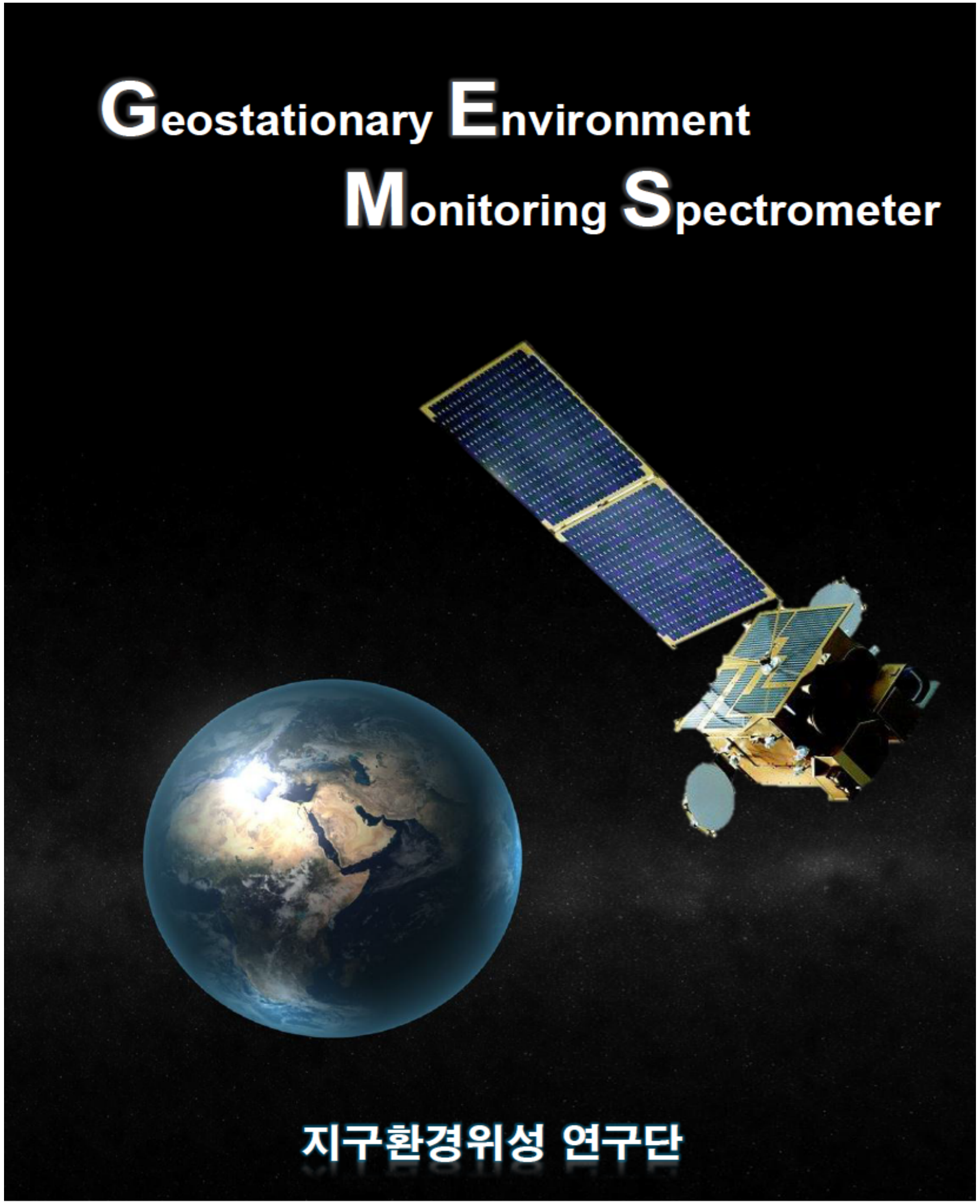

GESC
Global Environment
Satellite research Center

Overview and Status of GEMS

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Outline

- GEMS Program
  - Status
  - Baseline Products
  - Specification
- Issues
  - Nominal radiance near Korea vs. SNR
  - Predicted Performance
- Status of algorithm development
- Summary

Status of GEMS Mission

- **GK-2 Program**
  - SRR in Apr., 2012; SDR in Feb. 2014
- **Budget**
  - GEMS Program passed Mid-term review on Dec. 4, 2013, and now is in Main Phase till launch. (* Launch : Dec., 2018)
- **Prime Contractor**
  - Selection of main contractor for the Joint Development with KARI on May 13th , 2013 (International Contractor: Ball Aerospace & Technologies Corp.)

    * AMI contract with ITT;   GOCI-2 contract with Astrium
- **Design review**
  - SDR finished in October 28-29, 2013
  - PDR finished in March, 2014
  - CDR planned in 2015
- **Changes in Environment**
  - Air quality forecast in operation since 2013 by NIER/ME

    → GEMS to be an operational sat. (e.g. data assimilation of model with sat. data)
  - CEOS ACC for GEO AQ (TEMPO over N. America and S-4 over Europe)
  - ‘KORUS-AQ’ airborne campaign planned in 2016 (airborne GEMS considered)

GEMS Design

- Step-and-stare UV-Visible imaging spectrometer scanning at least 8 x per day in 30 minutes
- Daily solar and dark calibration
- images coadded at each position + mirror move back < 30 minutes
- Scanning Schmidt telescope and Offner spectrometer
- Diffusers for on-orbit solar calibration and onboard LED light source
- 2-axis scan mechanism with gyro feed capability
- Redundant electronics for 10-year lifetime

Calibration assembly
(open/closed/Diff1/Diff2)

Telescope assembly

Telescope
Optics

Spectrometer
Optics

FPA

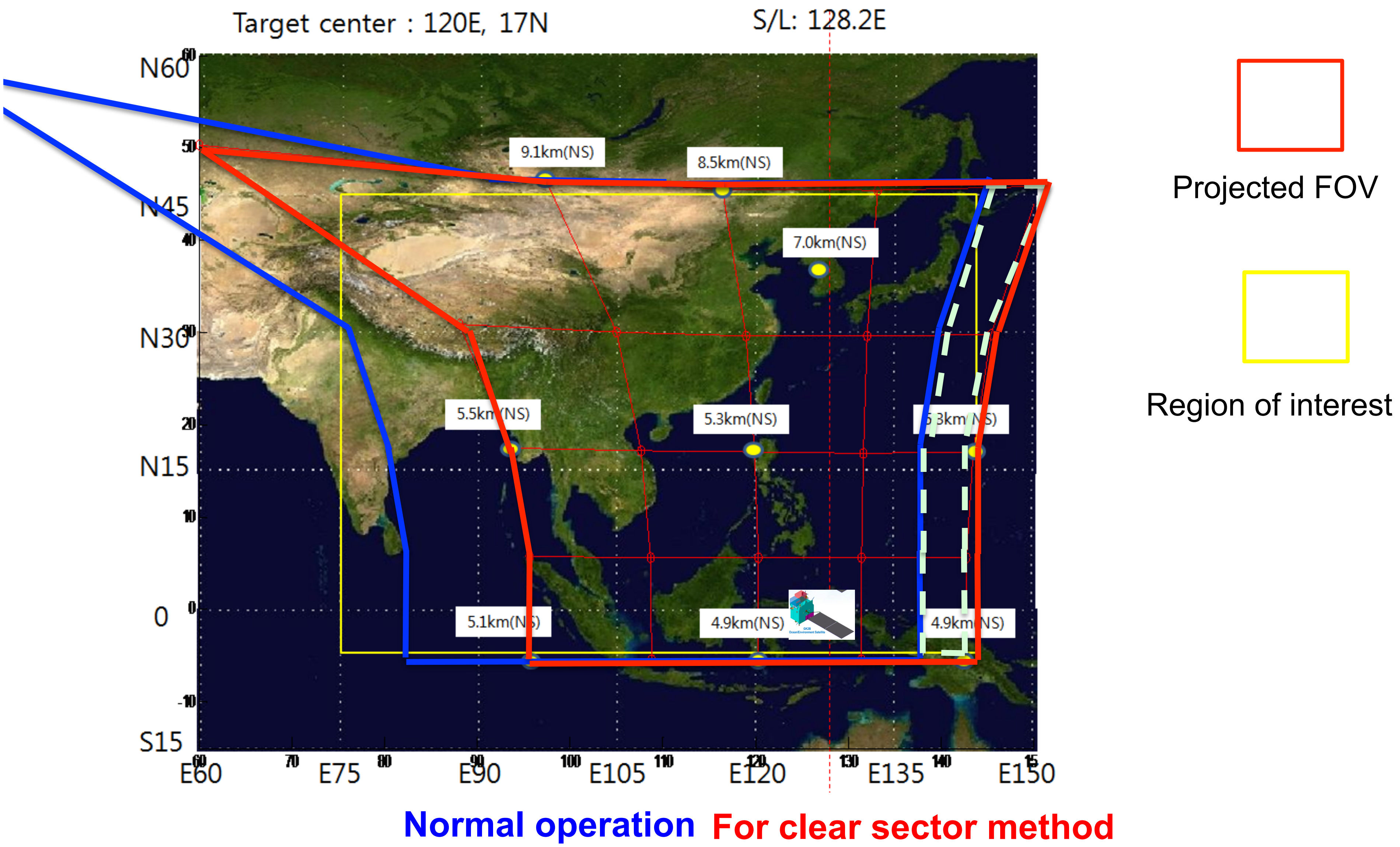
Scan mechanism

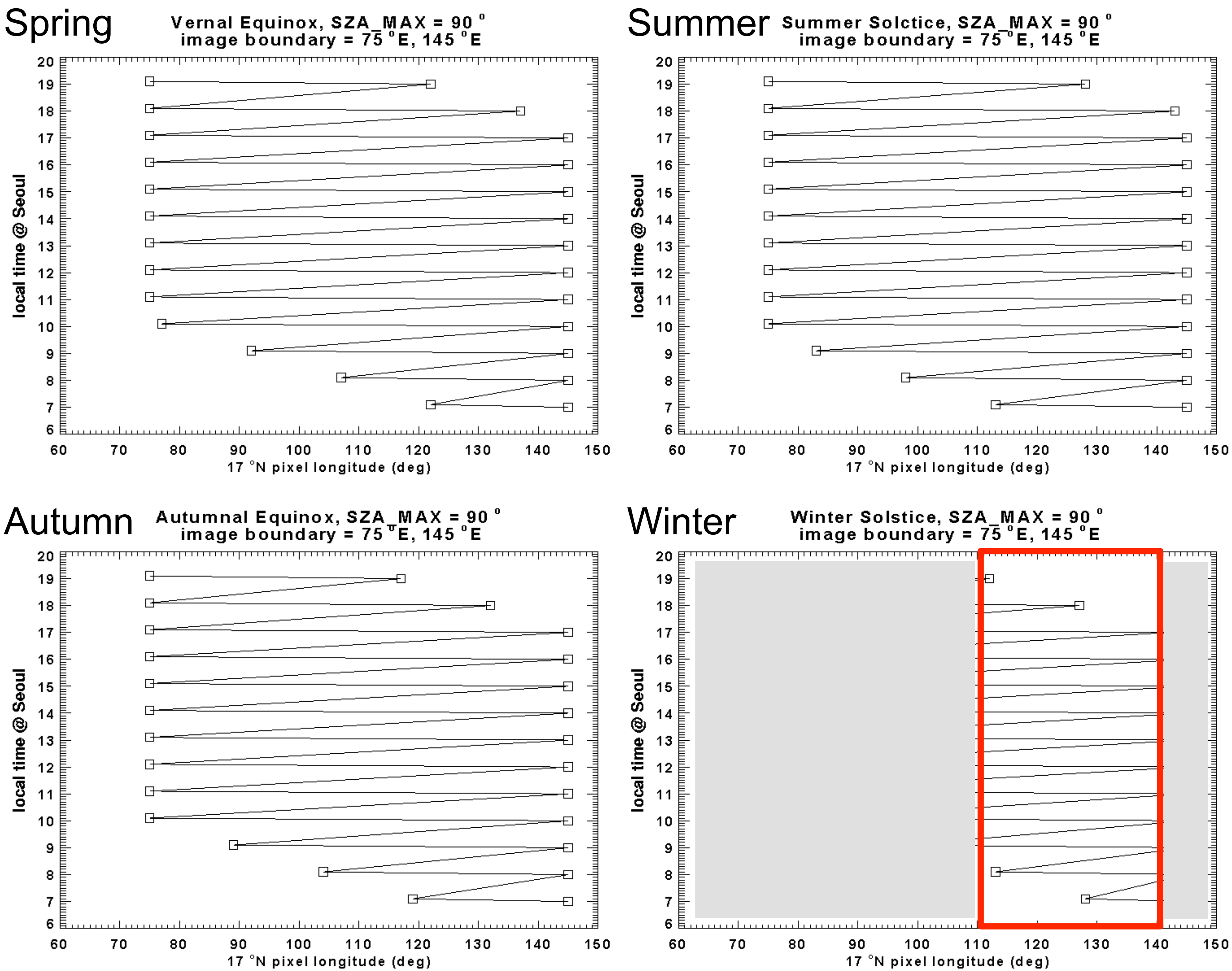
Courtesy, KARI / BATC

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	7 x 8	< 70	BOAS / DOAS
SO_2	Aerosol precursor	$6x10^{8}$	$1x10^{17}$	$6x10^{14}$	$1x10^{16}$	310-330	7 x 8 x 4 pixels x 3 hours	< 50 (60*)	
HCHO	Proxy for VOCs	$1x10^{15}$	$3x10^{16}$	$3x10^{15}$	$1x10^{16}$	327-357	7 x 8 x 4 pixels	< 50 (60*)	
O_3	Oxidant, pollutant	$4x10^{17}$	$2x10^{18}$	$1x10^{18}$	3%(TOz) 5% (Strat) 20% (Trop)	300-340	7 x 8	< 70	TOMS, OE
AOD (AI, SSA, AEH)	Air quality, Climate	0 (AOD)	5 (AOD)	0.2 (AOD)	20% or 0.1@ 400nm	300-500	3.5 x 8	< 70	Multi-spectral O_2-O_2
Clouds	Data quality, climate	0 (COD)	50 (COD)	17 (COD)		300-500	7 x 8		Raman, O_2-O_2
Surface Property	Environment	0	1	-		300-500	7 x 8		Multi-spectral

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




Spring
Vernal Equinox, SZA_MAX = 90 °
image boundary = 75 °E, 145 °E
Summer
Summer Solctice, SZA_MAX = 90 °
image boundary = 75 °E, 145 °E
Autumn
Autumnal Equinox, SZA_MAX = 90 °
image boundary = 75 °E, 145 °E
Winter
Winter Solstice, SZA_MAX = 90 °
image boundary = 75 °E, 145 °E
local time @ Seoul
17 °N pixel longitude (deg)

GEMS Day in the Life

- 5:30 a.m. Dark calibration

- 6:00 a.m.-6:30 a.m. wake up & imaging
- 6:30 a.m.-7:00 a.m. resting & transmitting

- 7:00 a.m.-7:30 a.m. imaging
- 7:30 a.m.-8:00 a.m. resting & transmitting

- …30 min. interval imaging & resting ~ 6:00 p.m.

- 6:30 p.m. Dark calibration & sleep

- 11:00 p.m. Daily solar cal.(working diffuser)
- 01:00 a.m. Semi-annual solar cal.(reference diffuser)

- **Scan mirror active**
- **all the time**

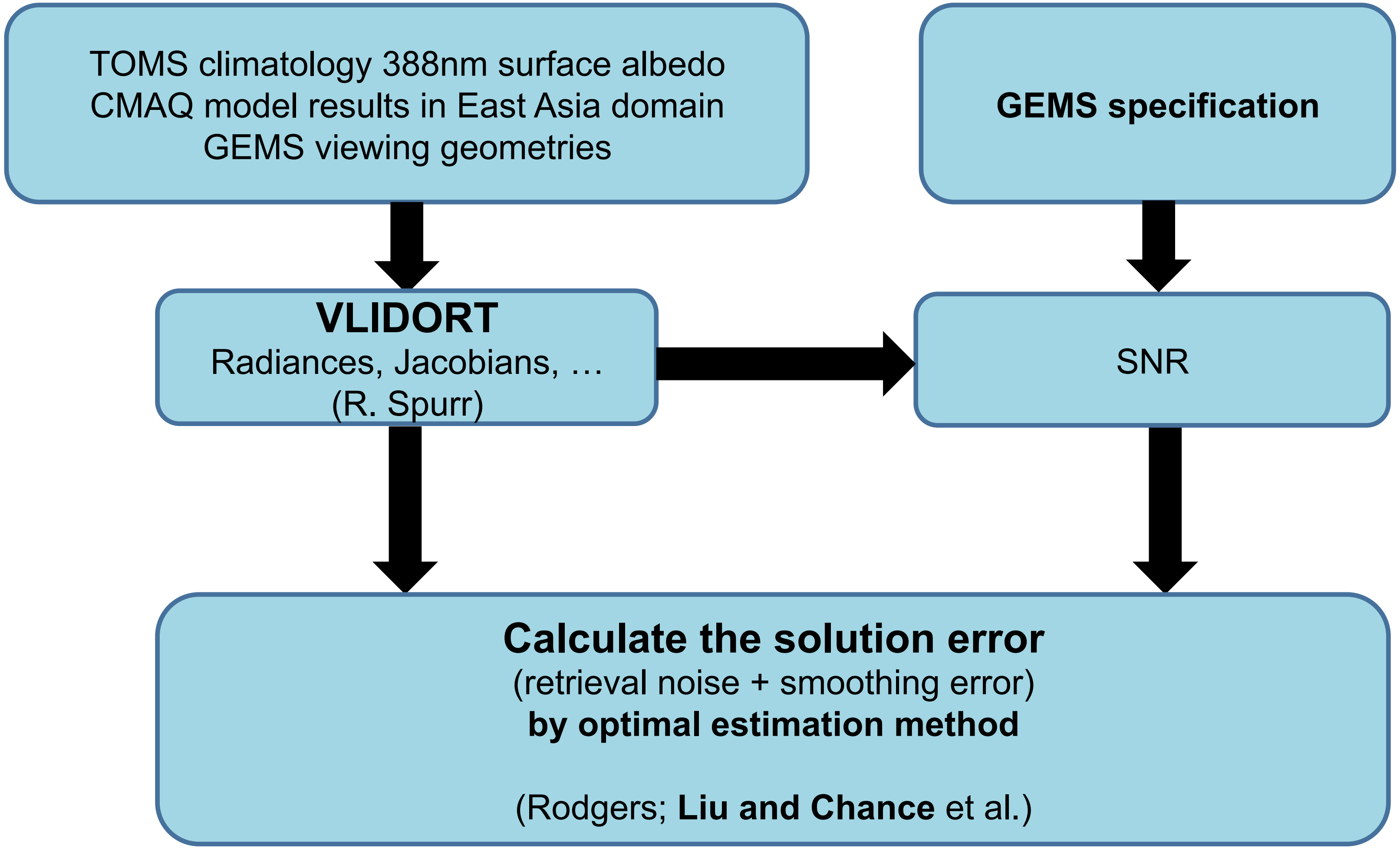
Comparison of Specification

	GEMS	GEOCAPE [TEMPO]	Sentinel-4
Spectral range(nm)	300 – 500 nm	[290 – 690 nm]	305-500 / 750-775
Spectral resol(nm)	0.6 (3 samples)	[0.6]	0.5 / 0.12
Spatial resol	7 km NS x 8 km EW @ Seoul 3.5 km NS x 8 km EW for aerosol	[2.0 km NS x 4.5 km EW]	8 km @ 45 N
Spatial coverage	5 S – 45 N 75 E – 145 E	30 N - 65 N 40 W – 60 E	30 N – 65 N 30 W – 150 W
Obs. time	30 min	[1 hour]	1 hour
Detector @ T	CCD @ 258 K	[CCD @ ~255 K]	CCD @ <220 K
Onboard calibration	Solar, cal light source	[Solar]	Solar, cal light source
Volume (m^3)	1.1 x 1.2 x 0.9	[1 x 1.1 x 1]	~1.1 x 1.2 x 0.9
Mass (Kg)	140	[100]	150
Power (W)	200 (on orbit) / 100 (transfer)	[100]	180
Data rate (Mbps)	40	[9]	25 Mbps

SNR & Nominal Radiance [$Wm^{-2}sr^{-1}\mu m^{-1}$]	GEMS Wave-length	GEMS Nominal radiance: Goal	GEMS Nominal radiance: Threshold	GEMS SNR @ λ [nm]	GEOCAPE Wave-length	GEOCAPE Nominal radiance	GEOCAPE SNR	Sentinel-4 Wave-length	Sentinel-4 Nominal radiance	Sentinel-4 SNR
	300-315	4.93	7.98	*252 @300*	305-330	33.5		305 310 315	1.10 2.90 18.0	160 320 630
	315-325	30.4	43.4	720 @320			720 [1290]	320	30.9	900
	325-335	63.8	86.6	*1273 @325* *1504 @357*	320-329	54.3	[480]			
	335-357	65.2	91.4		327-356	53.3		350	70.9	1000
	357-423	71.6	108.7					400	91.4	1200
	423-451	86.4	130.8	1500 @430	423-451	67.3	[1230]	450	101	1400
	451-500	103.7	145.5	1459 @500				500	73.1	1400

	GEMS	GEOCAPE [TEMPO]	Sentinel-4
Ref.		Kelly Chance	Ben Veihelmann, Cathy Clerbaux

- Performance prediction -
Error analysis using the optimal estimation method



Calculation domain & conditions

Temporal domain

0 – 7 UTC (every hours) X 12 month

Spatial domain

75 – 145 longitude X 5 – 45 latitude (2 deg. resol.)

→ **~ 70,000 runs**

Atmosphere profiles

CMAQ calculation results in East Asia (~70,000 profiles)

6 gases (**O_3, NO_2, H_2CO, SO_2, $C_2H_2O_2$, H_2O**), BrO, OClO, O_4 and **Aerosol**

Actual viewing geometry for a geostationary satellite at 128.2° E

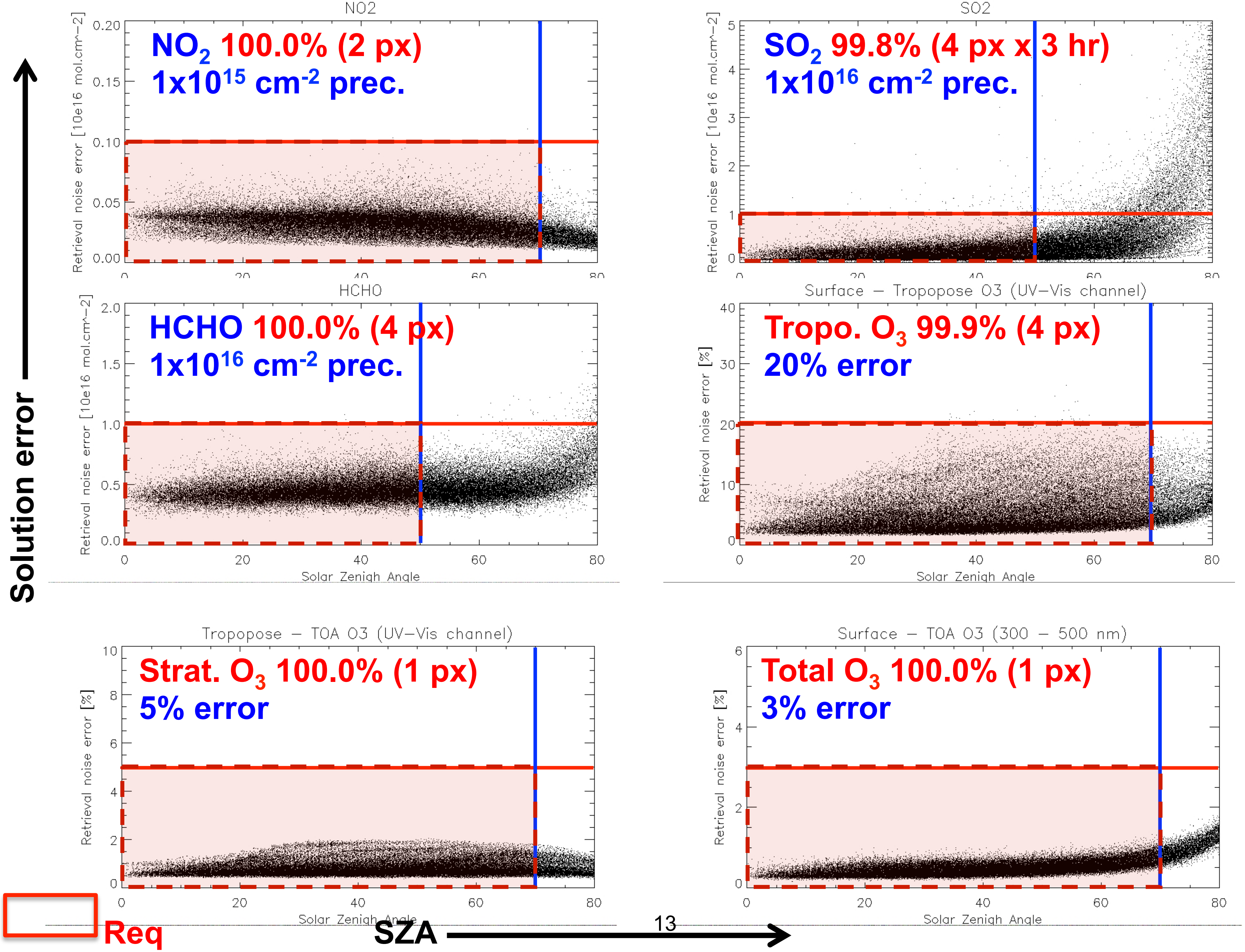
No cloud (under consideration)

RTM calculation and sensitivity calculation (VLIDORT)

300-500 nm at 0.6 nm FWHM, every 0.2 nm

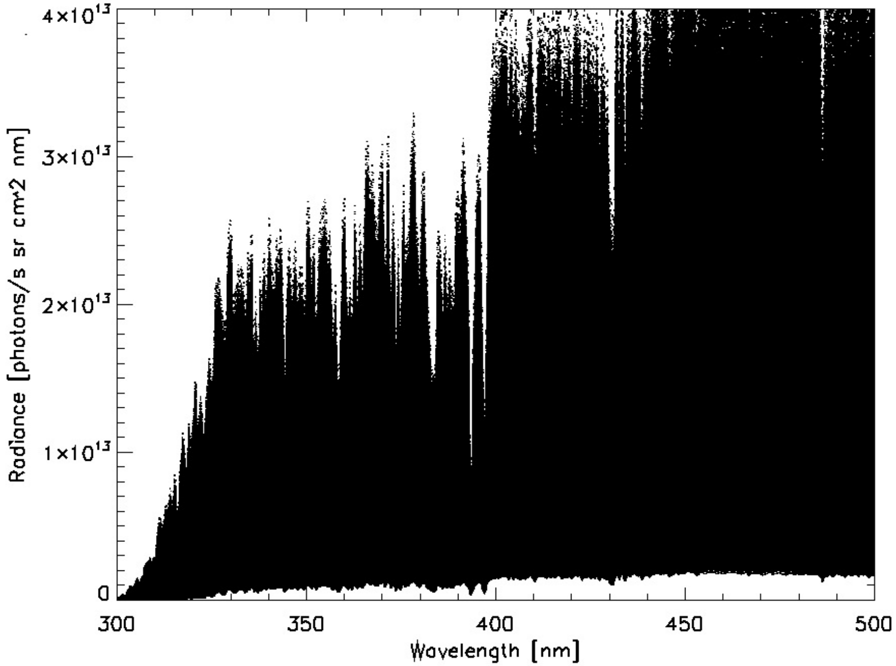
GEMS SNR

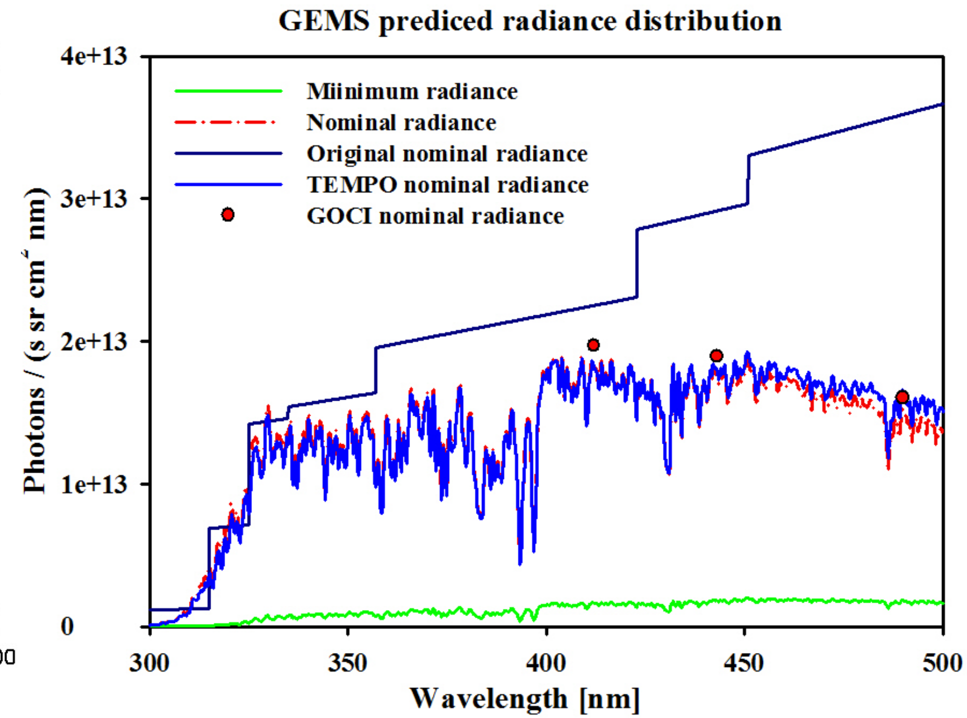
Climatology surface reflectance from TOMS at 388nm



Solution error
NO2
NO2 100.0% (2 px)
1x10^15 cm^-2 prec.
Retrieval noise error [10e16 mol.cm^-2]
SO2
SO2 99.8% (4 px x 3 hr)
1x10^16 cm^-2 prec.
Retrieval noise error [10e16 mol.cm^-2]
HCHO
HCHO 100.0% (4 px)
1x10^16 cm^-2 prec.
Retrieval noise error [10e16 mol.cm^-2]
Solar Zenigh Angle
Surface – Tropopose O3 (UV–Vis channel)
Tropo. O3 99.9% (4 px)
20% error
Retrieval noise error [%]
Solar Zenigh Angle
Tropopose – TOA O3 (UV–Vis channel)
Strat. O3 100.0% (1 px)
5% error
Retrieval noise error [%]
Solar Zenigh Angle
Surface – TOA O3 (300 – 500 nm)
Total O3 100.0% (1 px)
3% error
Retrieval noise error [%]
Solar Zenigh Angle
Req
SZA

Nominal radiance near Korea and SNR





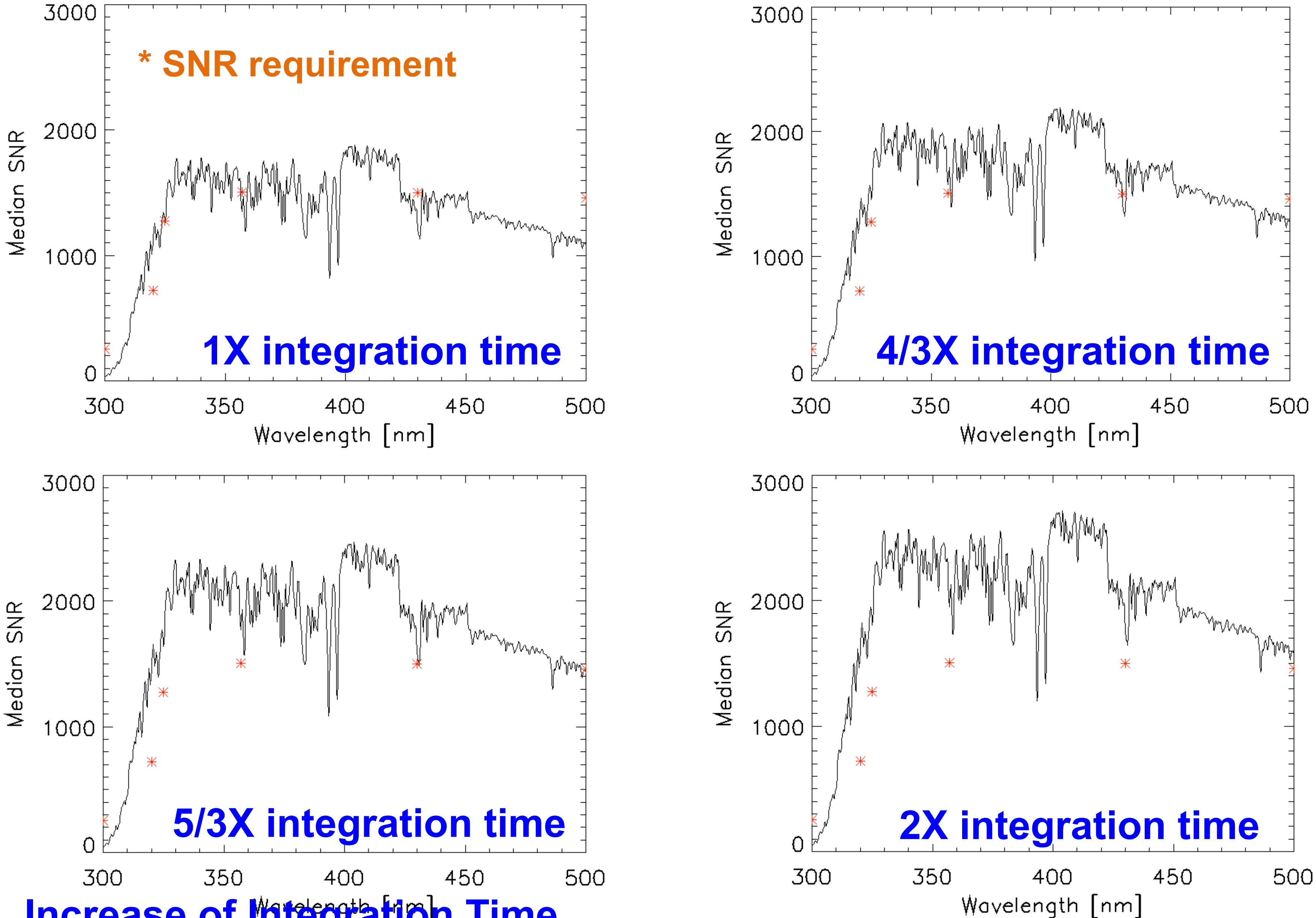
- **Darker nominal radiance near Korea → decrease of SNR**
- Near 300 nm → Important for ozone retrieval

• GOCI most probable measured radiance (all pixels including cloud)

(one daily cycle per month for 1 year in 2012,

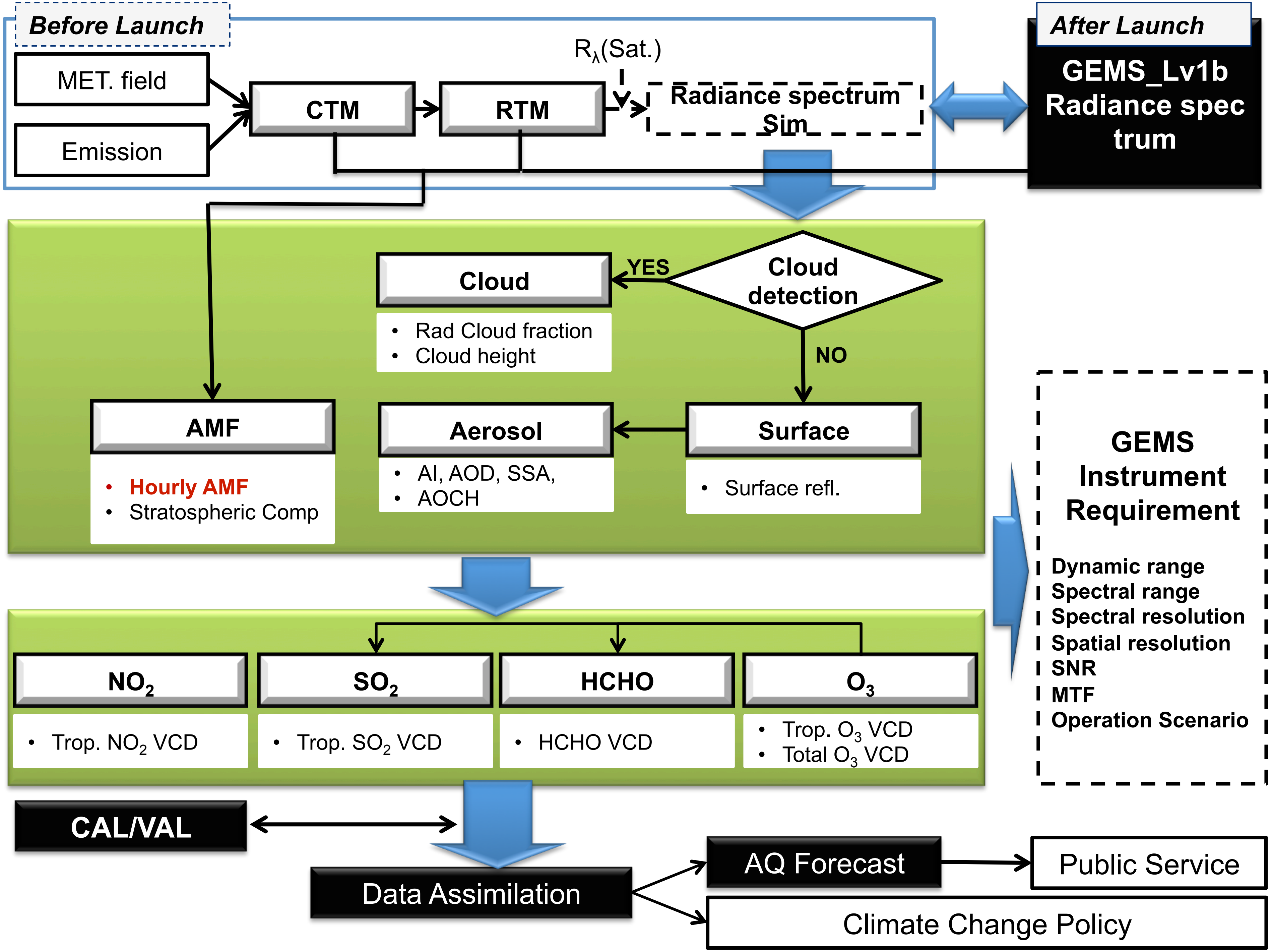
Lat = 25N~48N, Long = 115E~145E)

Predicted SNR @ nominal radiance with different integration time



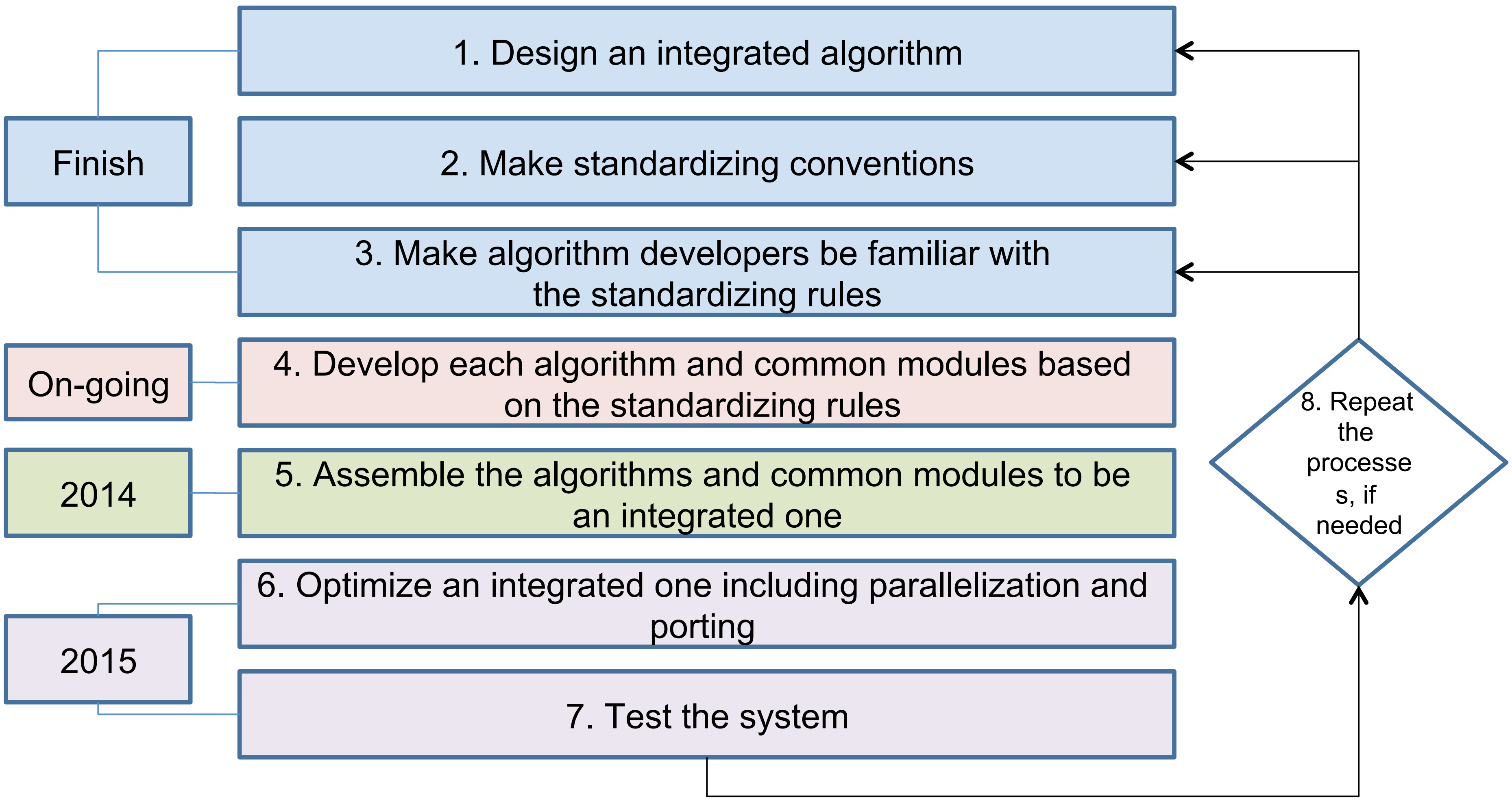
Increase of Integration Time

Issues: 1) signal saturation, 2) pointing stability



Before Launch
MET. field
Emission
CTM
RTM
R_λ(Sat.)
Radiance spectrum Sim
After Launch
GEMS_Lv1b Radiance spectrum
Cloud
YES
Cloud detection
NO
Rad Cloud fraction
Cloud height
AMF
Hourly AMF
Stratospheric Comp
Aerosol
AI, AOD, SSA,
AOCH
Surface
Surface refl.
GEMS Instrument Requirement
Dynamic range
Spectral range
Spectral resolution
Spatial resolution
SNR
MTF
Operation Scenario
NO_2
Trop. NO_2 VCD
SO_2
Trop. SO_2 VCD
HCHO
HCHO VCD
O_3
Trop. O_3 VCD
Total O_3 VCD
CAL/VAL
Data Assimilation
AQ Forecast
Public Service
Climate Change Policy

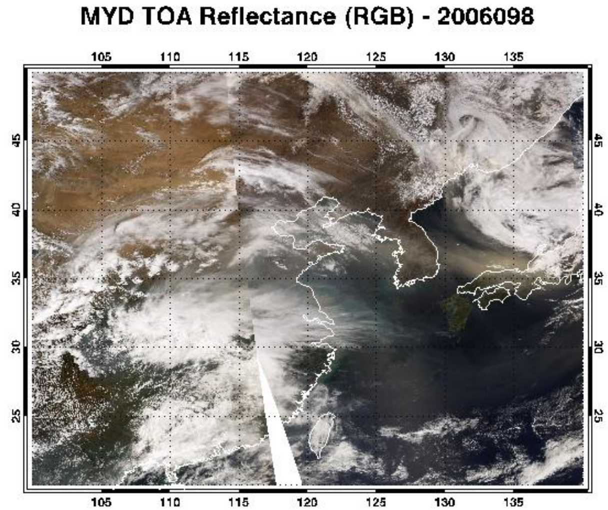
GEMS Unified algorithm development schedule



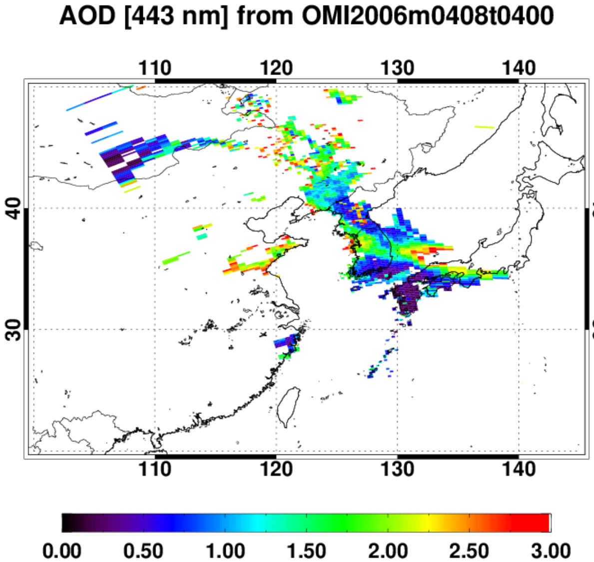
Aerosol Retrieval

- Retrieval test with OMI L1B data

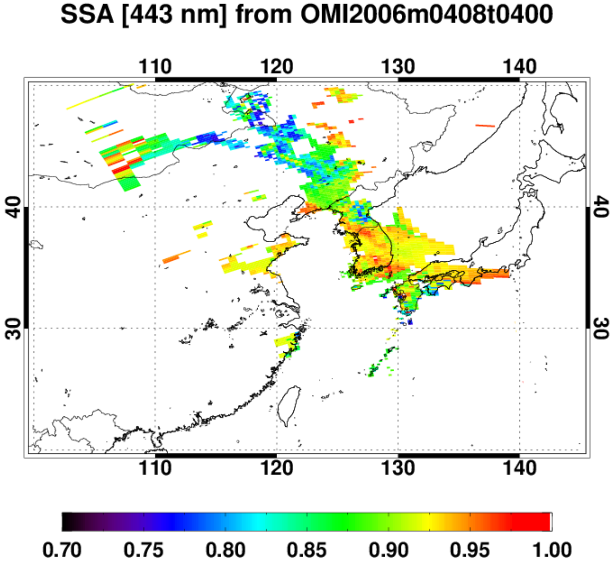
MODIS RGB :2006/04/08



Retrieved AOD [443 nm]



Retrieved SSA [443 nm]



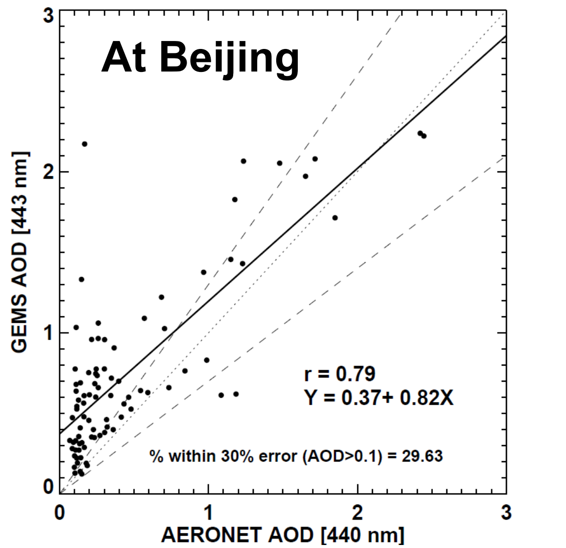
AOD validation

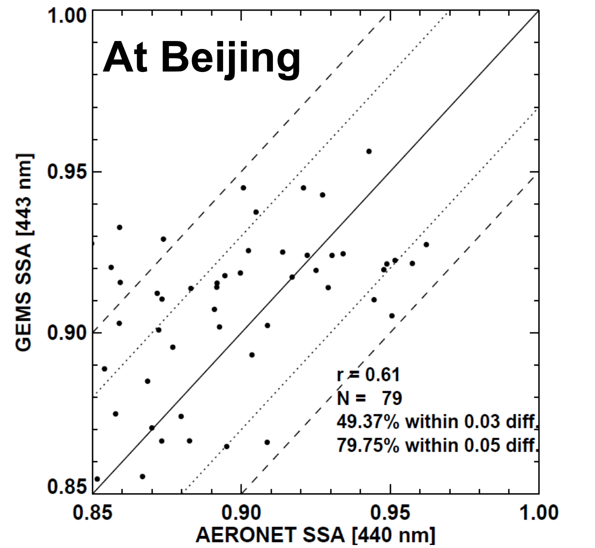
AERONET direct measurement(lev2.0)
2005. 01 ~ 12,
Within ±1 hr, 0.5˚ x 0.5˚

SSA validation

AERONET inversion data(lev2.0)
2005. 01 ~ 12,
Within ±6 hr, 0.5˚ x 0.5˚

(M.J. Kim)

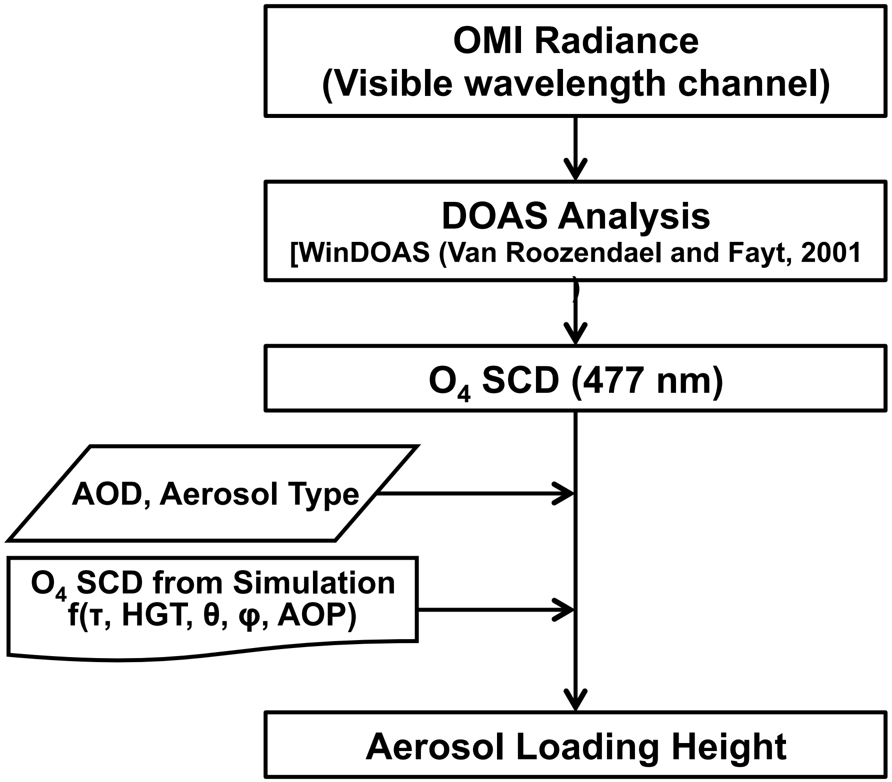


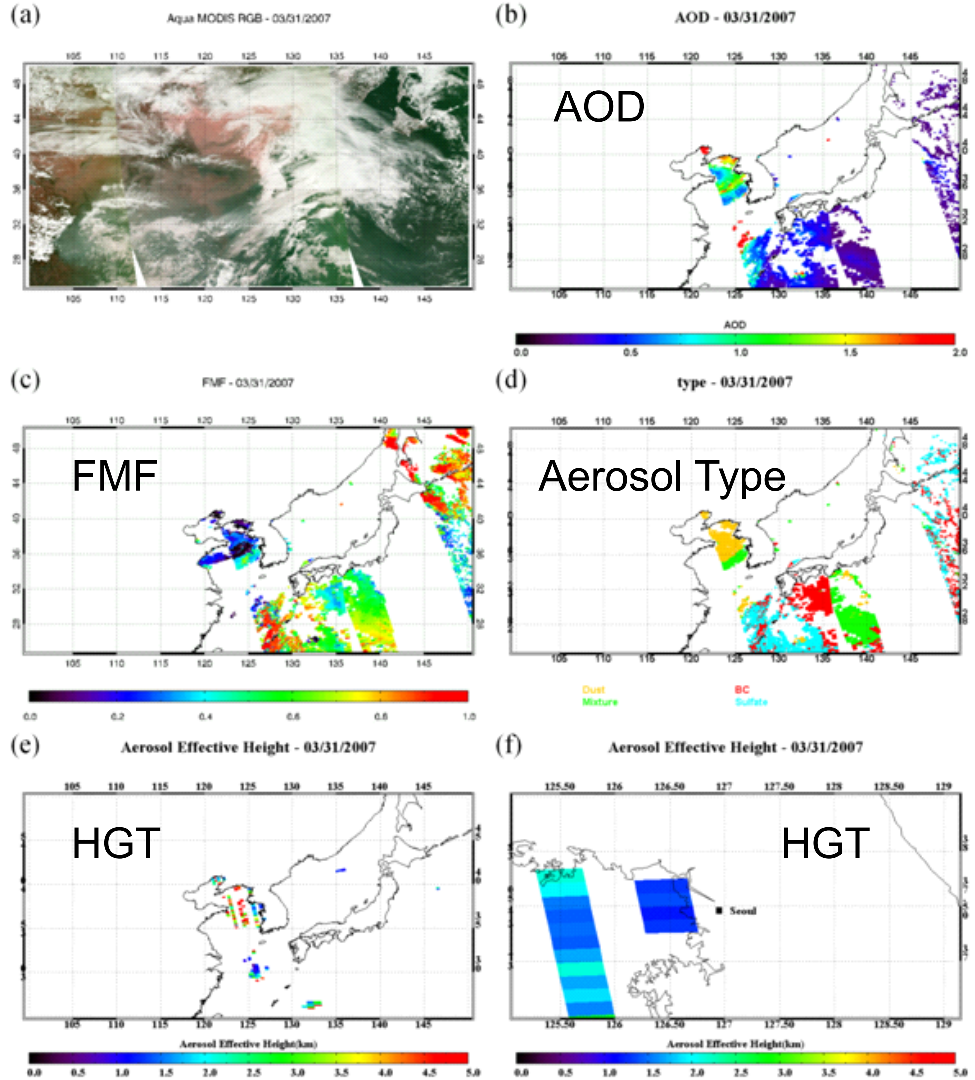


Aerosol Retrieval

- Feasibility study for aerosol loading height retrieval : O_4 algorithm

Flowchart of O_2-O_2 algorithm





(S.S. Park)

Total ozone

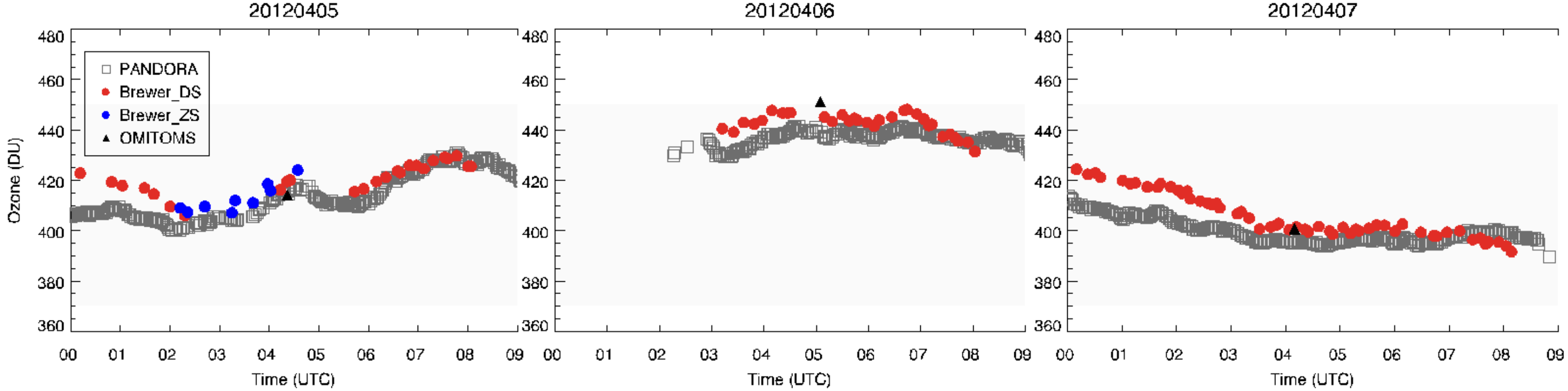


Figure 1. Preliminary comparisons from Three day during the Dragon campaign, 5 April 2012. Compariso n of total ozone between PANDORA (square), single Brewer (circles), OMI TOMS(triangle).

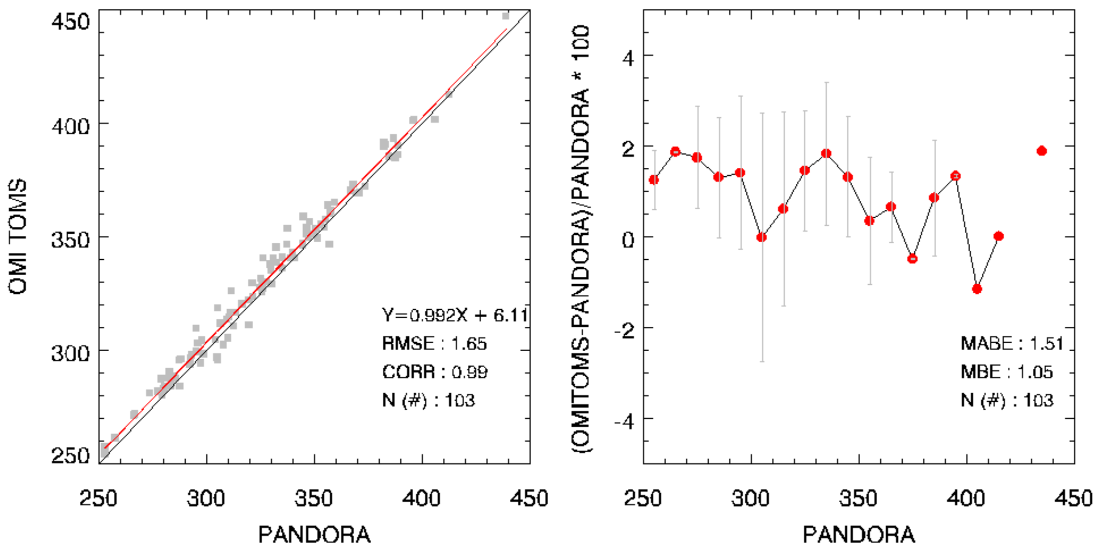


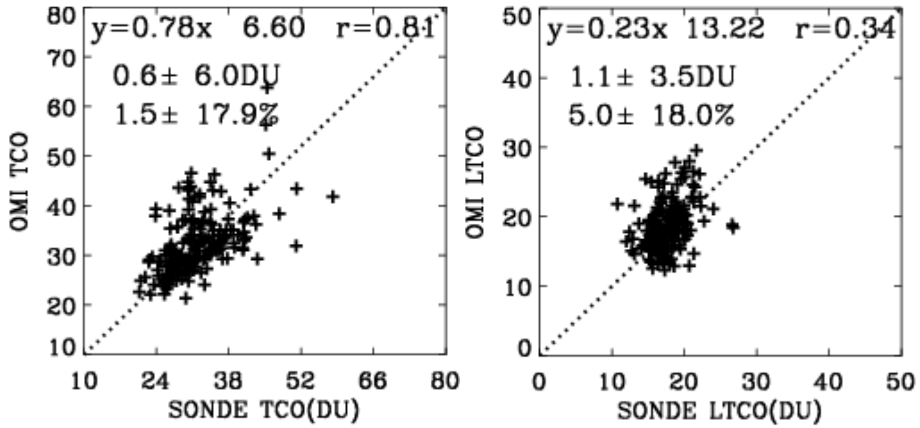
Figure2. The comparison between Sa tellite and PANDORA at Seoul (left) d uring 2012. The result of comparison s hows that V9 results have a good agree ment with Pandora. Relative differenc e of OMI satellite and PANDORA as a f unction of Pandora ozone. Bias is 1.05 %

(J.H. Kim)

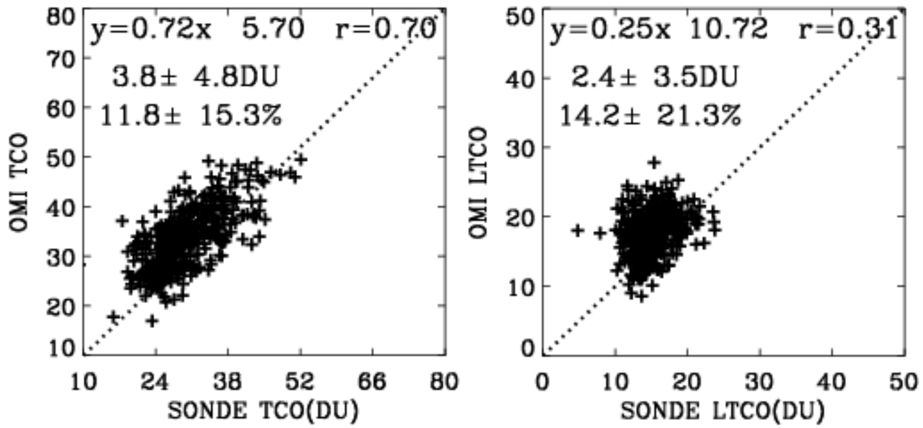
Tropospheric Ozone

■ OMI vs. Ozonesonde Tropospheric O3

SODA



HOHE



2nd evaluation	Correlation coefficient (R)	a, Slope	b, Intercept	RMSE	Error (%)
O3 (Trop)	0.15-0.24	0.15-0.27	<25.5 DU	*8.5-17 DU (17-30%)*	5.1-10.2 DU *(17-34%) [depending on SZA]*

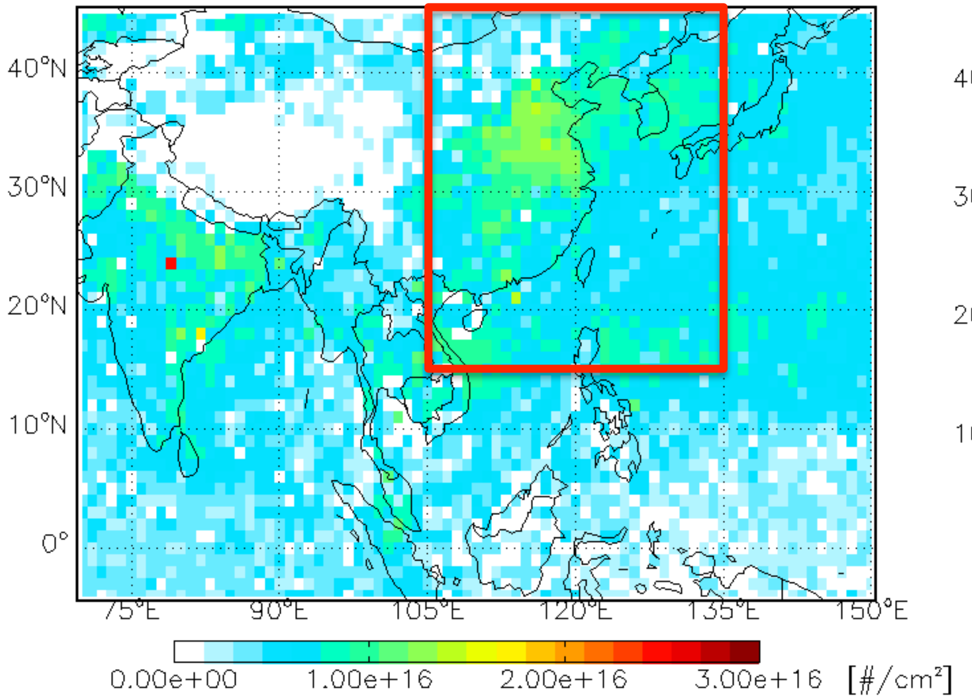
(J.H. Kim)

HCHO retrieval

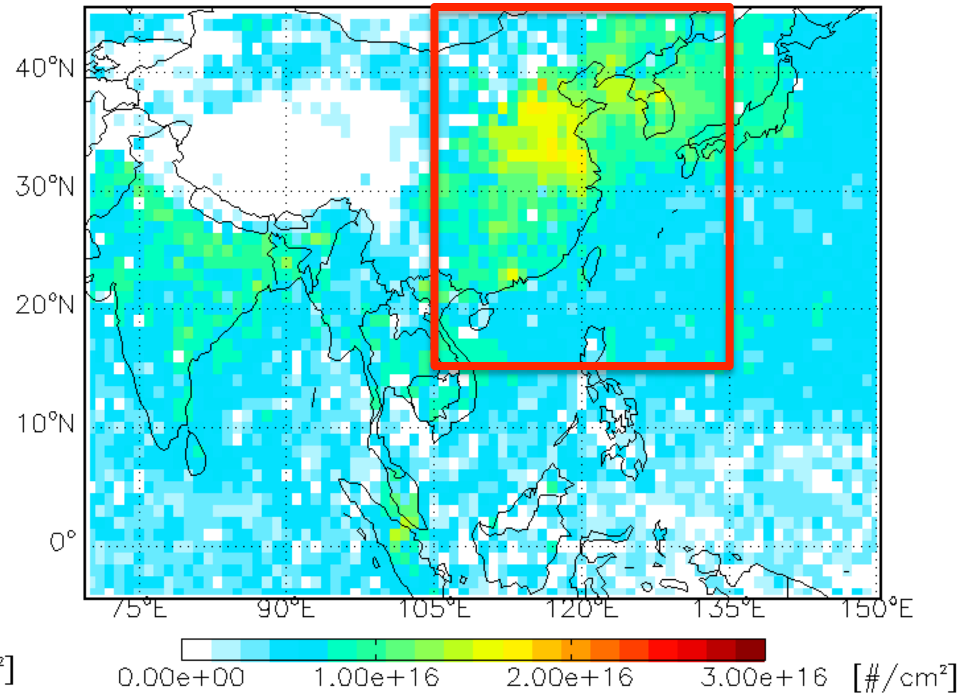
- Retrieval test with OMI L1B data

Monthly mean OMI HCHO VCD : composite on 1°x1° for June, 2006

HCHO VCD with hourly AMF



OMI standard HCHO VCD

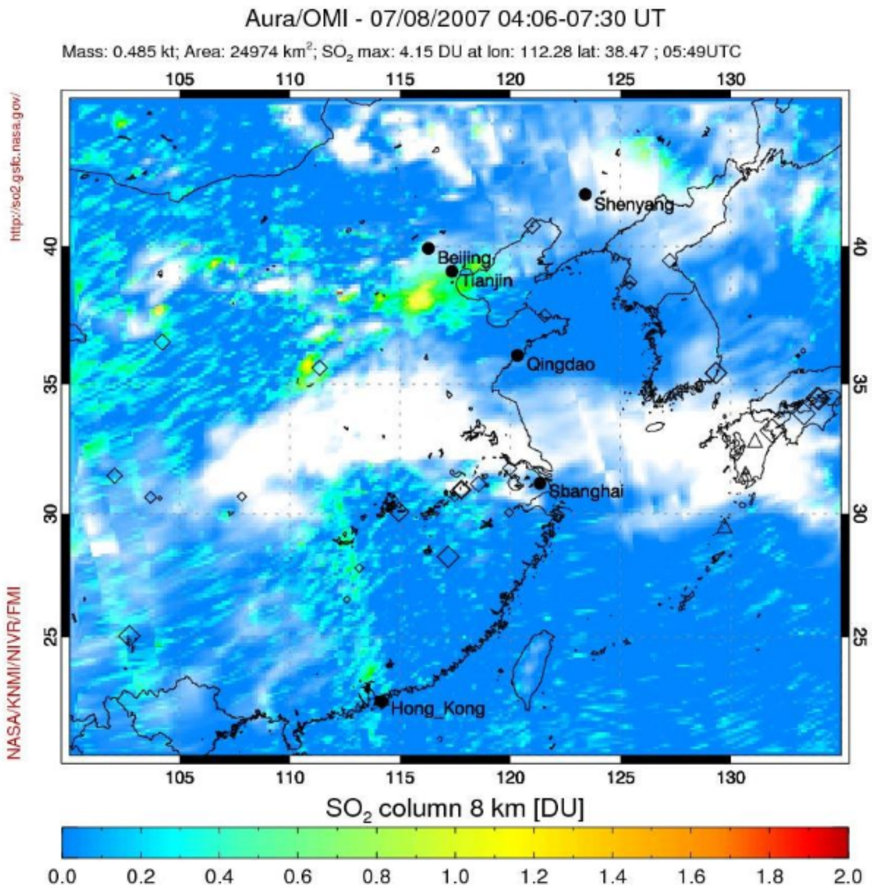


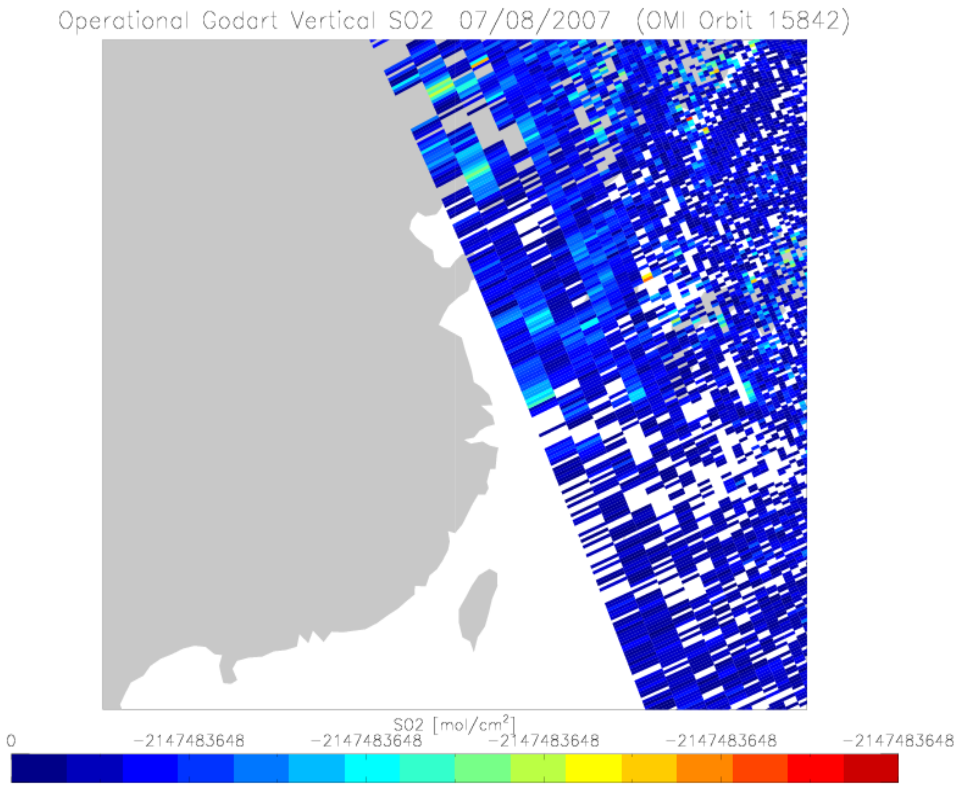
- The figures represent averaged re-grid HCHO VCD from OMI for a month (June,2006)
- OMI passes over East Asia at 13-14 LCT, and OMI HCHO products use AMF at 328 nm
- We calculate 328 nm AMF at 14 LCT to apply the AMFs to OMI
- Averaged relative differences over East Asia : 19 %

(R.J. Park)

SO_2 retrieval

- Retrieval test with OMI lv1B data





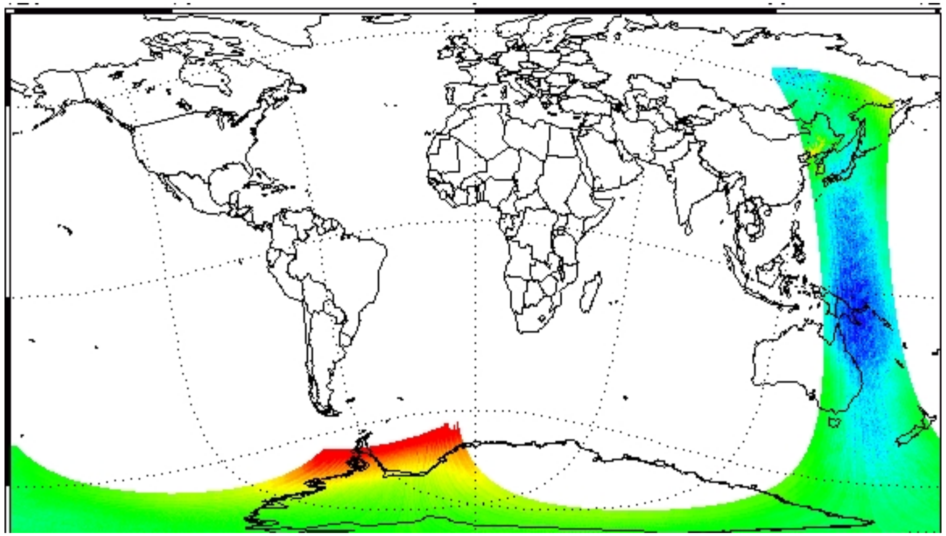
(http://so2.gsfc.nasa.gov/)

1 DU = 2.69×10^{16} molecules/cm^2 = 0.029 g/m^2

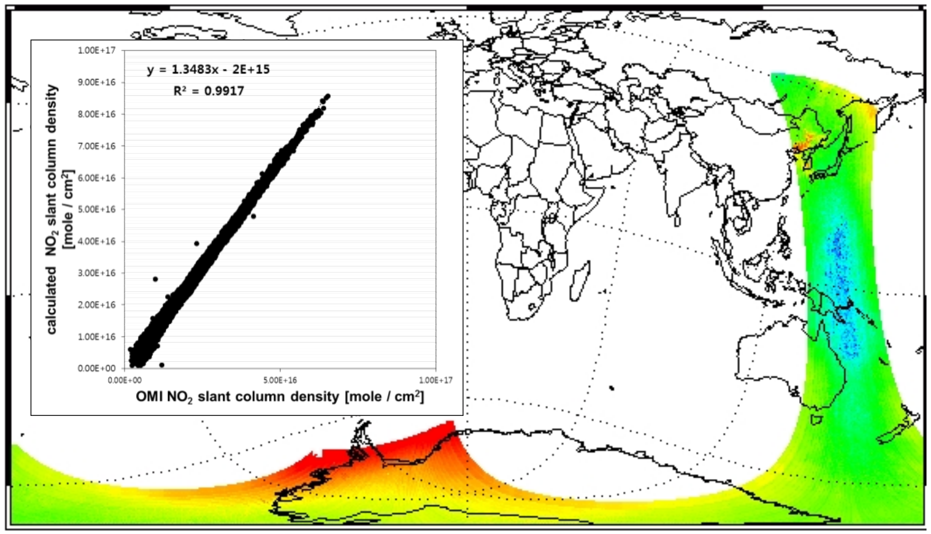
(Y.J. Kim)

NO_2 retrieval

OMI-DOAS NO2 slant column density (2008 -01-02)



DOAS algorithm slant column density (2008 -01-02)



Ring, O_3_228K, O_3_295K NO_2_294K, NO_2_231K, O_4_294K, H_2O_280K_HITRAN2008 (issues with sample "ring " calculation)

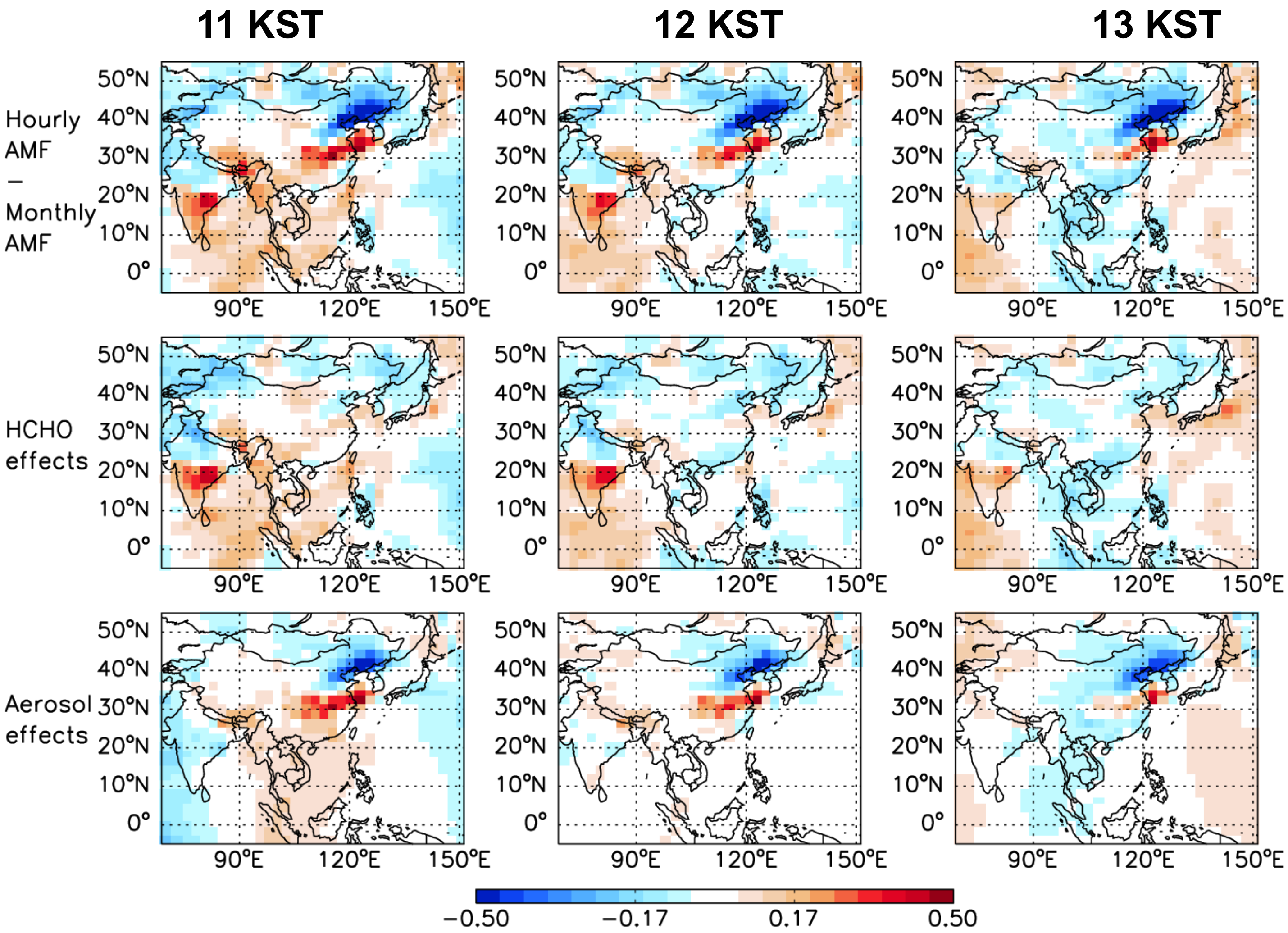
Fitting window : 390.0 nm ~ 475.0 nm

Background Radiance : clean area such as Pacific ocean

(H. Lee, Y.J. Kim)

Issues in Algorithm Development

- Effect of Hourly AMF variation to gas retrieval
- Aerosol shielding effect of Trace gas retrieval
- Radiometric polarization correction



(R.J. Park)

Summary

- GEMS is now in main phase, after PDR in 2014 and planned to be la unched in Dec., 2018.
- GEMS is expected to provide information on trace gas and aerosol wi th their precursors in high spatial and temporal resolution
  - O_3 NO_2 HCHO SO_2 AOD/AI/AEH, (possibly CHOCHO, BrO)
  - Clouds, surface reflectance, UV radiation.
- The predicted performance of trace gases from the initial design of G EMS satisfies the product accuracy requirements of NO_2, HCHO, O_3. Meanwhile, the estimated accuracy of SO_2 product seems to be quest ionable, and the performance near Korea is in danger. Thus the opera tion requires the increase of SNR by spatial coadding (lowering resolu tion), longer observation time, or reduced E-W scan range (or more fr equent operation).
- The data assimilation between CTM and GEMS data is important with the air quality forecast in operation.
- Collaboration with Team of TROPOMI, Sentinel-4 & TEMPO is desira ble in calibration, algorithm development and application.

Acknowledgement

GEMS Science Team

Ministry of Environment (MoE), Rep. of Korea
NIER, MoE
KEITI, MoE

Ministry of Science, ICT & future Planning (MSIP)
KARI