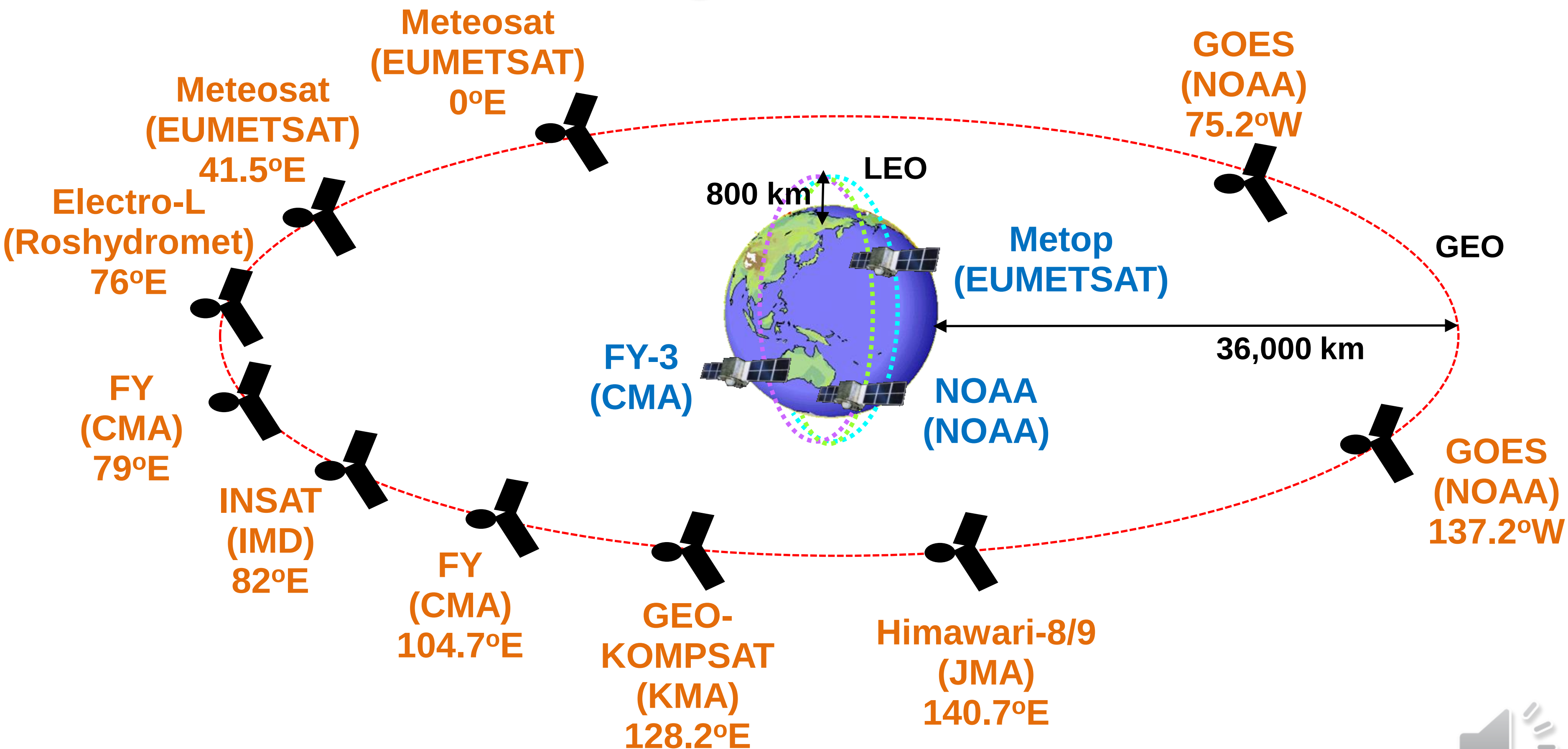
Toward the upgrade of Geo-Ring observation



Kotaro BESSHO (JMA) and Kenneth Holmlund (WMO)

WMO Vision for WIGOS in 2040 for GEO

	Application	Satellite/Instrument
VIS/IR Imager w/ rapid repeat cycles	Cloud amount/type/top height/temperature, wind, sea/land surface temperature, precipitation, aerosols, snow cover, vegetation cover, albedo, atmospheric stability, fires, volcanic ash, sand/dust storm, convective initiation	• **NOAA: GOES-16,17/ABI** • **JMA: Himawari-8,9/AHI** • **KMA: GK-2A/AMI** • **CMA: FY-4A,4B/AGRI** • **EUMETSAT: MTG-I1/FCI (2022)**
Hyperspectral IR Sounder	Atmospheric temperature/humidity, wind, rapidly evolving mesoscale features, sea/land surface temperature, cloud amount/top height/temperature, atmospheric composition	• **NOAA: under consideration** • **JMA: under consideration** • **KMA: under consideration** • **CMA: FY-4A,4B/GIIRS** • **EUMETSAT: MTG-S1/IRS (2024)**
Lightning Mapper	Lightning, location of intense convection, life cycle of convective systems	• **NOAA: GOES-16,17/GLM** • **JMA: under consideration** • **KMA: under consideration** • **CMA: FY-4A/LMI** • **EUMETSAT: MTG-I1/LI (2022)**
UV/VNIR Sounder	Ozone, trace gases, aerosol, humidity, cloud top height	• **NASA: TEMPO (2022)** • **JMA: N/A** • **KMA: GK-2B/GEMS** • **CMA: N/A** • **EUMETSAT: MTG-S1/UVN (2024)**

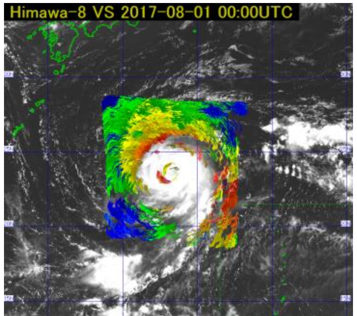
➢ CGMS will strive to advance the new generation of GEO satellites, including advanced imaging, IR sounding and lightning mapping for the whole **geostationary ring**. It is also agreed that CGMS will strive to work towards operational hourly daytime UV/VIS mapping of air quality from geostationary orbit.

Comparison of current and future Imagers

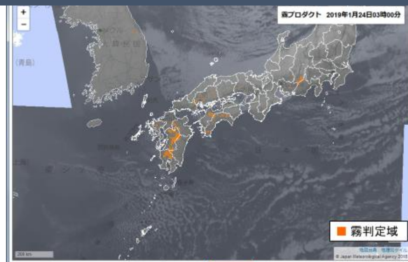
	Himawari-8/9 AHI (JMA)	GOES-R ABI (NOAA)	GeoXO Baseline (NOAA)	MTG FCI (EUMETSAT)	MSG SEVIRI (EUMETSAT)	FY-4A AGRI (CMA)	GK-2A AMI (KMA)	Applications
VIS	0.47 (1)	0.47 (1)	0.47 (1)	0.44 (1)		0.47	0.455	aerosol, surface features
	0.51 (1)		0.55 (1)	0.51 (1)			0.511	aerosol, vegetation
	0.64 (0.5)	0.64 (0.5)	0.64 (0.5)	0.64 (1/0.5)	0.635	0.65	0.642	fog, insolation, winds
NIR	0.86 (1)	0.86 (1)	0.86 (1)	0.86 (1)	0.81	0.825	0.86	vegetation, winds
				0.91 (1)	0.6 - 0.9			water vapour, winds
		1.38 (2)	1.38 (2)	1.38 (1)		1.375	1.38	thin cirrus
	1.6 (2)	1.61 (1)	1.61 (1)	1.61(1)	1.64	1.61	1.61	cloud phase, snow/ice
	2.3 (2)	2.26 (2)	2.25 (2)	2.25 (1/0.5)		2.25		particle size, vegetation
IR	3.9 (2)	3.90 (2)	3.9 (1)	3.8 (2/1)	3.92	3.75	3.85	microphysics, fires
	6.2 (2)	6.15 (2)	6.185 (2)	6.3 (2)	6.25	6.25	6.24	WV, winds, rainfall
	6.9 (2)	7.00 (2)	6.95 (2)			7.1	6.95	WV, winds, rainfall
	7.3 (2)	7.40 (2)	7.3 (2)	7.35 (2)	7.35		7.34	WV, winds, SO_2
	8.6 (2)	8.50 (2)	8.5 (2)	8.70 (2)	8.70	8.5	8.60	cloud phase, SO_2
	9.6 (2)	9.70 (2)	9.61 (2)	9.66 (2)	9.66		9.63	total O_3, turbulence
	10.4 (2)	10.3 (2)	10.35 (2)	10.5 (2/1)	10.8	10.7	10.4	SST, clouds temp
	11.2 (2)	11.2 (2)	11.2 (2)			11.0	11.2	SST, clouds temp, rainfall
	12.4 (2)	12.3 (2)	12.3 (2)	12.3 (2)	12.0		12.3	TPW, dust, ash
	13.3 (2)	13.3 (2)	13.3 (2)	13.3 (2)	13.4	13.5	13.3	air temp, cloud height

- All current imagers have similar performance.
- NOAA/GeoXO imager will have a slight improvement of observation capabilities such as additional band and etc.
- **The Geo-Ring of VIS/IR Imagers has been already established, and will be updated gradually.**

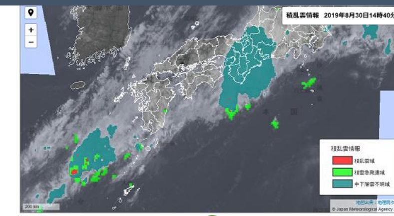
Various application of VIS/IR Imagers



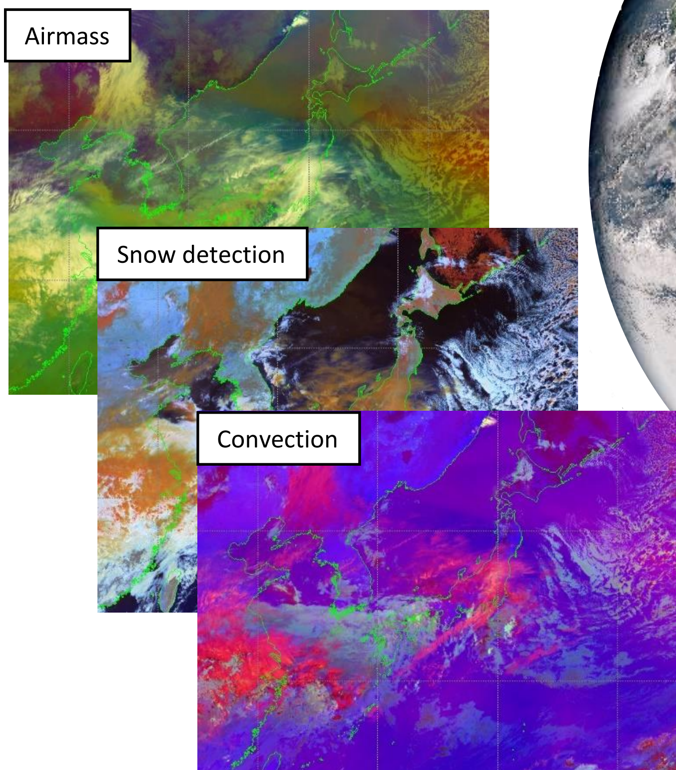
TC intensity monitoring



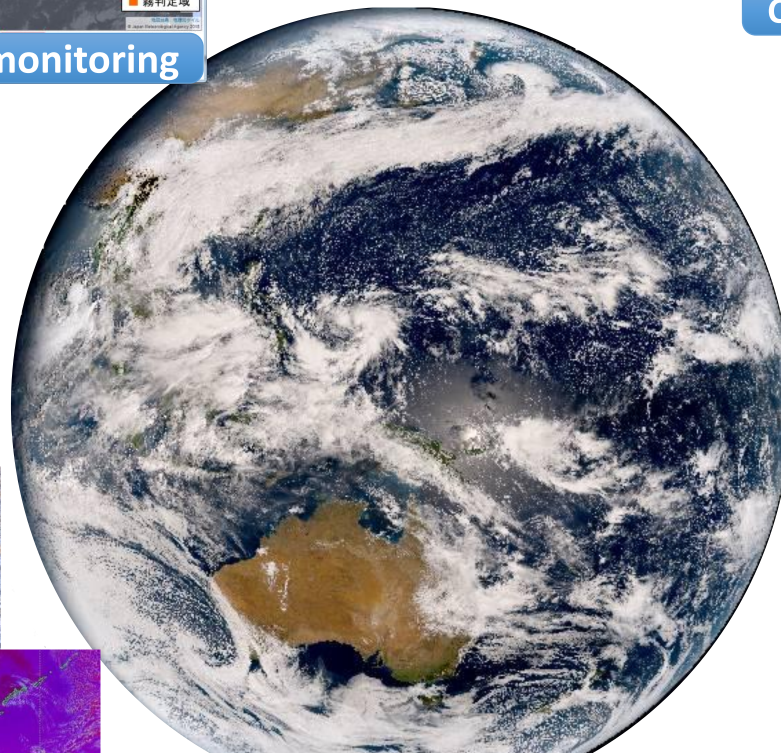
Fog area monitoring



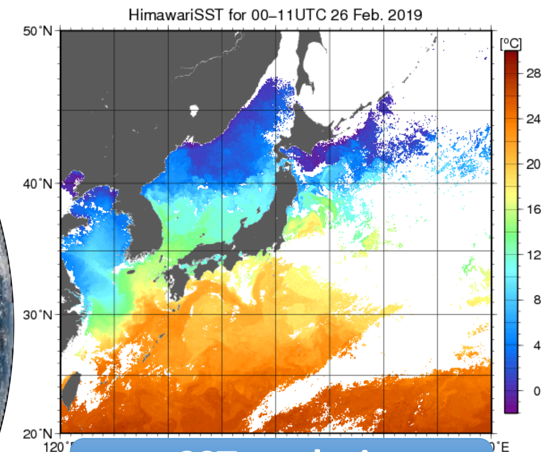
Convection monitoring



Weather watch by various RGBs

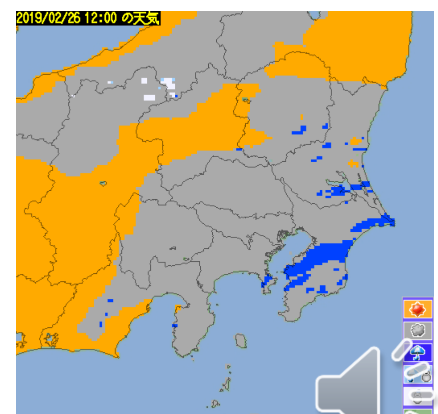


True Color Imagery



SST analysis

Dust and volcanic ash monitoring



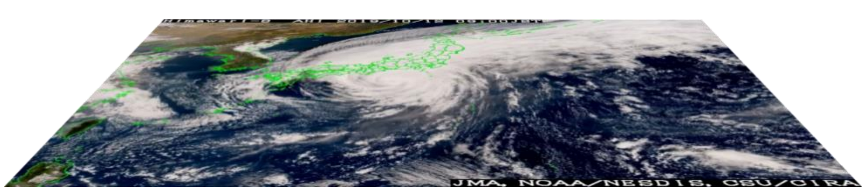
Weather discrimination

Hyperspectral Infrared Sounder (HIS)

- Hyperspectral Infrared Sounder (HIS) can observe the atmospheric vertical profiles of temperature, moisture and so on.
- Observation data from HIS on LEO has contributed the improvement of NWP.
- To improve the forecast for severe weather such as tropical cyclone, heavy rain and tornado, the observation of atmospheric vertical profiles of temperature and moisture is very important.
- It is expected that observation data from Geo-Ring of HISs on GEO (GeoHIS) will improve the results of not only global NWP, but also regional one.
- GeoHIS will improve the nowcast for severe weather, too.

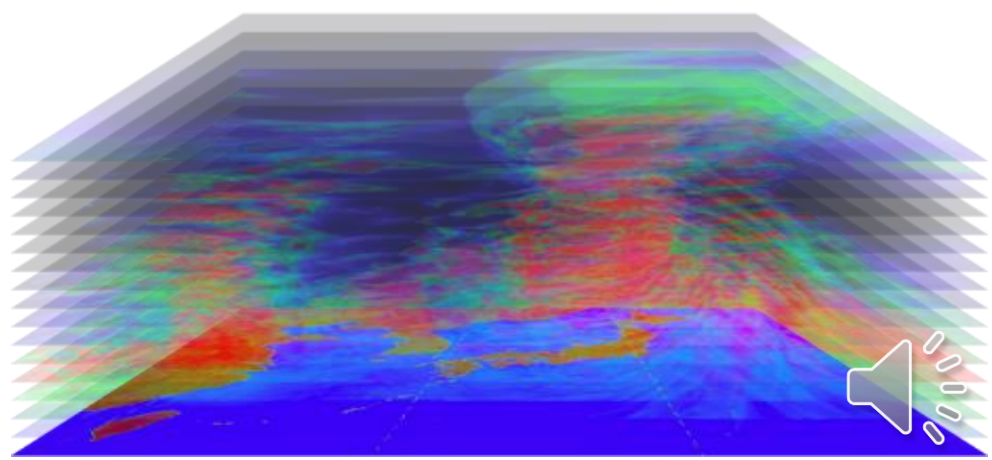
Imager: 2D

Observe cloud surface, sea surface and ground surface



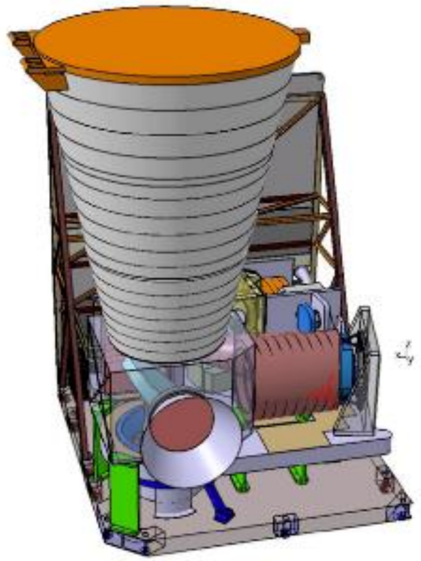
HIS: 3D

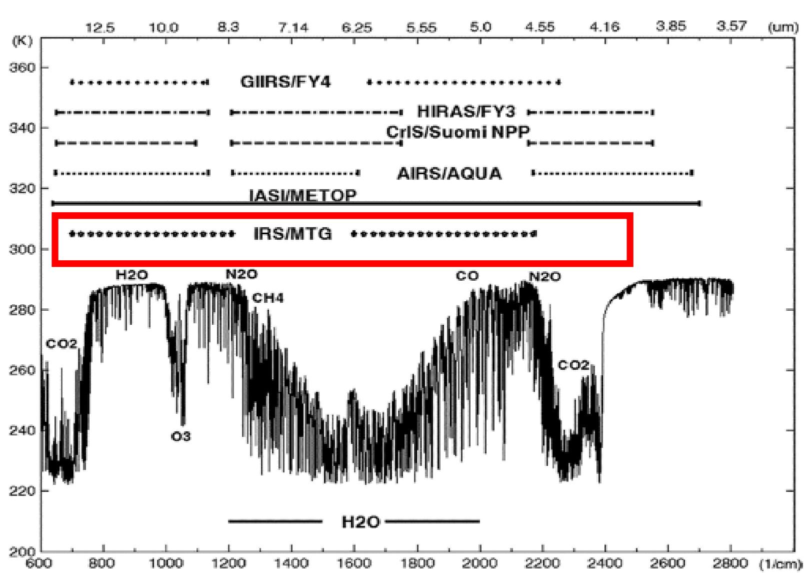
Observe the atmospheric vertical profiles



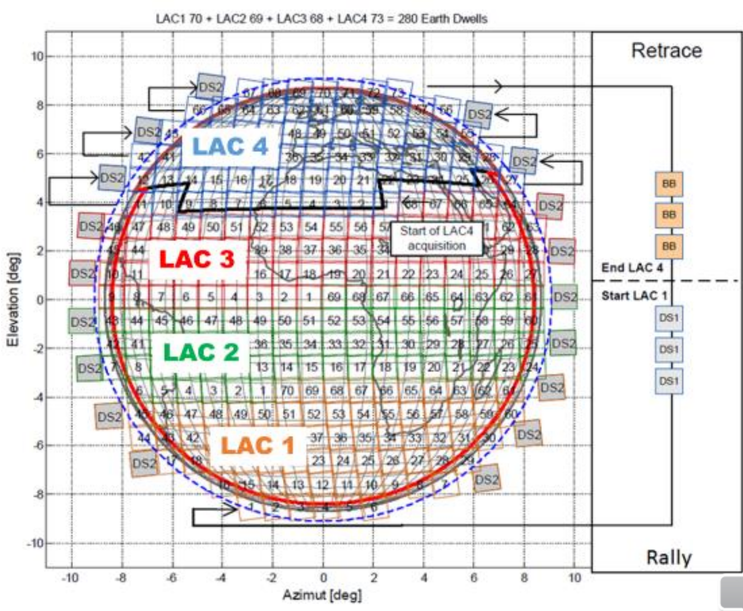
Example of HIS: IRS for MTG

- Spectral bands
  - LWIR: 680 – 1210 cm^{-1} (8.26 – 14.70 μm)
  - MWIR: 1600 – 2250 cm^{-1} (4.44 – 6.25 μm)
- Number of L1 spectral channels: 1960
  - Sampling interval: ~0.6 cm^{-1}
- Full disc coverage in 60 minutes, Europe region in 30 minutes
- Spatial resolution: 4 x 4 km at nadir





Wavelength of various LEO/GEO HIS



Observation pattern of IRS

Current and future GEO/LEO HISs

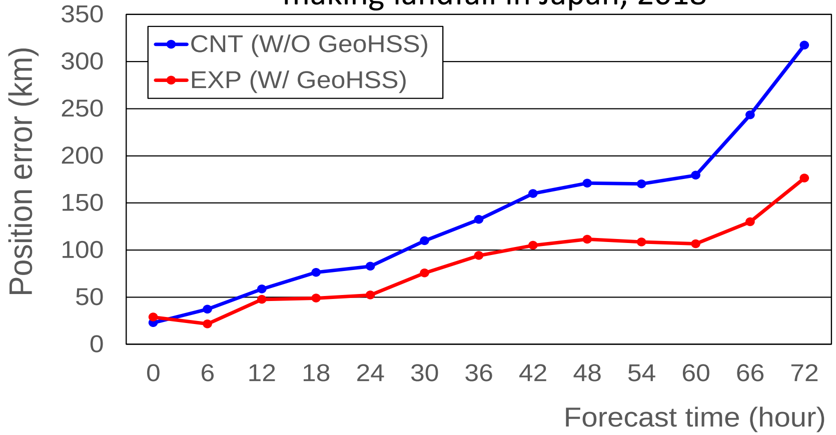
- IRS is now in production for an installation on MTG-S, which will be launched in early 2024.
- GXS is under Phase-A Study by potential suppliers.
- Observation capability and performance of GIIRS are upgraded in FY-4B.
- Other future GeoHISs are under consideration.

Name of sensor	IRS	GXS	GIIRS		IASI
Satellites	MTG-S	GeoXO (under consideration)	FY-4A	FY-4B	Metop-A, -B, -C
Year of launch	2024	2036	2016	2021	2006, 2012, 2018
Spatial resolution (SSP)	IR: 4 km	IR: 4 km VIS (DNB): 0.6 km	IR: 16 km VIS: 2 km	IR: 12 km VIS: 1 km	IR: 12 km
Spectral coverage	8.26 – 14.70 µm 4.44 – 6.25 µm	9.13 – 14.70 µm 4.44 – 5.92 µm 0.5 – 0.9 µm	8.85 – 14.29 µm 4.44 – 6.06 µm 0.55 – 0.90 µm	8.85 – 14.70 µm 4.44 – 6.06 µm 0.55 – 0.90 µm	8.26 – 15.50 µm 5.00 – 8.26 µm 3.62 – 5.00 µm
Spectral resolution (sampling interval)	0.754 cm^{-1} (~0.6 cm^{-1})	0.625 cm^{-1}	0.8 cm^{-1}, 1.6 cm^{-1} (0.625 cm^{-1})	0.8 cm^{-1} (0.625 cm^{-1})	0.5 cm^{-1} (0.25 cm^{-1})
Observation area and frequency	FD: every 60 min	Sounding Disk (62-deg LZA region): every 30 min	5000 x 5000 km^2: every 67 min	5000 x 5000 km^2 : every 45 min	8 sec/swath (2200 km)
Calibration accuracy	0.5 K@280 K	1.0 K @300 K	1.5 K	0.7 K	0.5 K

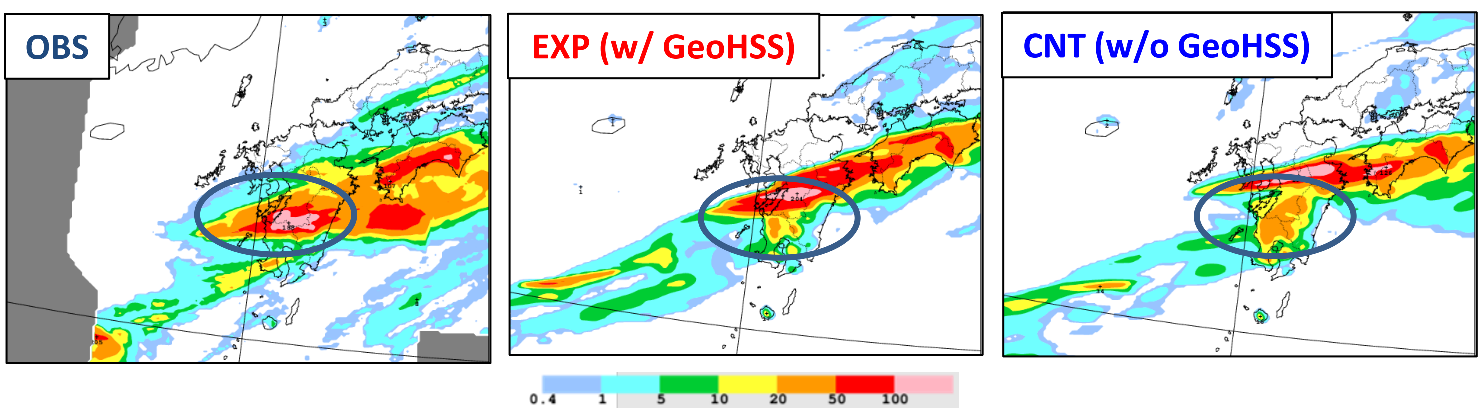
OSSE of GeoHIS

- Several experiments were implemented with [Okamoto *et al.* (2020)]
  - ➢ Operational DA configuration (incl. use of AIRS/CrIS/IASI in global model)
  - ➢ Hypothetical IRS on GEO at 140.7 E, hourly full-disk obs w/ 30 km spatial resolution from ERA5
- Global DA (upper figure)
  - ➢ ~140 km improvement in typhoon position for 3-d forecast (time of landing)
- Regional DA (bottom figures)
  - ➢ Better location of the heaviest rain area which caused devastating floods

Averaged track forecast errors (4 typhoons) making landfall in Japan, 2018

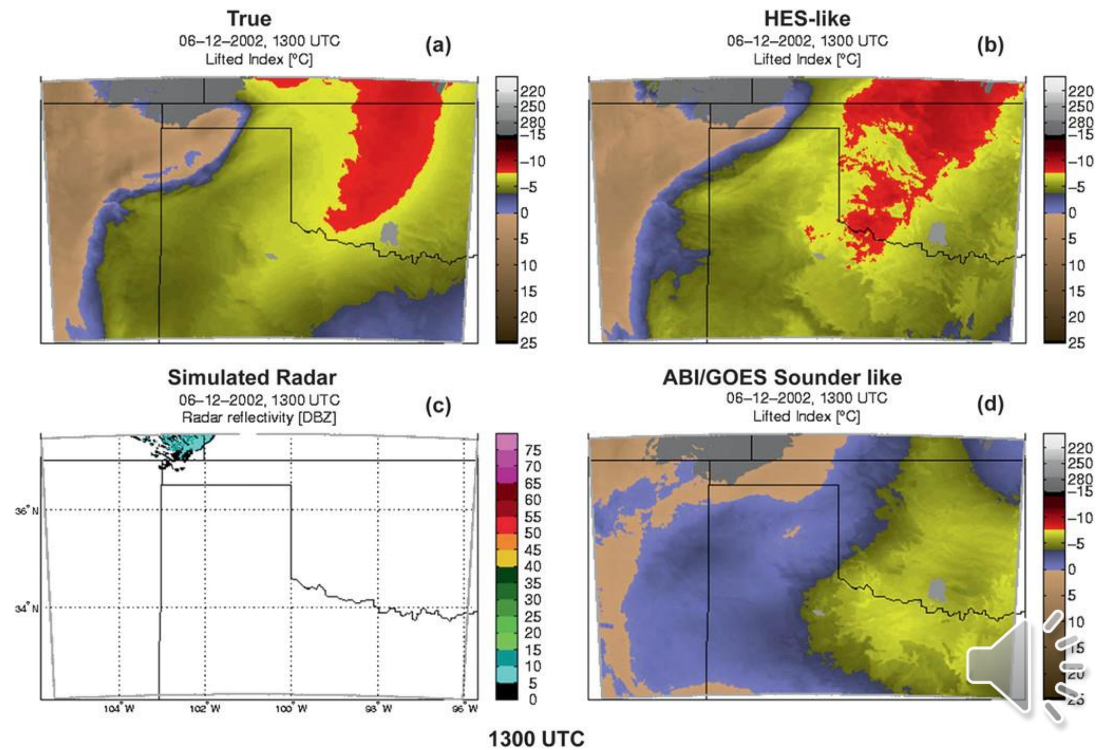


3-hour accumulated rainfall (mm), 12-h forecast valid at 0900 UTC on 2020-07-04



Application of GeoHIS for Nowcasting

- ***Instability index***
  - Since GeoHIS can obtain more information on the vertical profile of the lower atmosphere than Imager, it is expected that the estimation accuracy of instability index will be greatly improved by using its observation data.
- ***Tropical cyclone intensity monitoring***
  - Since the structure of the warm core of tropical cyclone is closely related to its intensity, comparing the temperature / humidity profile in TC eye obtained from the GeoHIS with the surrounding information may be useful for monitoring the TC intensity.
- ***3-D AMV***
  - Since AMV can be obtained three-dimensionally from GeoHIS in the entire troposphere (clear sky and above clouds), it is expected that the convergence region can be captured from the advection of water vapor in the lower troposphere.

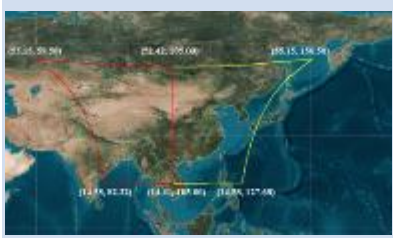
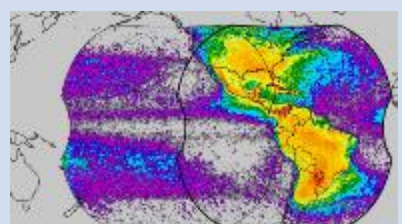
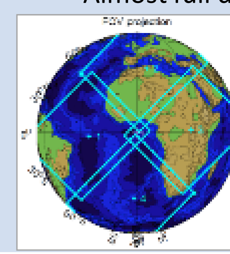


(a) The clear-sky LI (color regions) from true fields
(b) The clear-sky LI from HES-like simulations
(c) The simulated radar reflectivity
(d) The clear-sky LI from ABI/GOES Sounder–like simulations at 1300 UTC 12 Jun 2002.

The black–white regions in the LI plot are the cloud-top temperature from WRF model output, while red color shows the extreme unstable area.
Li et al. (2011)

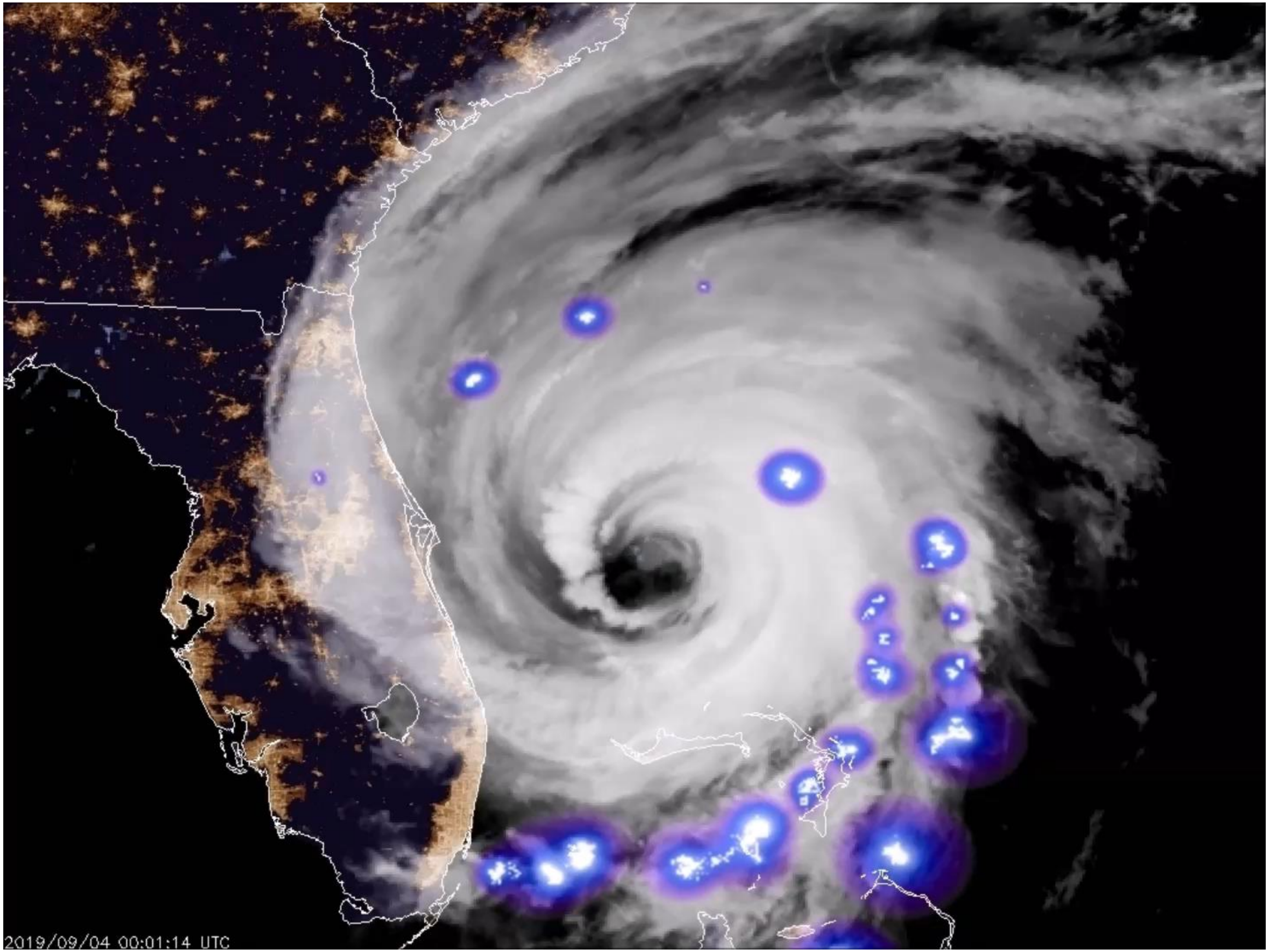
Lightning Mapper

- Lightning mapper is a sensor that observes lightning by detecting its flash with a high-speed camera.
- By mounting a lightning mapper on a geostationary satellite, it is possible to constantly observe a wide range of lightning including at sea, and it is expected to be particularly effective in monitoring convective activity, aeronautical meteorology, and typhoon monitoring.
- The Geo-Ring of lightning mappers can improve the lightning monitoring all over the world.

	LMI (CMA)	GLM (NOAA)	LI (EUMETSAT)
Satellites	FY-4A	GOES-R series	MTG-I series
Year of launch	2016	2016 (GOES-16) 2018 (GOES-17)	2022
Observation area	China and surrounding area 	East Pacific – America - Atlantic (2 satellites) 	Almost full disk 
Spatial resolution (SSP)	6 km	8 km	4.5 km
Accumulation time	2 ms	2 ms	1 ms
Image pickup device	CCD (Two cameras)	CCD (One camera)	CMOS (Four cameras)

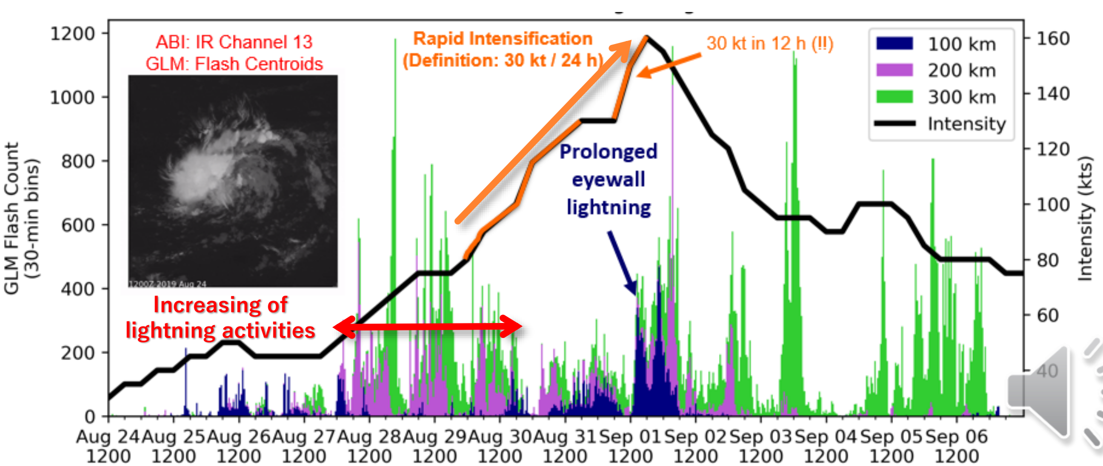
Observation sample of Lightning Mapper

Hurricane Dorian (2019)



Various application of Lightning Mappers

- ***Tropical cyclone intensity prediction***
  - It has been reported that lightning activity becomes active in the surrounding area of tropical cyclone before its rapid development.
  - By using lightning mapper, it is expected to improve the prediction accuracy of tropical cyclones that develop rapidly before landing.
- ***Nowcasting for lightning***
  - It is expected that the accuracy of nowcasting for lightning will be improved by using the observation results of the lightning mapper.
- ***Aeronautical meteorology***
  - Since the lightning mapper can observe inter-cloud lightning, the safety during takeoff and landing of the aircraft is improved.
  - The sensor enables monitoring of lightning conditions over sea, which improves safety on the route.
- ***NWP***
  - By assimilating the data from lightning mapper, it is expected that the accuracy of precipitation prediction by the regional model will be improved.
  - Improvements in short-time forecasts have been reported in cloud resolution model by using the sensor observation data.

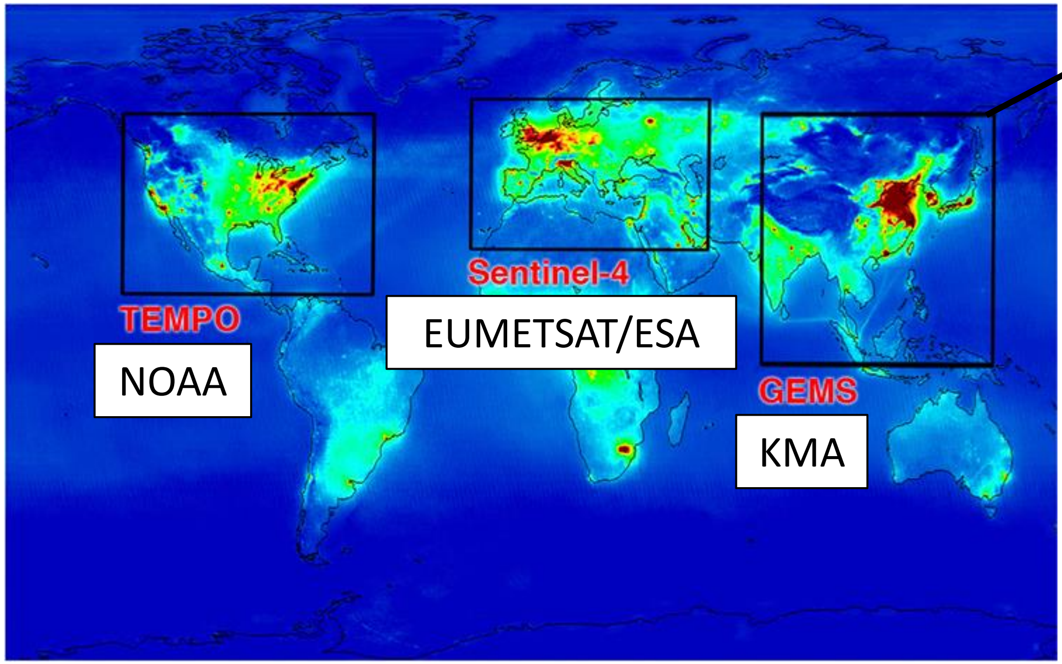


GOES-16 GLM flash count per km^2 in 30-min time periods (left axis) within 100, 200, and 300 km of Hurricane Dorian's (2019) storm center. The black line indicates maximum wind speed (kt; right axis). Duran et al. (2021)

UV/VNIR Sounder

➢ The main use of UV/VNIR Sounder is to monitor air pollutants in urban areas.

	GEMS (KMA)	TEMPO (NASA)	UVN (Sentinel-4)
Satellites	GEO-KOMPSAT-2B	Hosted payload on Intelsat-40e	MTG-S series
Year of launch	2020	2022	2024
Wavelength	290-490 nm 540-740 nm	300-500 nm	305-500 nm 750-775 nm
Wavelength resolution	0.6 nm	0.6 nm	0.5 nm (305-500nm) 0.12 nm (750-775nm)
Spatial resolution	2.2 km x 5.0 km	7 km x 7.2 km	8 x 8 km



Summary

- ***CGMS will strive to advance the new generation of GEO satellites, including advanced imaging, IR sounding and lightning mapping for the whole geostationary ring. It is also agreed that CGMS will strive to work towards operational hourly daytime UV/VIS mapping of air quality from geostationary orbit.***

- ***VIS/IR Imager***
  - The Geo-Ring of VIS/IR Imagers has been already established, and will be updated gradually.
- ***Hyperspectral IR Sounder***
  - It is expected that observation data from Geo-Ring of GeoHIS will improve the results of not only global NWP, but also regional one.
- ***Lightning Mapper***
  - The Geo-Ring of lightning mappers can improve the lightning monitoring all over the world.
- ***UV/VNIR Sounder***
  - The main use of UV/VNIR Sounder is to monitor air pollutants in urban areas.