8-10 October 2012, Seoul, Korea

Geostationary Environment Monitoring Spectrometer (GEMS) to monitor air quality and short-term climate forcer(SLCF) over Asia

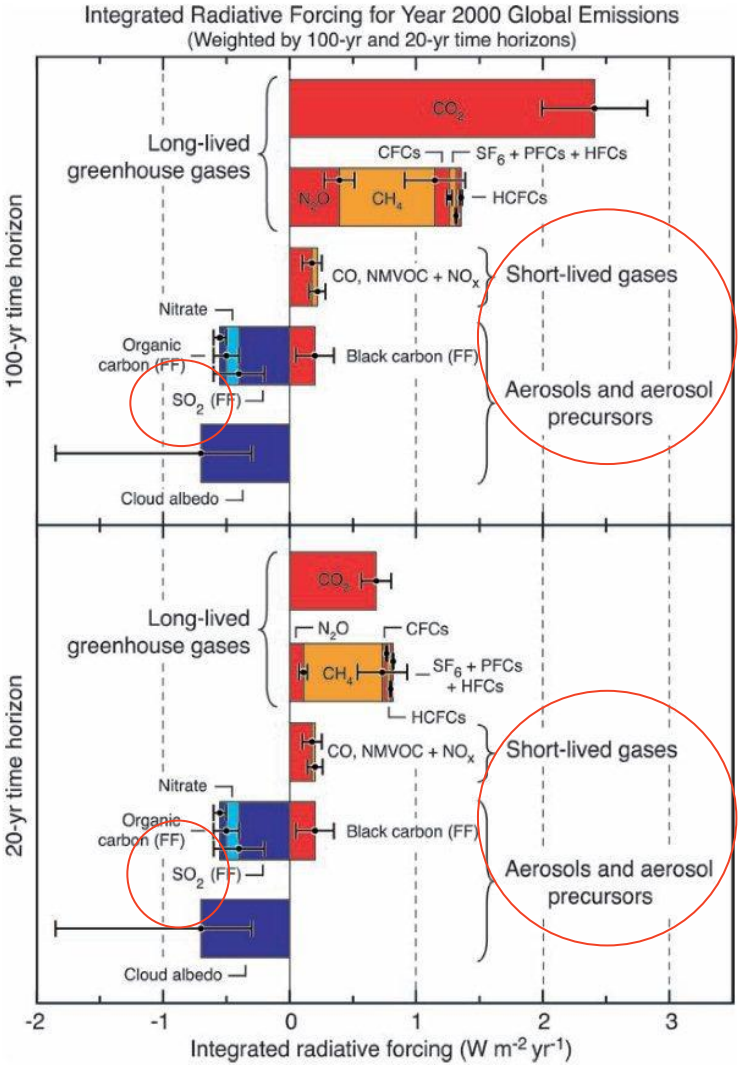
Jhoon Kim[1,2], GEMS Science Team

[1] P.I. GEMS, Yonsei University
[2] Director, GESC(Global Environment Satellite Center)

Outline

- Introduction
- GEMS Mission
- Summary

Improving Air Quality and Limiting Short-Term Climate Changes



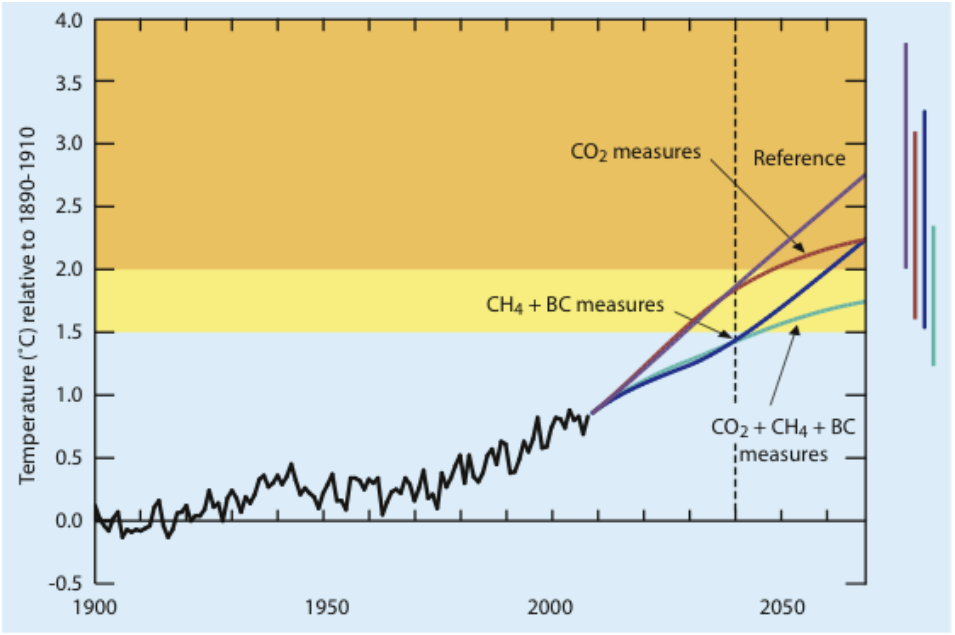
(IPCC, 2007)

RIO+20 UN Conference on Sustainable Development (UNCSD)

20-22 June, 2012

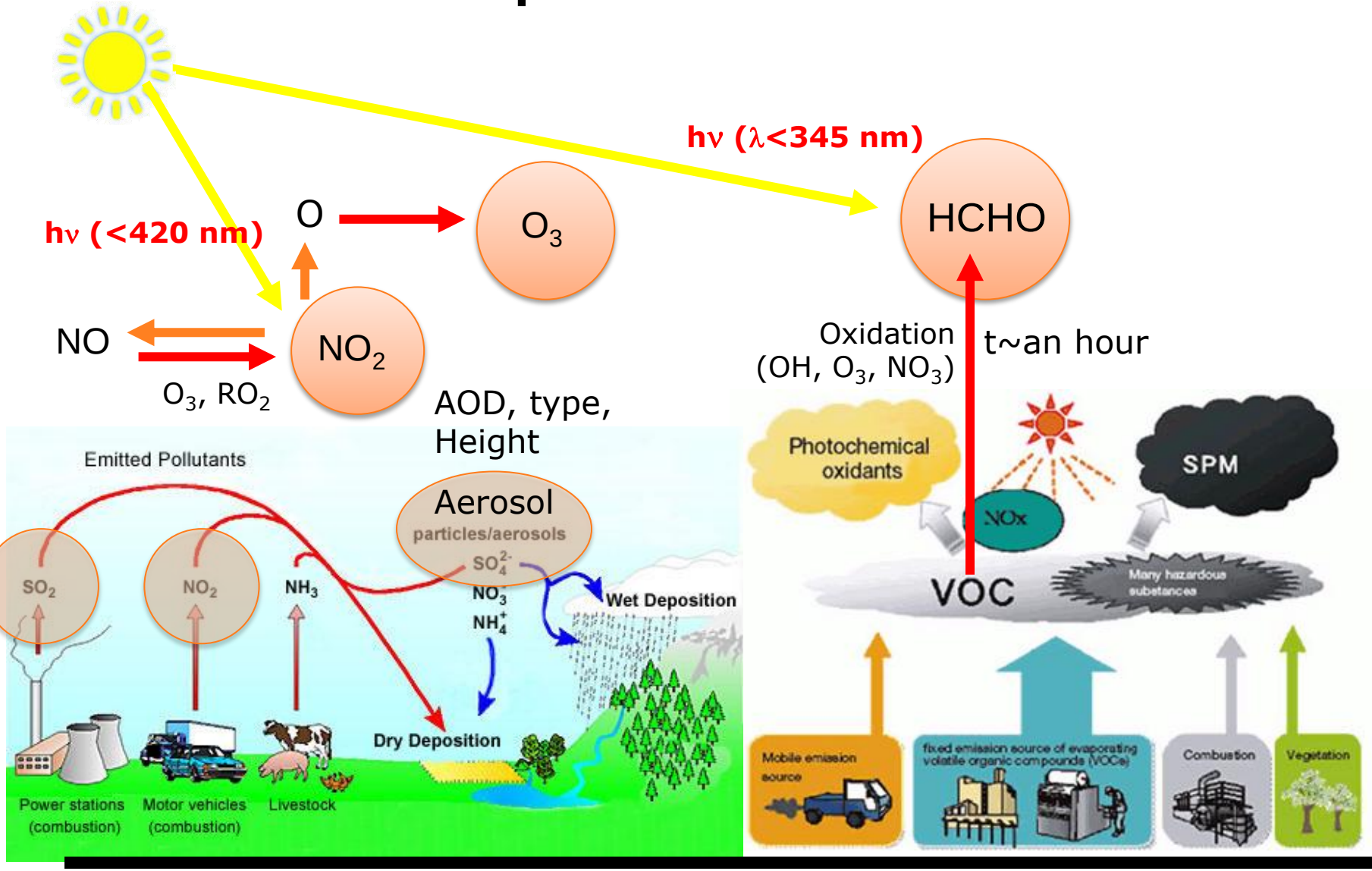
Achim Steiner, UNEP Executive Director

"Need action on SLCFs, black carbon, tropospheric ozone, and methane… "



Integrated Assessment of Black Carbon and Tropospheric Ozone (UNEP/WMO, 2011)

Measurements of precursors of ozone + aerosol



Satellite Remote Sensing of Atmospheric Composition

Satellite		ERS-2	Terra	Envisat		Aura			METOP		GOSAT	S-4, G-CAPE GEMS GMAP-Asia
Sensors	TOMS	GOME	MOPITT	SCIA-MACHY	MIPAS	HRDLS	OMI	TES	IASI	GOME2	TANSO	
Orbit	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	LEO	GEO
Launch	1979	1995	1999	2002	2002	2003	2003	2003	2007	2007	2009	(2018)
O_3	O	O		O	●	O	O	O	O, ●	O		O
H_2O	O	O		O		O		O				
CO			O	O	●				O			
NO				O	●	O						
NO_2		O		O	●	O	O		O	O		O
HNO_3					●	O		O	●			
CH_4			O	O	●	O		O	O		O	
HCHO		O		O								O
SO_2		O		O			O			O		O
BrO		O		O						O		
CO2				O					O		O	
Aerosol	O			O		O	O	O		O		O

O : Column ● : Profile

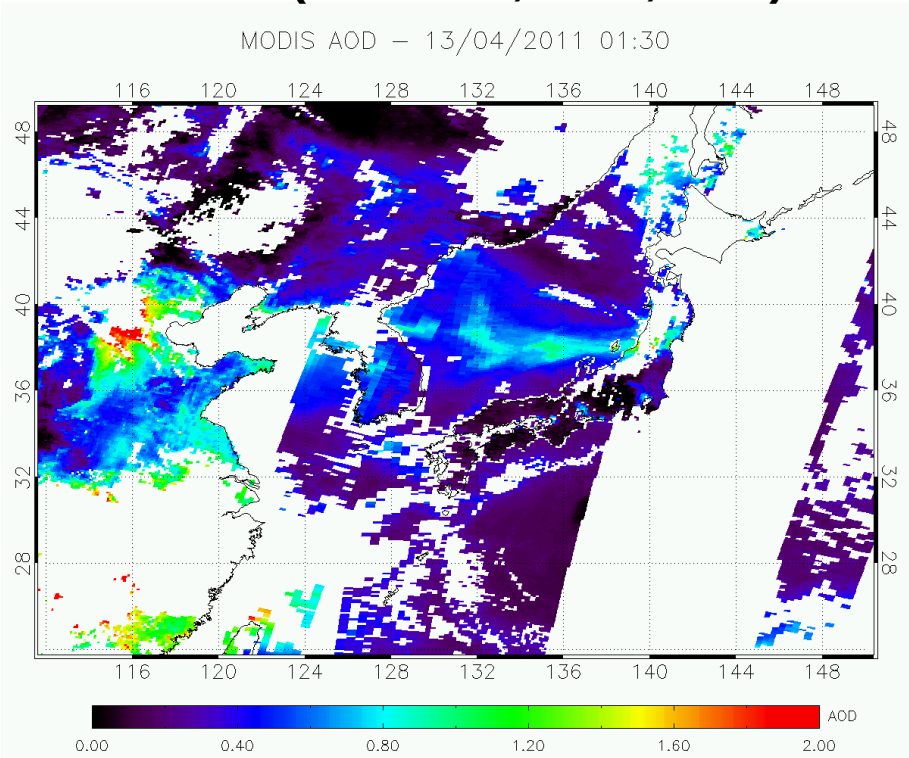
PS : Polar sun-synchronous GEO : Geostationary

(Courtesy, C.H. Song)

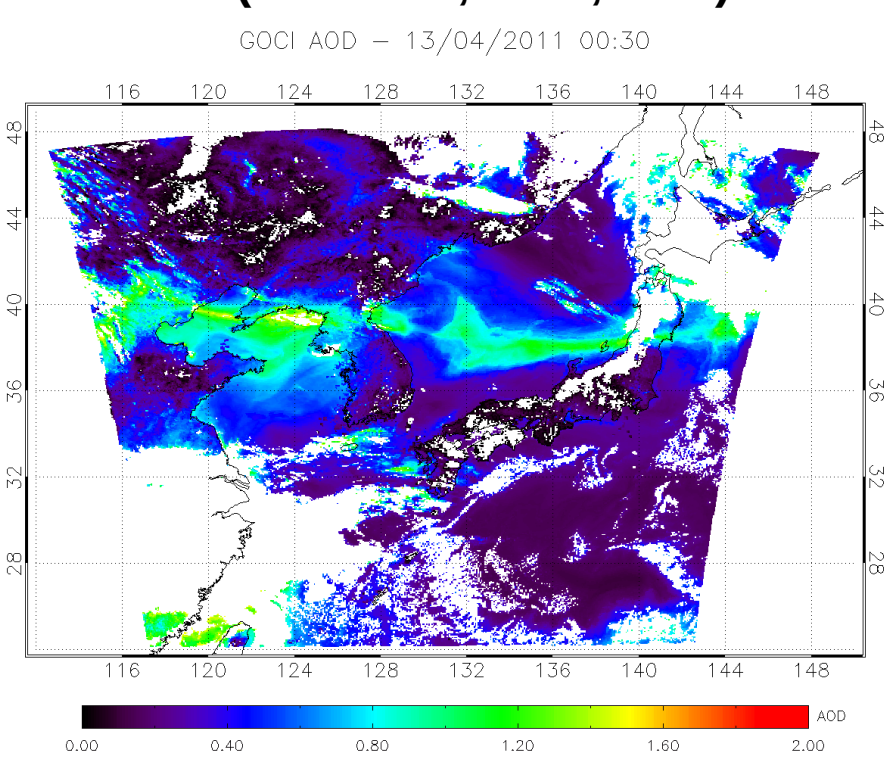
LEO satellite vs. GEO(COMS, Launched on June 26, 2010)

An example from GOCI onboard the COMS, launched on June 26, 2010

MODIS (Lee et al., 2012, ACP)



GOCI (Lee et al., 2010, RSE)

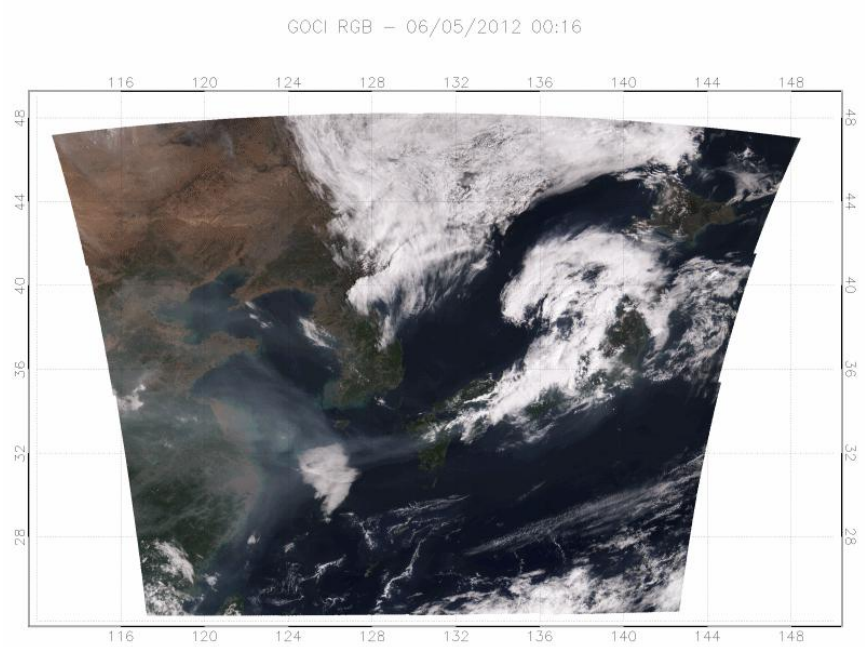


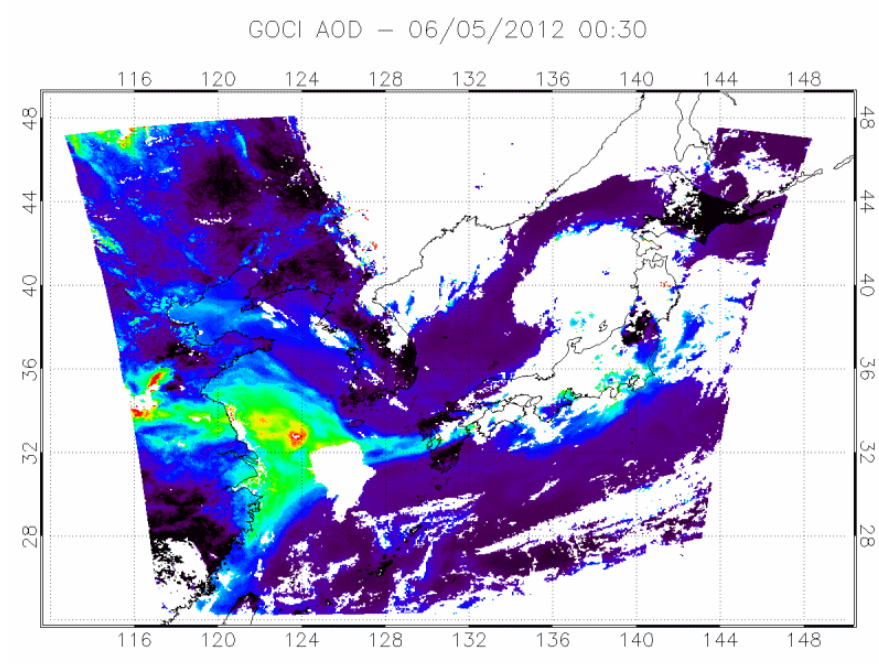
Hourly AOD, FMF, Aerosol type

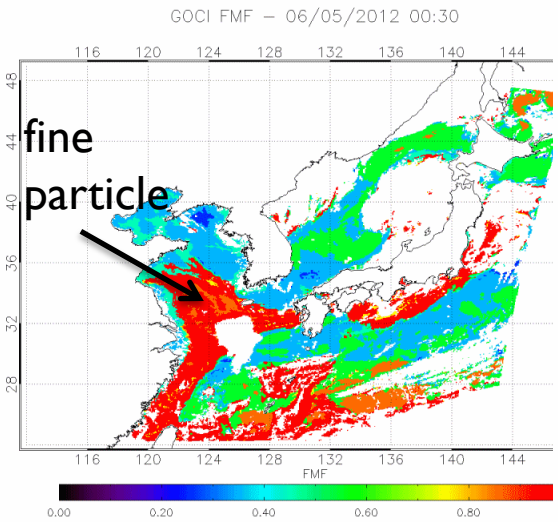
2 LEOs
(2 x 1/day)

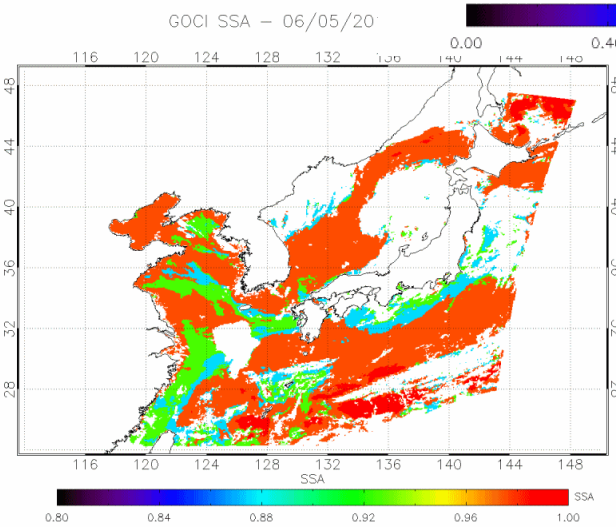
1 GEO (hourly)

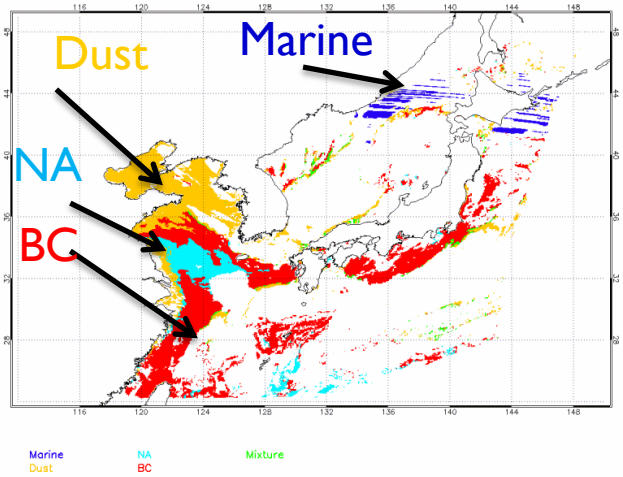
GOCI 2012/5/6


GOCI RGB – 06/05/2012 00:16

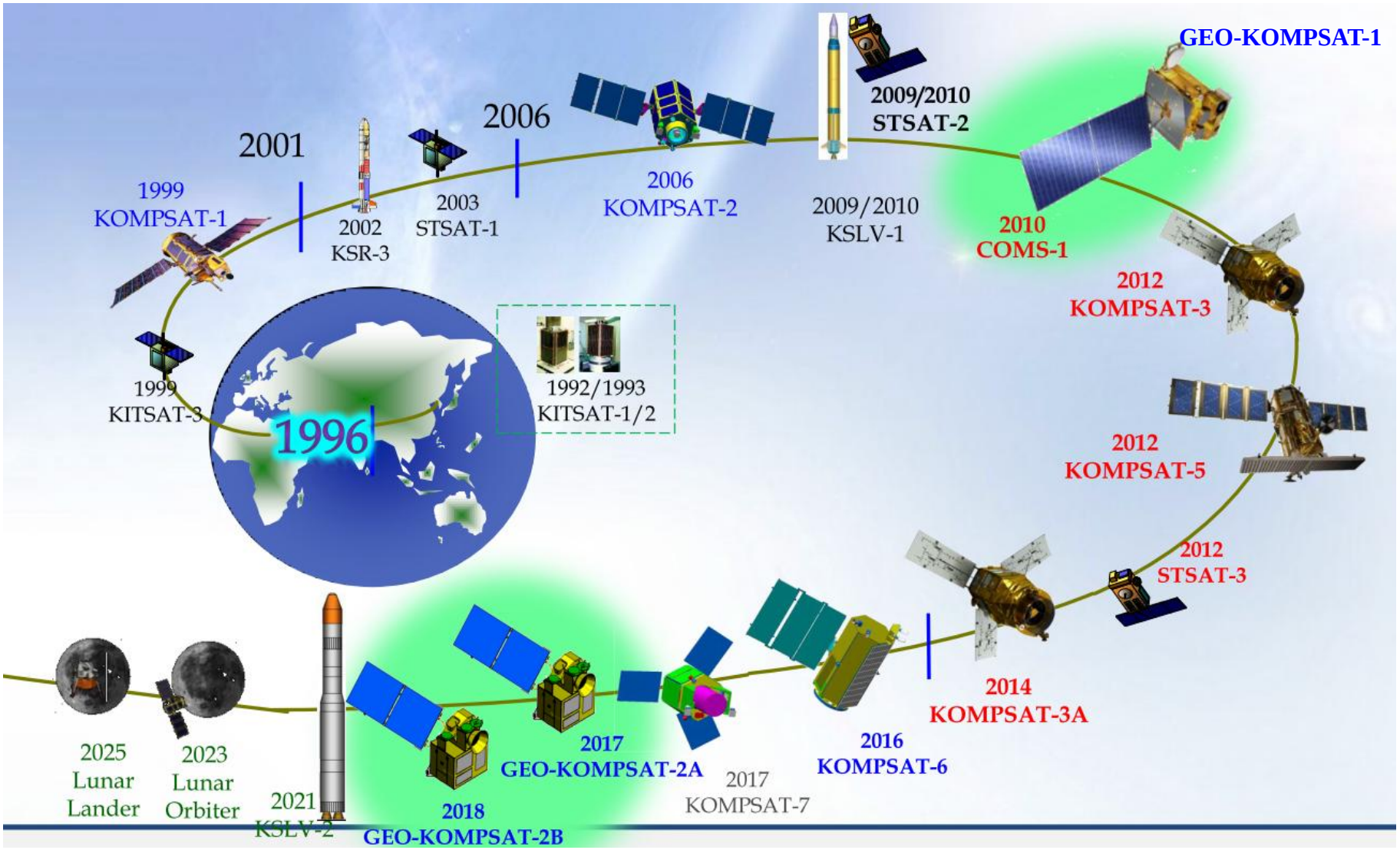

GOCI AOD – 06/05/2012 00:30
AOD
0.00
0.40
0.80
1.20
1.60
2.00


GOCI FMF – 06/05/2012 00:30
fine
particle
FMF
0.00
0.20
0.40
0.60
0.80


GOCI SSA – 06/05/20
SSA
0.80
0.84
0.88
0.92
0.96
1.00

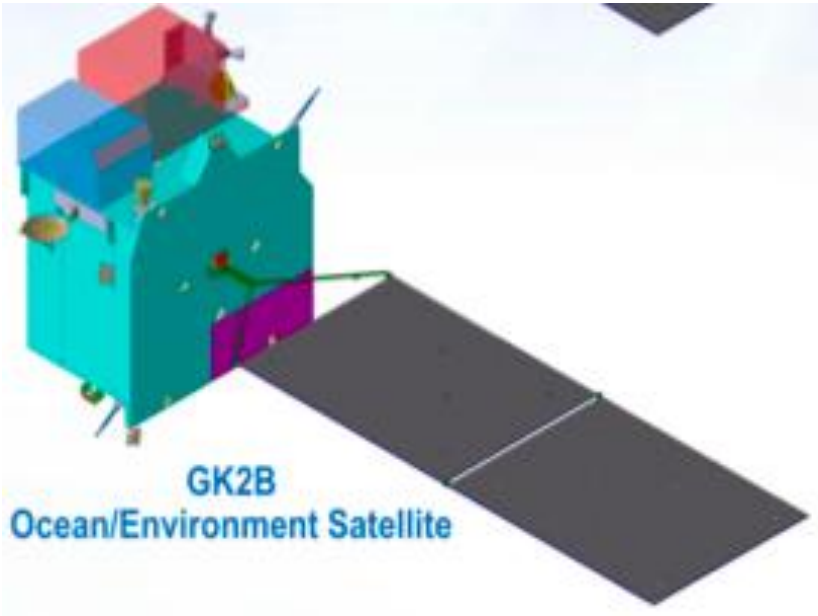

Dust
Marine
NA
BC
Marine
Dust
NA
BC
Mixture

National Space Program of Korea



GEMS

(Geostationary Environment Monitoring Spectrometer)



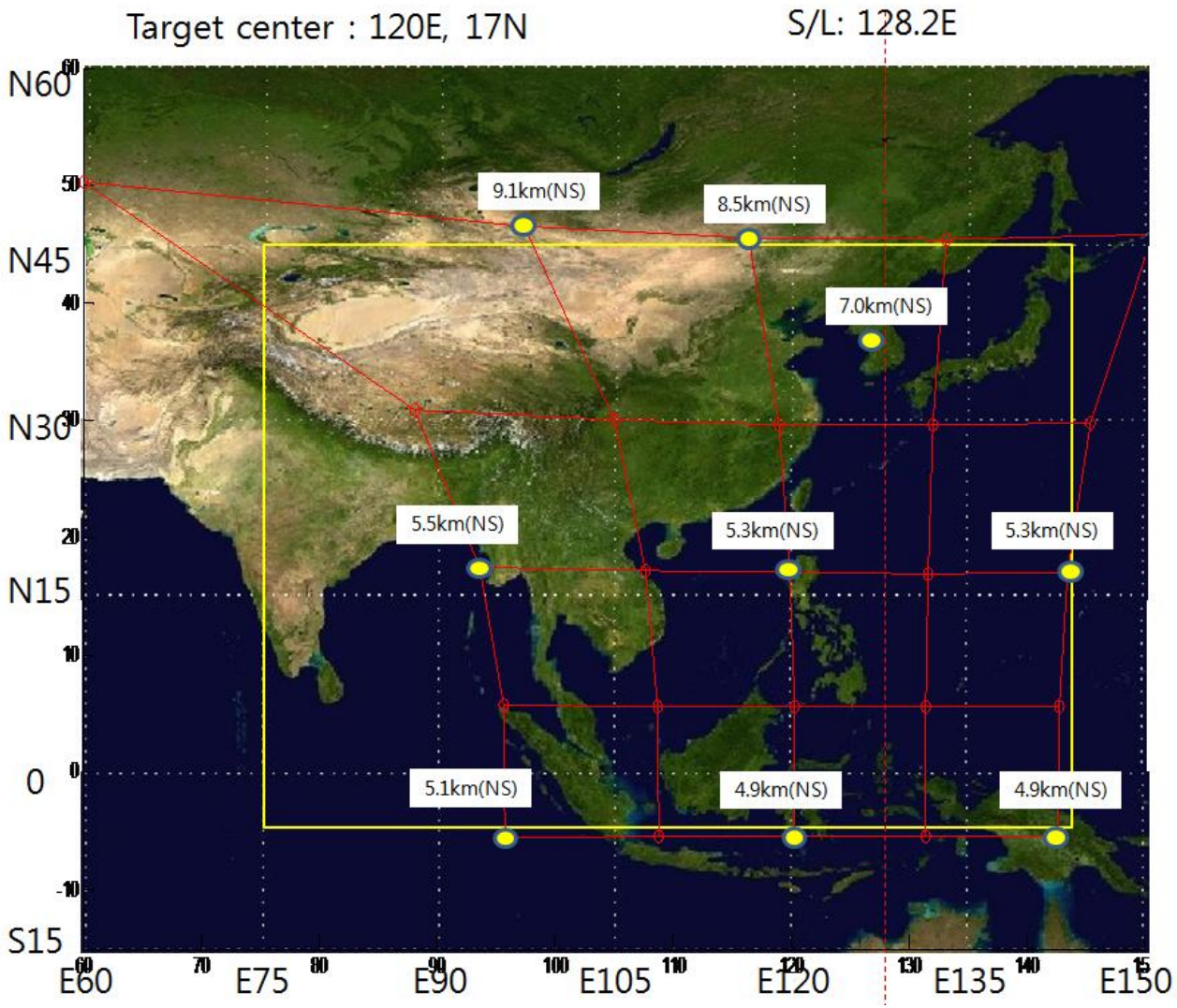
- GeoKOMPSAT-2A: AMI
- GeoKOMPSAT-2B: GEMS
  GOCI-2

- Project period: 2011 – 2018

Major specification

	Specification
Lifetime	> 7 yrs
Spatial coverage	5000 km x 5000 km (5° S ~ 45° N)
Duty cycle	8 times / 1 day
Spatial resolution	7 km (NS) @ Seoul
Spectral coverage	300 – 500 nm
Spectral resolution	0.6 nm
Products	O_3, NO_2, SO_2, HCHO, aerosol, cloud, surface reflectance
Optional IR payload	Under discussion (NASA EV-I, Japan..) - spectral coverage: 2~5 um - Products: CO_2, CH_4, CO

Projected FOV & GSD - NS GSD @ Seoul : 7.0km



Projected FOV

Region of interest

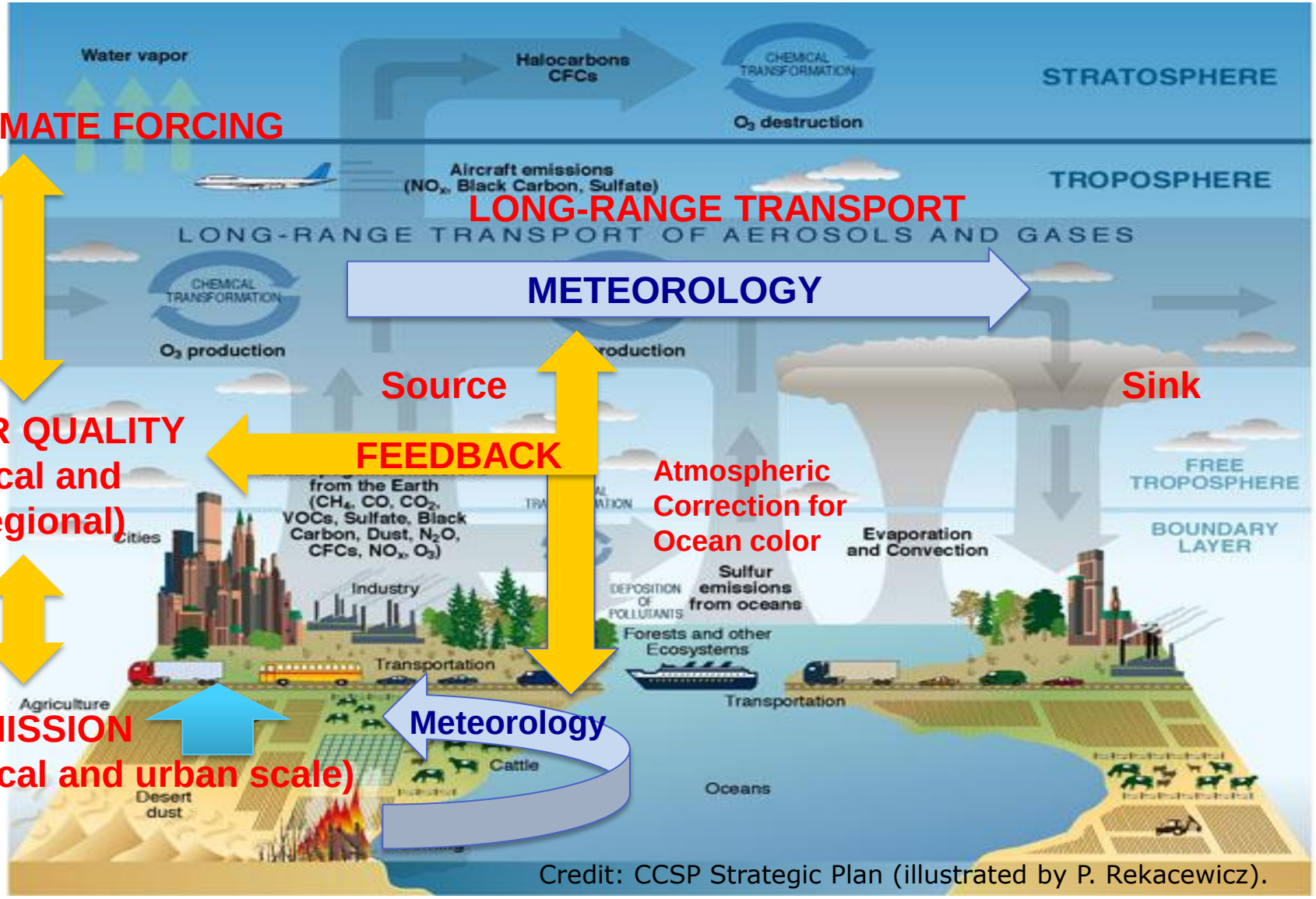
Satellite mission for atmospheric environment

Instru-ment	Detect-ors	Spectral Coverage [nm]	Spectral Resolution [nm]	Ground Pixel Size [km²]	Global Coverage
GOME (1995-2003)	Linear Arrays	240-790	0.17	40×320	3 days
SCIAMACHY (2002- 2012)	Linear Arrays	240-2380	0.26	30×60	6 days
OMI (2004-ongoing)	2-D CCD	270-500	0.42	13×12	daily
GOME-2 (2006-ongoing)	Linear Arrays	240-790	0.24	40×40	1.5 to 3 days
GEMS	*2-D*	*300-500*	*0.6*	*~7×8*	*Hourly*

[Courtesy, R.J. Park]

- **SCIA** - suites of atmospheric gases measured for 10 years
- **OMI** - higher spatial resolution, better coverage
- **GOME-2** - better spatial resolution, better coverage, continuity for 15 years
- **Geostationary**
  - better spatial resolution, several measurements per day
  - less cloud contamination
  - can overcome the limitation in global coverage by constellation

Objective: Measurement of air quality and SLCF in high temporal and spatial resolution

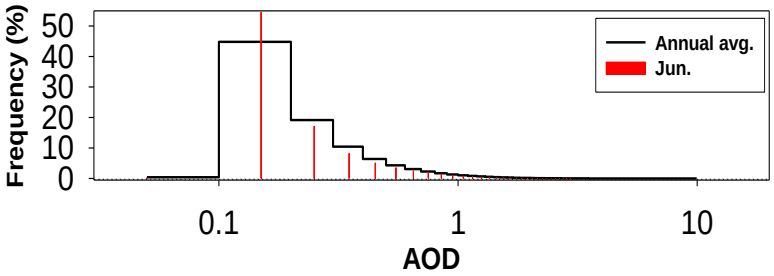


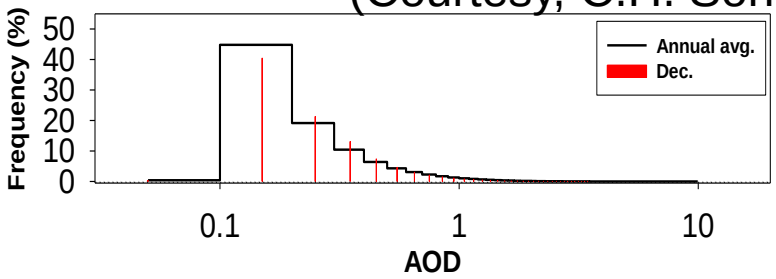
Credit: CCSP Strategic Plan (illustrated by P. Rekacewicz).

Monthly Average PDF (Jun., Dec.)

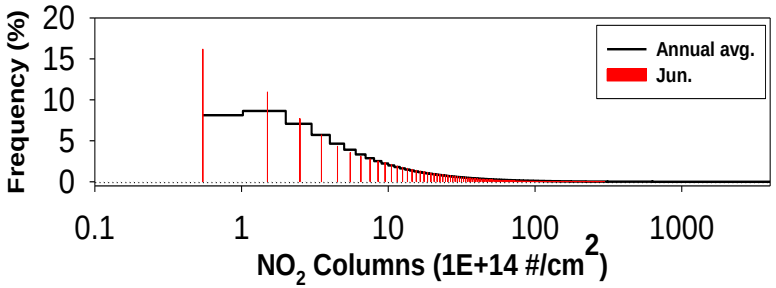
(Courtesy, C.H. Song)

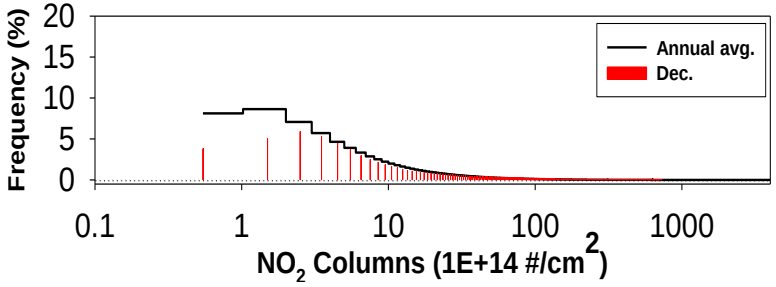
AOD



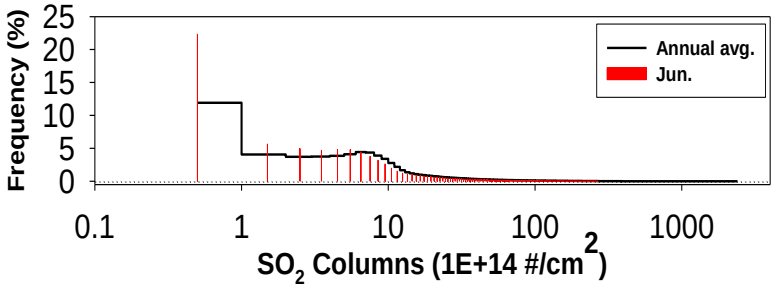


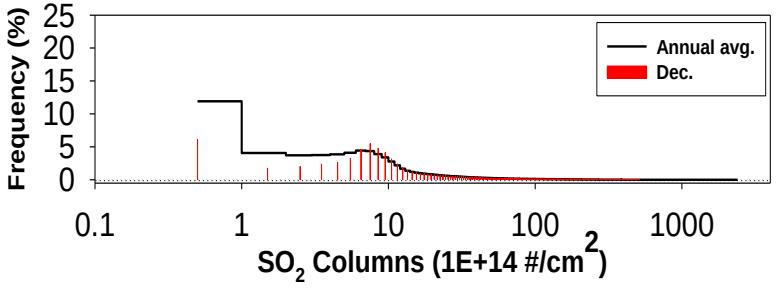
NO2



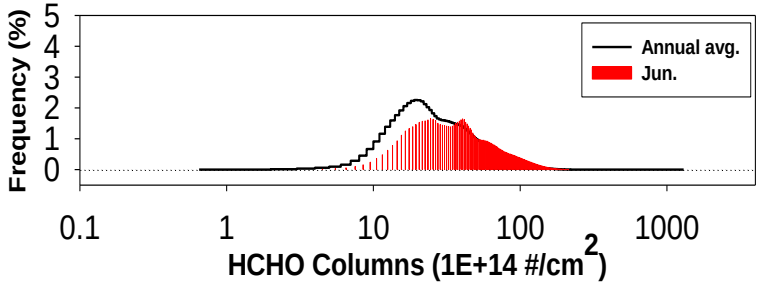


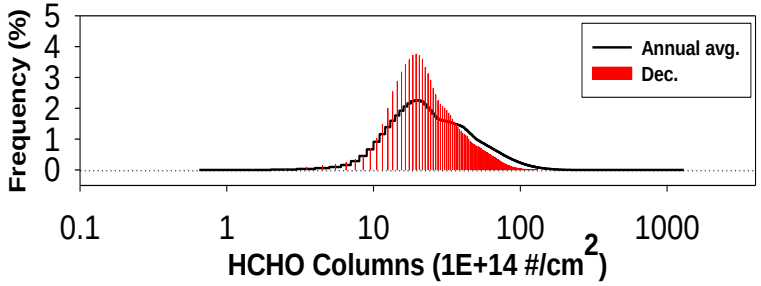
SO2





HCHO

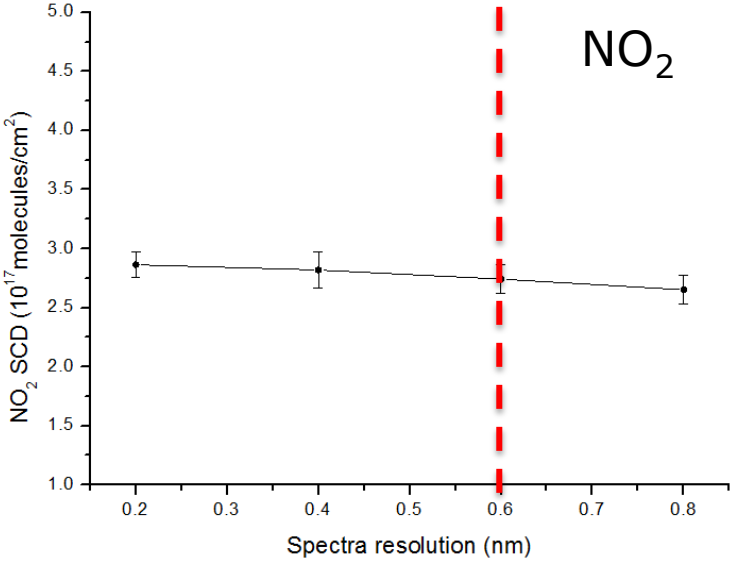


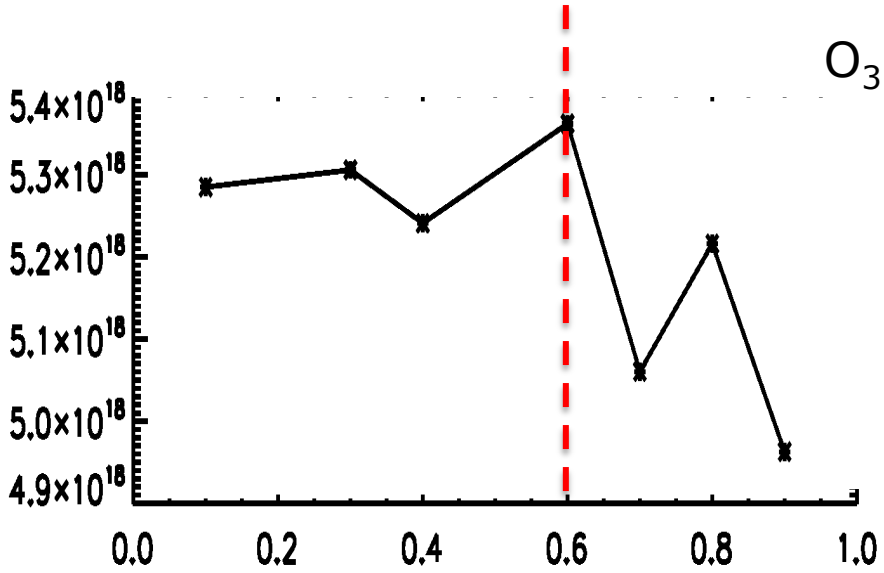


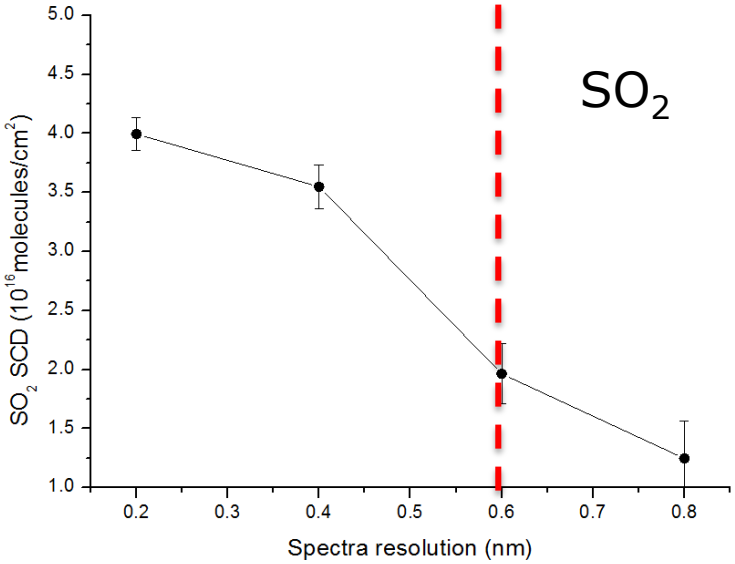
Baseline products

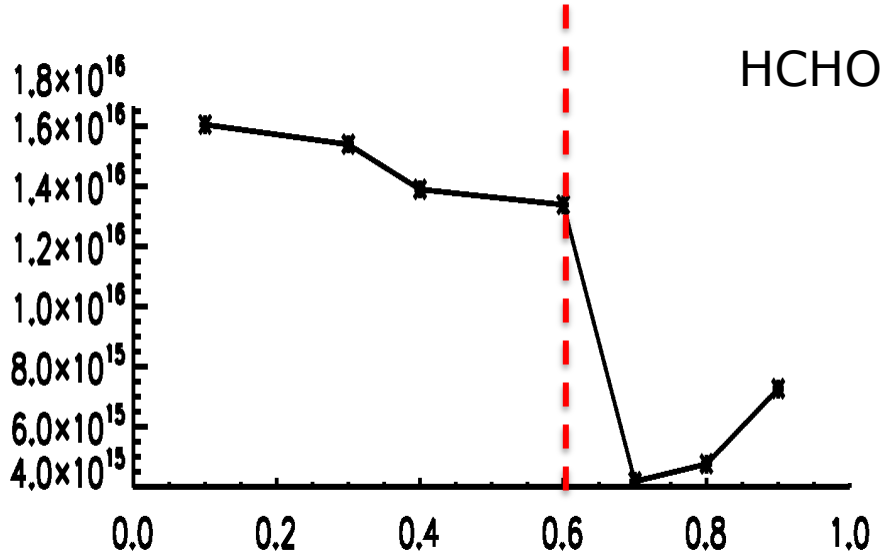
Product	Importance	Min (cm^{-2})	Max (cm^{-2})	Nominal (cm^{-2})	Accuracy	Spectral window (nm)	Spatial Resolution (km^2) @ Seoul	SZA (deg)	Retrieval
NO_2	Ozone precursor	$3x10^{13}$	$1x10^{17}$	$1x10^{14}$	$1x10^{15}$	425 - 450	56	< 70	DOAS
SO_2	Aerosol precursor	$6x10^{8}$	$1x10^{17}$	$6x10^{14}$	$1x10^{16}$	310 – 330	56 x 4 pixels	< 50 (60*)	DOAS
HCHO	Proxy for VOCs	$1x10^{15}$	$3x10^{16}$	$3x10^{15}$	$1x10^{16}$	327 – 357	56 x 4 pixels	< 50 (60*)	DOAS
O_3	Oxidant, pollutant	$4x10^{17}$	$2x10^{18}$	$1x10^{18}$	2% or 6 DU (TOz)	300-340	56	< 70	OE
AOD (AI, AOCH, AAOD)	Air quality, Climate	0 (AOD)	5 (AOD)	0.2	20% or 0.1@ 400nm	300-500	56	< 70	Multi-spectral
Clouds	Data quality, climate	0 (COD)	50 (COD)	17 (COD)		300-500	56		Raman, O_2-O_2
Surface Property	Environ-ment	0	1	-		300-500	56		Multi-spectral

Spectral resolution



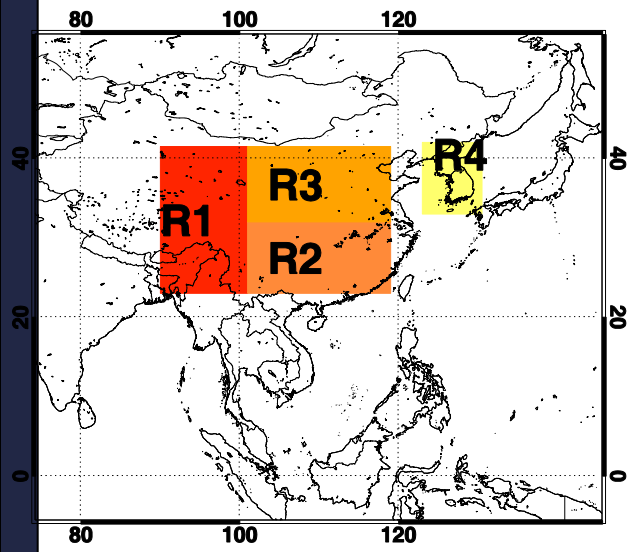


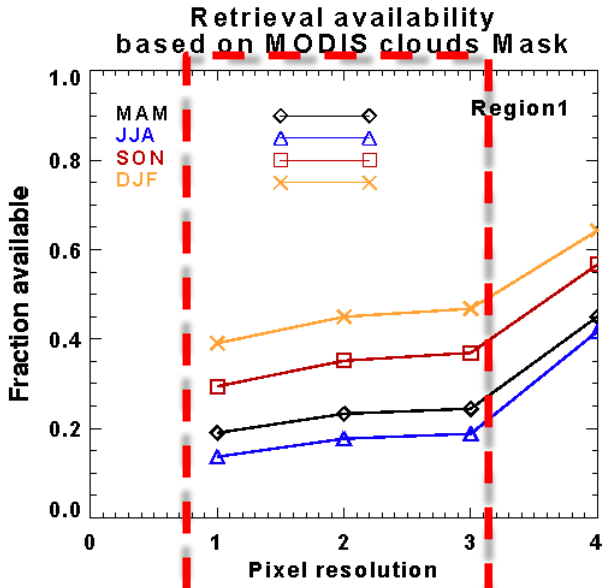


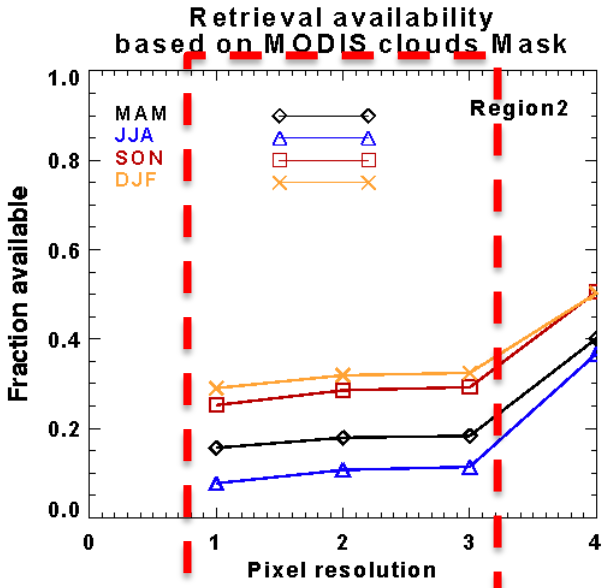


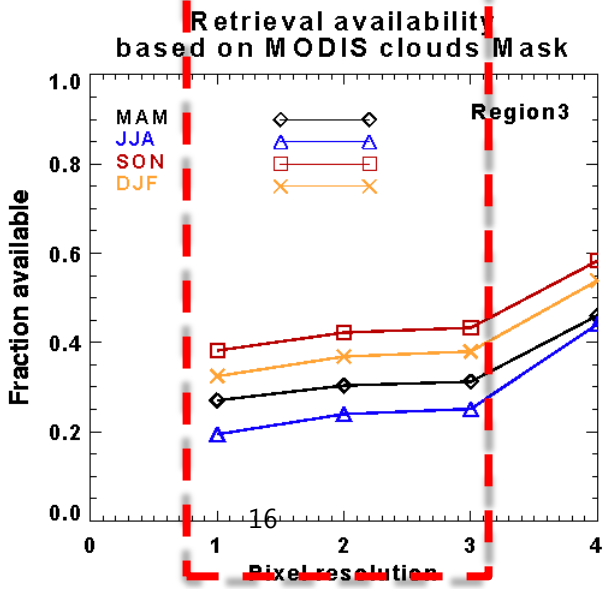
Spatial Resolution - cloud contamination

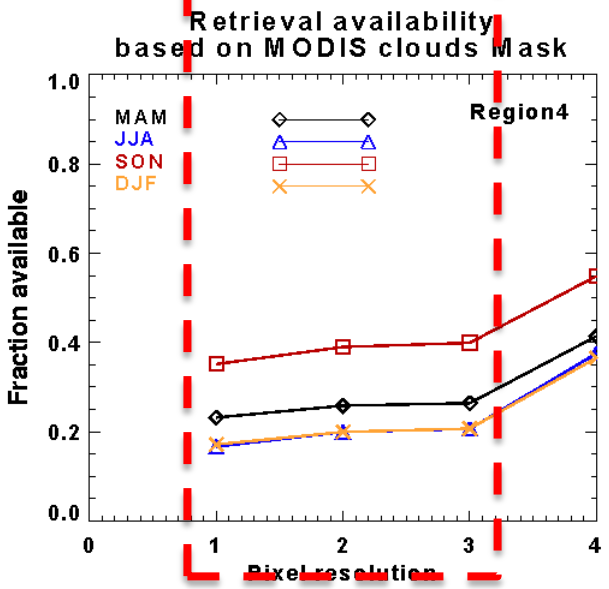
Pixel resolution	
1	7.5 x 7.5 ㎢
2	5 x 5 ㎢
3	2.5 x 7.5 ㎢
4	1.25 x 3.75 ㎢



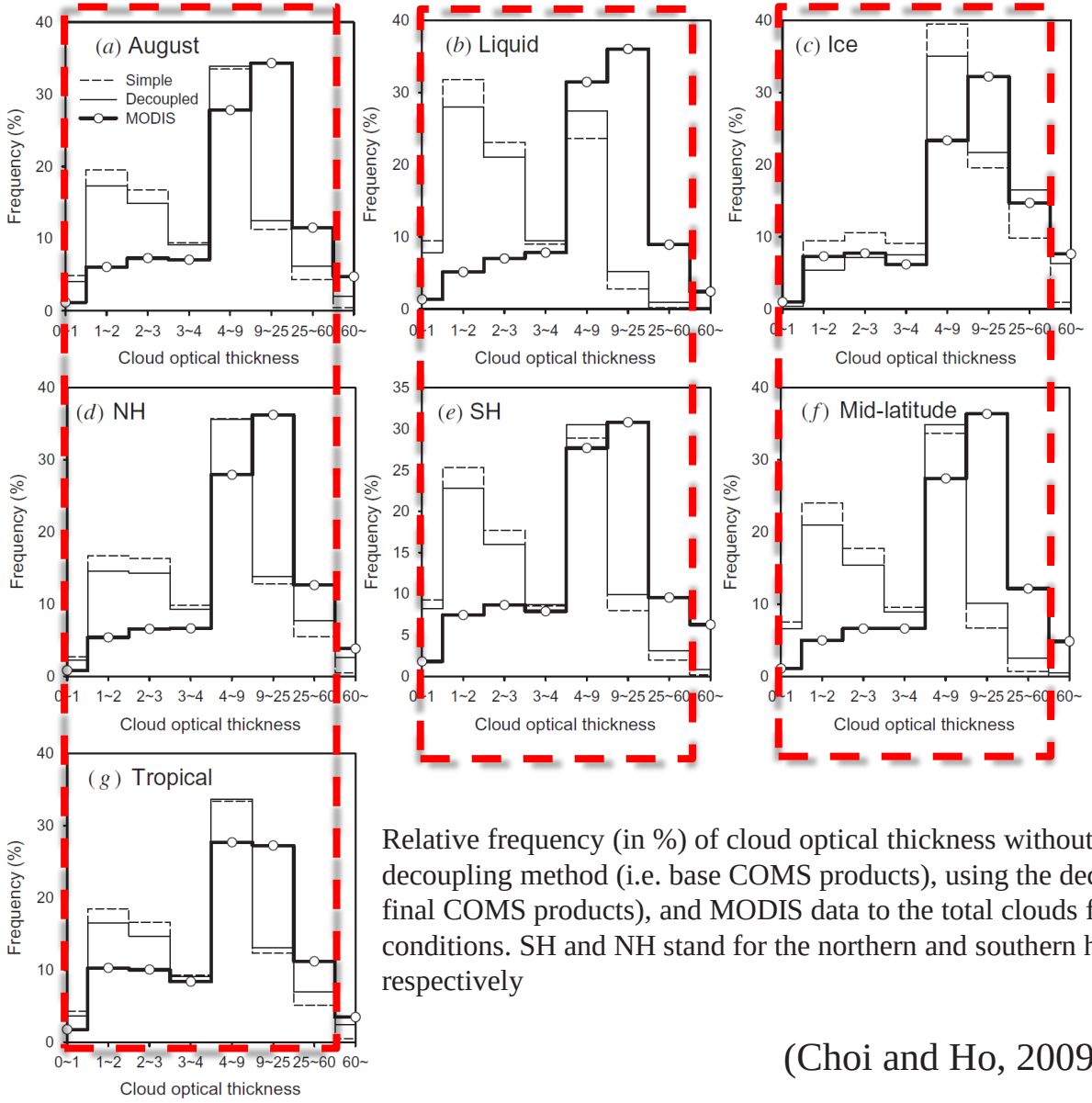








COD frequency distribution



Relative frequency (in %) of cloud optical thickness without using the IR-Visible decoupling method (i.e. base COMS products), using the decoupling method (i.e. final COMS products), and MODIS data to the total clouds for the corresponding conditions. SH and NH stand for the northern and southern hemispheres, respectively

(Choi and Ho, 2009, IJRS).

□ Baseline Data Products of Met-Imager (16-Channel)

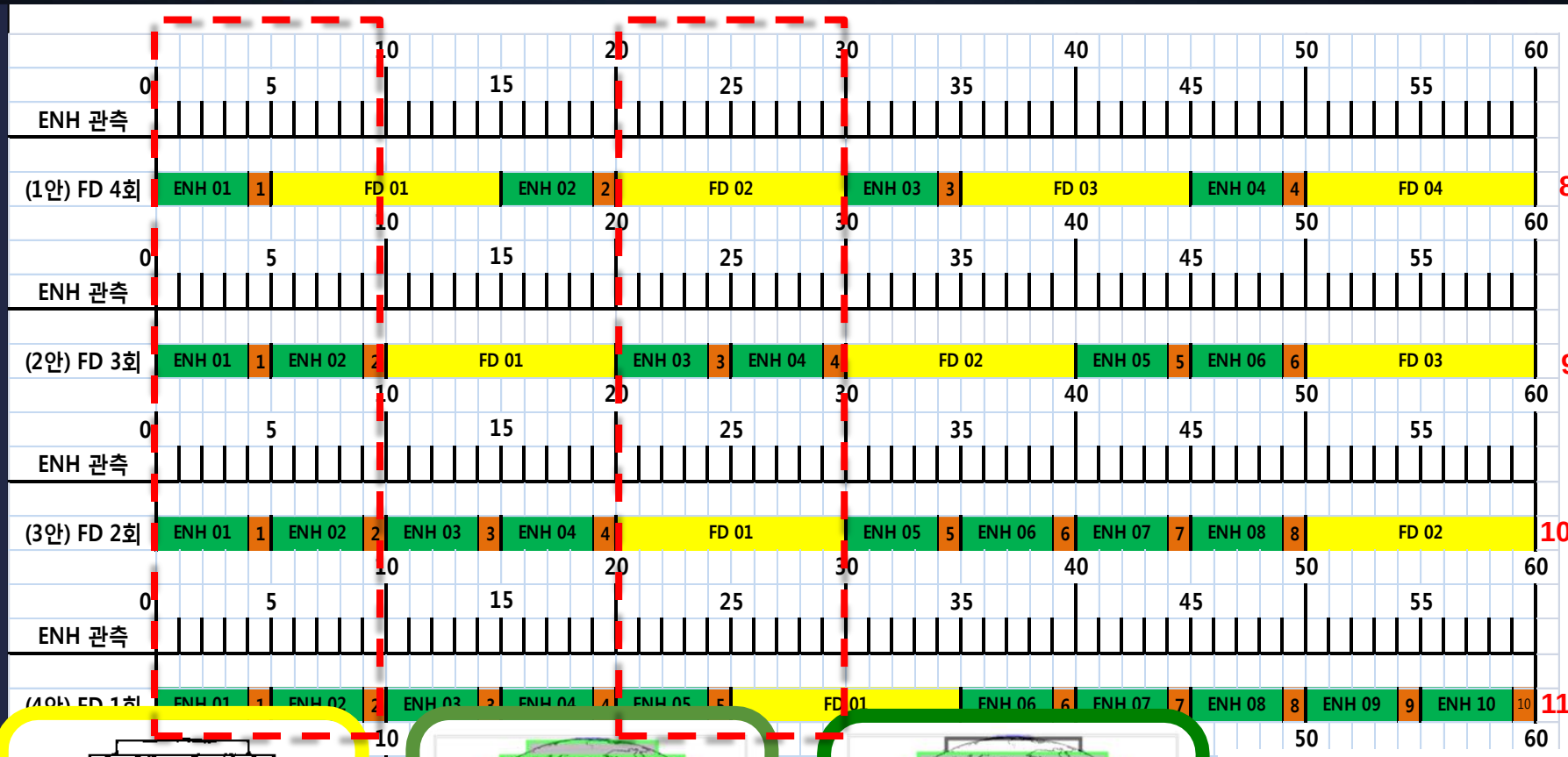
기 상 청
국가기상위성센터
National Meteorological Satellite Center

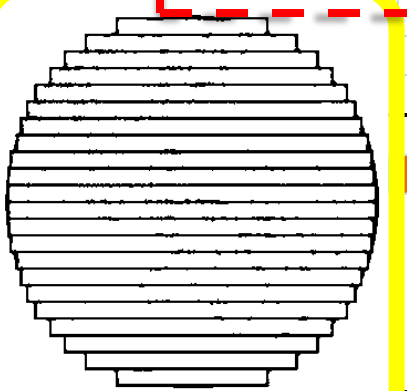
Wavelength Micrometers	0.47	0.64	0.865	1.378	1.61	2.25	3.90	6.185	6.95	7.34	8.5	9.61	10.35	11.2	12.3	13.3
Channel ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Aerosol Detection	X	X	X	X	X	X	X							X	X	
Suspended Matter/OD	X	X	X		X	X										
Clear Sky Masks		X		X	X		X		X	X	X			X	X	
Cloud & Moisture Imagery	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cloud Optical Depth		X				X	X							X	X	
Cloud Particle Size		X				X	X							X	X	
Cloud Top Phase										X	X			X	X	
Cloud Top Height														X	X	X
Cloud Top Pressure														X	X	X
Cloud Top Temperature														X	X	X
Hurricane Intensity													X			
Rainfall Rate/QPE								X		X	X			X	X	
Legacy Vertical Moisture Profile								X	X	X	X	X	X	X	X	X
Legacy Vertical Temp Profile								X	X	X	X	X	X	X	X	X
Derived Stability Indices								X	X	X	X	X	X	X	X	X
Total Precipitable Water								X	X	X	X	X	X	X	X	X
Downward Solar Insolation Surf	X	X	X		X	X										
Reflected Solar Insolation TOA	X	X	X		X	X										
Derived Motion Winds		X					X	X	X	X				X		
Fire Hot Spot Characterization		X					X							X	X	
Land Surface Temperature														X	X	
Snow Cover	X	X	X		X	X	X						X			
Sea Surface Temps							X				X		X	X	X	

(Courtesy, KMA)

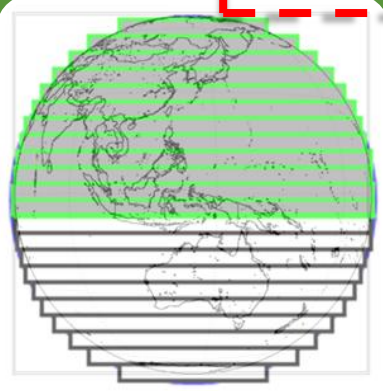
□ **Hourly** Operation Schedule Scenario(draft) of Met-Imager

기 상 청
국가기상위성센터
National Meteorological Satellite Center

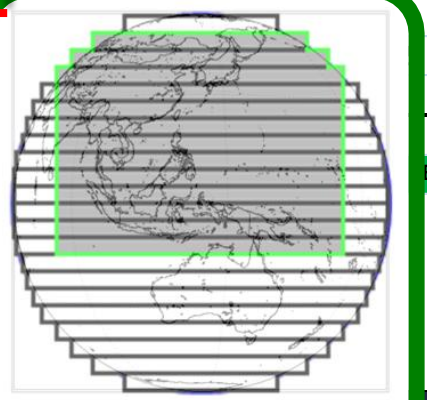




FD 10 min



NH 5 min



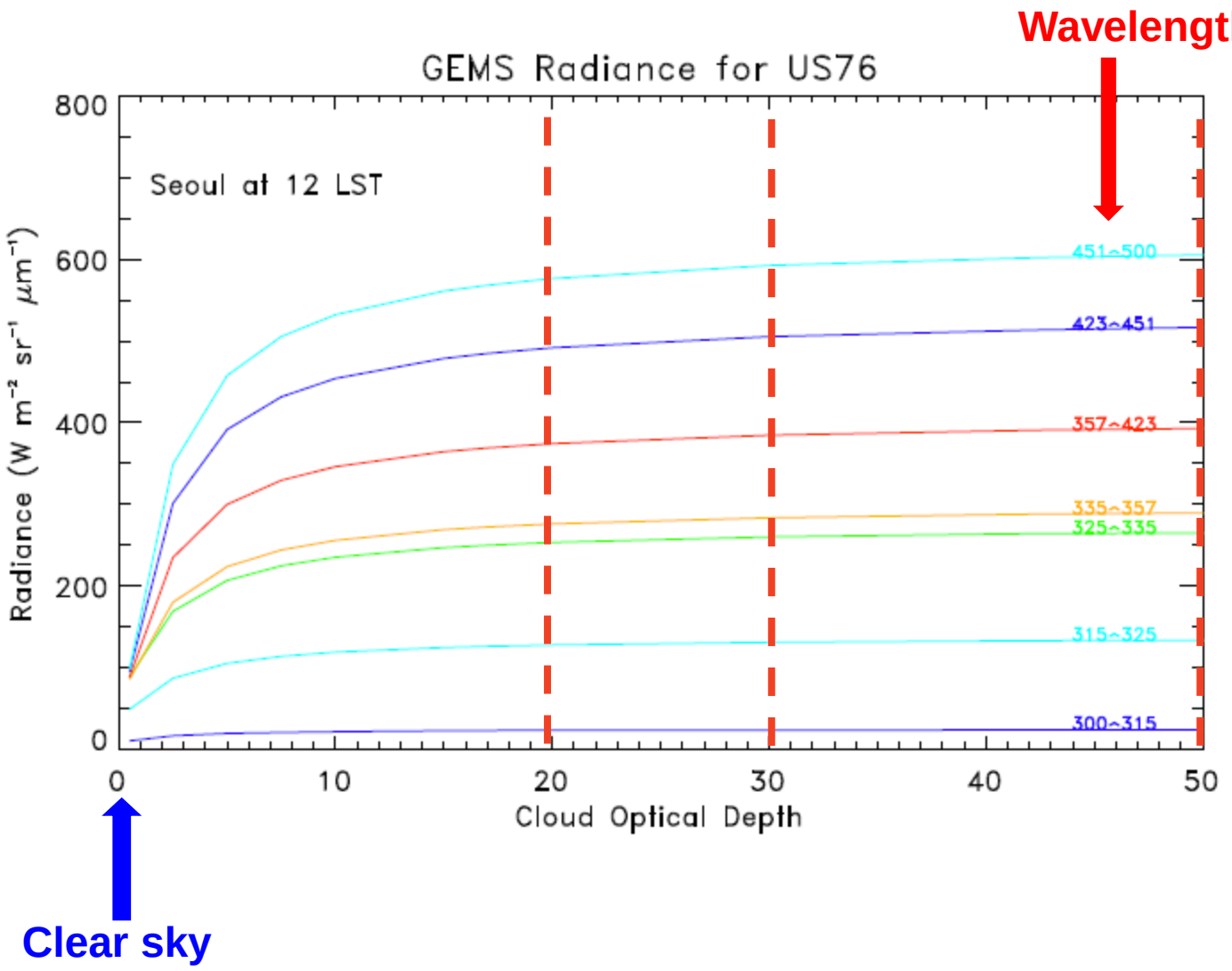
ENH 5 min

LA(Around Korea Peninsula 2000km x 2000km)

(Courtesy: KMA)

MINISTRY OF ENVIRONMENT

Input Radiance for different CODs



Current Status of GEMS Requirements(4/4)

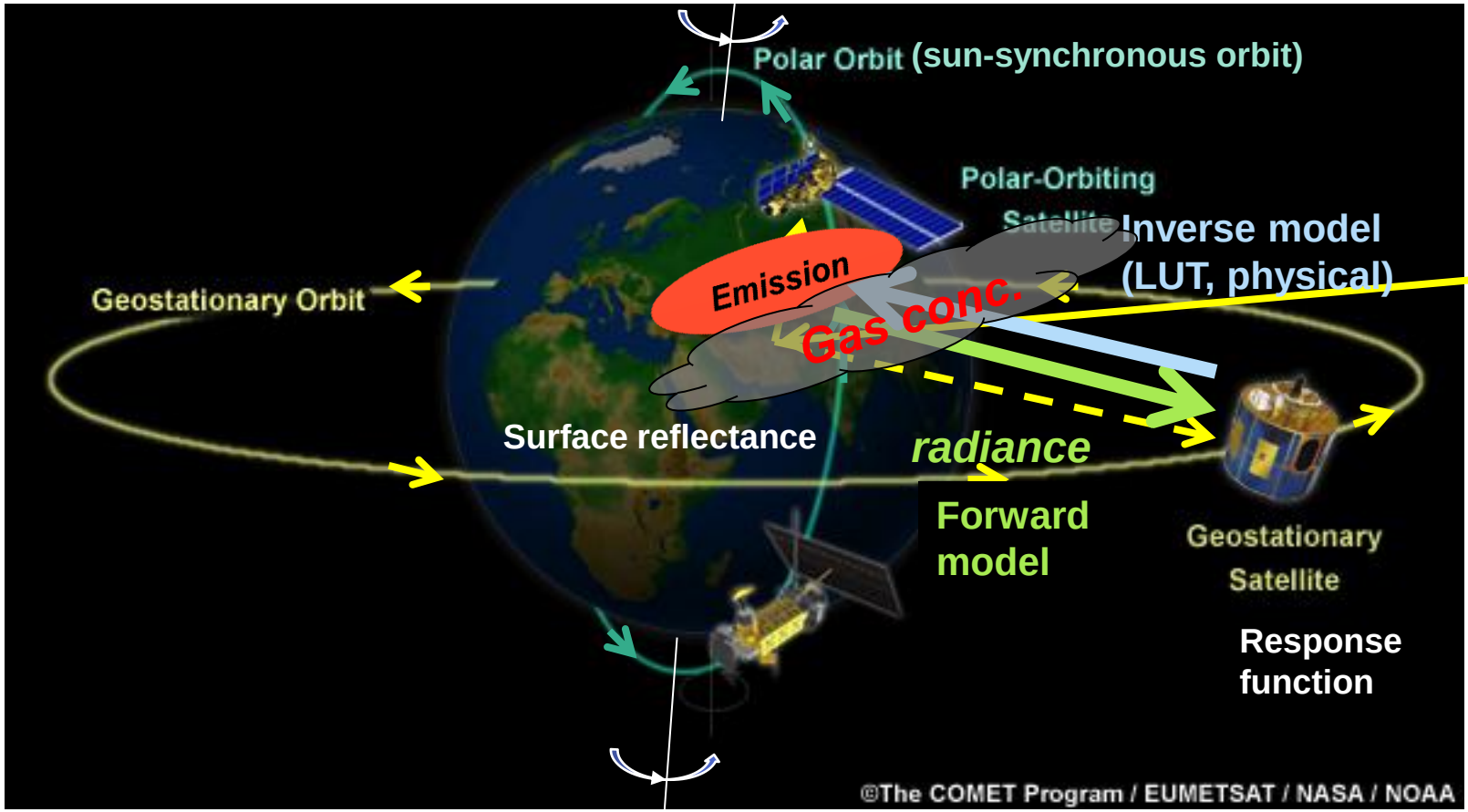
- **Input radiance level**

Spectral Range (nm)	Minimum Radiance[1] [W $m^{-2}sr^{-1}$ mm^{-1}]	Nominal Radiance[2] [W $m^{-2}sr^{-1}$ mm^{-1}]		Maximum Radiance [W $m^{-2}sr^{-1}$ mm^{-1}]		Signal to Noise Ratio[3]
		Goal	Threshold	Goal (COD=50)	Threshold (COD=30)	
300-315	0.15	4.926	7.98	24.52	23.94	160@305 320@310 630@315
315-325	0.61	30.41	43.36	133.99	131.25	720
325-335	2,27	63.766	86.63	264.90	260.18	
335-357	3.52	65.234	91.39	289.59	283.61	
357-423	4.40	71.562	108.66	393.05	384.59	
423-451	5.14	86.358	130.75	516.75	505.24	1500
451-500	5.11	103.744	145.49	605.40	592.35	1500

Intercomparison of Nominal Radiance and SNR

GEMS				GEOCAPE			Sentinel-4		
Wave-Length	Nominal Radiance		SNR	Wave-length	Closest Nominal	SNR	Wave-length	Closest Nominal	SNR
	Goal	Threshold							
300-315	4.926	7.98		305-330	33.5		305 310 315	1.10 2.90 18.0	160 320 630
315-325	30.41	43.36	720@320				320	30.9	900
325-335	63.766	86.63	Linearly Interpolate e xcept some li nes	320-329	54.3				
335-357	65.234	91.39		327-356	53.3		350	70.9	1000
357-423	71.562	108.66					400	91.4	1200
423-451	86.358	130.75	1500@430	423-451	67.3		450	101	1400
451-500	103.744	145.49	1500				500	73.1	1400
Measurement time: 30 min				Measurement time : 1 hour			Measurement time : 1 hour		

Retrieval Geometry



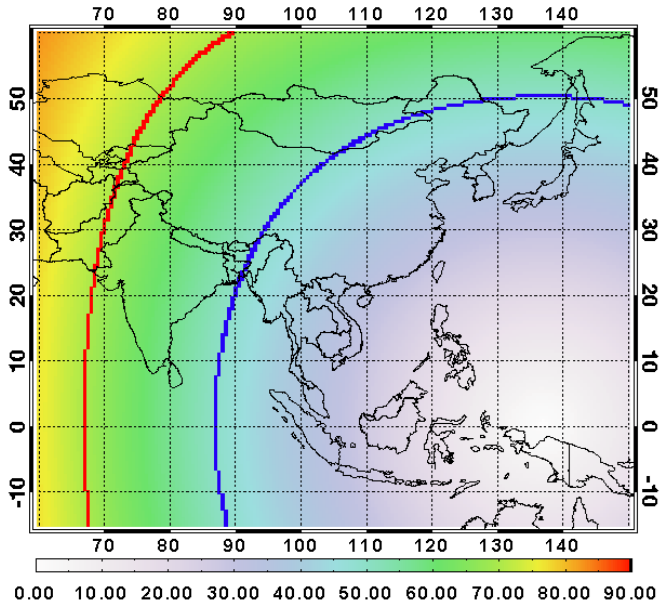
GEMS SZA

50°

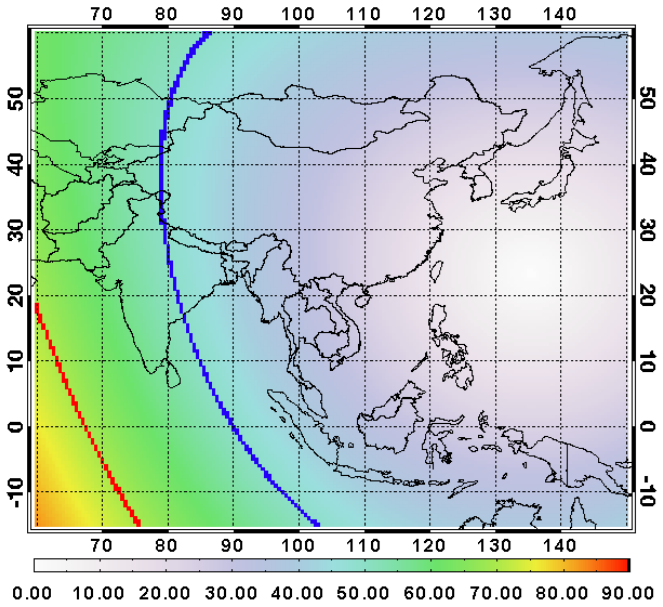
70°

90°

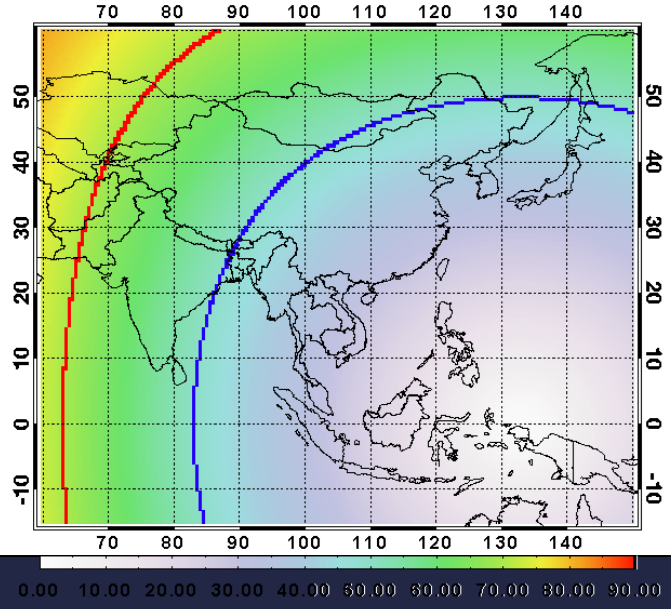
GEMS SZA_Vernal Equinox@Seoul Noon



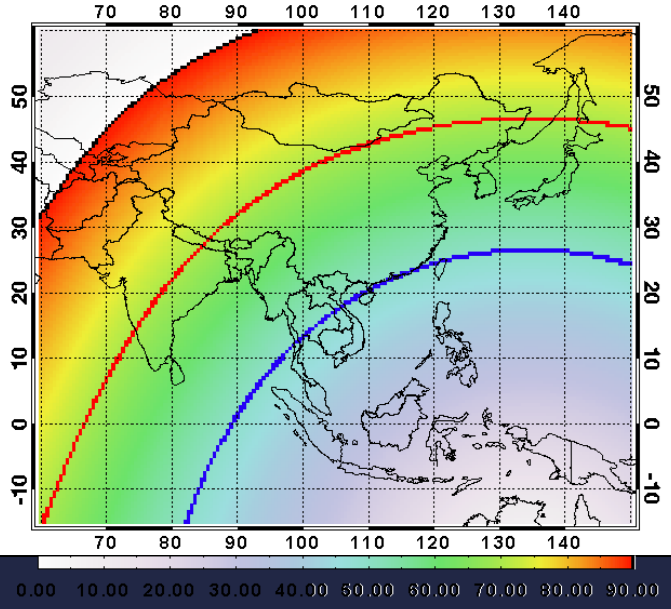
GEMS SZA_Summer Solctice@Seoul Noon

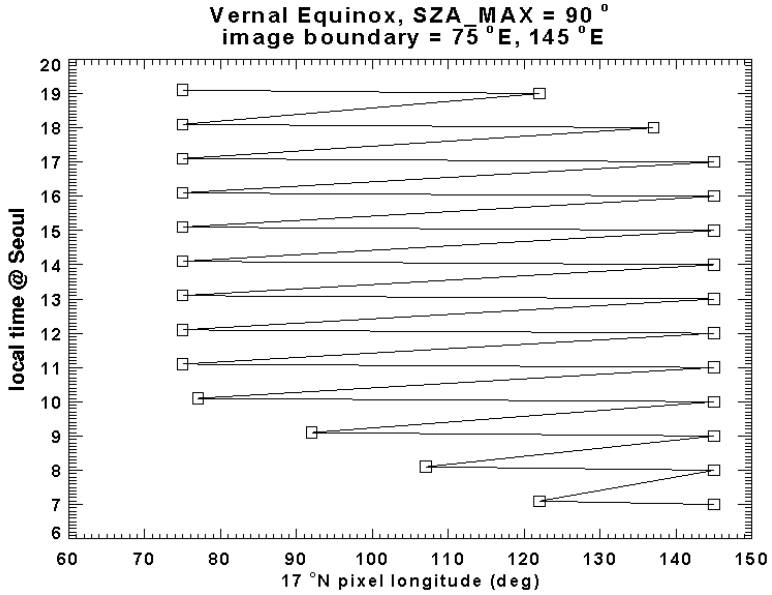


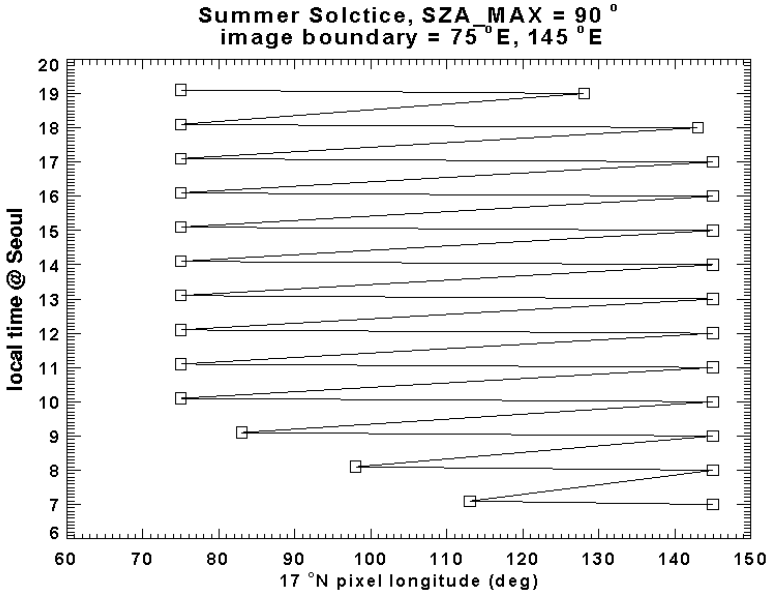
GEMS SZA_Autumnal Equinox@Seoul Noon

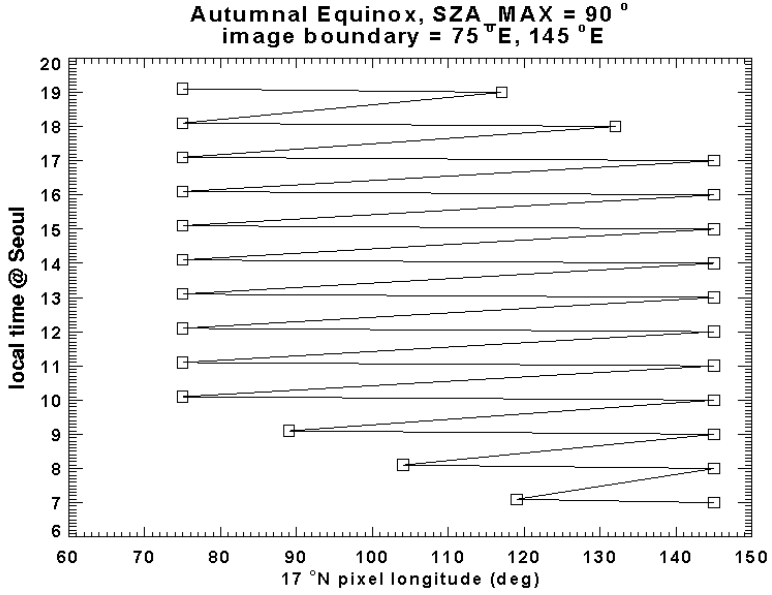


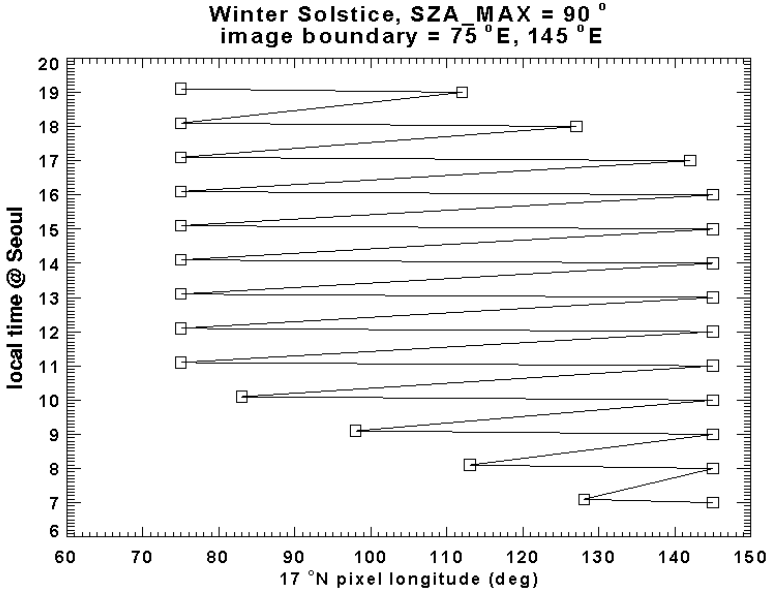
GEMS SZA_Winter Solstice@Seoul Noon

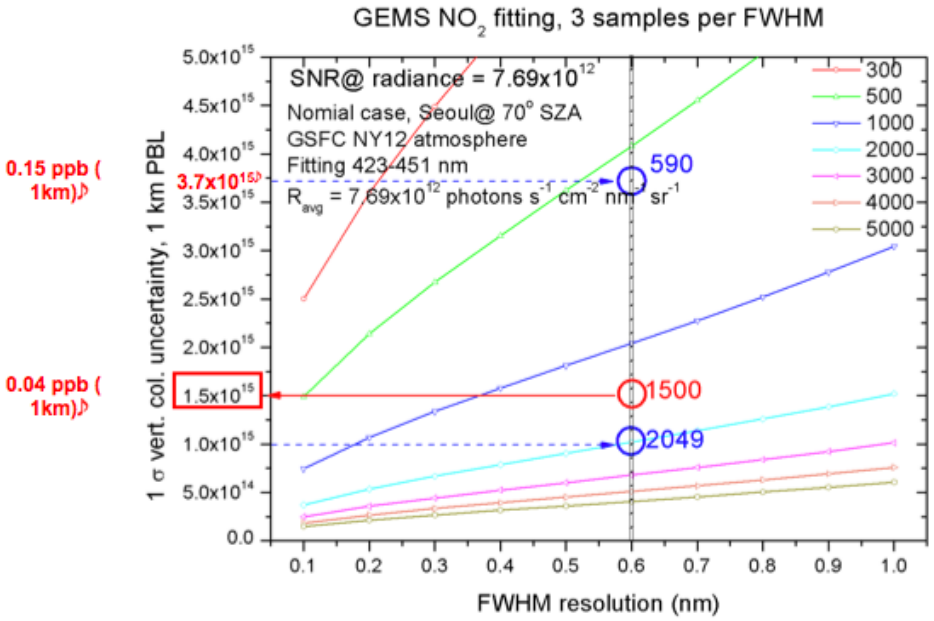


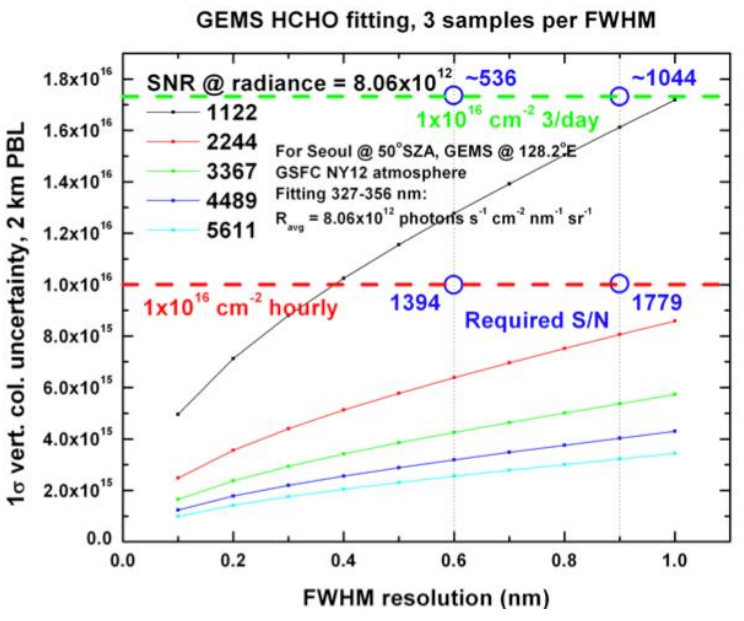

Vernal Equinox, SZA_MAX = 90 °
image boundary = 75 °E, 145 °E
local time @ Seoul
17 °N pixel longitude (deg)

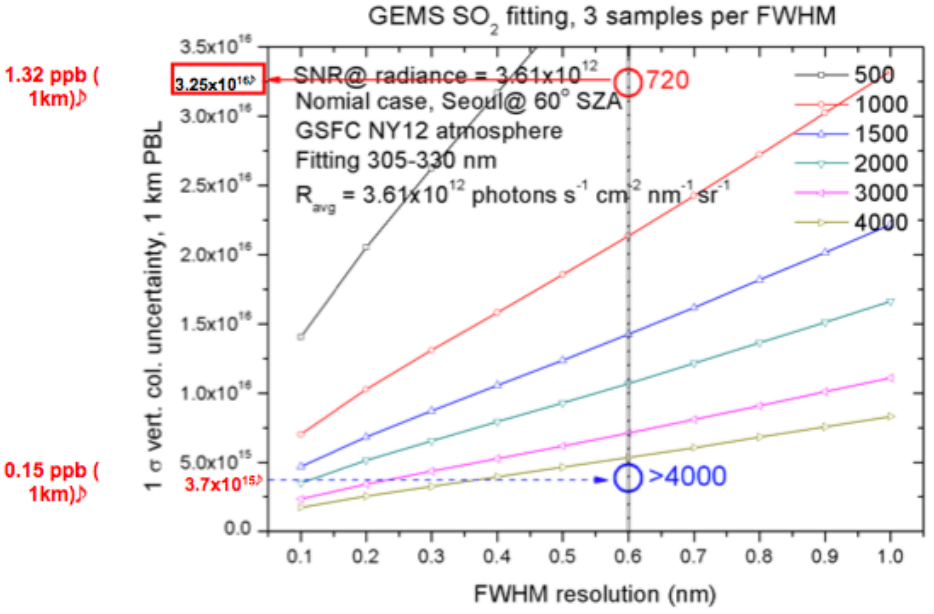

Summer Solctice, SZA_MAX = 90 °
image boundary = 75 °E, 145 °E
local time @ Seoul
17 °N pixel longitude (deg)

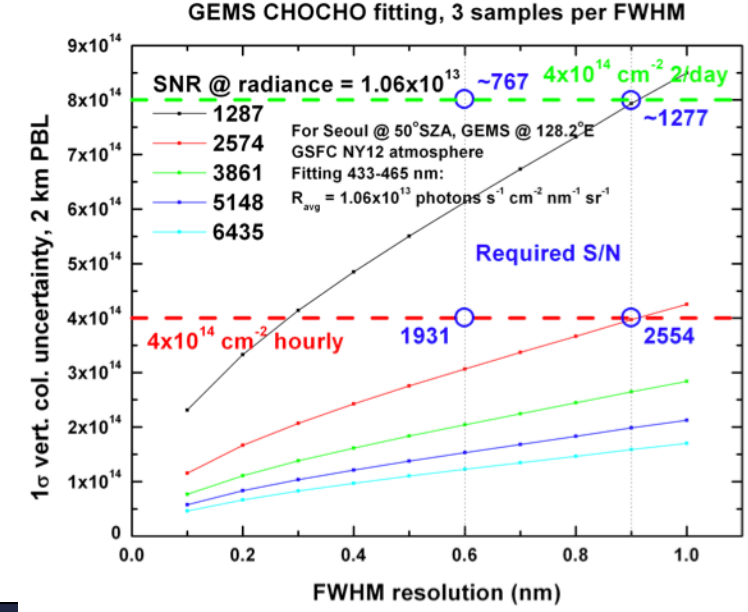

Autumnal Equinox, SZA_MAX = 90 °
image boundary = 75 °E, 145 °E
local time @ Seoul
17 °N pixel longitude (deg)


Winter Solstice, SZA_MAX = 90 °
image boundary = 75 °E, 145 °E
local time @ Seoul
17 °N pixel longitude (deg)


GEMS NO2 fitting, 3 samples per FWHM
SNR@ radiance = 7.69x10^12
Nomial case, Seoul@ 70° SZA
GSFC NY12 atmosphere
Fitting 423-451 nm
R_avg = 7.69x10^12 photons s^-1 cm^-2 nm^-1 sr^-1
0.15 ppb (1km)
3.7x10^15
0.04 ppb (1km)
1.5x10^15
590
1500
2049
300
500
1000
2000
3000
4000
5000
1 σ vert. col. uncertainty, 1 km PBL
FWHM resolution (nm)


GEMS HCHO fitting, 3 samples per FWHM
SNR @ radiance = 8.06x10^12
~536
~1044
1x10^16 cm^-2 3/day
1122
2244
3367
4489
5611
For Seoul @ 50°SZA, GEMS @ 128.2°E
GSFC NY12 atmosphere
Fitting 327-356 nm:
R_avg = 8.06x10^12 photons s^-1 cm^-2 nm^-1 sr^-1
1x10^16 cm^-2 hourly
1394
1779
Required S/N
1σ vert. col. uncertainty, 2 km PBL
FWHM resolution (nm)


GEMS SO2 fitting, 3 samples per FWHM
SNR@ radiance = 3.61x10^12
Nomial case, Seoul@ 60° SZA
GSFC NY12 atmosphere
Fitting 305-330 nm
R_avg = 3.61x10^12 photons s^-1 cm^-2 nm^-1 sr^-1
1.32 ppb (1km)
3.25x10^16
0.15 ppb (1km)
3.7x10^15
720
>4000
500
1000
1500
2000
3000
4000
1 σ vert. col. uncertainty, 1 km PBL
FWHM resolution (nm)


GEMS CHOCHO fitting, 3 samples per FWHM
SNR @ radiance = 1.06x10^13
~767
4x10^14 cm^-2 2/day
~1277
1287
2574
3861
5148
6435
For Seoul @ 50°SZA, GEMS @ 128.2°E
GSFC NY12 atmosphere
Fitting 433-465 nm:
R_avg = 1.06x10^13 photons s^-1 cm^-2 nm^-1 sr^-1
Required S/N
4x10^14 cm^-2 hourly
1931
2554
1σ vert. col. uncertainty, 2 km PBL
FWHM resolution (nm)

SNR Requirements

Wavelengths (nm)	SNR	Related gas	Uncertainty (cm^{-2})	SZA (deg)	Remark
315-325	1500* 720	SO_2	1.0×10^{16} 3.3×10^{16}	60	YJK, KC
327-356	1394* 1500* 720	HCHO	1.0×10^{16} 1.0×10^{16} 2.1×10^{16}	50 70	KC YJK, KC
423-451	2049* 1500	NO_2	1.0×10^{15} 1.5×10^{15}	70	YJK, KC
433-465	1931*	CHOCHO	4.0×10^{14}	50	KC

* Spatial coadding is required to increase the SNR.

Cf. Kelly Chance (2011), Y.J. Kim

Option to increase SNR

1. Request larger volume and mass budget.
   - Takes longer time. Requested to system engineer at KARI.
   - → not realistic at this stage?
2. Request for longer observation time
   - 30min → 45 min … (not an option at this moment)
   - Mechanical disturbance needs to be minimized and characteristics should be provided to GOCI and system engineer

3. Lower spatial resolution
   - 7 x 8 km^2 → 14 x 8 km^2 … → 28 x 8 km^2

4. Reduce E-W Scan coverage
   - 5,000 km → 4,000 km → … 3,000 km (@winter or local mode)
   - Need mechanism to have adaptable scan speed

Operation mode

Operation mode		Observation Freq. (min)	E-W Scan coverage (@lat. of Seoul)
Normal		60*	75 E – 145 E (70 deg wide)
Special	EA(East Asia)	60*	110 E – 140 E (30 deg wide)
	EEA(Enhanced East Asia)	60*	115 E – 130 E (15 deg wide)
	LA(Local Area)	< 30	In emergency by ground command

- Imaging time 30 minutes + Transmission 30 minutes to avoid mechanical disturbance with GOCI-2

Current Status of GEMS Requirements(1/4)

System Attributes	Requirements
Lifetime	> 7 years [option : >10 years]
Reliability	> 0.85 @EOL
Field of regard	> 5000 km (N/S) × 5000 km (E/W) N/S range : 45°N~5°S E/W range : selectable between 75°E~145°E Orbital position :116.2E<Pos.<128.2E
Duty cycle / Imaging time	8 images during daytime (30 min imaging + 30 min rest) × 8 times / day
Ground sampling distance	< 7 km (N/S) at Seoul GSD area < 56 km^2 at Seoul (Aspect Ratio shall be less than 1:3)

Current Status of GEMS Requirements(2/4)

System Attributes	Requirements
Spectral range	300 nm to 500 nm
Spectral resolution	< 0.6 nm
Spectral sampling	< 0.2 nm
Signal-to-noise ratio	> 720 @ 320nm > 1500 @ 430nm
Data quantization	≥ 12 bits
MTF (instrument level)	> 0.3 in N/S direction @Nyquist frequency > 0.3 in E/W direction @Nyquist frequency
Imaging navigation	1 pixel
Pointing stability*	48 microrad/2s
Pointing accuracy	0.02 deg

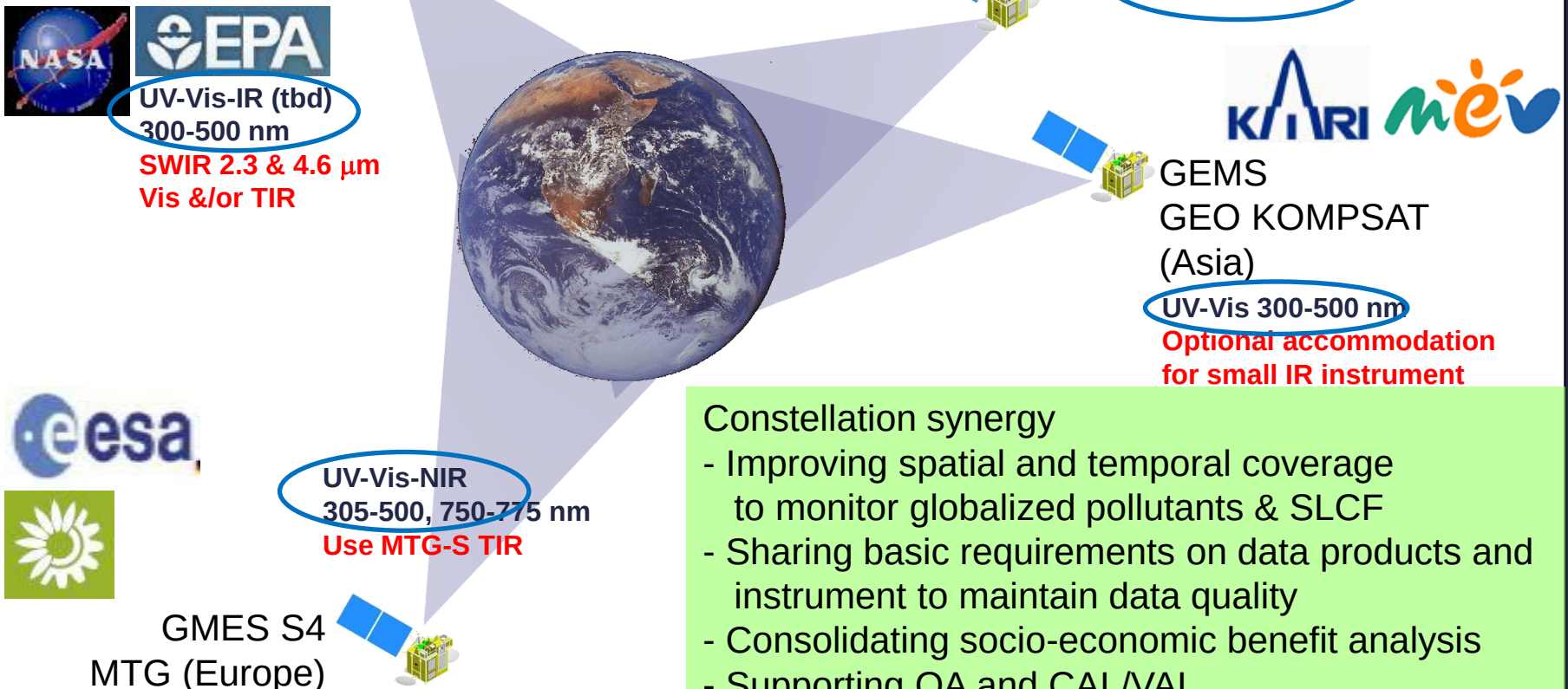
*For standard operation

Current Status of GEMS Requirements(3/4)

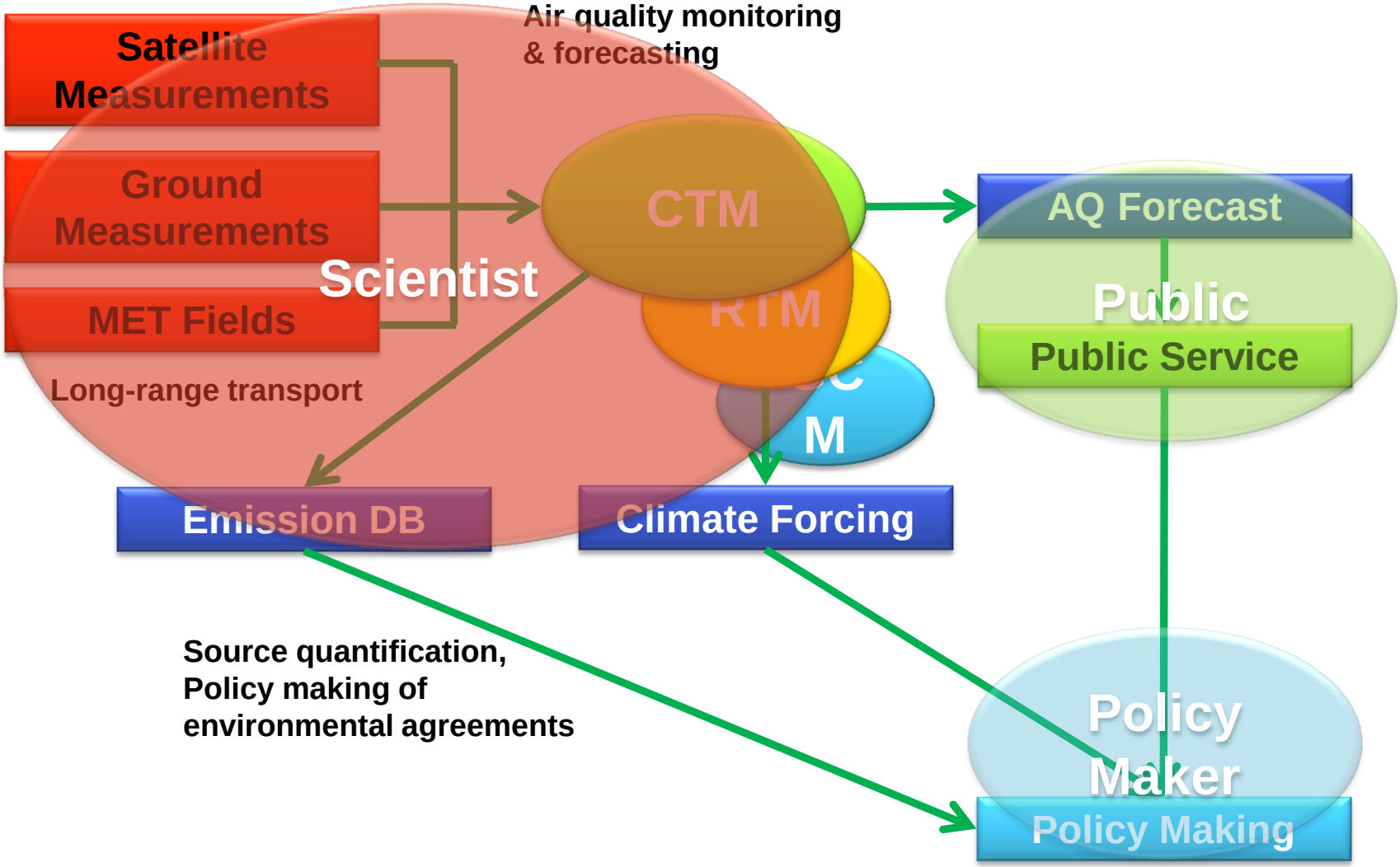
System Attributes	Requirements
Radiometric calibration accuracy	< 4% (including lamp uncertainty)
Spectral calibration Accuracy	< 0.02 nm
Spectral calibration stability	< 0.02 nm (within 24hr)
Polarization factor	< 2% (310-500nm) No inflection point within 20nm for all the wavelength range
Spectral Feature	< 0.05% (within 3 nm)
Stray Light	< 2% (310-500 nm)

CEOS (Committee on Earth Observation Satellites)

Constellation of GEO Mission to study Air Quality and Clima



Constellation synergy
- Improving spatial and temporal coverage to monitor globalized pollutants & SLCF
- Sharing basic requirements on data products and instrument to maintain data quality
- Consolidating socio-economic benefit analysis
- Supporting QA and CAL/VAL


Air quality monitoring
& forecasting
Satellite Measurements
Ground Measurements
MET Fields
Scientist
Long-range transport
CTM
RTM
M
Emission DB
Climate Forcing
AQ Forecast
Public
Public Service
Source quantification,
Policy making of
environmental agreements
Policy Maker
Policy Making

Summary

- GEMS, a geostationary mission is expected to contribute monitoring air quality and SLCF in Asia in high temporal and spatial resolution.
  - UV-Vis observations will allow a common set of tropospheric column products to be produced over the industrialized Northern Hemisphere at **~8 km spatial resolution and 1 hour refresh**
    - **O_3 NO_2 HCHO SO_2 AOD (possible CO, CH_4, and CO_2 ?)**
  - Aerosol detection in the UV will allow **absorbing aerosol** to be distinguished from total AOD, providing information on aerosol speciation and important to the air quality/climate interface
- GEMS can contribute to understand the globalization of pollution events, source/sink identification, and long-range transport of pollutants and SLCD, as a part of the CEOS ACC.
- User requirements have been finalized and is reflected in the RFP which shall be issued soon.
- Coordinated efforts among scientists around the world are desirable in defining requirements, developing algorithm, processing data, and future applications.

Acknowledgement

Ministry of Environment (MoE), Rep. of Korea

NIER, MoE

KEITI, MoE

Ministry of Education, Science & Technology (MEST)

KARI

GEMS Science Team