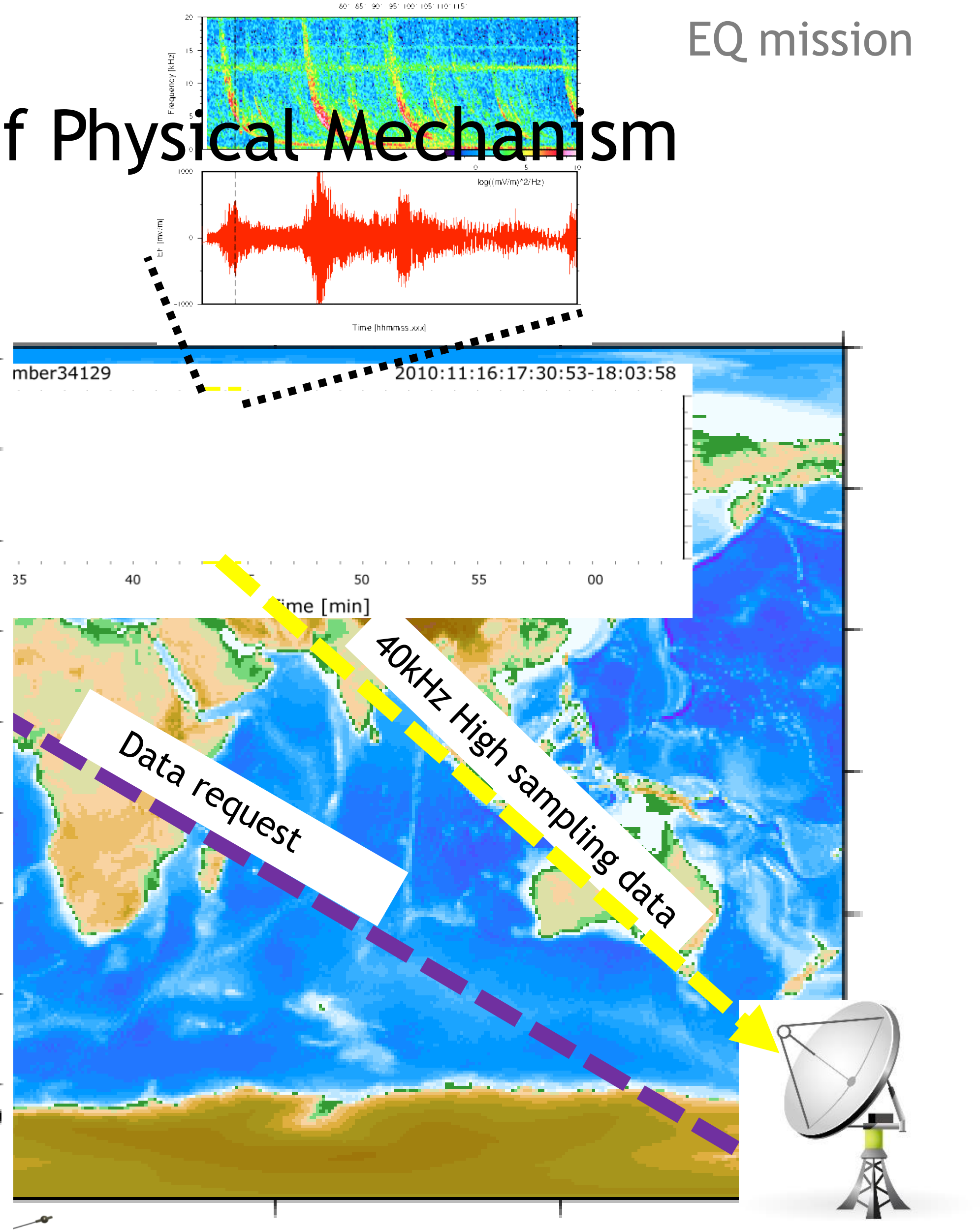




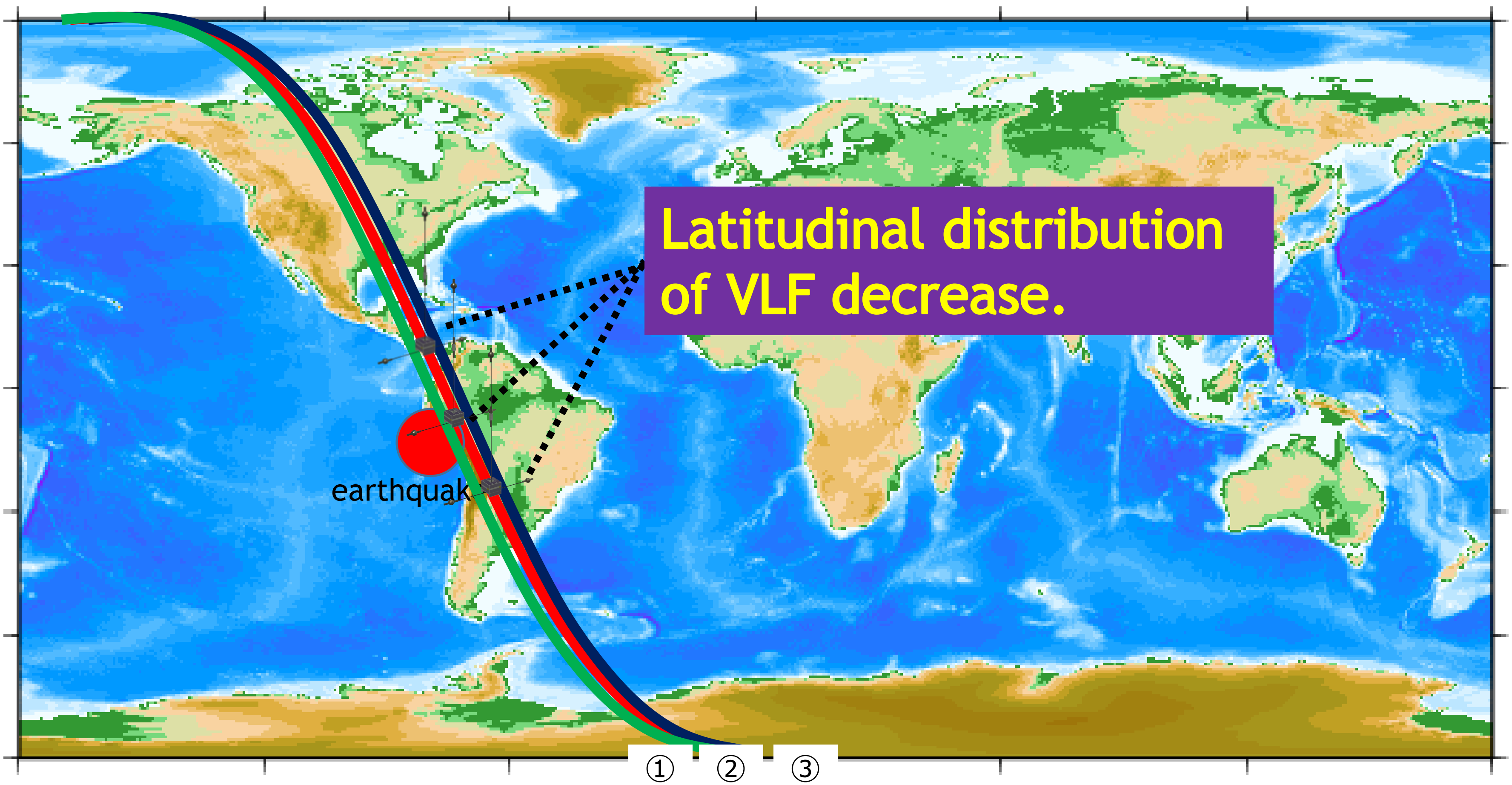
	Attitude **control** accuracy	Attitude **determination** accuracy
DC	1 deg.	7 deg.
AC	5 deg.	37 deg.

Plan A: Understanding of Physical Mechanism

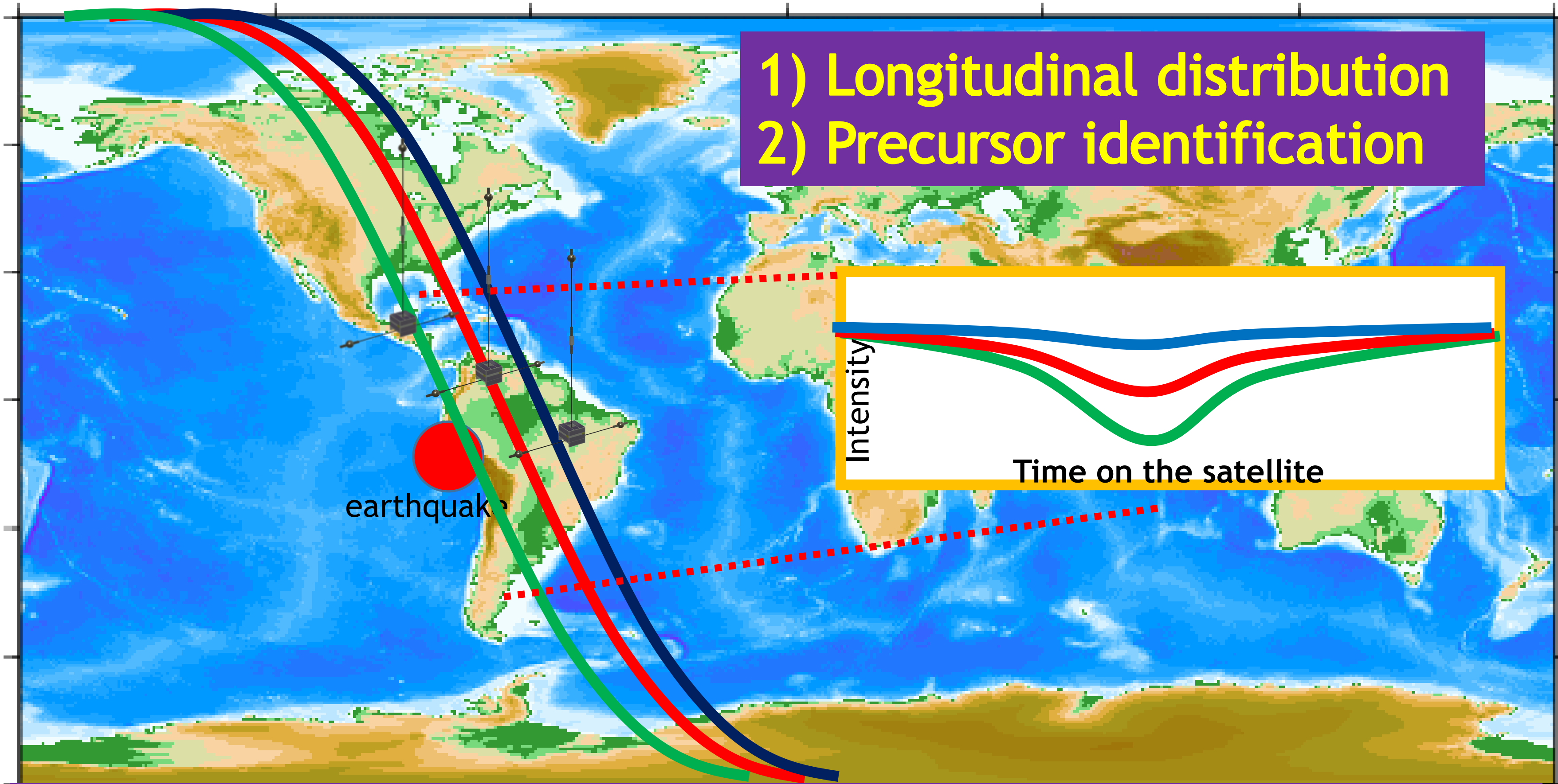




Plan B
Early phase: Investigation of Latitudinal Distribution

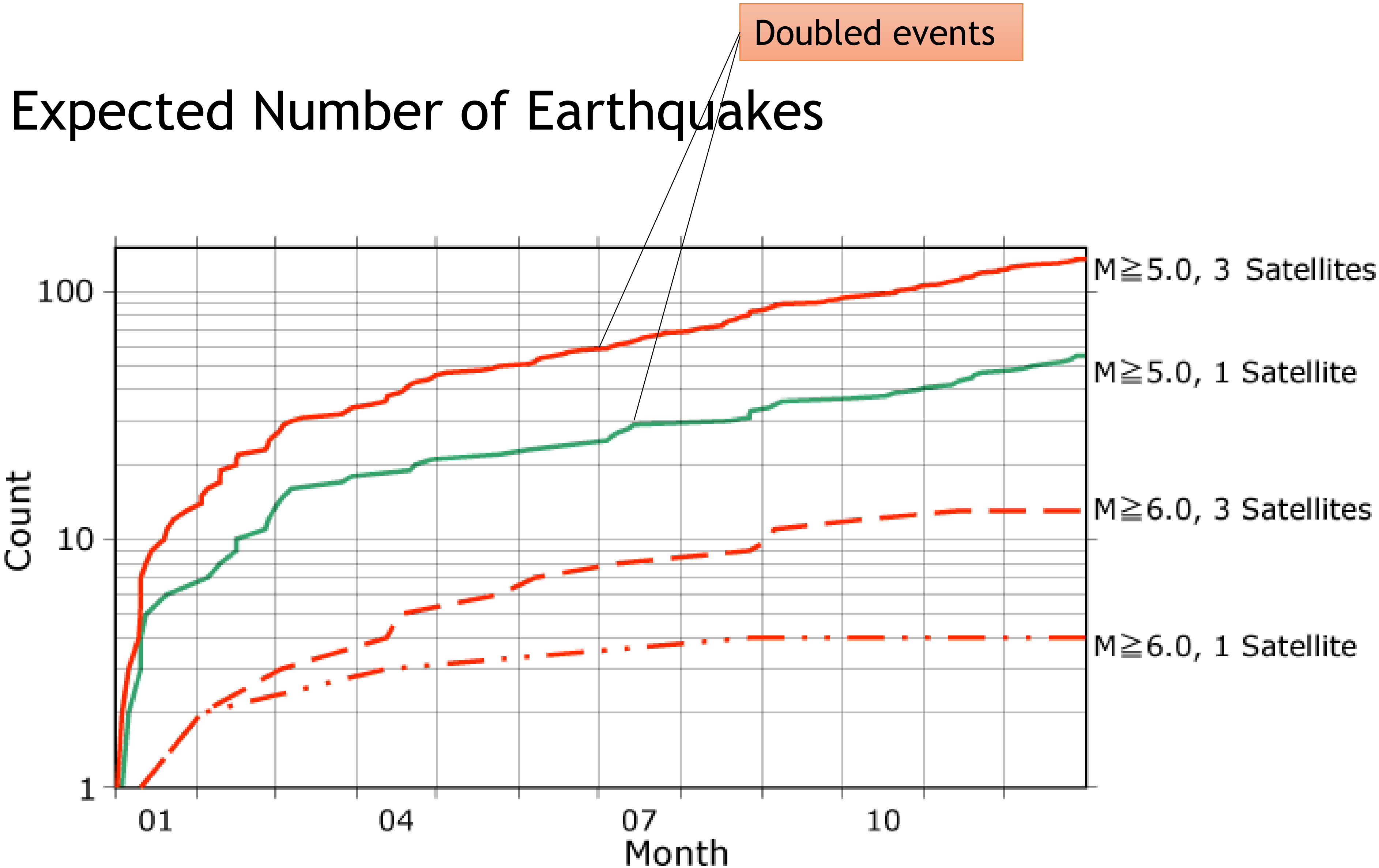


Plan B
Late phase : Feasibility of Real-time Identification
: Robust Verification of Phenomenon



Distance among the satellites > radius of precursor(500km)

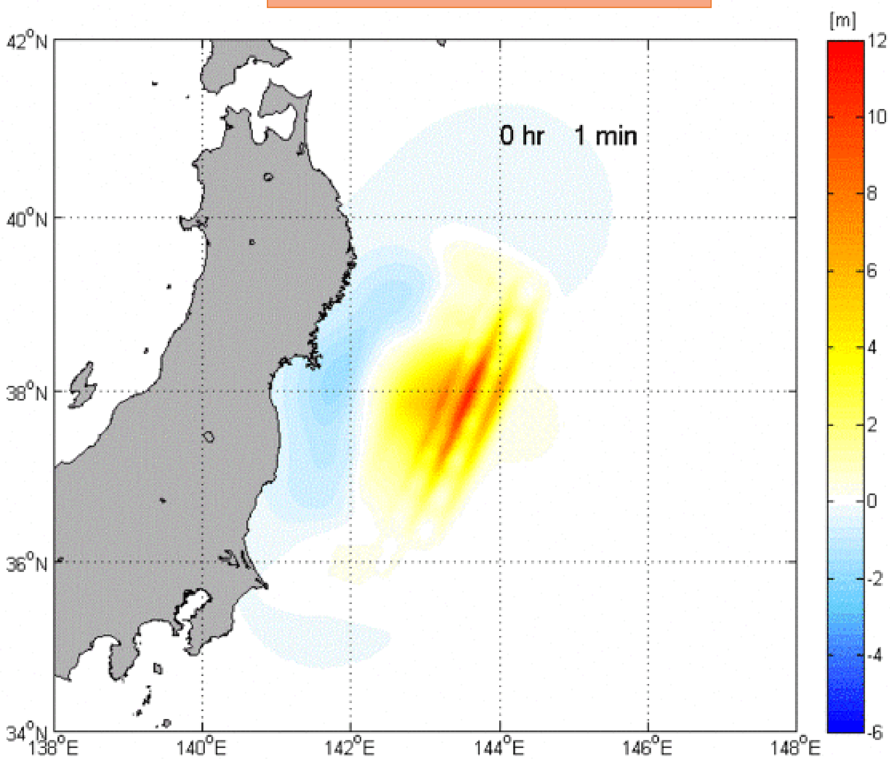
Expected Number of Earthquakes



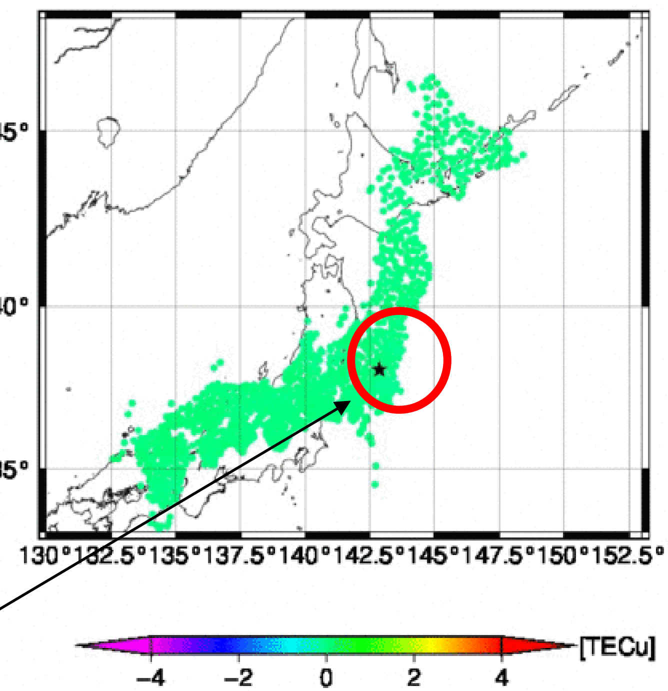
Mission 2: **Investigation of tsunami ionospheric hole for early warning system (Tsunami mission)**

2011.3.11 Tohoku Earthquake (Japan)

Height of Tsunami



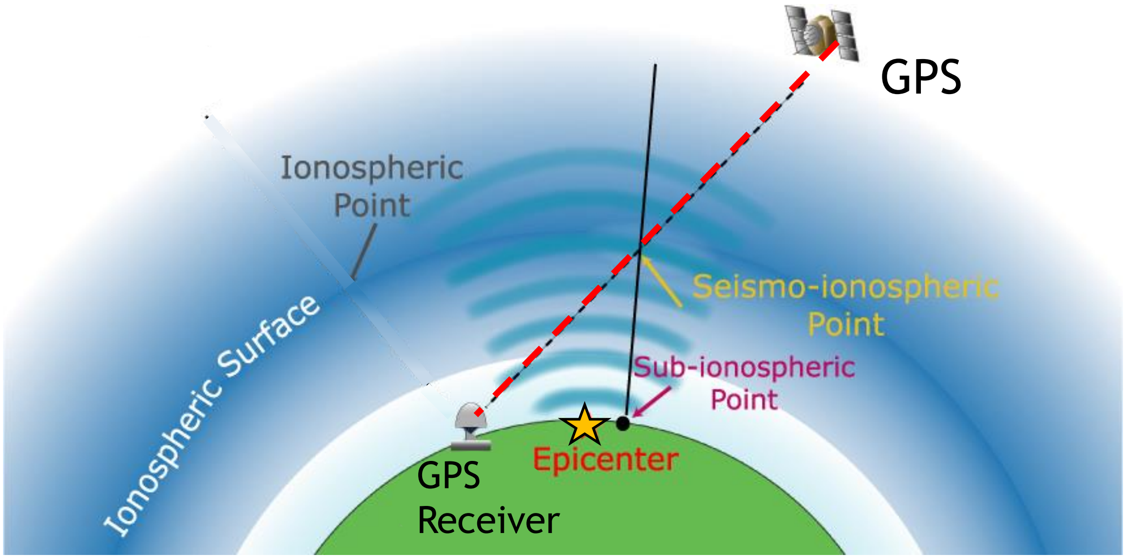
Total Electron Content (TEC) in Ionosphere



We discovered **Tsunami Ionospheric Hole (TIH)**

Kakinami & Kamogawa et al., Geophs. Res. Lett. (2012)

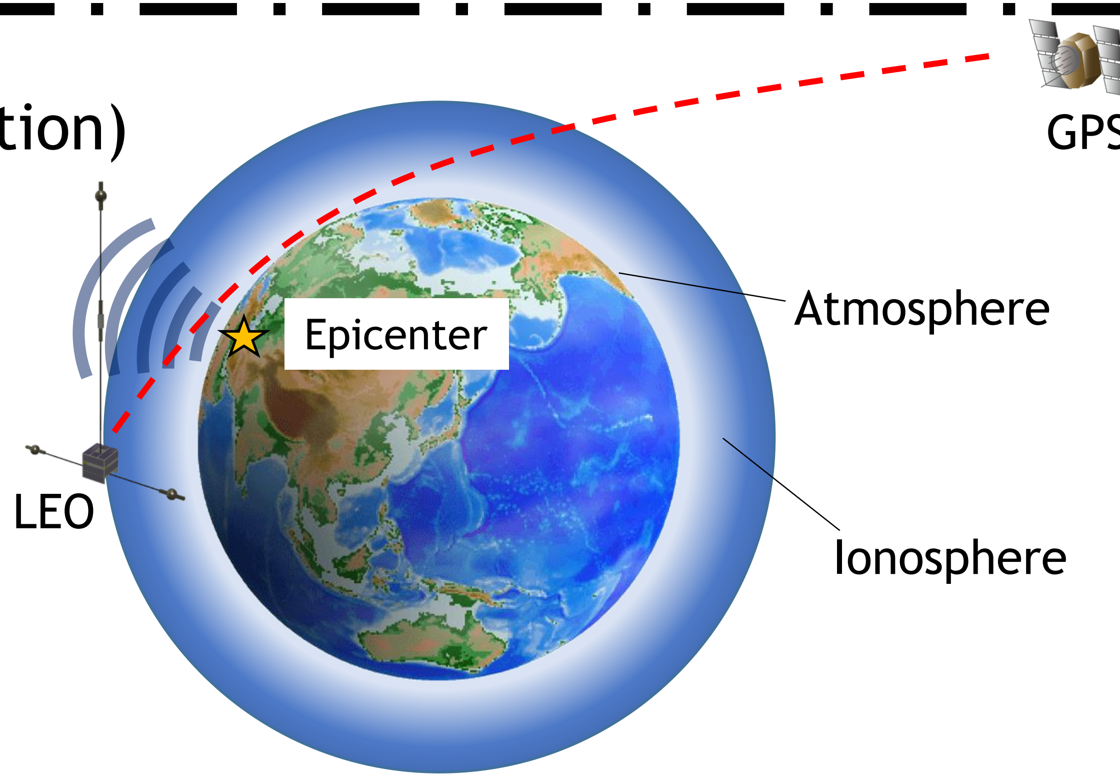
Ground observation



GPS stations are not uniformly distributed

GPS stations are not far from the coast

Satellite observation
(GPS **occultation** observation)



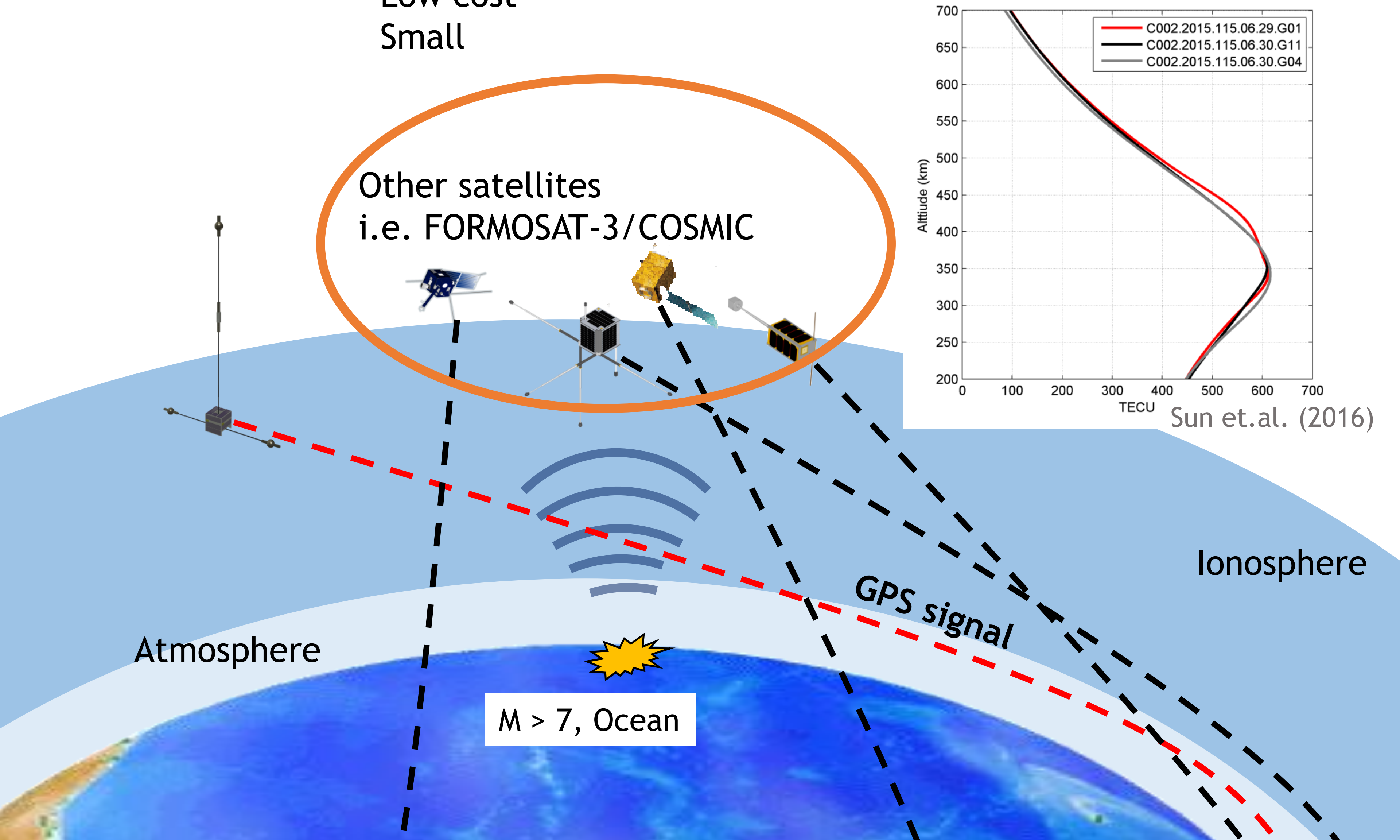
Satellite observation can monitor the whole area in the earth

Observation

GPS receiver

Low power consumption
Low cost
Small

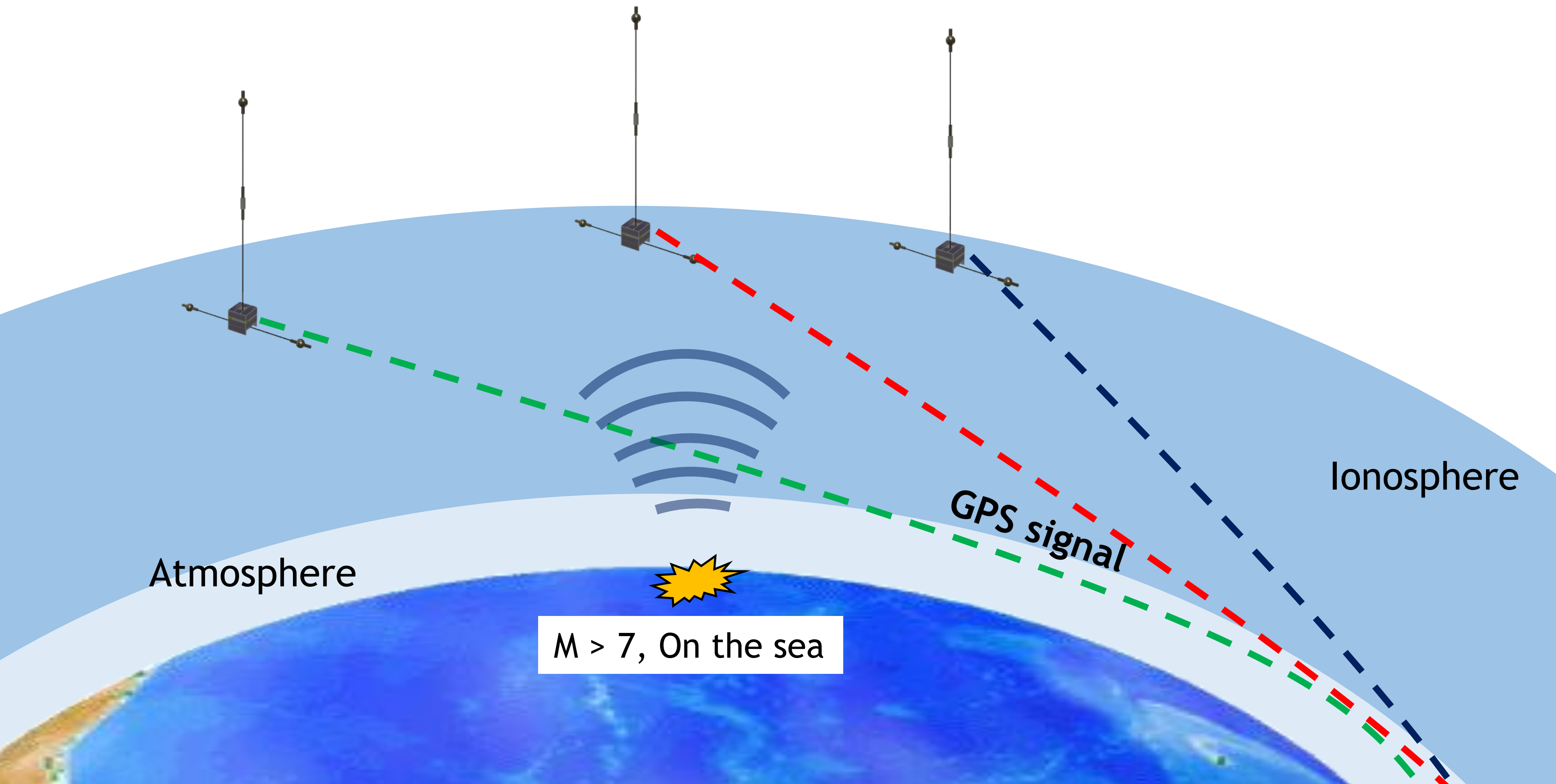
Electron Density Profile



Sun et.al. (2016)

Plan B: Constellation Observation

Verification feasibility for satellite-based tsunami early warning system from real time monitoring



Mission 3:
Study of lightning-related phenomena for lightning prediction. (Lightning mission)

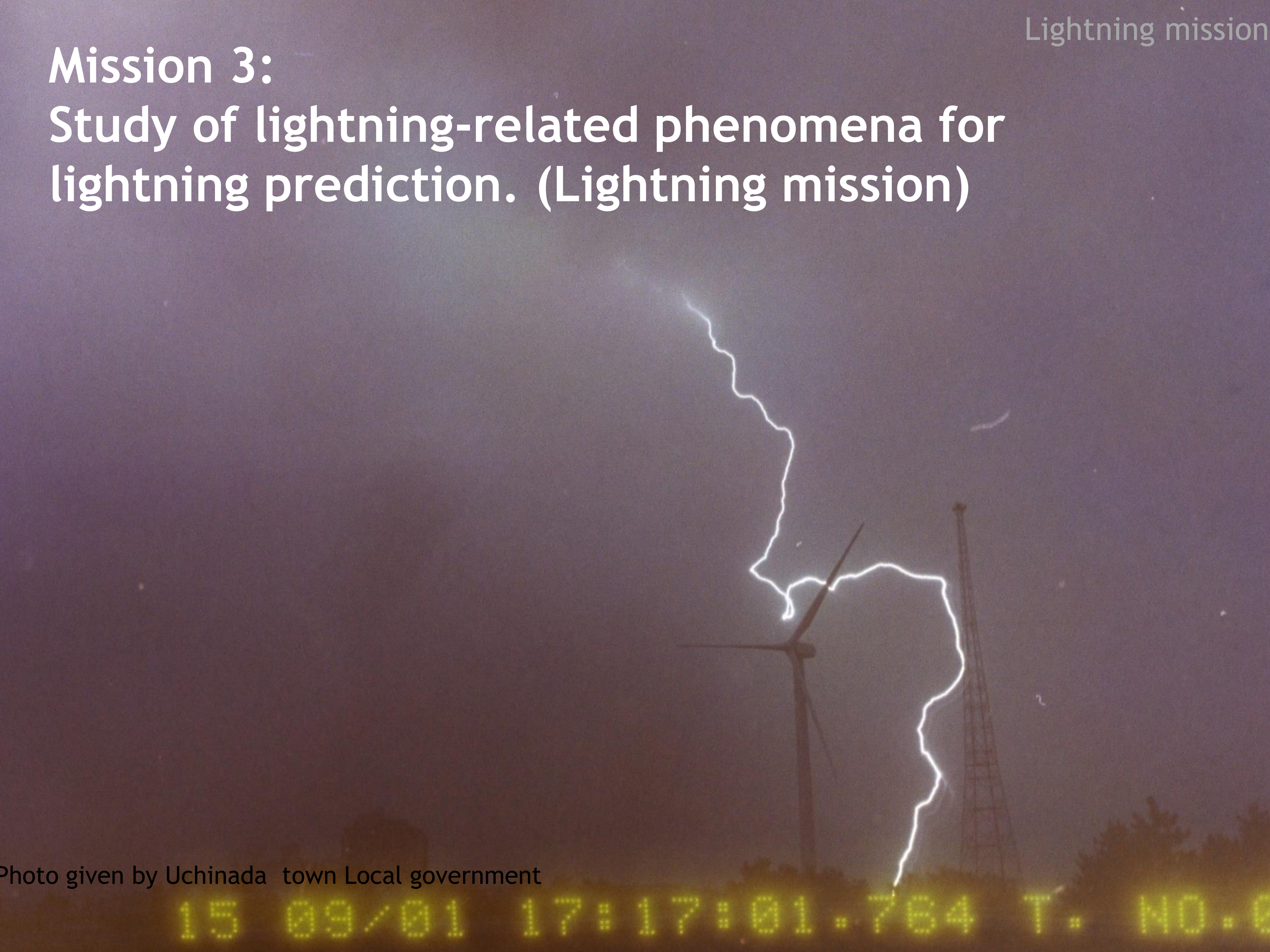
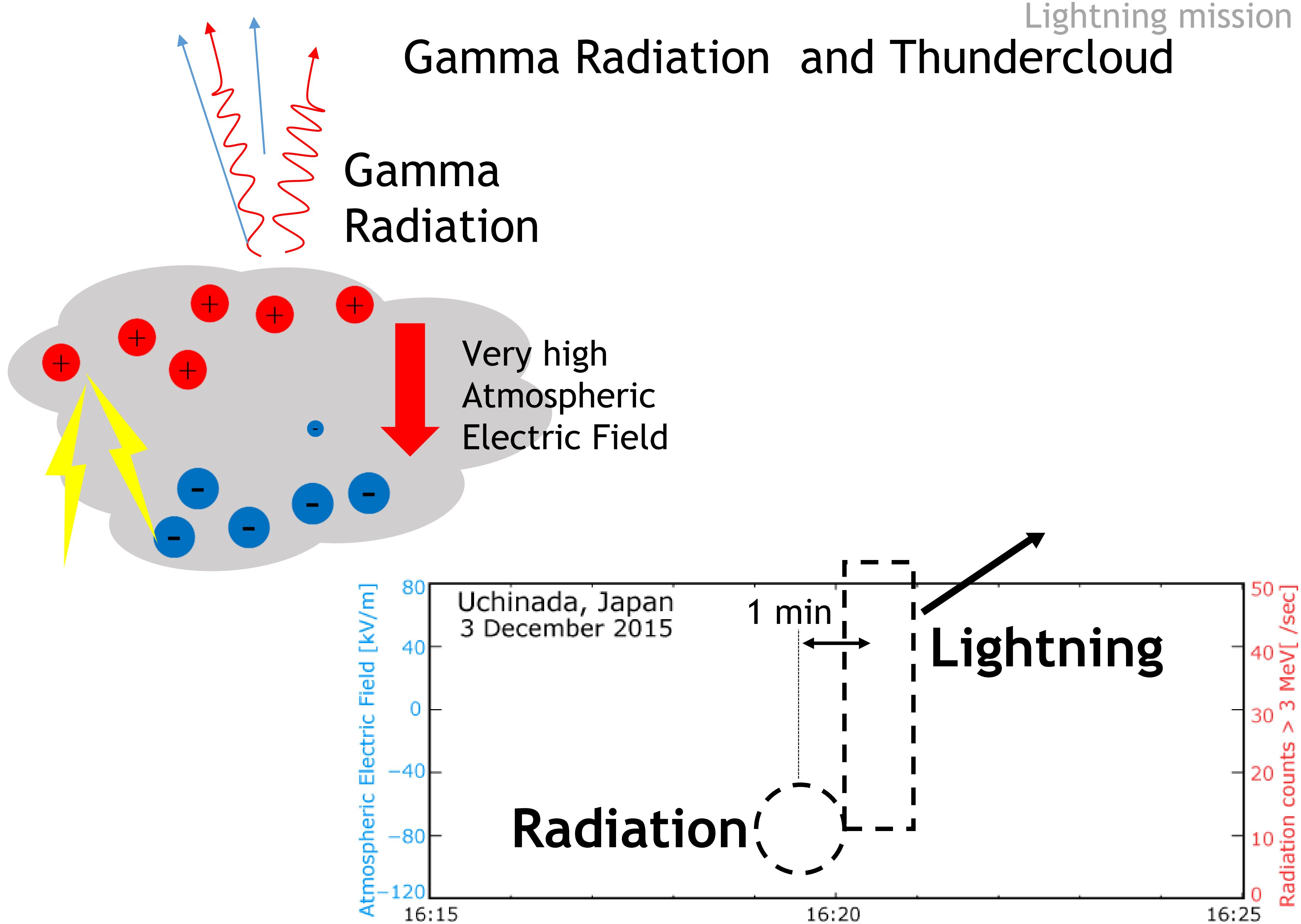


Photo given by Uchinada town Local government

Gamma Radiation and Thundercloud



We will find new lightning prediction technique

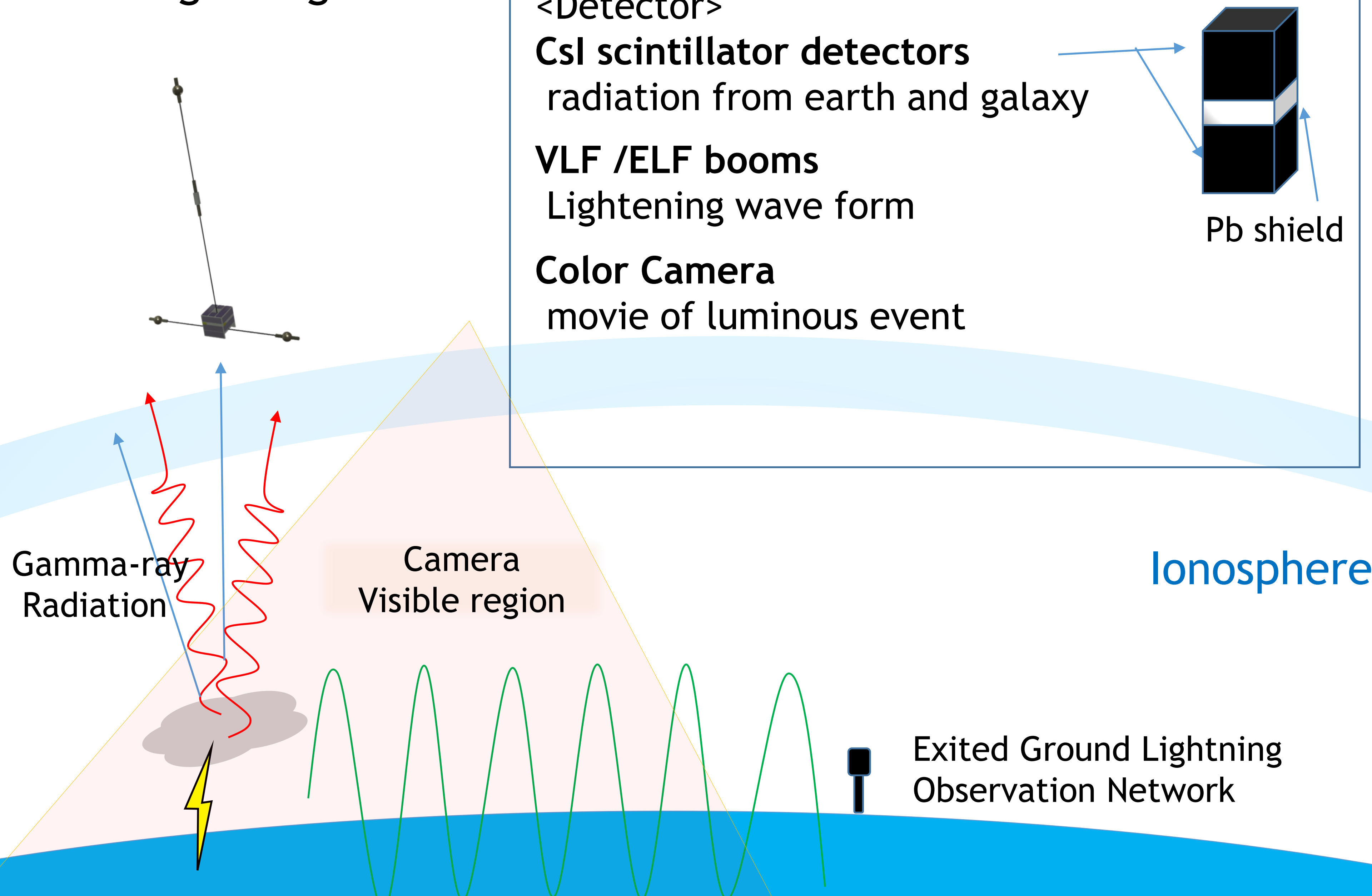
Plan A: Verifying statistical correlation between gamma ray and lightning.

<Detector>

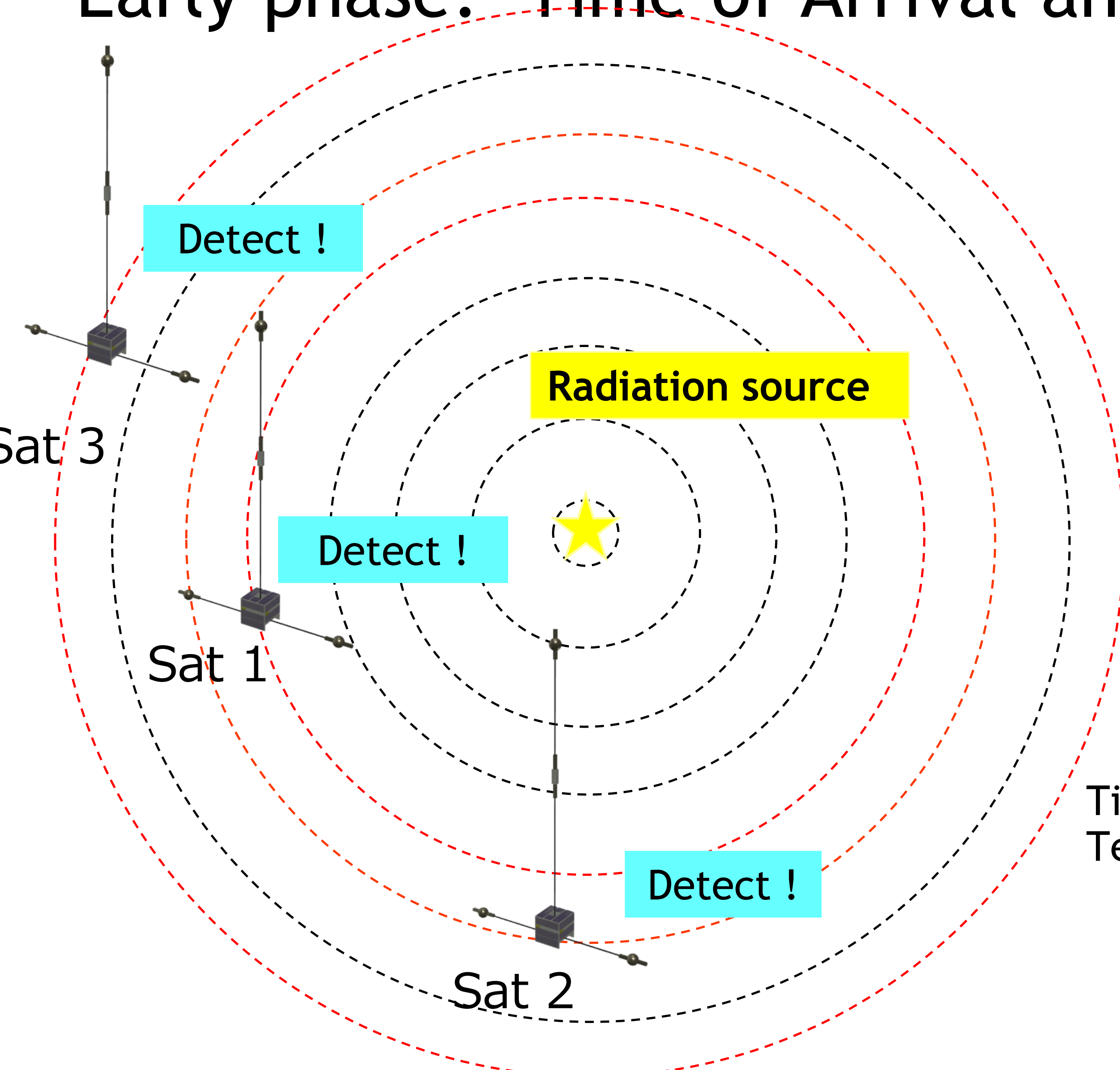
CsI scintillator detectors
radiation from earth and galaxy

VLF /ELF booms
Lightening wave form

Color Camera
movie of luminous event



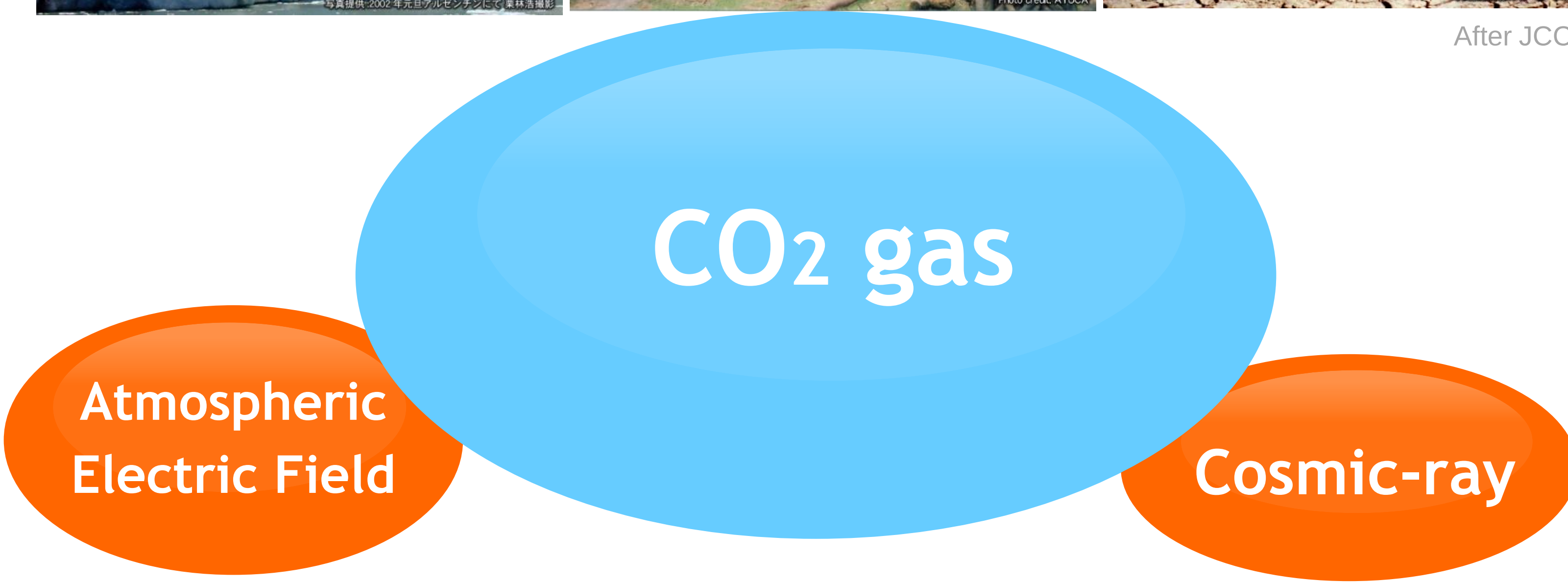
Plan B
Early phase: Time of Arrival analysis (TOA)



Time accuracy: 100µ sec
Temporal resolution:±15km

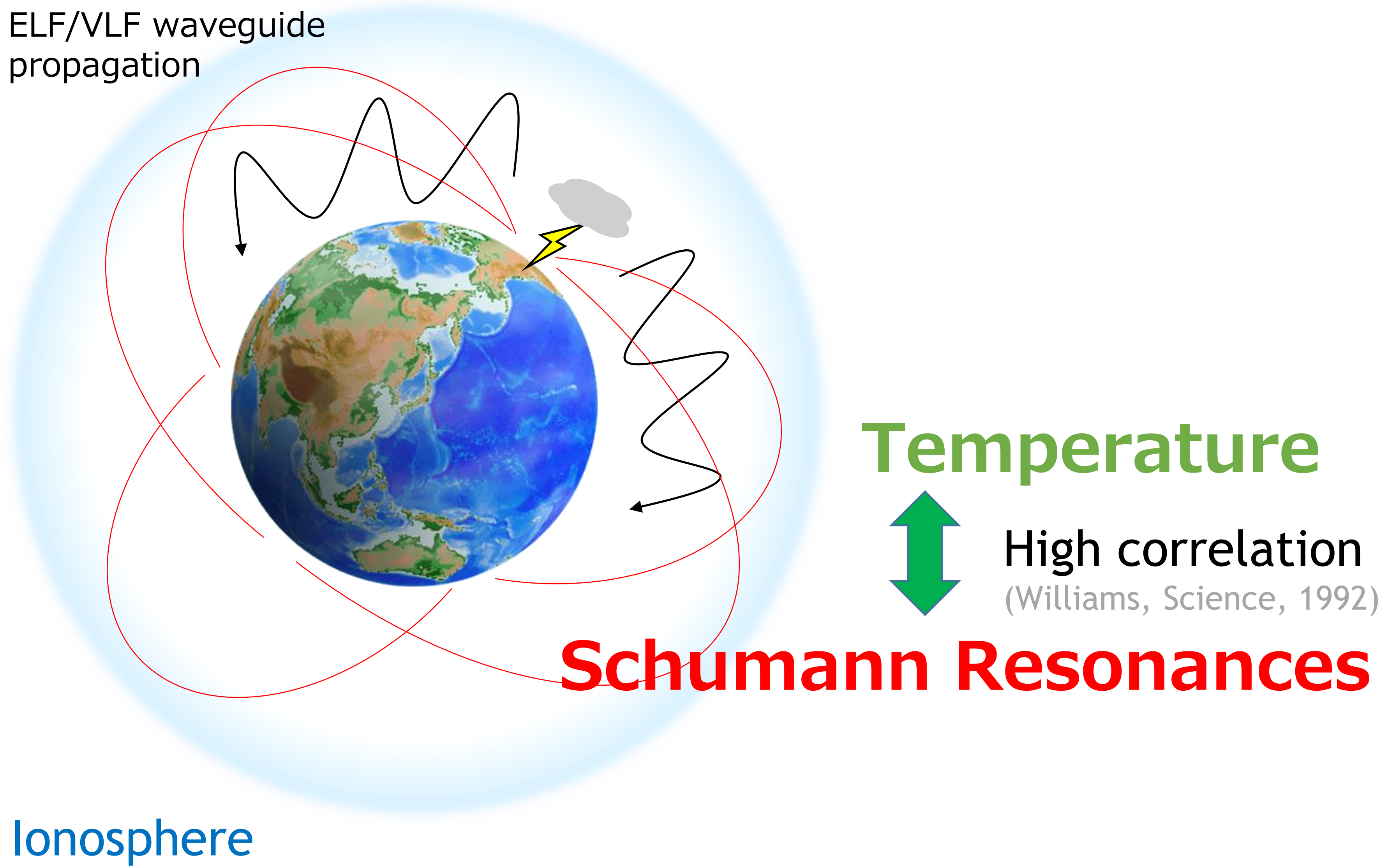
Mission 4
Study of global lightning for global warming understanding (Global warming mission)


After JCCCA

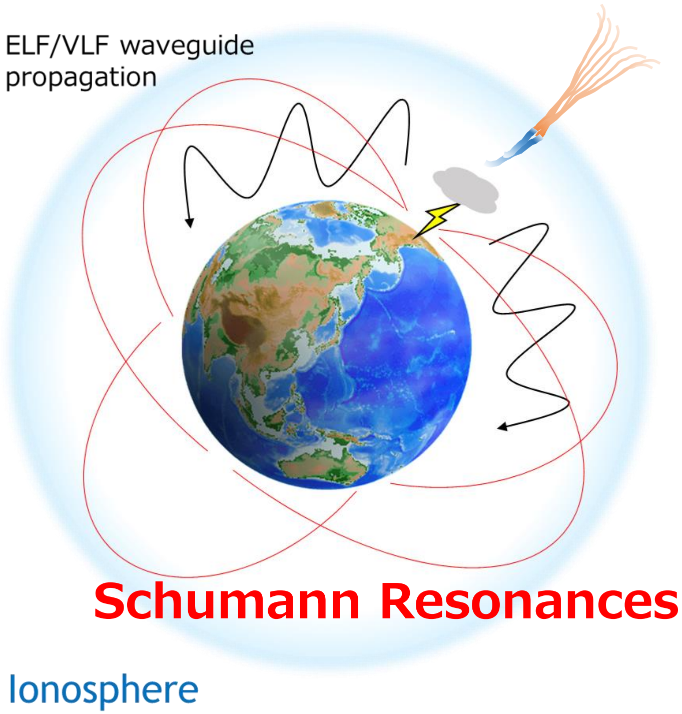


Multiple factors?

Global Electric Circuit (GEC)



Transient luminous events (TLEs)



Gigantic-Jet at summit of Mt. Fuji, Japan

TLE emit TLEs emit 10 times stronger ELF wave than Schumann resonances

We investigate how much TLE event influence on the Schumann resonance intensity for global warming study.

Plan A : Schumann resonance and TLE observation

<Detector and object >

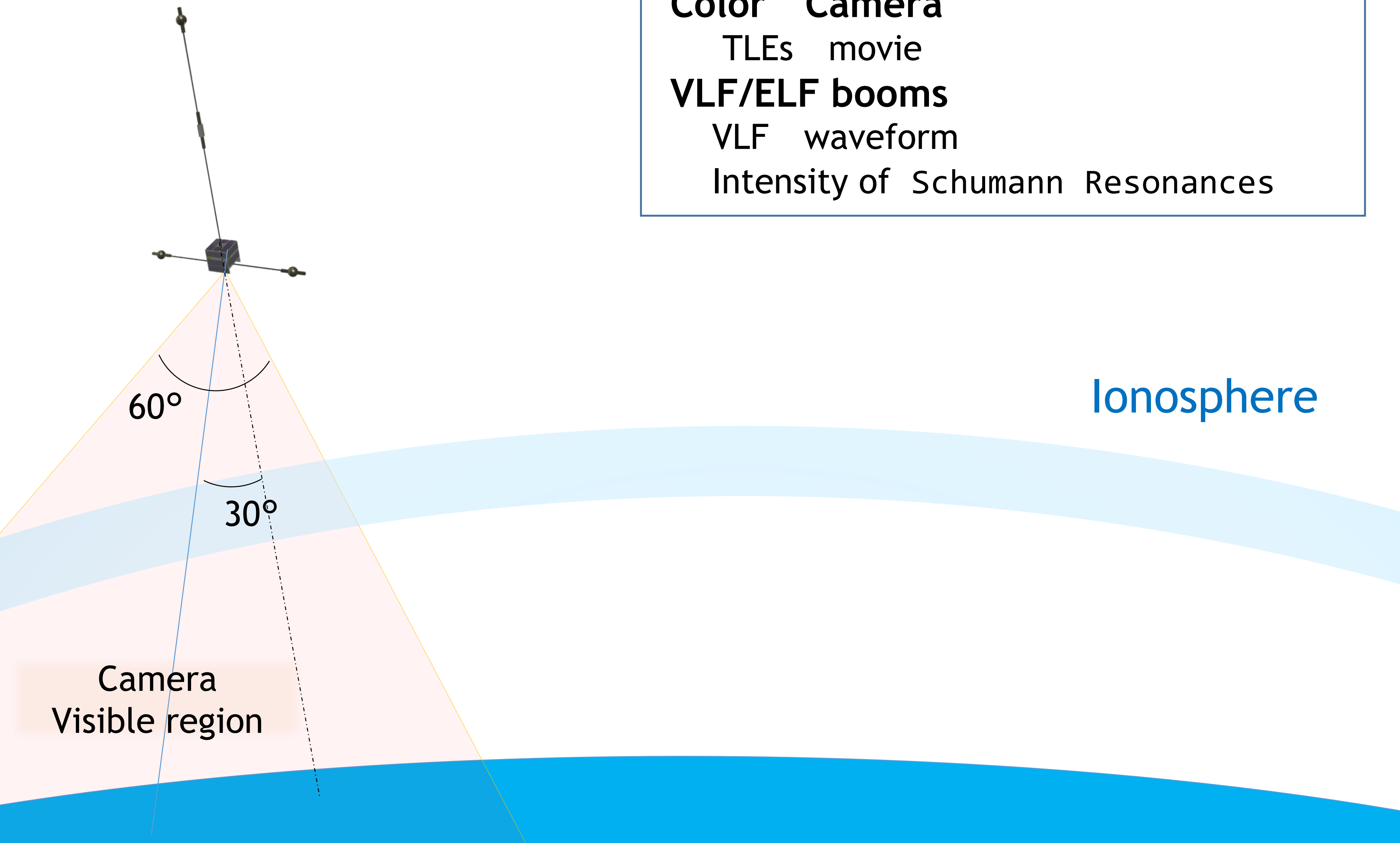
Color Camera

TLEs movie

VLF/ELF booms

VLF waveform

Intensity of Schumann Resonances



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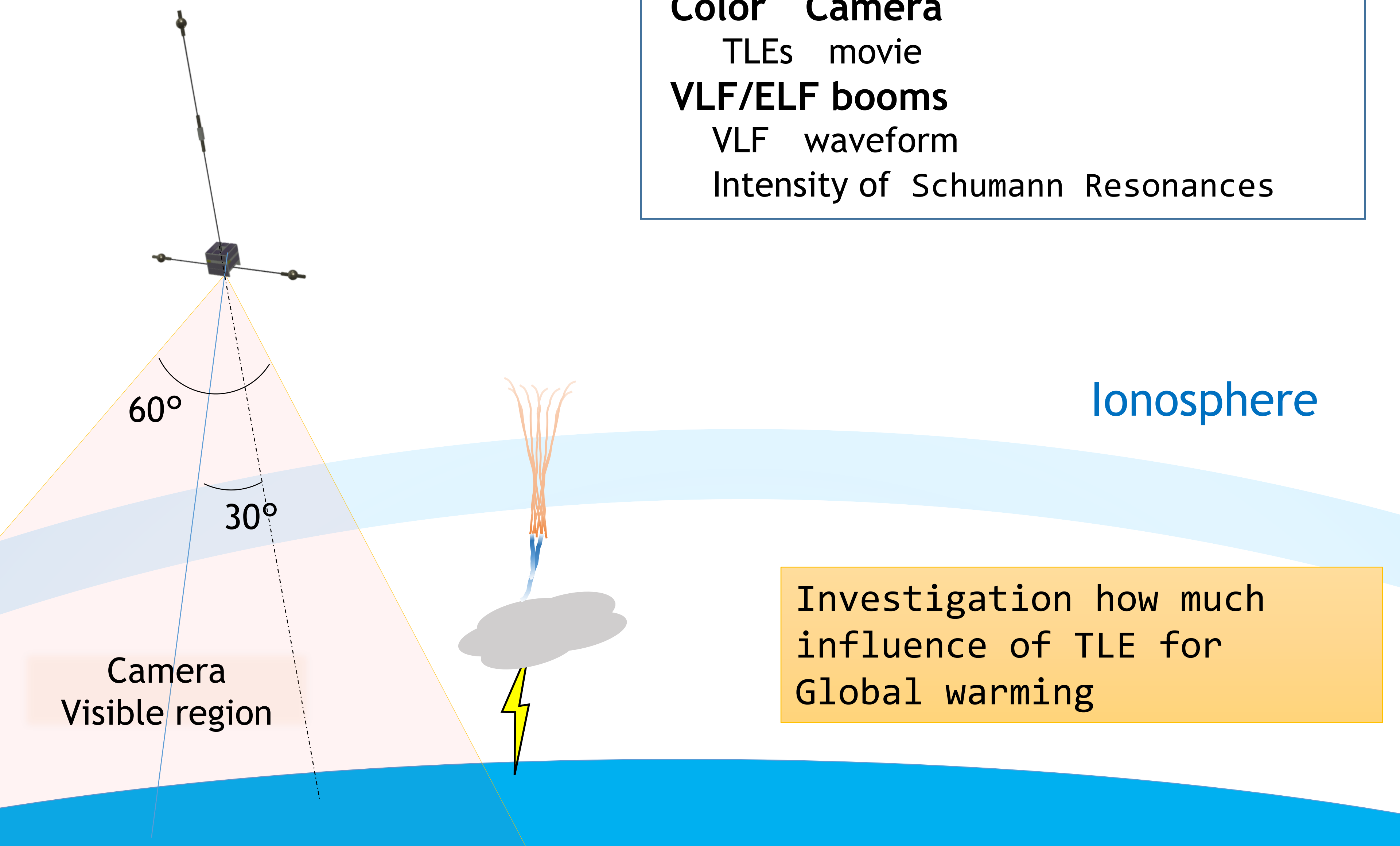
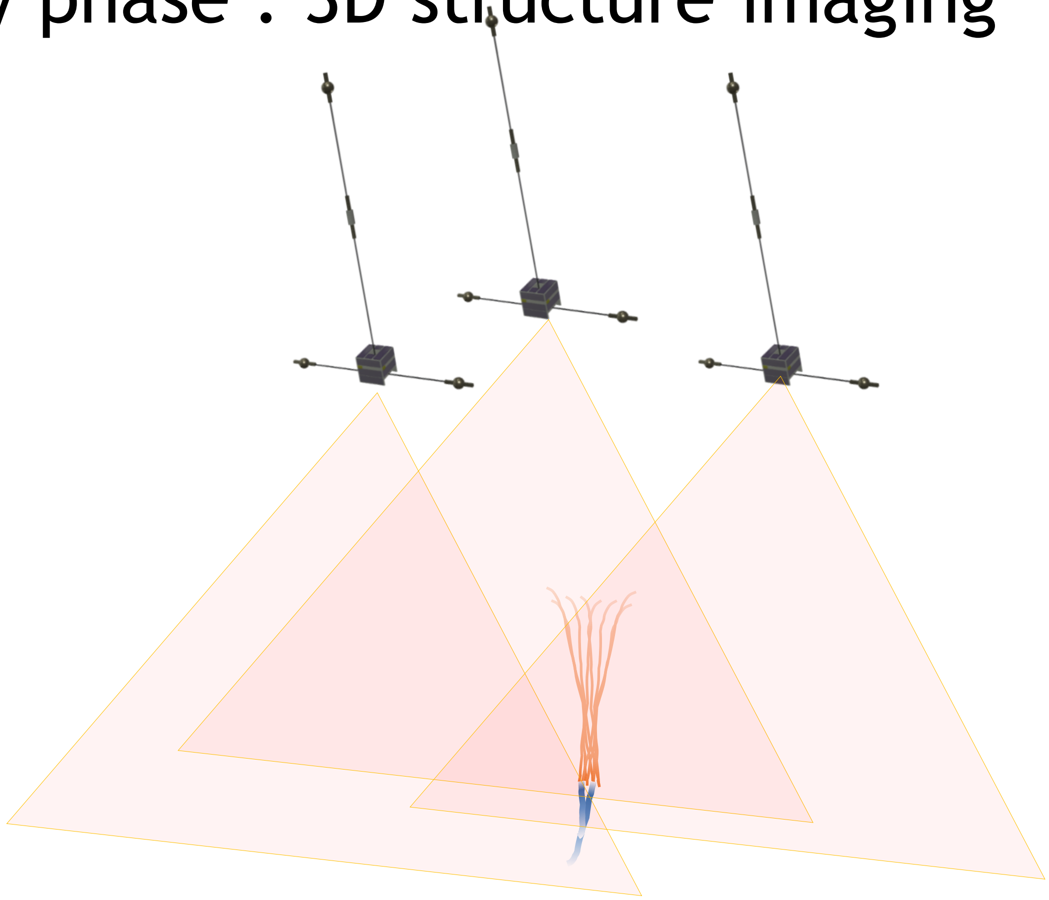


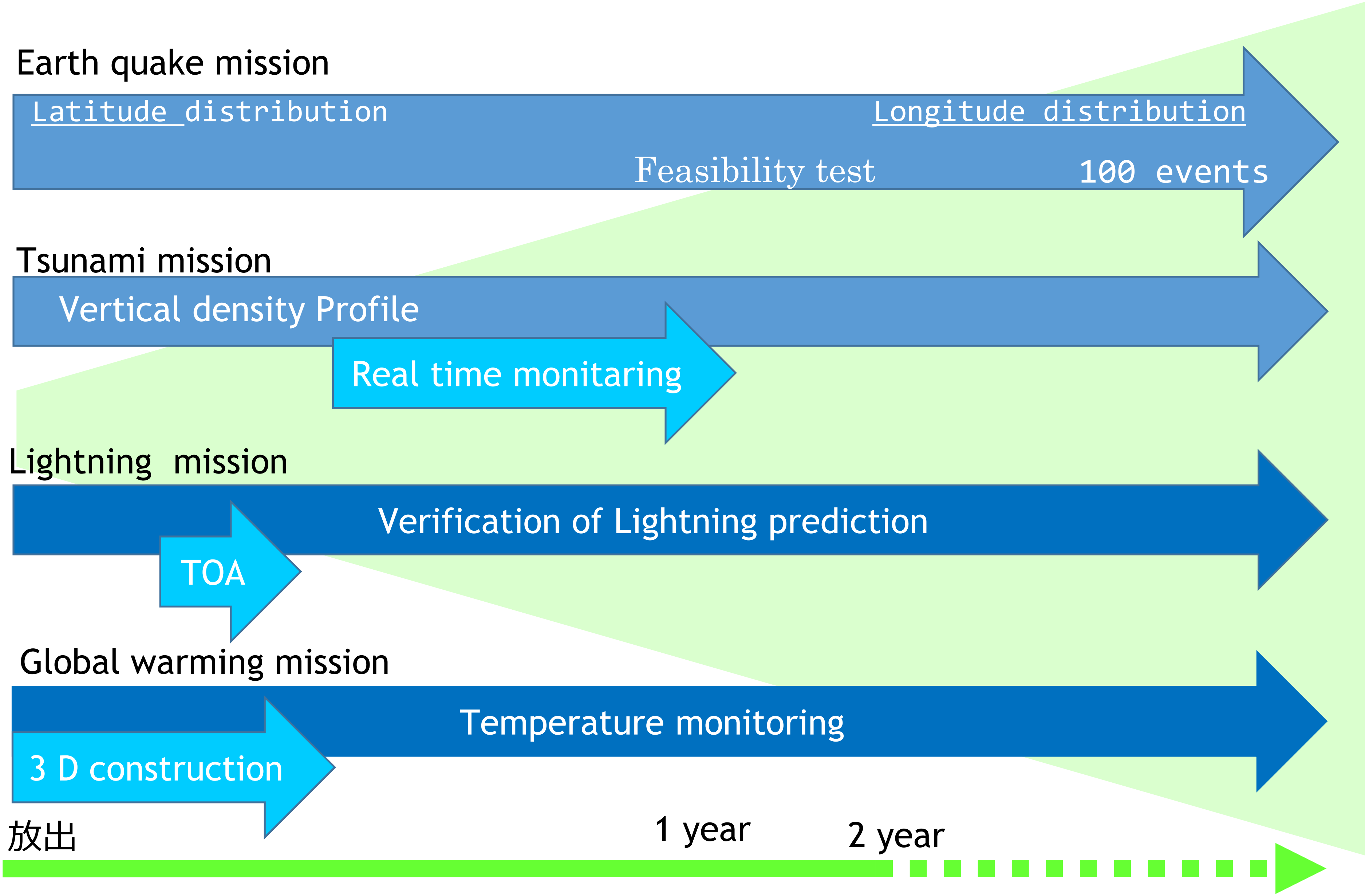
Investigation how much influence of TLE for Global warming

Plan B
Early phase : 3D structure imaging



- Constructing 3D structure
- Investigating discharge current for GEC study

Operation Sequence

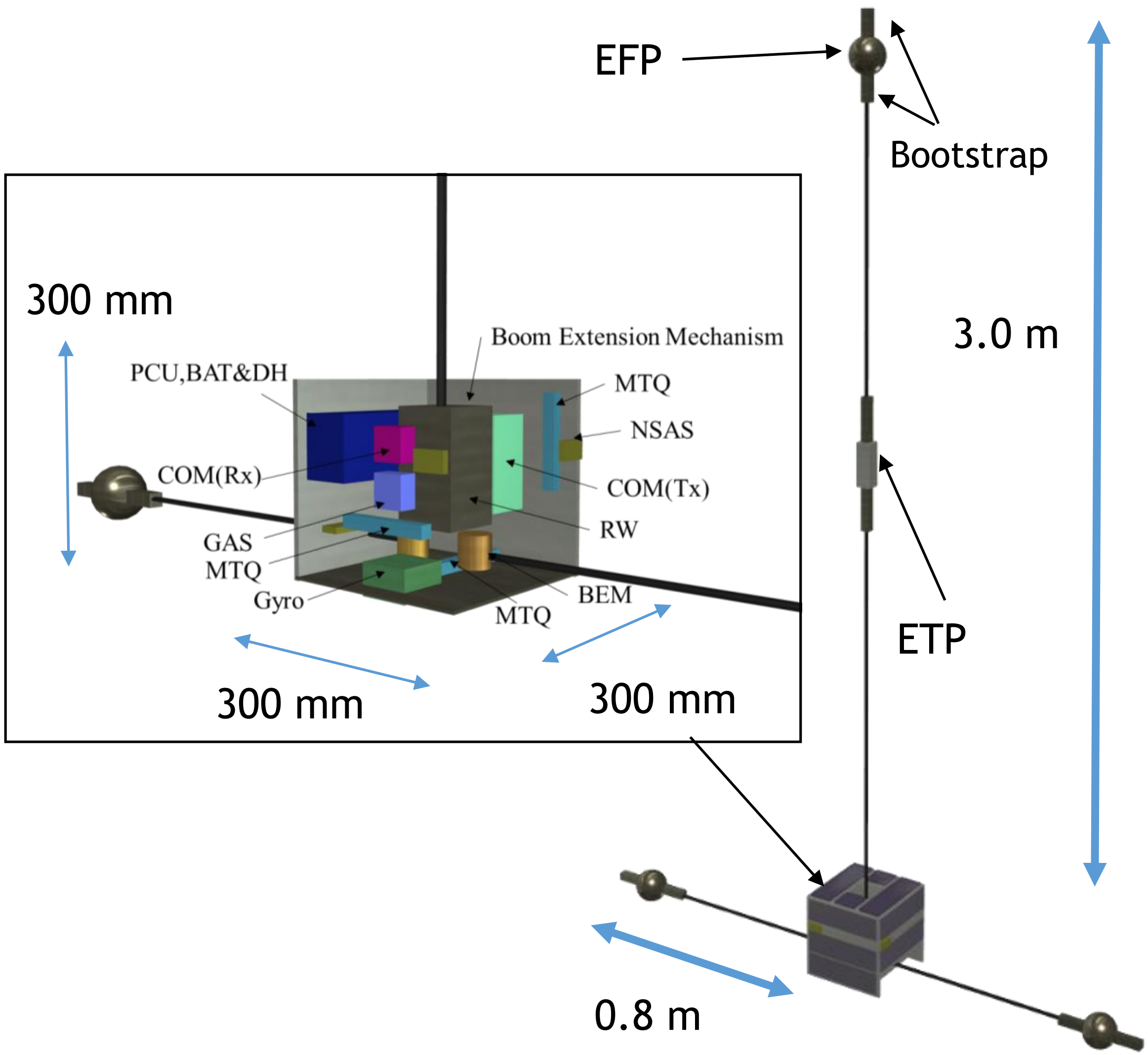


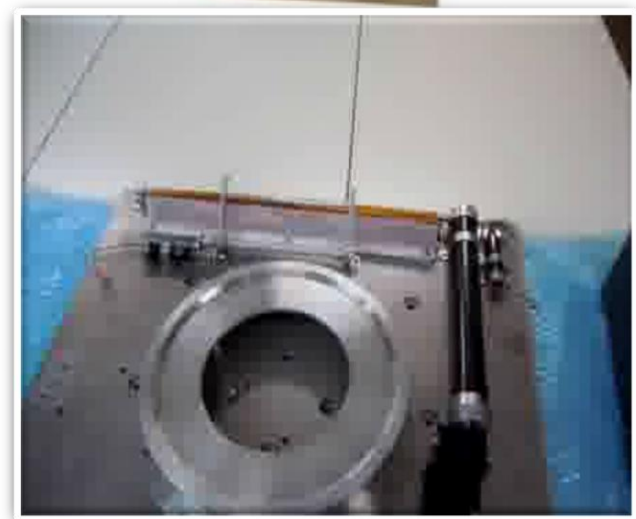
Mass and Power Distribution

	Components	Qty.	Mass[kg]	Power[W]
EPS	Solar Panel	1	0.6	
	Power control Unit	1	1.5	1.5
	BAT	1	1.5	
COM	Antenna	2	0.1	N/A
	Transmitter and Receiver	1	0.74	TX ON: 4.6
				TX OFF: 1
DH	On-board Computer	1	0.8	5
ADCS	Geomagnetic Acquisition Sensor	1	0.14	0.1
	NSAS	6	0.3	0.9
	MEMS Gyro	1	0.2	0.3
	IR Earth Sensor	1	0.03	0.13
	Magnetic Torquer	3	1.2	1.5
	Reaction Wheel	3	3.3	2.1
Mission	EFP	3	0.3	0.3
	ETP	1	0.1	0.2
	CSI	2	9.4	0.8
	OPC	1	0.02	1
	GTO	1	0.2	1.5
STR	HEATER	1	0.1	1
	STRUCTURE + Harness	1	16.97	N/A
	BOOM (Long)	1	1.1	N/A
	BOOM (Short)	2	1.4	N/A
TOTAL			**40**	**20.9**

Spacecraft System Overview

Components layout





First natural frequency of longer boom is estimated to be around 3 Hz.

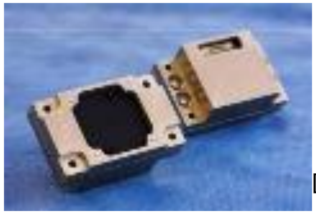
[1] http://www.i-qps.net/i-qps/service.html

Attitude Determination and Control

Mission requirement for
electric field measurement

	determination	Control
DC	1	7
AC	5	37

(degree)

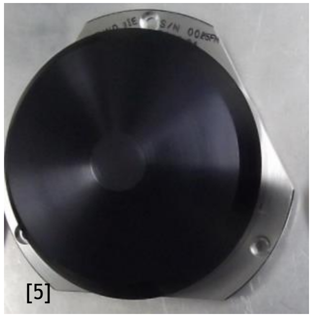

[1]


[2]


[3]


[4]

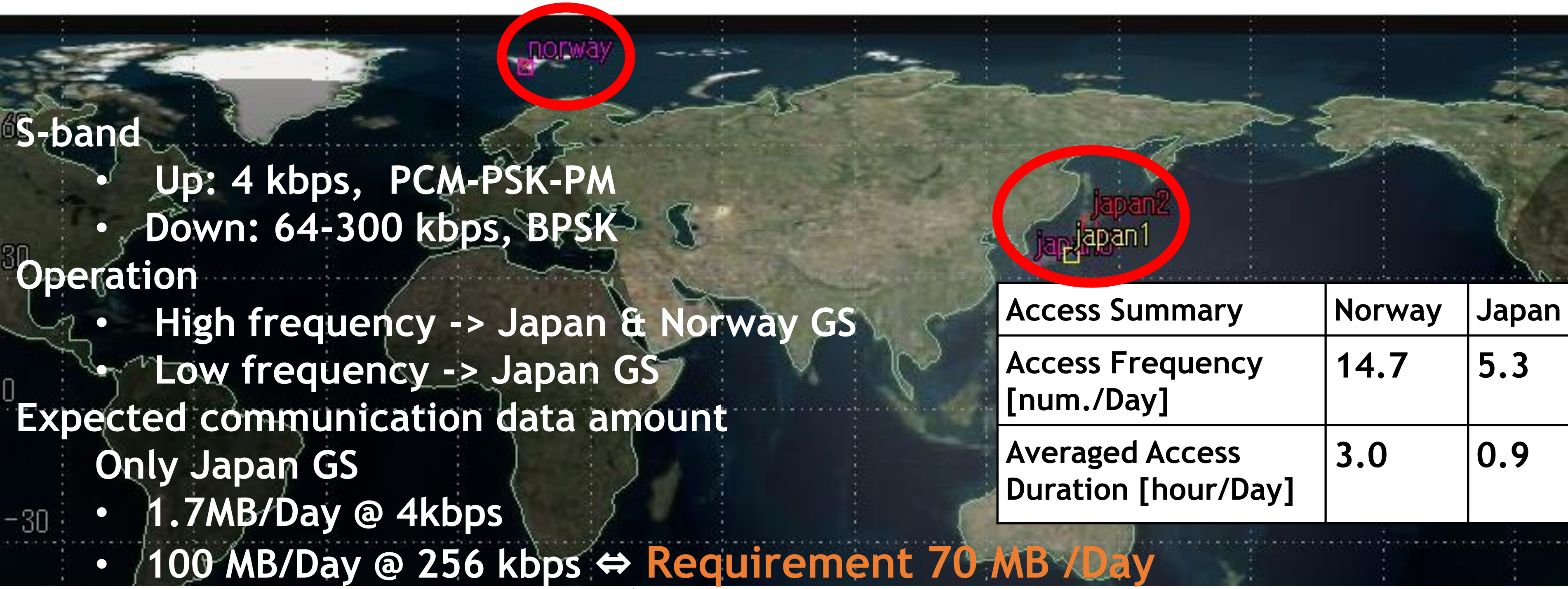
- Attitude determination with
  - 6-sun sensors
  - Earth sensor (or star sensor)
  - 3-axes geomagnetic aspect sensor
  - 3-axes mems gyro


[5]

- Zero-momentum control with 3 axis RWs
- Unloading with 3-axes magnetic torquers
- Avoidance of the boom natural frequency

[1] http://www.axelspace.com
[2] Kaplan. C., LEO Satellites: Attitude Determination and Control Components ; Some Linear Attitude Control Techniques
[3] http://www.tierra.co.jp/
[4] http://www.sensonor.com/
[5] https://makesat.com/products/reaction-wheel

Communication



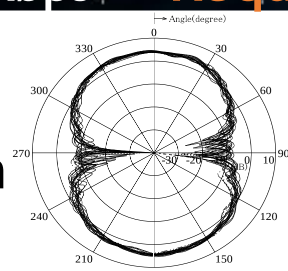
S-band
- Up: 4 kbps, PCM-PSK-PM
- Down: 64-300 kbps, BPSK

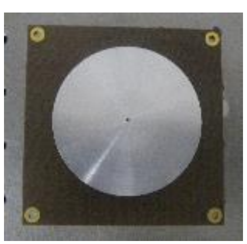
Operation
- High frequency -> Japan & Norway GS
- Low frequency -> Japan GS

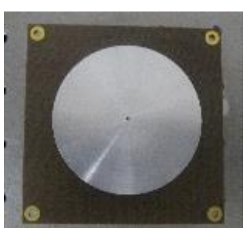
Expected communication data amount
Only Japan GS
- 1.7MB/Day @ 4kbps
- 100 MB/Day @ 256 kbps ⇔ Requirement 70 MB /Day

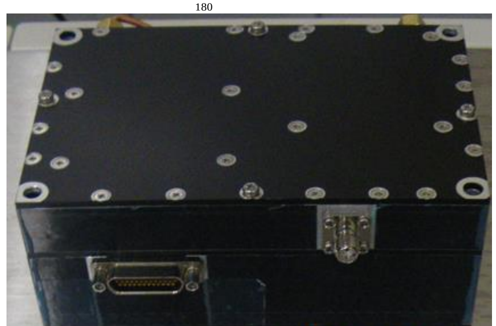
Access Summary	Norway	Japan
Access Frequency [num./Day]	14.7	5.3
Averaged Access Duration [hour/Day]	3.0	0.9

2 patch antenna
 -> omni antenna pattern
  for emergency









http://www.dst.co.jp/

Downlink Link Margin @ 256kbps
- Larger than 0 dB for worst case

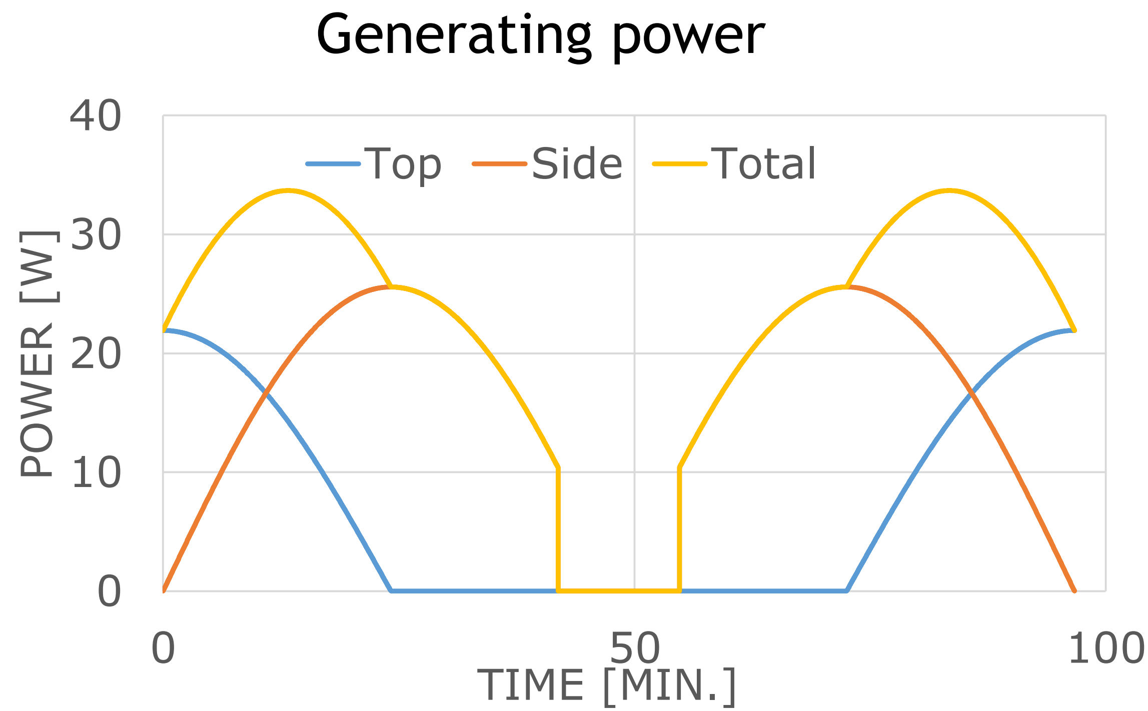
Uplink Link Margin
- Larger than 10 dB for worst case

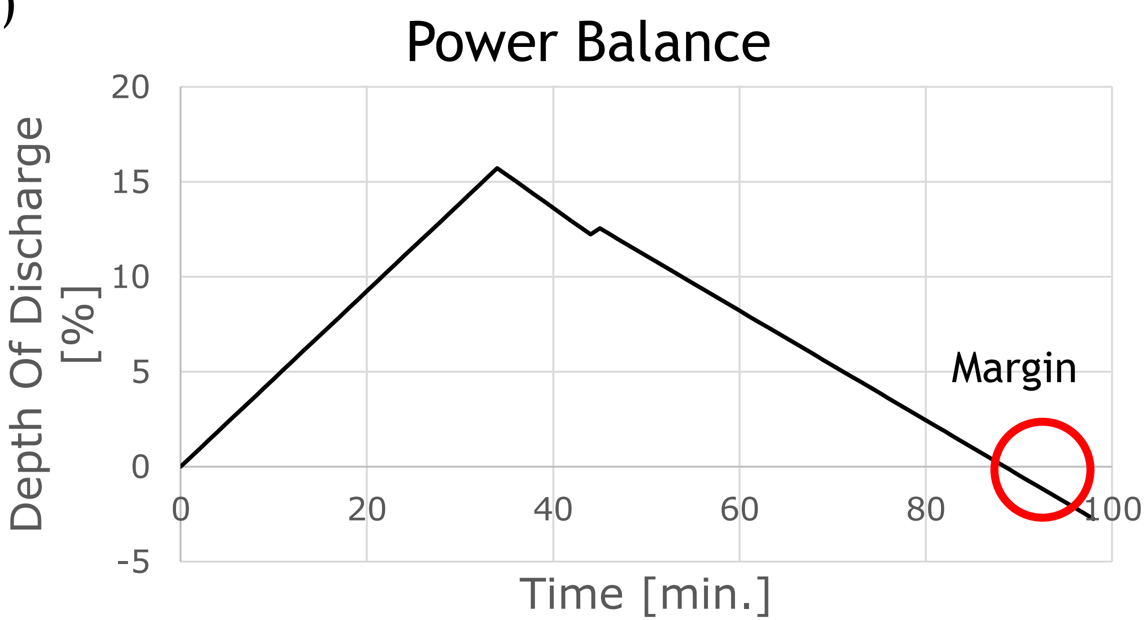
Enough Link Margin,
Enough data communication amount

Power

Maximum Power Supply
-> 34 w

Body mount (7S2P / 7S3P)
(Solar cells are covered with SnO_2)



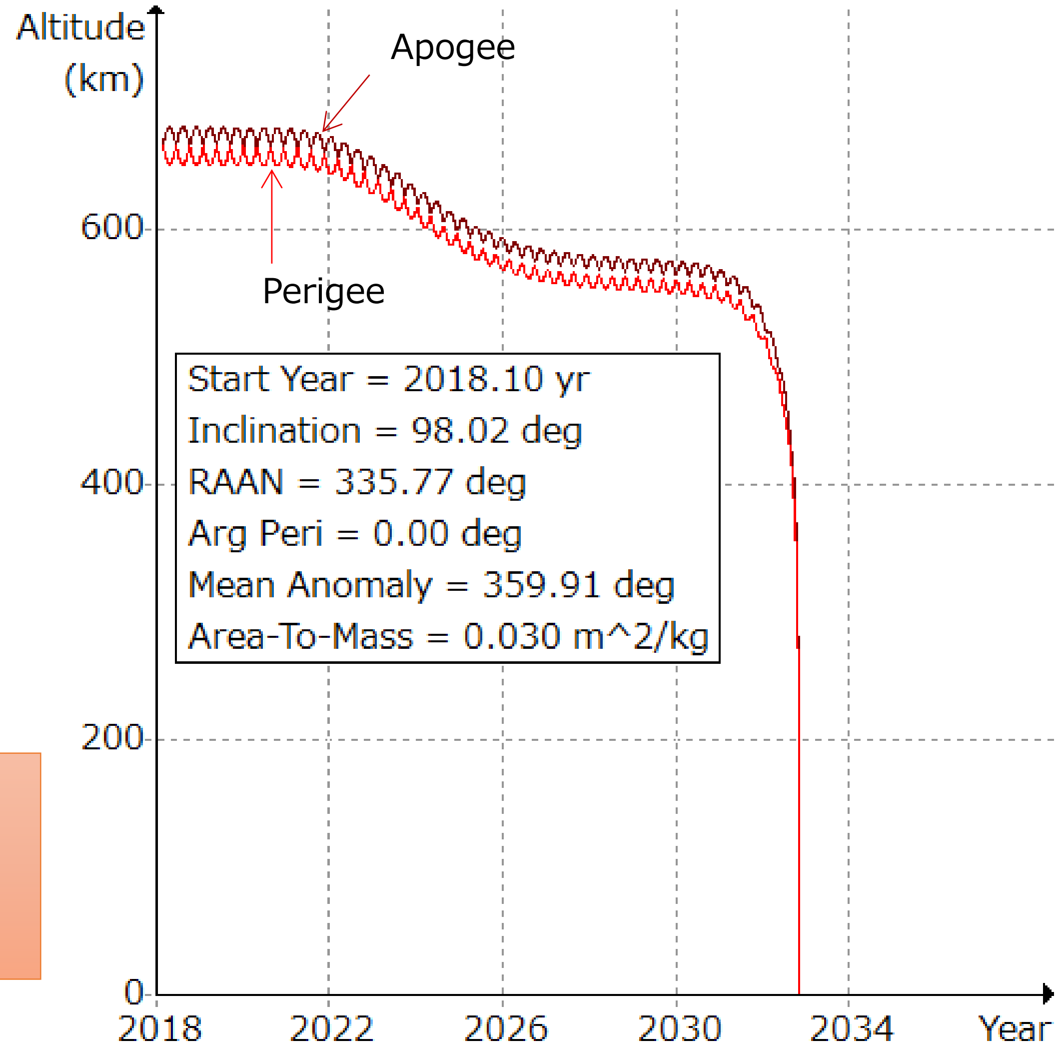


De-orbiting Analysis

DOM-1500

Effective Area :
total surface area /4

De-orbiting can be achieved within 20 years



Cost Estimate and Funding

Plan A

$ 4,000,000

Plan B

$ 30,000,000

Team and Funding Sources:

Several university groups

Competitive scientific research funding

e.g. Grant-in-Aid for Scientific Research (KAKENHI)

科研費
KAKENHI

International university group

Several national institute in Japan

Space Agency: JAXA

National project

10 years after our mission ….

Concluding remarks

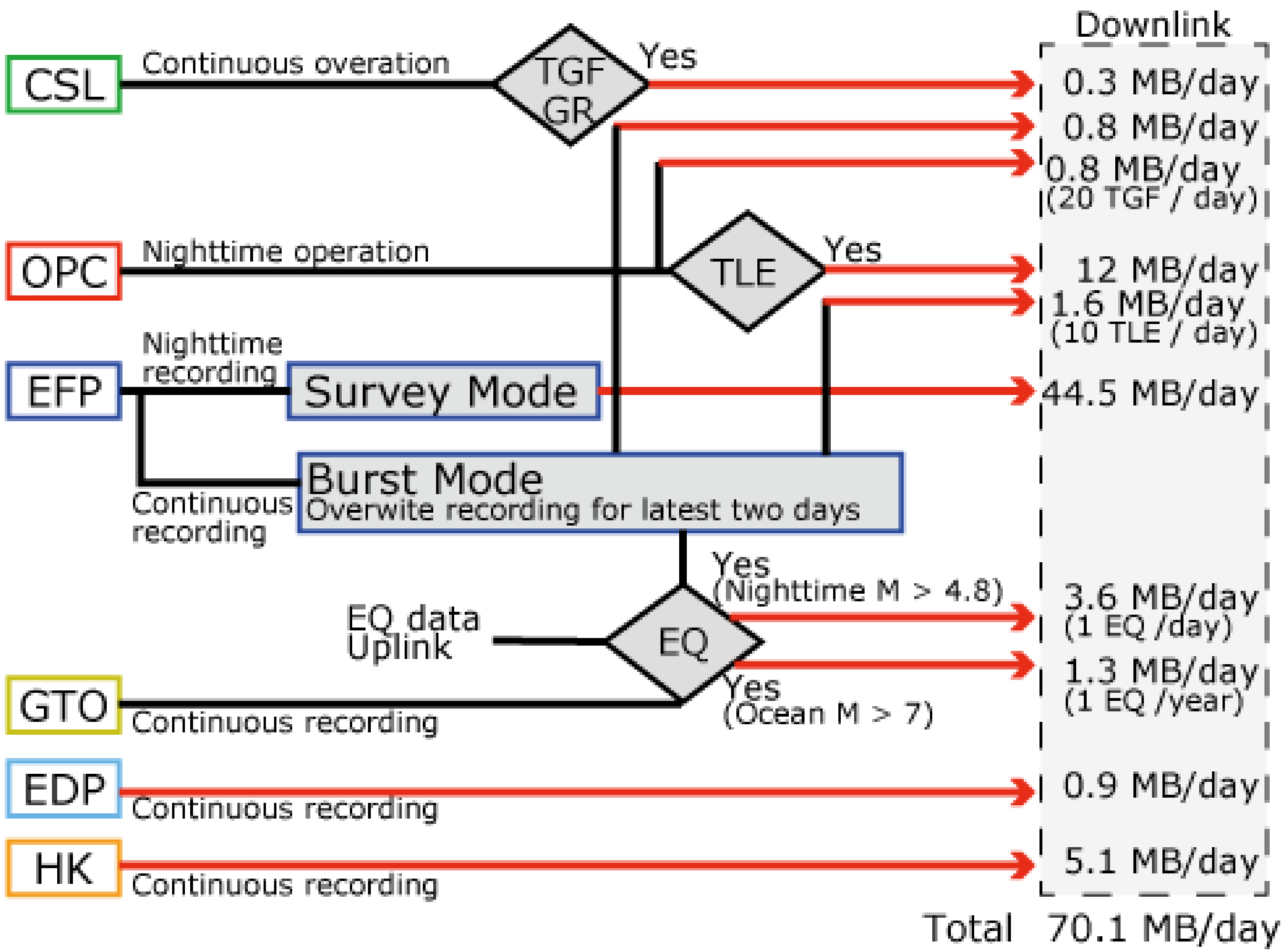
- Natural disasters often produce signals of atmospheric and space electricity before and after the event.
- Electricity monitoring is applicable to other natural disasters such as land sliding, volcano eruption, and forest fire.
- Space-based monitoring of such signals contributes to mitigate the disaster.
- On-board electromagnetic measurement is small, simple and matured technology and low cost.
- This project will show “innovative science” using microsatellites.

Thank you for your attention!!

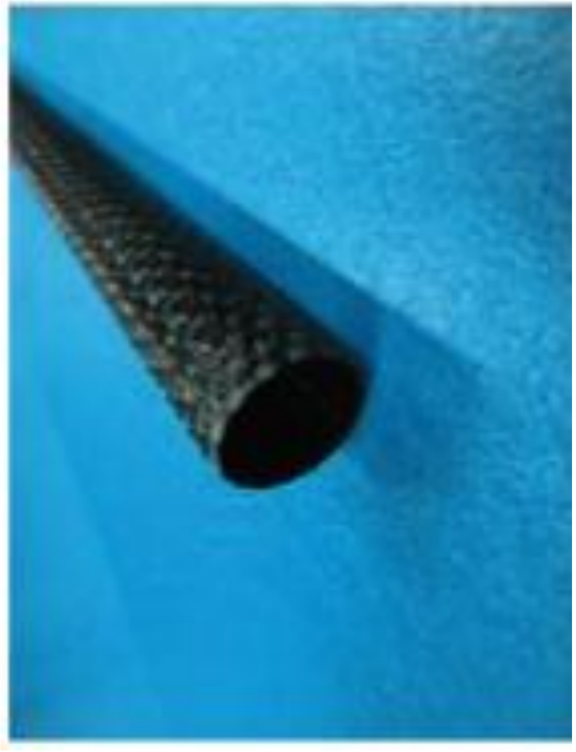
Disturbance Estimation -> 0.14Nms/rev

Gravity gradient	0.16×10^{-5}	Nm
Solar Radiation Pressure	0.0022×10^{-5}	Nm
Residual magnetism	2.3×10^{-5}	Nm
Aerodynamic	0.011×10^{-5}	Nm

Mission data



boom



[1] http://www.i-qps.net/i-qps/service.html

[2] Yokomatsu et al; Deployment Experiments on Stiffened Tri-axial Tubular CFRP Boom for Boom-Membrane Integrated Space Structures

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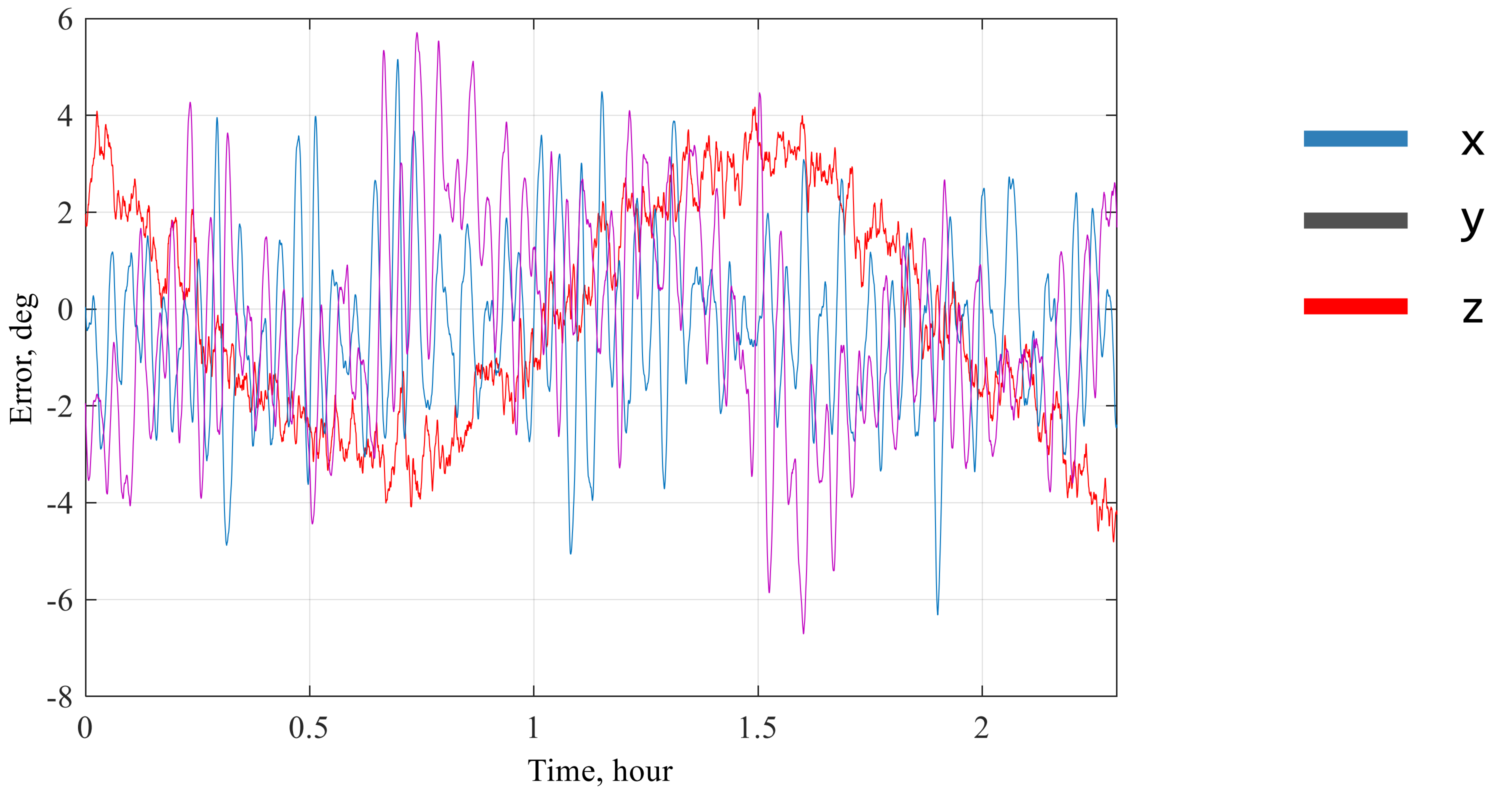
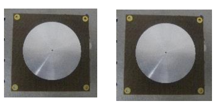
TOTAL			**40**	**20.9**

Simulation Results of Attitude Control incl. determination error

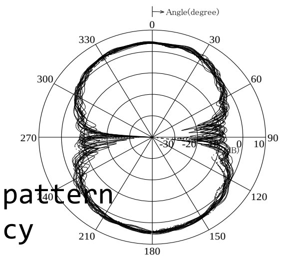


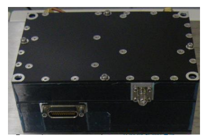
Communication

- S-band system
  - Up: 4 kbps, PCM-PSK-PM
  - Down: 64-300 kbps, BPSK
- Japan and Norway GS
- Expected communication data amount
  - 7MB/Day @ 4kbps
  - 530 MB/Day @ 300kbps



2 patch antenna
-> omni antenna pattern
for emergency

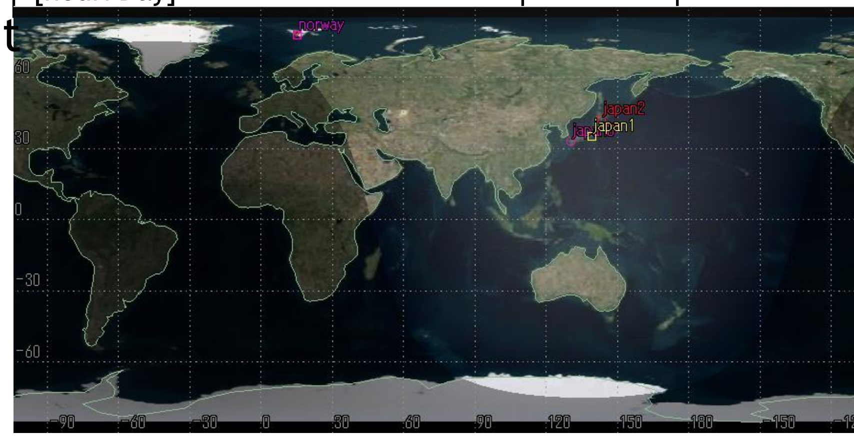




[1]

Access Summary

	Norway	Japan
Access Frequency [num./Day]	14.7	5.3
Averaged Access Duration [hour/Day]	3.0	0.9



Downlink Link Margin @ 256kbps

	Unit	min	max
Transmit EIRP	dBW	-7.13	-1.63
Transmitter Power	W	0.300	0.300
Internal Loss	dB	-3.9	-3.9
Antenna Gain	dBi	2	7.5
Free propagation range	km	2485.20	666.00
Atmospheric absorption loss	dB	-0.00305	-0.00305
Rain fade	dB	-0.08	-0.00557
Receiving G/T	dB/K	6.54	6.54
Antenna Gain	dBi	35.58	35.58
Internal Loss	dB	-2.50	-2.50
System noise temp.	K	450	450
Receiving C/N0	dBHz	60.54	77.55
Required Eb/N0(BER : 10^{-5})	dB	6	6
Symbol Rate	kbps	256	256
Required C/N0	dBHz	-60.08	-60.08
Hardware loss	dB	-1.5	-1.5
Link Margin	**dB**	**0.20**	**17.21**

Uplink Link Margin

	Unit	min	max	Command Margin	min	max	
Transmitter Power	W	10	10	Required Eb/No	9.303	9.303	dB
Internal Loss	dB	-0.9	-0.9	Modulation Loss	11.14	11.14	dB
Antenna Gain	dBi	36.2	36.2	Demodulation Loss	2.4	2.4	dB
Transmit EIRP	dBW	45.3	45.3	Coding Gain	2.498	2.498	dB
Free propagation range	km	2485.2	666	Required C/No	56.36	56.36	dBHz
Free propagation loss	dB	-166.8	-155.33	**Link Margin**	**11.33**	**22.78**	**dB**
Atmospheric absorption loss	dB	-0.003	-0.003				
Rain fade	dB	-0.079	-0.079	Carrier Margin	min	max	
Antenna Gain	dBi	-10	-10	Required S/N	10.00	10.00	dB
Internal Loss	dB	-0.90	-0.90	Modulation Loss	2.325	2.325	dB
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Received C/N0	dBHz	67.70	79.13				

Enough Link Margin, Enough data communication

[1] http://www.dst.c

Access Summary

	Norway	Japan
Access Frequency [num./Day]	14.7	5.3
Averaged Access Duration [hour/Day]	3.0	0.9

Expected communication data amount

- 7MB/Day @ 4kbps
- 530 MB/Day @ 300kbps

Downlink Link Margin @ 256kbps

	Unit	min	max
Transmit EIRP	dBW	-7.13	-1.63
Transmitter Power	W	0.300	0.300
Internal Loss	dB	-3.9	-3.9
Antenna Gain	dBi	2	7.5
Free propagation range	km	2485.20	666.00
Atmospheric absorption loss	dB	-0.00305	-0.00305
Rain fade	dB	-0.08	-0.00557
Receiving G/T	dB/K	6.54	6.54
Antenna Gain	dBi	35.58	35.58
Internal Loss	dB	-2.50	-2.50
System noise temp.	K	450	450
Receiving C/N0	dBHz	60.54	77.55
Required Eb/N0(BER ：10^{-5})	dB	6	6
Symbol Rate	kbps	256	256
Required C/N0	dBHz	-60.08	-60.08
Hardware loss	dB	-1.5	-1.5
Link Margin	**dB**	**0.20**	**17.21**

Uplink Link Margin

	Unit	min	max	Command Margin	min	max	
Transmitter Power	W	10	10	Required Eb/No	9.303	9.303	dB
Internal Loss	dB	-0.9	-0.9	Modulation Loss	11.14	11.14	dB
Antenna Gain	dBi	36.2	36.2	Demodulation Loss	2.4	2.4	dB
Transmit EIRP	dBW	45.3	45.3	Coding Gain	2.498	2.498	dB
Free propagation range	km	2485.2	666	Required C/No	56.36	56.36	dB Hz
Free propagation loss	dB	-166.8	-155.33	**Link Margin**	**11.33**	**22.78**	**dB**
Atmospheric absorption loss	dB	-0.003	-0.003				
Rain fade	dB	-0.079	-0.079	Carrier Margin	min	max	
Antenna Gain	dBi	-10	-10	Required S/N	10.00	10.00	dB
Internal Loss	dB	-0.90	-0.90	Modulation Loss	2.325	2.325	dB
System noise temp.	K	700	700	Required C/No	42.32	42.32	dB
Received G/T	dB/K	-39.35	-39.35	**Link Margin**	**25.37**	**36.81**	**dB**
Received C/N0	dBHz	67.70	79.13				

Mass		40 kg
Volume		300 x 300 x 300 mm
Maximum Power Supply		34 W, Body mount (7S2P / 7S3P) (Solar cells are covered with SnO_2)
Power storage		5.8 Ah (Max DOD:15.7 %)
Lifetime		2 year
ADCS	Attitude Determination Accuracy	1° NSAS(6), GAS(1), MEMS Gyro(1), IR Earth Sensor(1)
	Attitude Control Accuracy	7° RW(3), MTQ(3)
COM		S-band Up: 4 kbps, PCM-PSK-PM Down: 64-300 kbps, BPSK
Ground Station		Norway (Svalbard) , Japan

	Plan A	Plan B
Total	**4,000,000**	**30,000,000**
Mission Payloads		
Satellite Bus		
IA&T		
Ground Systems		
Project Management & SE		

Funding Sources

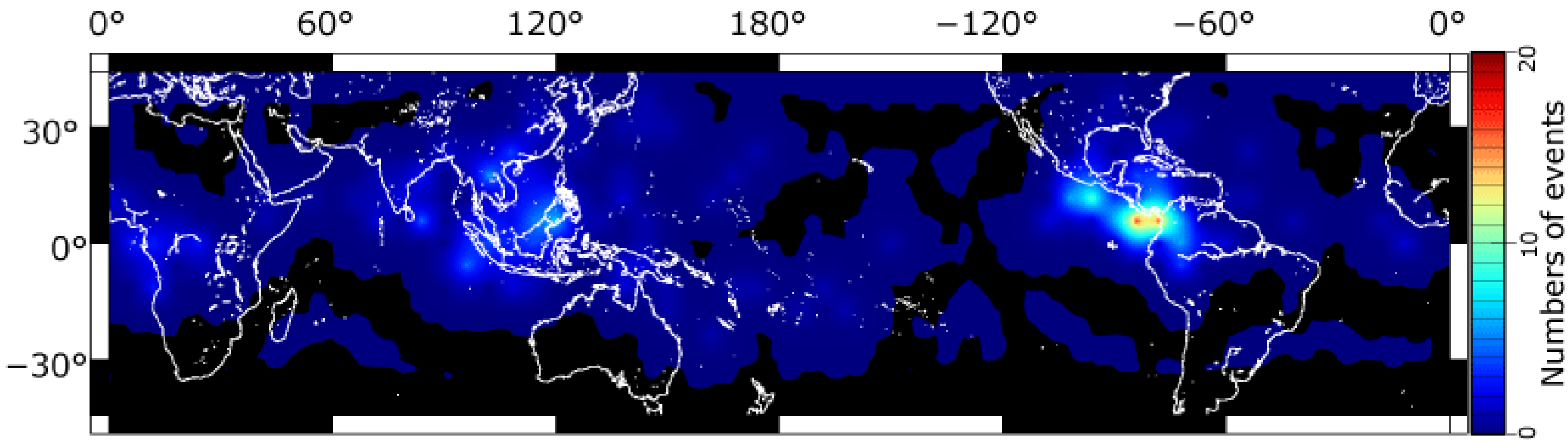
Grant-in-Aid for Scientific Research (KAKENHI)

- Up to 300 M JPY expected
- Funded Tohoku University's SPRITE-SAT

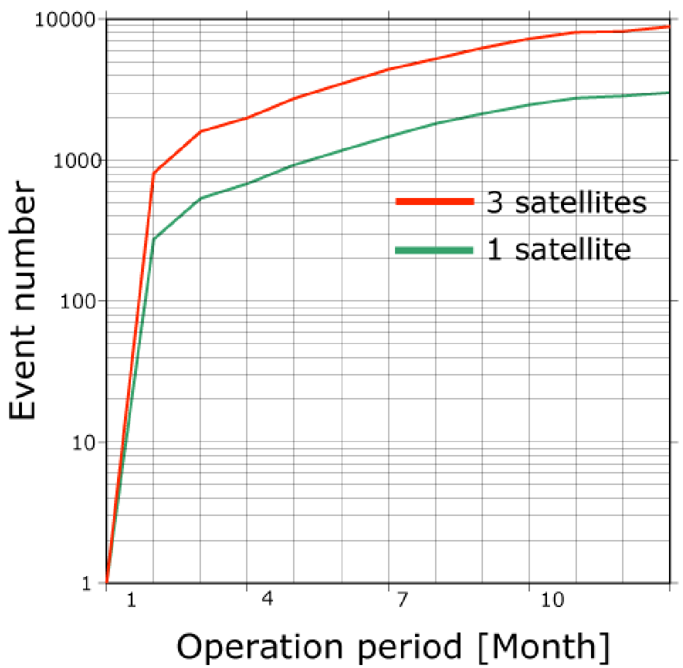
Official Development Assistance (ODA)

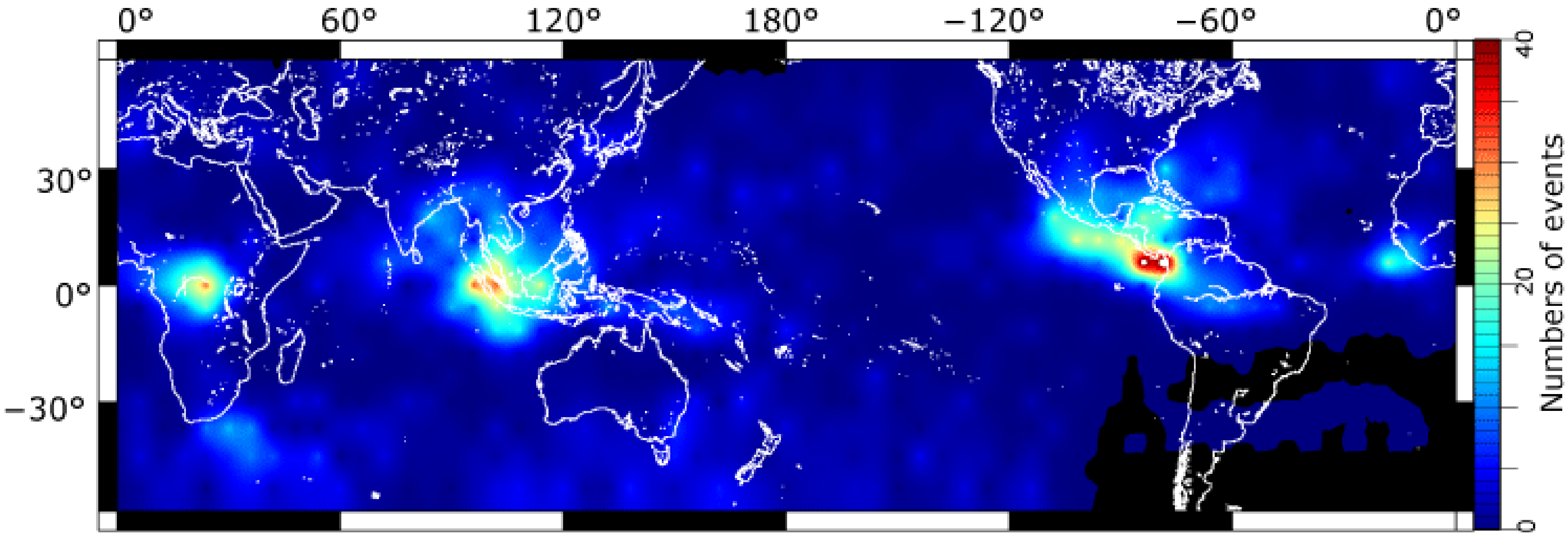
- First case: 40 B JPY to Vietnam
- Especially for countries participating in UNISEC's CanSat Leadership Training Program

Proposal will be submitted to JSPS (KAKENHI) **this month** by Prof. Kamogawa for next fiscal year funding.

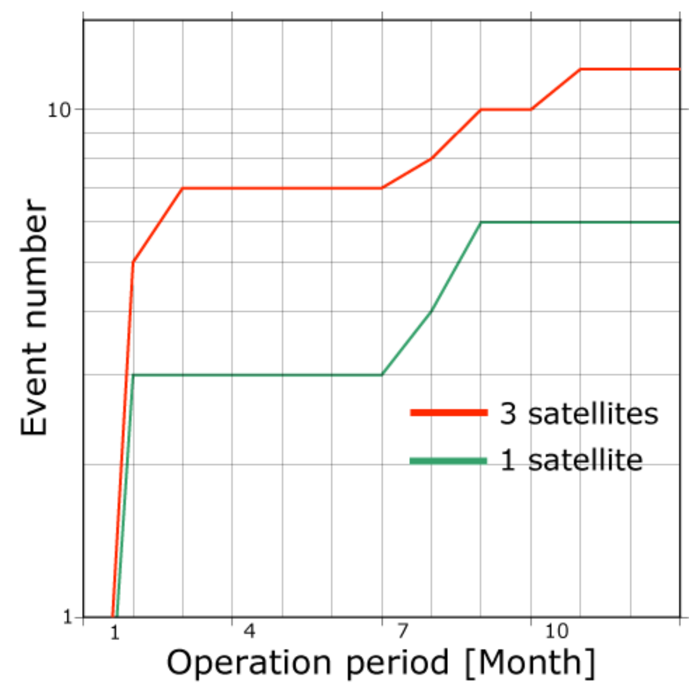


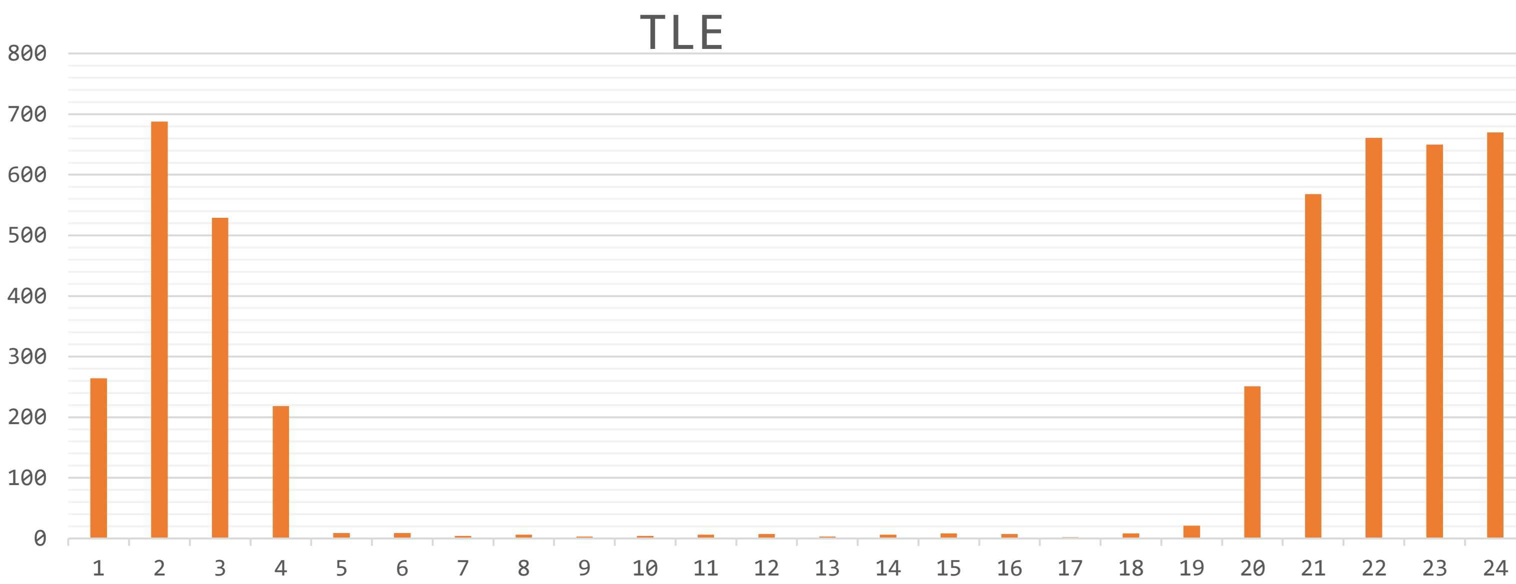
TLE map and Event number

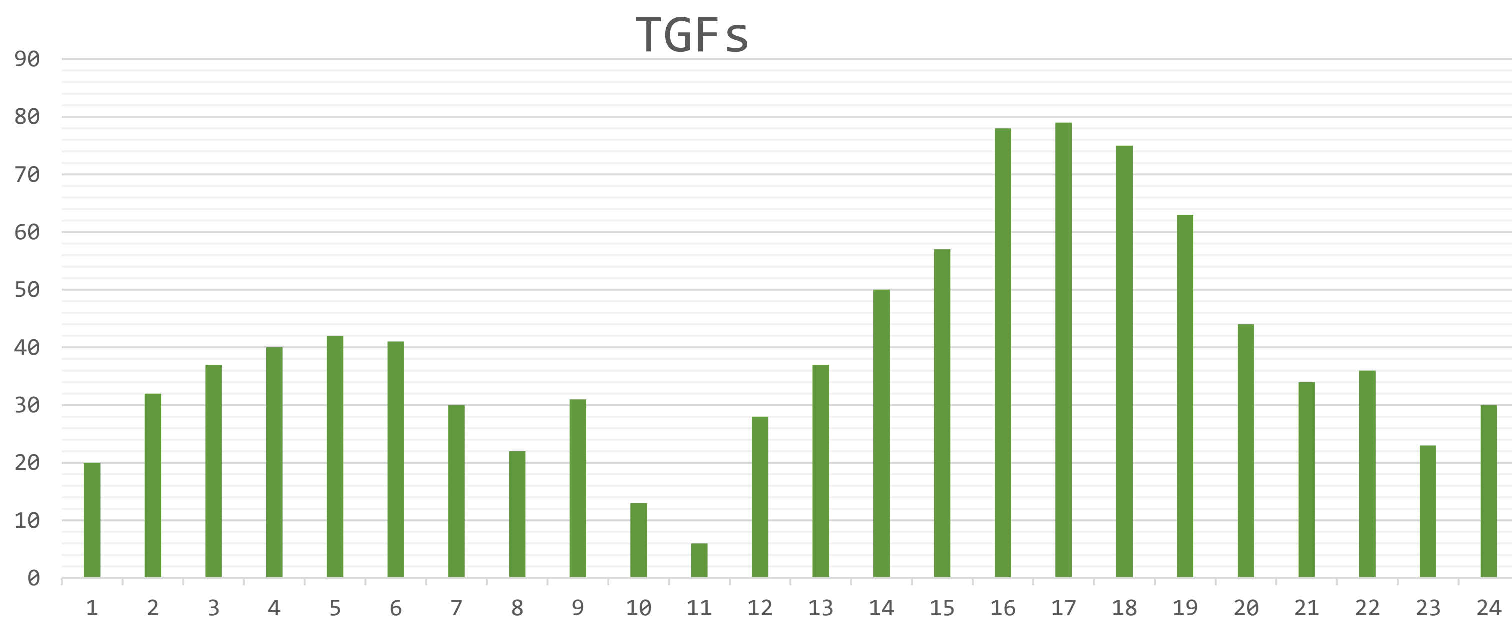


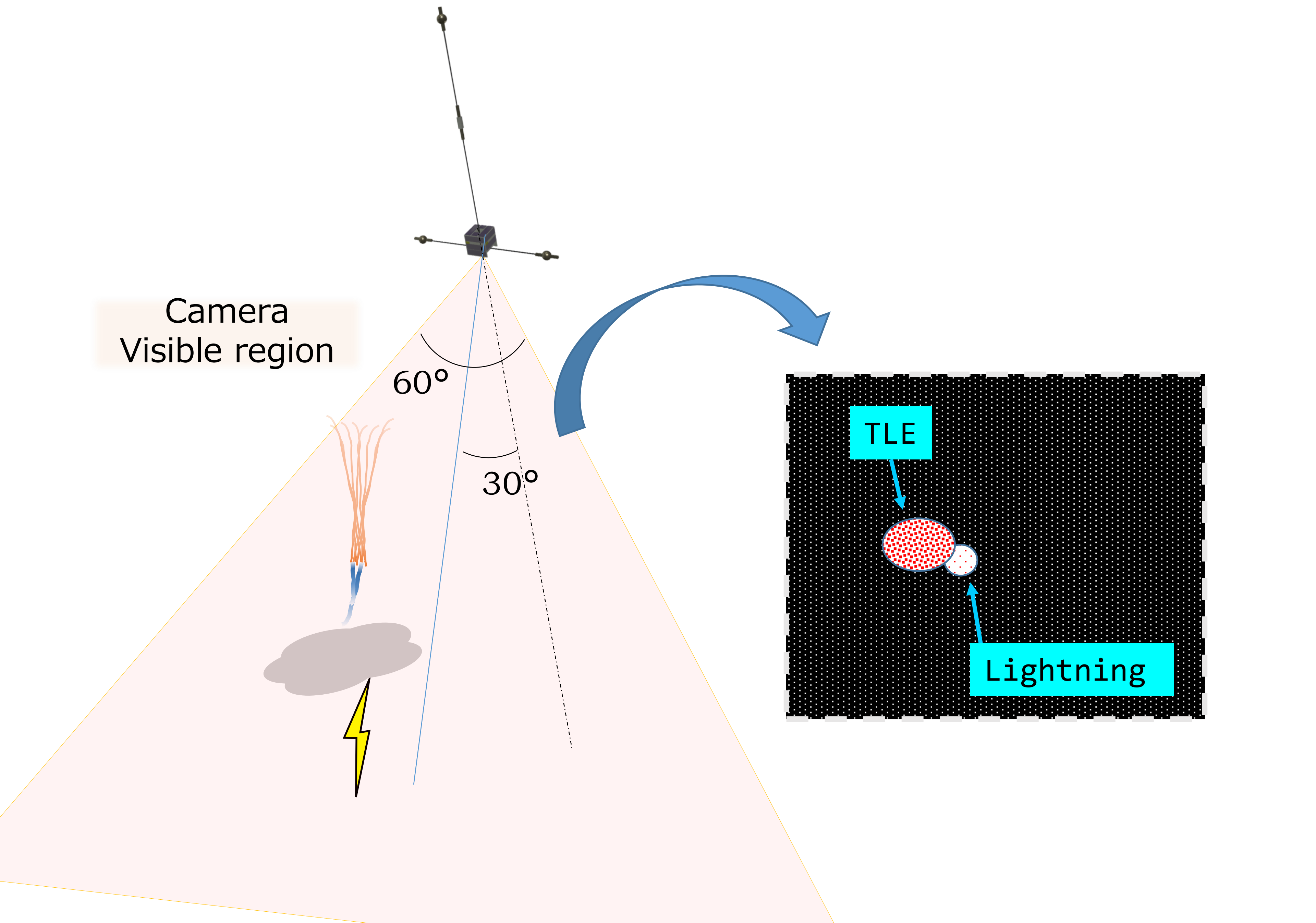


TGFs map and Event number




TLE
800
700
600
500
400
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

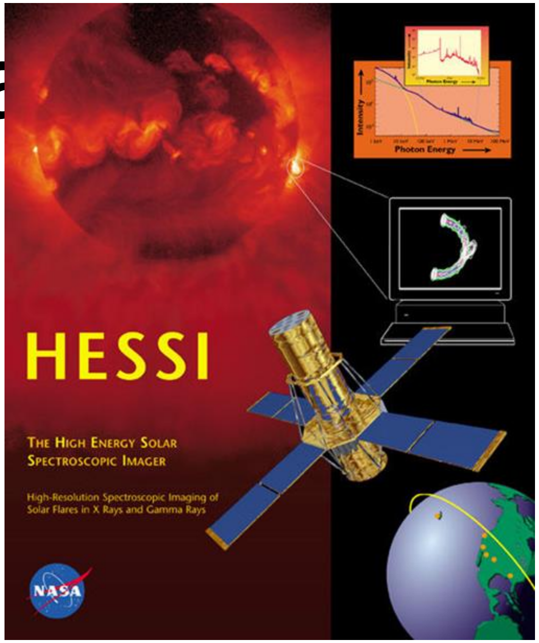

TGFs
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


Camera
Visible region
60°
30°
TLE
Lightning

How to estimate TGF and TLE events

Purpose
estimation of detect number using orbit calculation
→We need global cata

	Ground observation
Lightning	WWLLN
Earthquake	USGS
TGF	×



http://hesperia.gsfc.nasa.gov/rhe

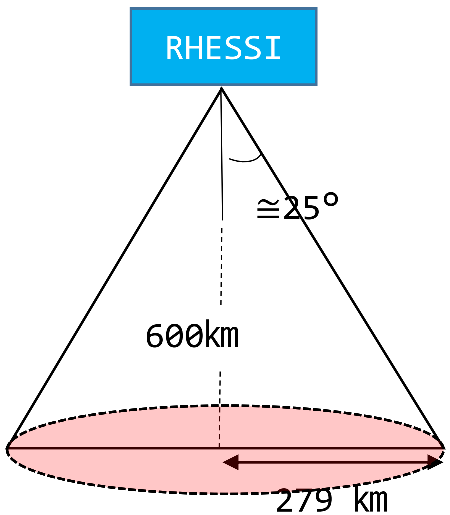
JEM-GLIMS mission

http://www.nasa.gov/mission_pages/station/research/experiments/121.html

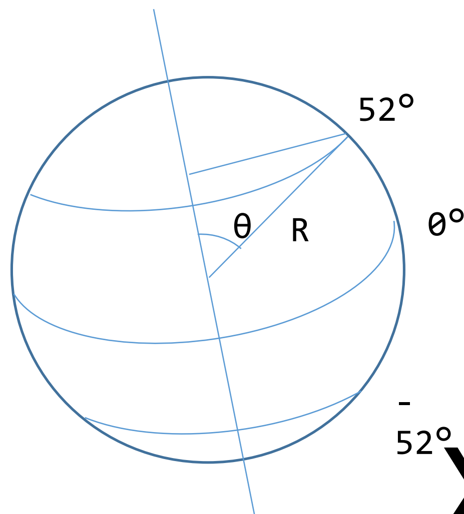
- Satellite have only visible data then

→ We estimated whole events by rate of satellite detectable area and orbital area.

Estimation of whole data amount



:



= 975 : X

X=6.92×10^5

Visible area : S1

S1 $= \pi r^2 = 3.14 * 279 * 279$

=2.44 ×10^5 [km^2]

Ornbital area : S2

S2 $= 2 * \int_0^{(90-38)^\circ} 2\pi R sin\theta * R d\theta$

$= 4\pi R^2 [1 - cos\theta]_0^{52^\circ}$

=4*3.14*6371*6371*(1-0.61)

=1.98×10^8 [km^2]

How to make TGF standard model

1) Download data set as follows.

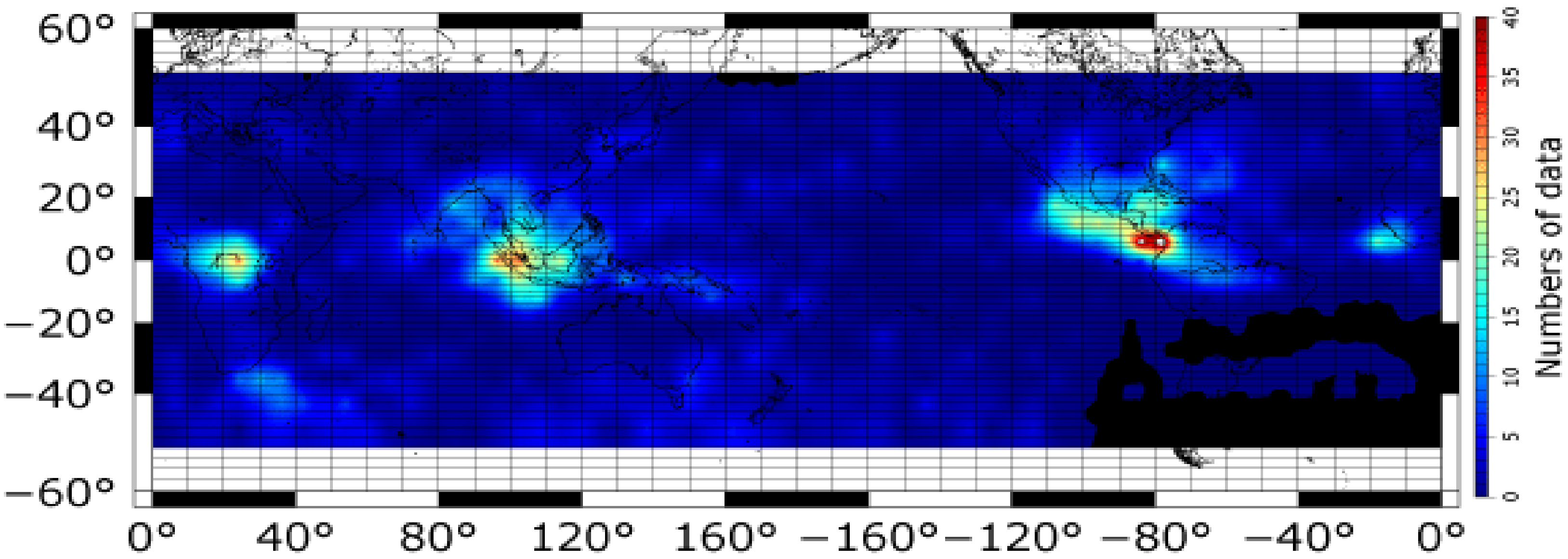
http://scipp.ucsc.edu/~dsmith/tgflib_public/data/

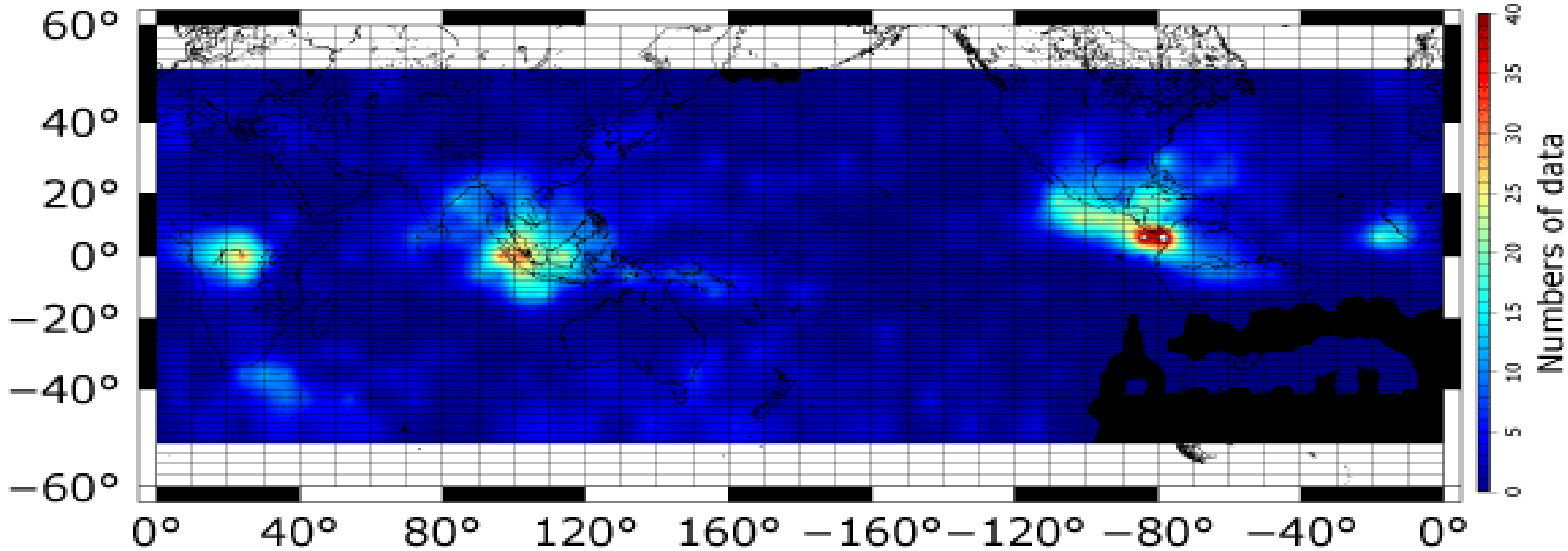
2) Separate events in bin

a) Space : 6 ° (longitudinal and latitudinal)

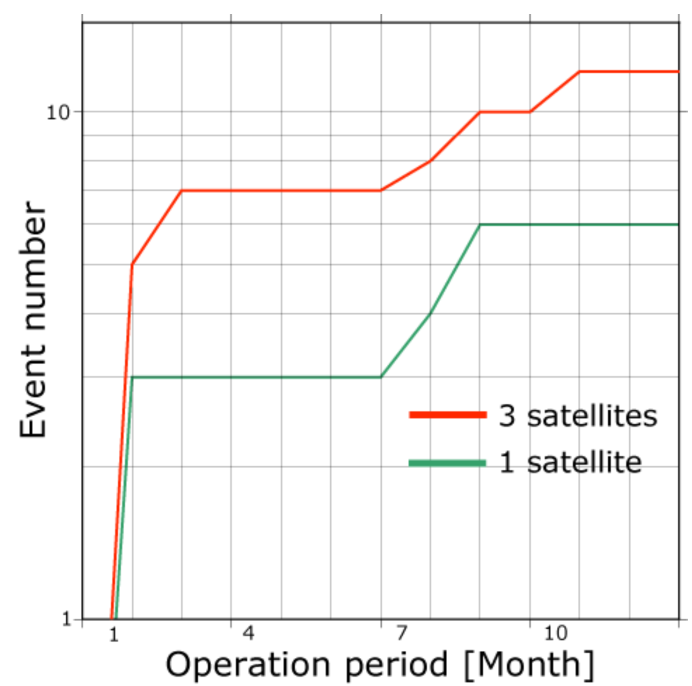
b) Season : Summer (5 ~ 10) and Winter (11 ~ 4)

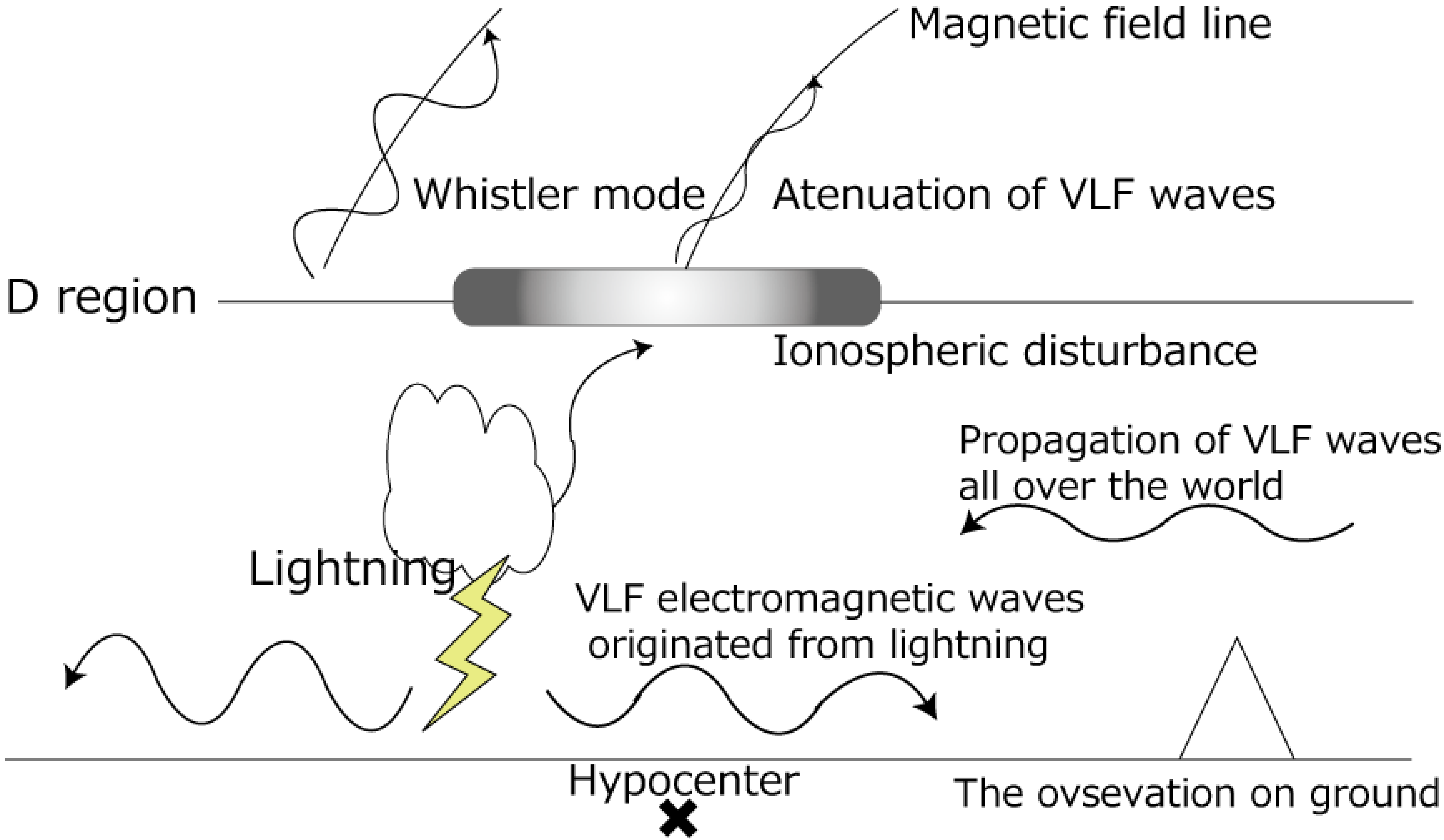
c) Time zone : Day (LT 6 ~ 18) and Night (LT 0 ~6, 18 ~ 24)



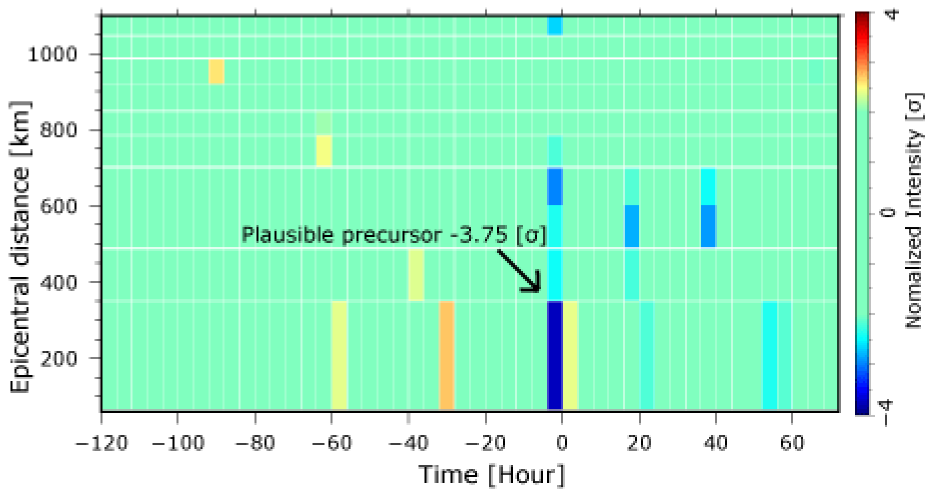


Orbit calculation
Using GOSAT



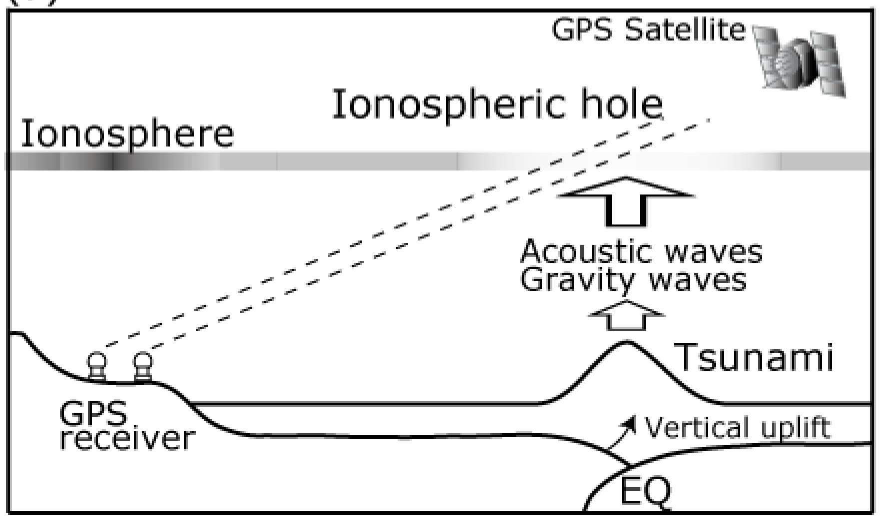


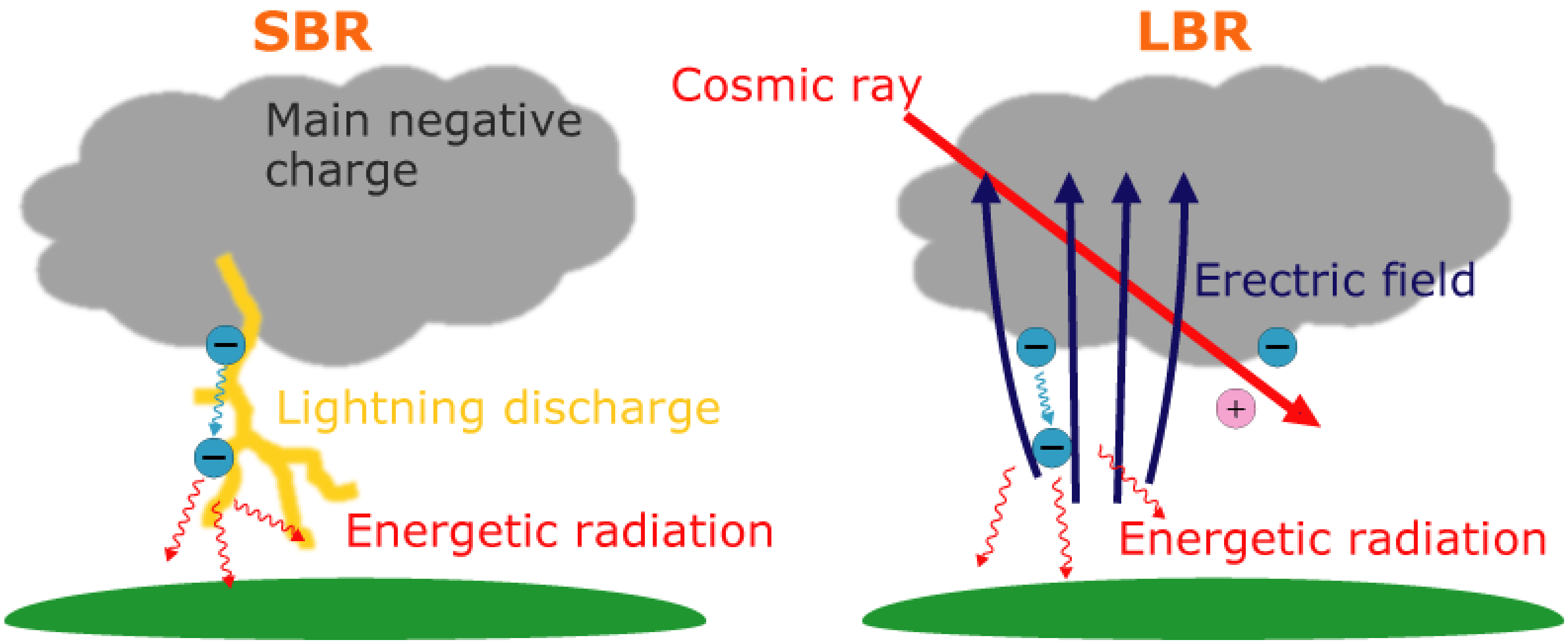
Magnetic field line
Whistler mode
Atenuation of VLF waves
D region
Ionospheric disturbance
Propagation of VLF waves
all over the world
Lightning
VLF electromagnetic waves
originated from lightning
Hypocenter
The ovsevation on ground

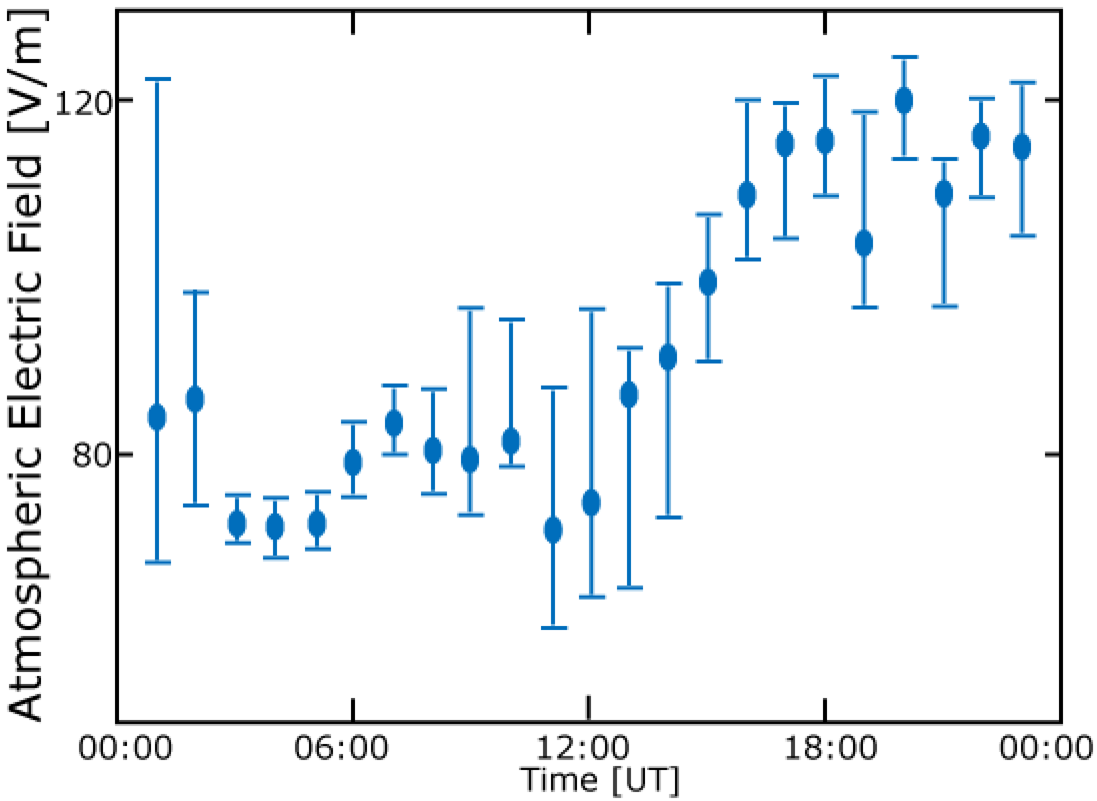


Plausible precursor -3.75 [σ]
Epicentral distance [km]
1000
800
600
400
200
−120
−100
−80
−60
−40
−20
0
20
40
60
Time [Hour]
4
0
−4
Nomalized Intensity [σ]

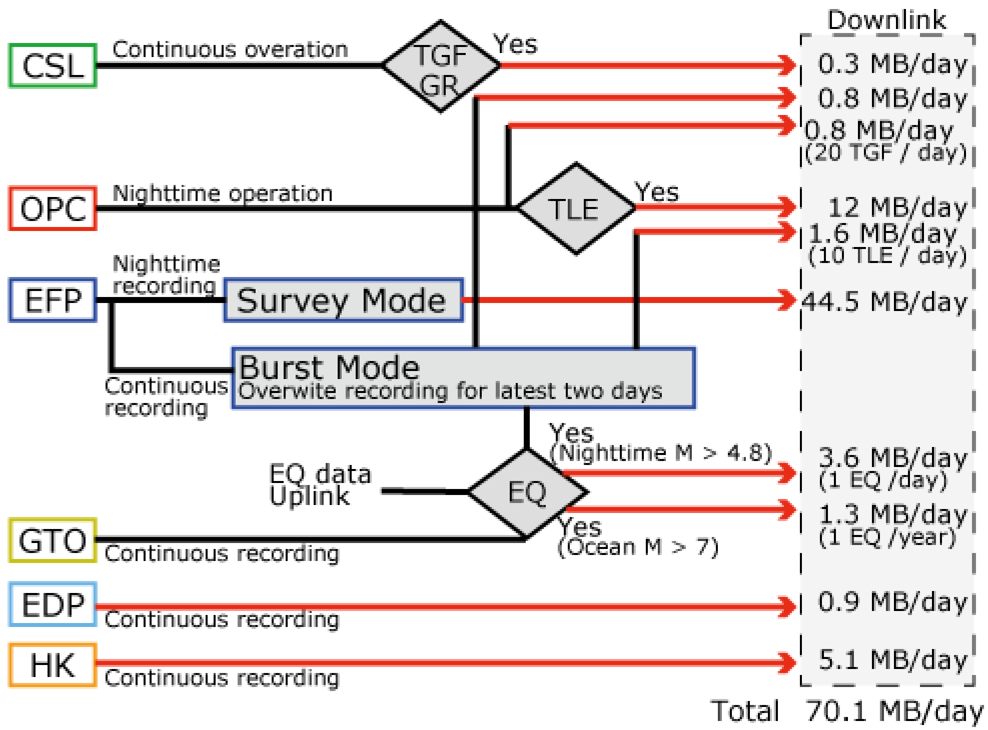
(a)

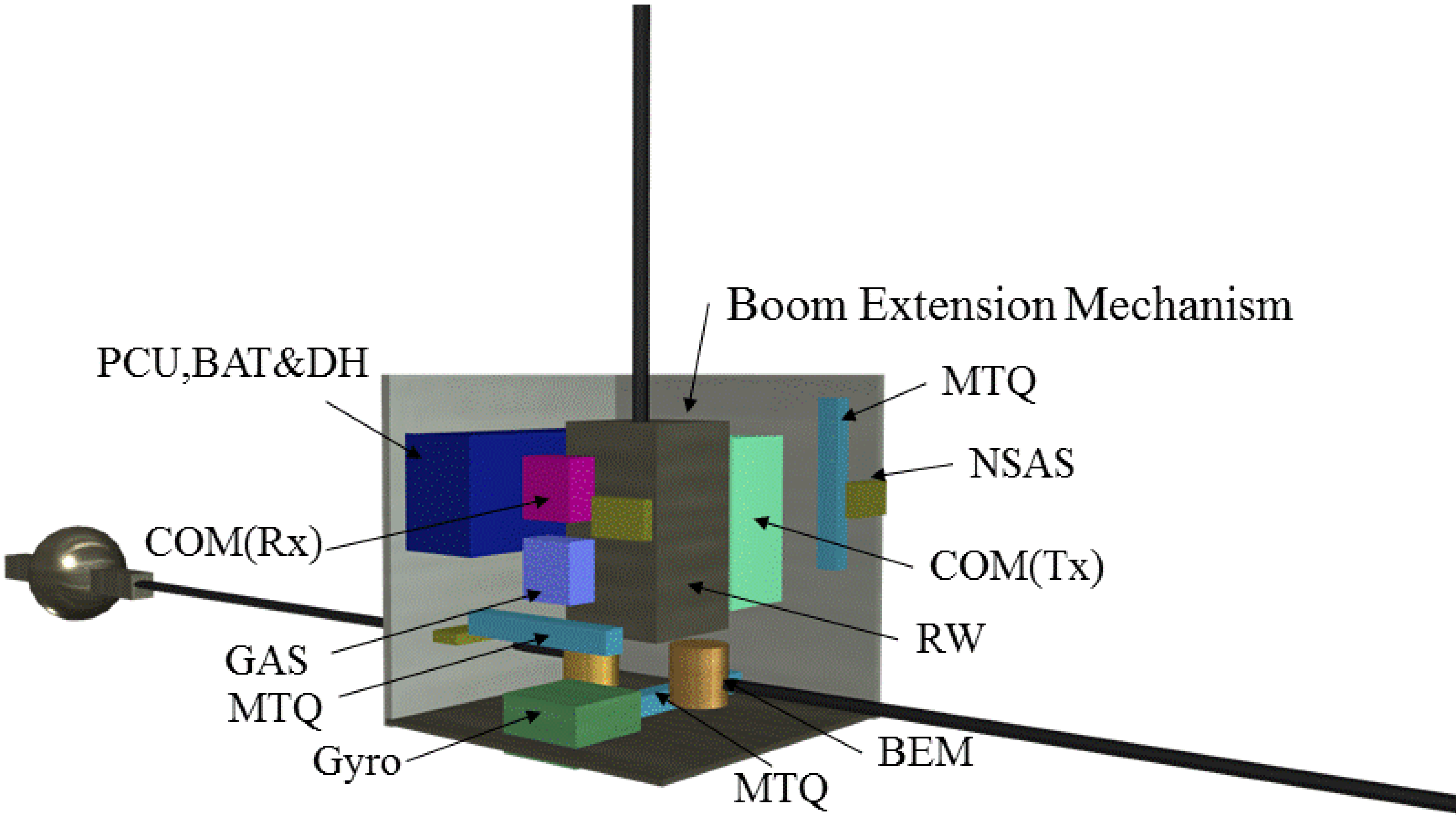

GPS Satellite
Ionospheric hole
Ionosphere
Acoustic waves
Gravity waves
Tsunami
GPS
receiver
Vertical uplift
EQ


SBR
LBR
Cosmic ray
Main negative charge
Erectric field
Lightning discharge
Energetic radiation
Energetic radiation

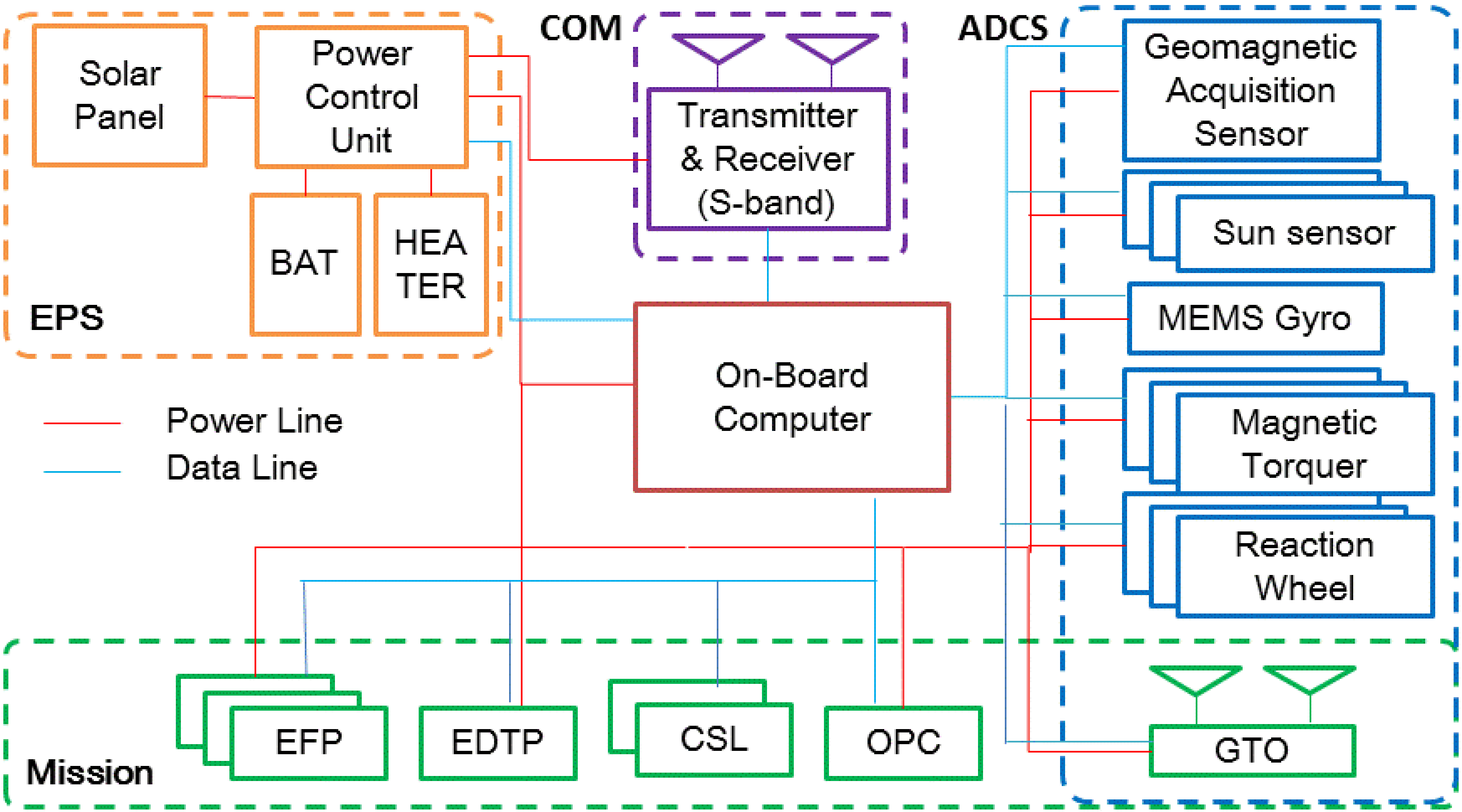


Atmospheric Electric Field [V/m]
120
80
00:00
06:00
12:00
18:00
00:00
Time [UT]

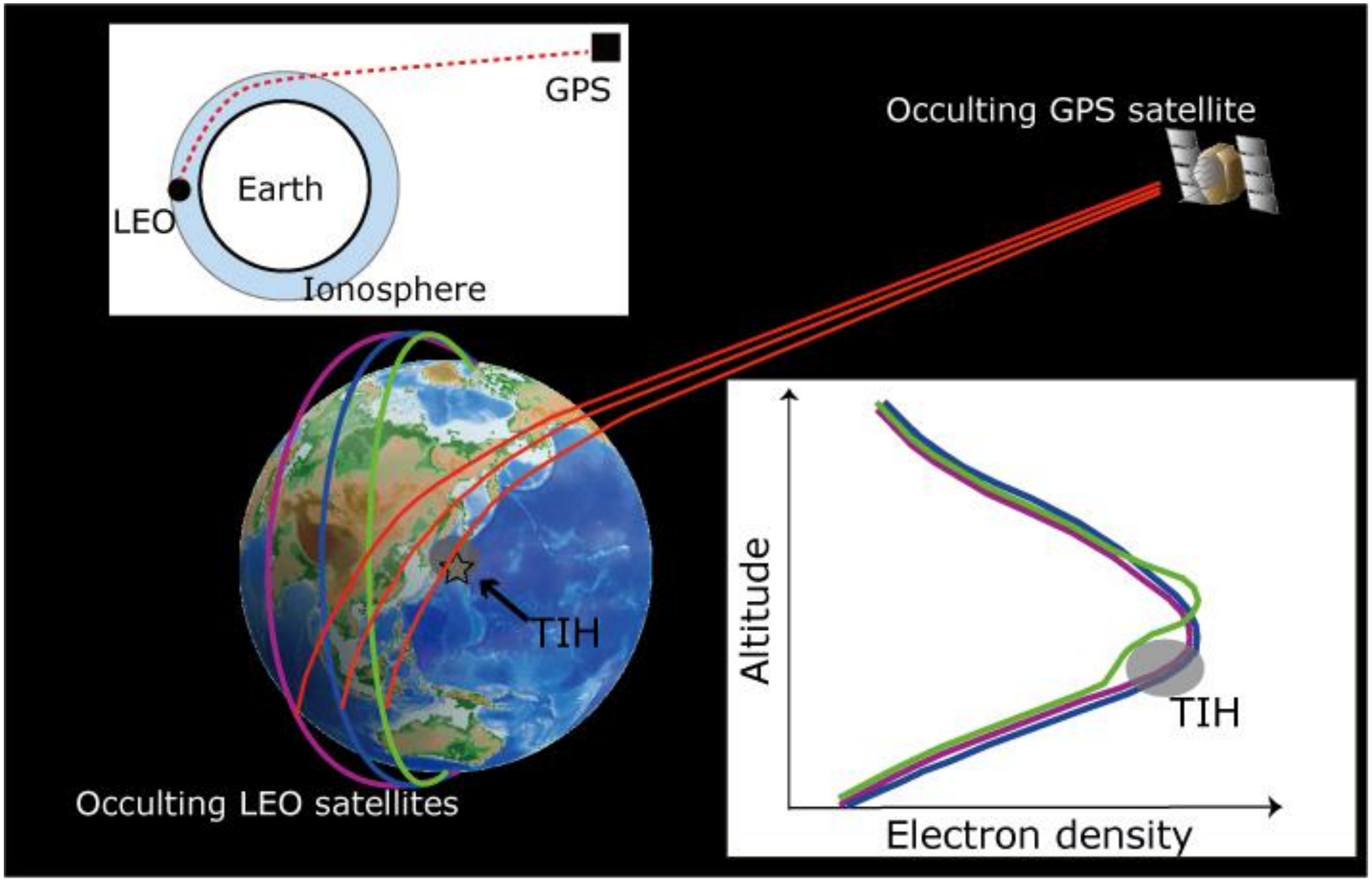

Downlink
CSL
Continuous overation
TGF
GR
Yes
0.3 MB/day
0.8 MB/day
0.8 MB/day
(20 TGF / day)
OPC
Nighttime operation
TLE
Yes
12 MB/day
1.6 MB/day
(10 TLE / day)
EFP
Nighttime
recording
Survey Mode
44.5 MB/day
Burst Mode
Overwite recording for latest two days
Continuous
recording
Yes
(Nighttime M > 4.8)
3.6 MB/day
(1 EQ /day)
EQ data
Uplink
EQ
1.3 MB/day
(1 EQ /year)
Yes
(Ocean M > 7)
GTO
Continuous recording
EDP
Continuous recording
0.9 MB/day
HK
Continuous recording
5.1 MB/day
Total 70.1 MB/day



Boom Extension Mechanism
PCU,BAT&DH
MTQ
NSAS
COM(Rx)
COM(Tx)
RW
GAS
MTQ
Gyro
BEM
MTQ



COM
ADCS
Solar Panel
Power Control Unit
BAT
HEA TER
EPS
Transmitter & Receiver (S-band)
Geomagnetic Acquisition Sensor
Sun sensor
MEMS Gyro
On-Board Computer
Magnetic Torquer
Reaction Wheel
Power Line
Data Line
EFP
EDTP
CSL
OPC
GTO
Mission



GPS
Earth
LEO
Ionosphere
Occulting GPS satellite
TIH
Altitude
TIH
Electron density
Occulting LEO satellites