GESC
Global Environment
Satellite research Center

Status of GEMS Science

Jhoon Kim

P.I., GEMS
Yonsei University

GEMS Science Team

Changwoo Ahn
Jay Al-Saadi
P.K. Bhartia
Kevin Bowman
Greg Carmichael
Kelly Chance
Yunsoo Choi
Ron Cohen
Russ Dickerson
David Edwards
Annmarie Eldering
Ernest Hilsenrath
Daneil Jacob
Scott Janz
Thomas Kurosu
Qinbin Li

Xiong Liu
Randall Martin
Steve Massie
Jack McConnel*
Tom McElroy
Jessica Neu
Mike Newchurch
Stan Sander
Jochen Stutz
Omar Torres
Dong Wu
Liang Xu
Ping Yang
Dusanka Zupanski
Milija Zupanski

Heinrich Bovensmann
John Burrows
Joerg Langen
Pieternel Levelt
Ulrich Platt
Piet Stamnes
Pepijn Veefkind
Ben Veihelmann
Thomas Wagner

Myung Hwan Ahn
Yong Sang Choi
Myeongjae Jeong
Jae Hwan Kim
Young Joon Kim
Hanlim Lee
Kwang Mog Lee
Rokjin Park
Seon Ki Park
Chul Han Song
Jung Hun Woo
Jung-Moon Yoo

Seung Hoon Lee
Sang Soon Yong
D.G. Lee
J.P Gong
Dai Ho Ko
S.H. Kim
J.H. Yeon
Y.C. Youk
...

Jin Seok Han
Chang Keun Song
Sang Deog Lee

M.H. Lee
H.W. Seo

Sukjo Lee
Youdeog Hong
J.S. Kim

Hajime Akimoto
Sachiko Hayashida
Hitoshi Irie
Yasko Kasai
Kawakami Shuji

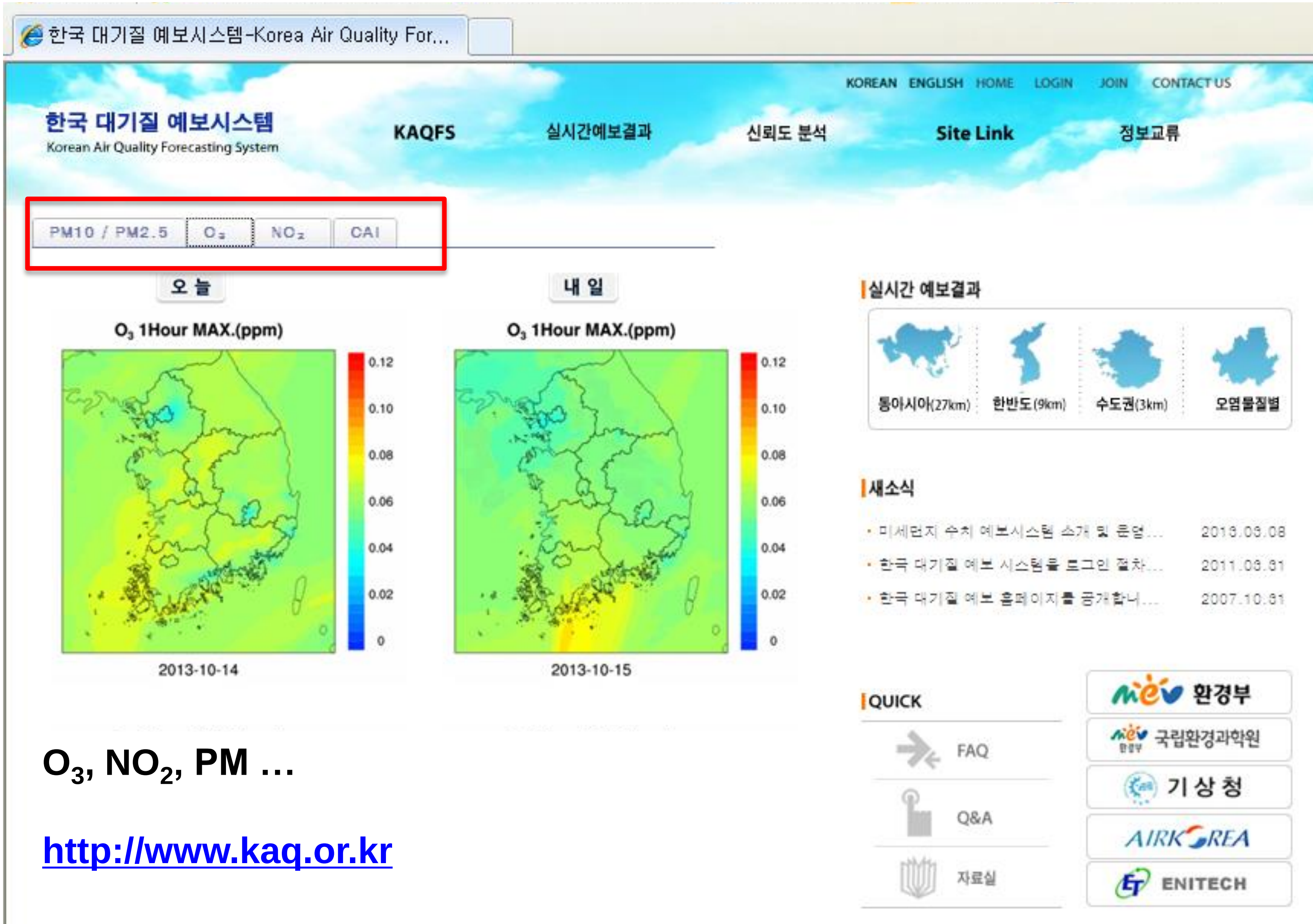
Charles Wong

Sangseo Park, Mijin Kim, Ukkyo Jeong, M.J. Choi; Ju Seon Bak, Kanghyun Baek;
Hyeong-Ahn Kwon, H.J. Cho; K.M. Han, Jihyo Chong, Kwanchul Kim; J.H. Park, Y.J. Lee;
Bo-Ram Kim, M.A. Kang J.H. Yang, Sujeong Lim, S.W. Jeong ;

Outline

- GEMS Program
  - Status
  - Baseline Products
  - Specification
- Issues
  - Nominal radiance vs. SNR
  - RTS
- Summary

Air Quality Forecast in Operation



O_3, NO_2, PM …

http://www.kaq.or.kr

Status of GEMS Mission

- **Budget**
  - Budget request proposal was approved on Dec. 2010 by the Government Budget Review Committee led by the Ministry of Planning and Finance
  - Three criteria in Gov. Budget Rev. Comm.:
    - ✓ Demand from the relevant Ministry: strong demand under Climate Change Monitoring & Adaptation Program of MoE.
    - ✓ Maturity of technology: TRL ≥ 6 with OMI heritage in LEO

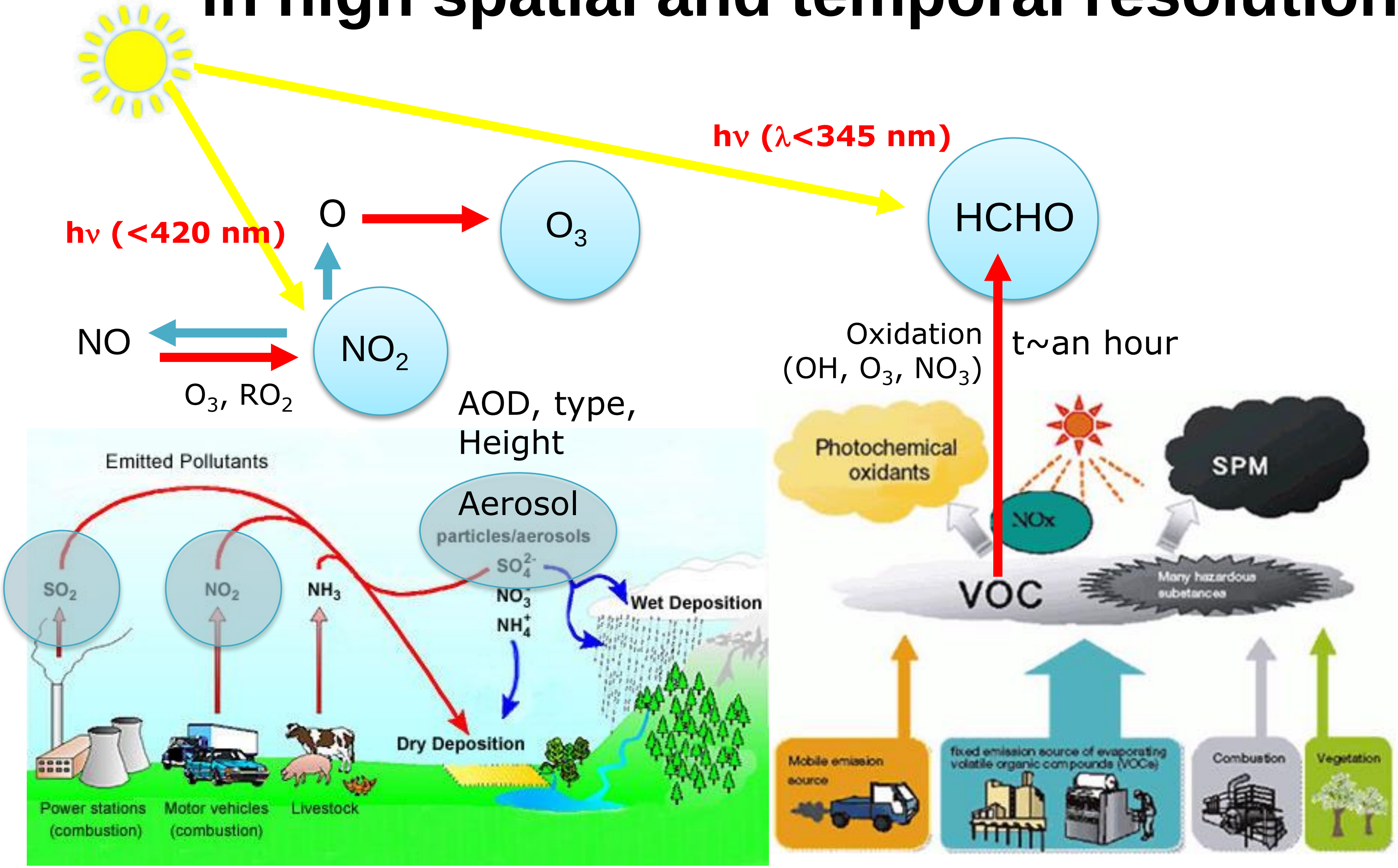
      * Governmental Technical Review is still remained before PDR (Q1 2014)
    - ✓ Social Benefit of the Mission: B/C ratio = 1.8 (CVM, ABM, COS; benefit for public and industry)

- **Prime Contractor**
  - Selection of main contractor for the Joint Development with KARI on May 13th , 2013 (International Contractor: Ball Aerospace & Technologies Corp.)

- **Changes in Environment**
  - **Domestic**
    - GEMS, included as one of the 140 New National Agenda(2013)
    - Air quality forecast in operation since 2013 by NIER (data assimilation of model with sat. data)
  - **International**
    - Increased attention on SLCF

- **International Collaboration**
  - Recognized as a part of Geostationary AQ Constellation by CEOS ACC
  - ToR for NASA-NIER/ME collaboration endorsed by NASA HQ and NIER/ME
  - Bilateral agreement between Korea MEST and U.S. NASA
  - MOU between KARI and NSO
  - MOU with NCAR(2010), Harvard CfA (2011), UCLA(2012); Agreement with NASA(2011)

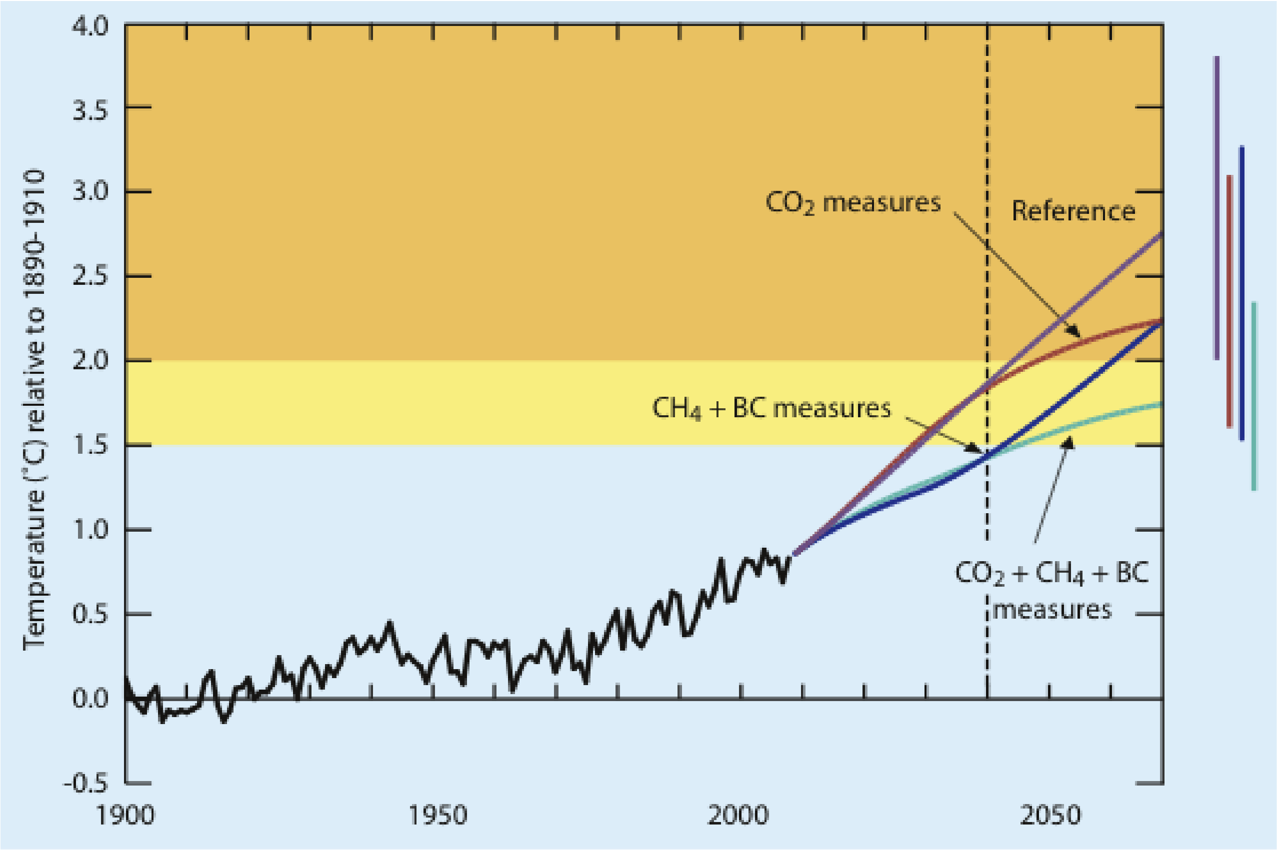
GEMS: Measurements of ozone & aerosol with their precursors in high spatial and temporal resolution



Improving Air Quality and Limiting Short-Term Climate Changes

RIO+20 UN Conference on Sustainable Development (UNCSD) 20-22 June, 2012

Achim Steiner,
UNEP Executive Director

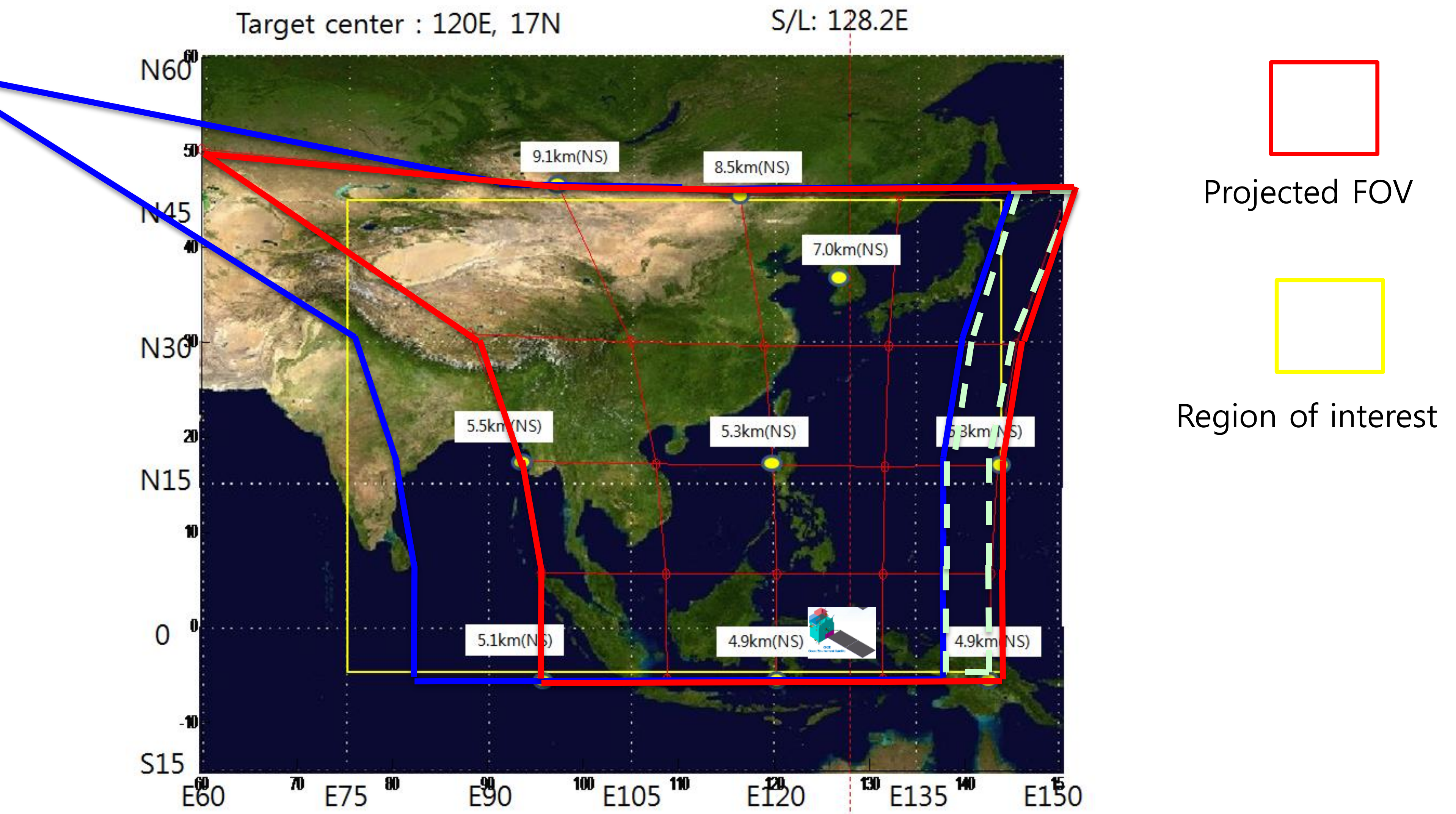


"Need action on SLCFs, black carbon, tropospheric ozone, and methane… "

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	3×10^{13}	1×10^{17}	1×10^{14}	1×10^{15}	425-450	56	< 70	BOAS / DOAS
SO_2	Aerosol precursor	6×10^{8}	1×10^{17}	6×10^{14}	1×10^{16}	310-330	56 x 4 pixels	< 50 (60*)	
HCHO	Proxy for VOCs	1×10^{15}	3×10^{16}	3×10^{15}	1×10^{16}	327-357	56 x 4 pixels	< 50 (60*)	
O_3	Oxidant, pollutant	4×10^{17}	2×10^{18}	1×10^{18}	3%(TOz) 5%(Strat) 20%(Trop)	300-340	56	< 70	TOMS, OE
AOD (AI, SSA, AOCH)	Air quality, Climate	0 (AOD)	5 (AOD)	0.2 (AOD)	20% or 0.1@ 400nm	300-500	56	< 70	Multi-spectral O_2-O_2
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

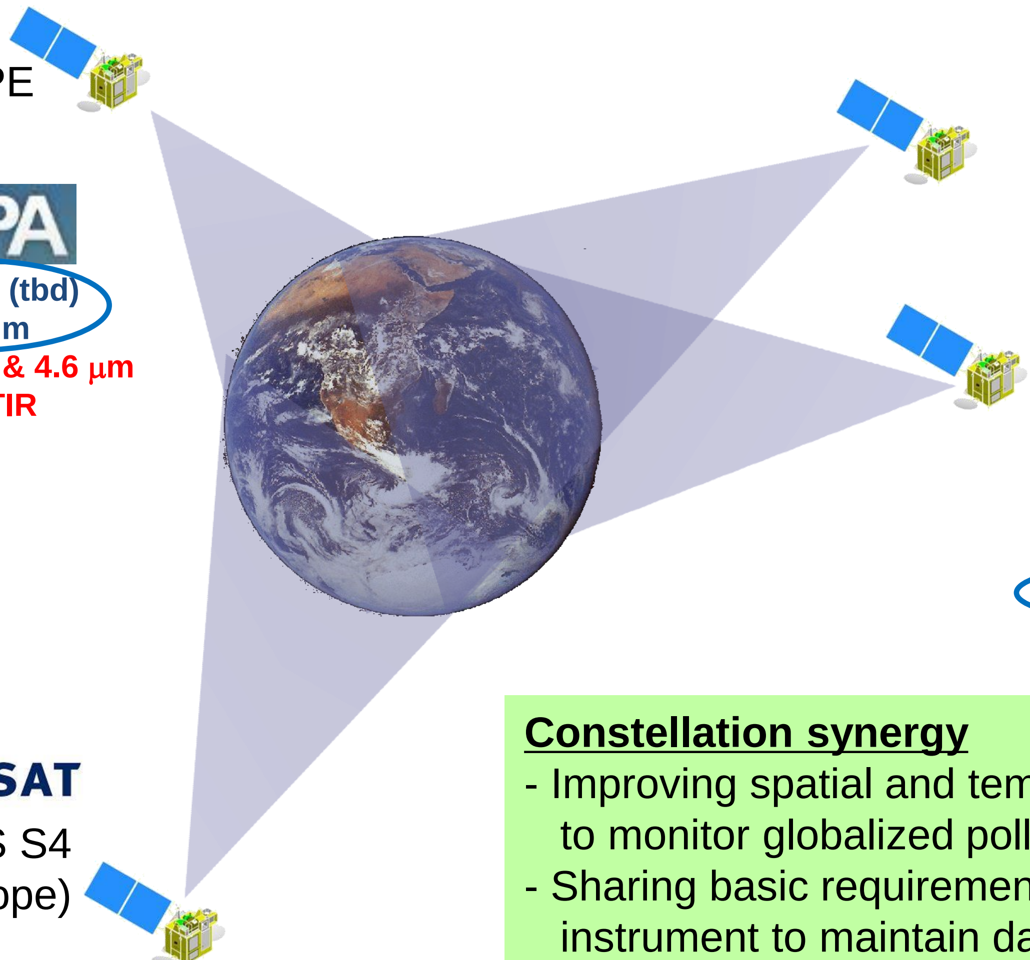
Projected FOV & GSD - NS GSD @ Seoul : 7.0km



Normal operation **For clear sector method**

CEOS (Committee on Earth Observation Satellites)
ACC (Atmospheric Composition Constellation)

Constellation of GEO Missions to study Air Quality and Clim



TEMPO / GEO-CAPE (America)

UV-Vis-IR (tbd) 300-500 nm
SWIR 2.3 & 4.6 μm
Vis &/or TIR

GMAP-Asia (Asia-Pacific)

GEMS
GEO KOMPSAT
(Asia)

UV-Vis 300-500 nm
Optional accommodation for small IR instrument

GMES S4
MTG (Europe)

UV-Vis-NIR
305-500, 750-775 nm
Use MTG-S TIR

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

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	20 N – 60 N 30 W – 150 W
Obs. time	30 min	[1 hour]	1 hour
Detector @ T	CCD @ 278 K	[CCD @ ~255 K]	CCD @ 230 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)	110	[100]	150
Power (W)	200 (on orbit) / 100 (transfer)	[100]	180
Data rate (Mbps)	20 (up to 40)	[9]	25 Mbps

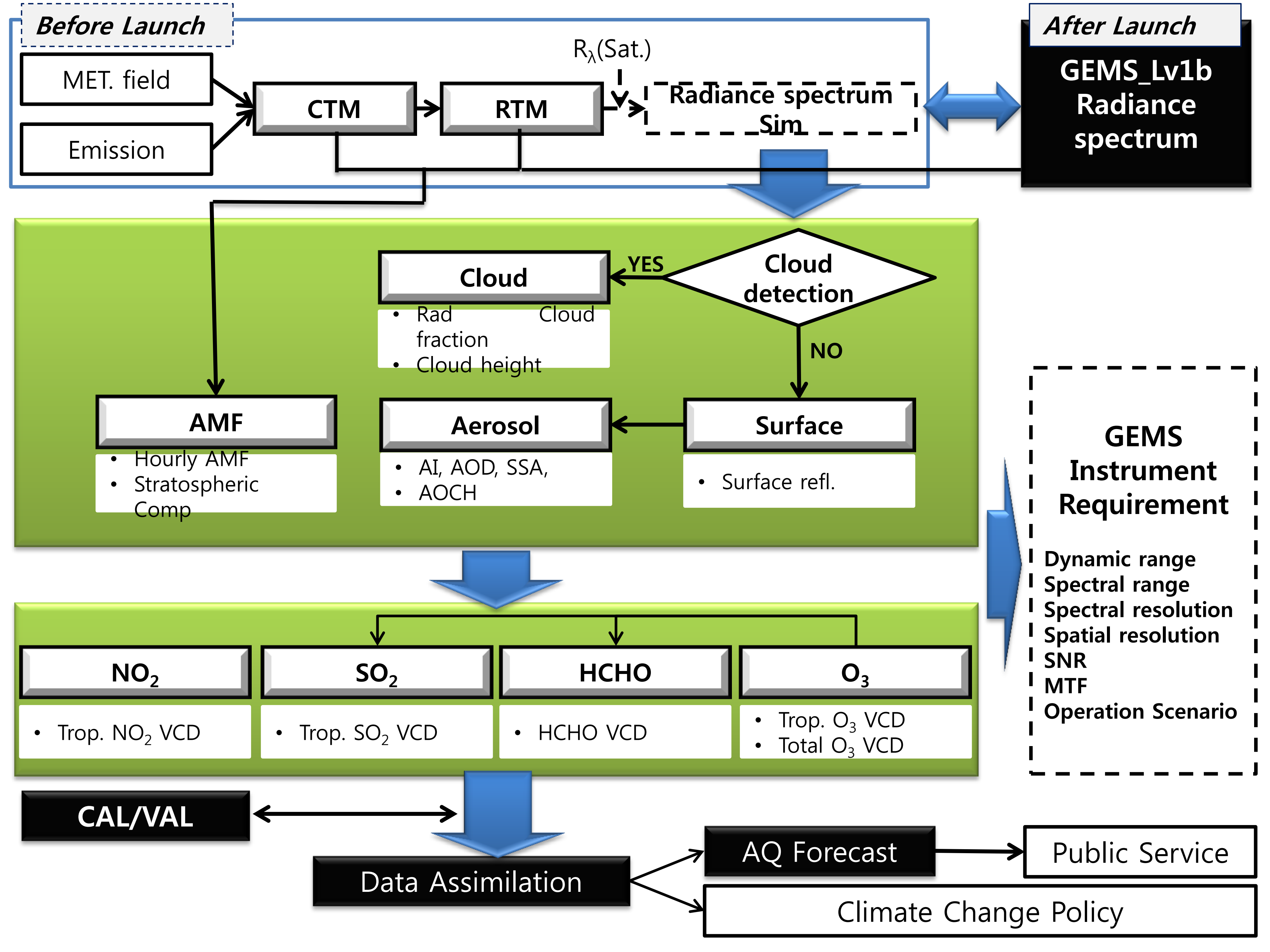
SNR & Nominal Radiance [$Wm^{-2}sr^{-1}\mu m^{-1}$]	GEMS Wave-length	GEMS Nominal radiance Goal	GEMS Nominal radiance Threshold	GEMS SNR @ λ [nm]	GEOCAPE [TEMPO] Wave-length	GEOCAPE [TEMPO] Nominal radiance	GEOCAPE [TEMPO] SNR	Sentinel-4 Wave-length	Sentinel-4 Nominal radiance	Sentinel-4 SNR
	300-315	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

Comparison of Baseline Products

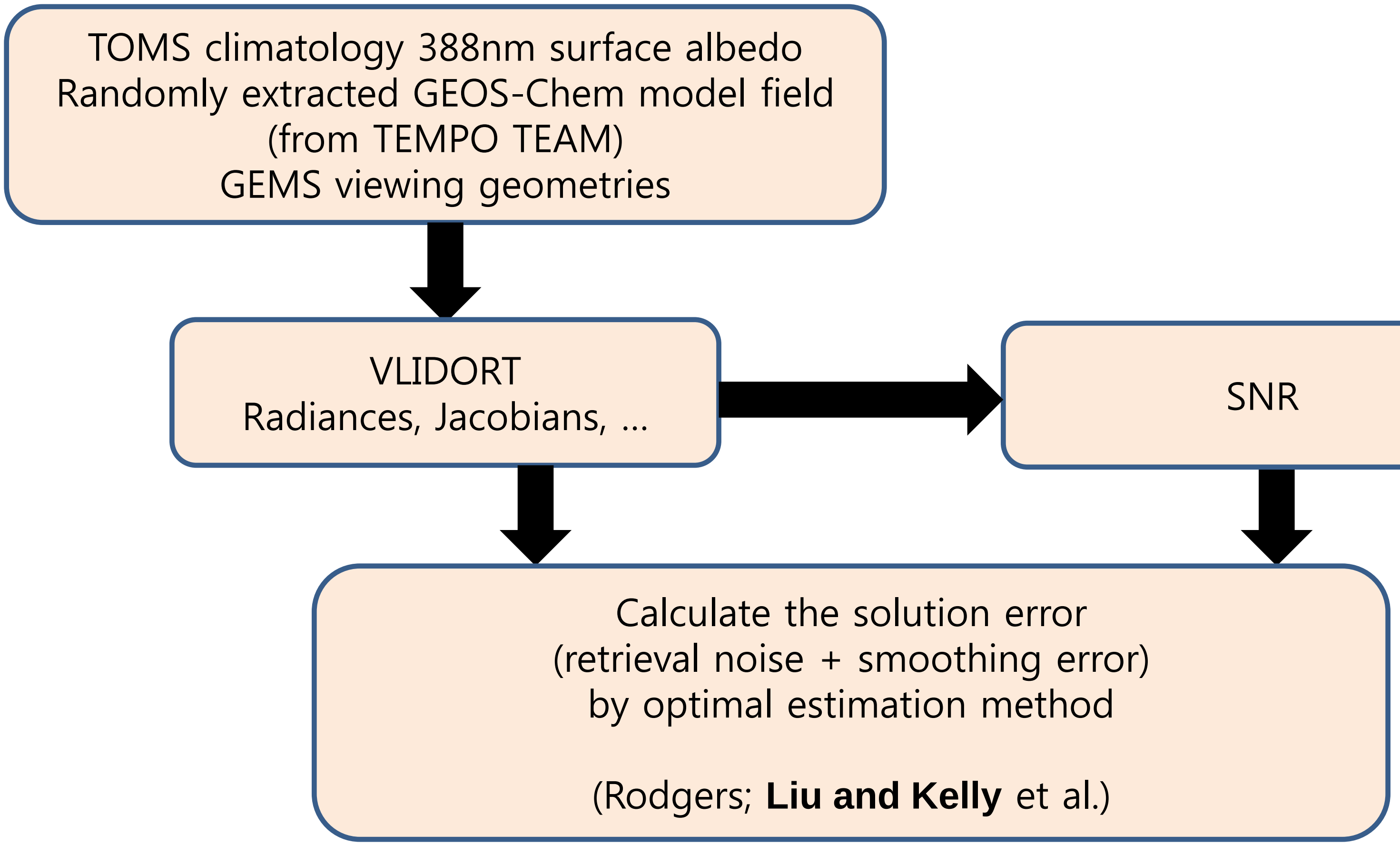
	GEMS	GEOCAPE [TEMPO]	Sentinel-4
Operation	2018-2027	2019-2021	2019-2028
Products	O_3, NO_2, O_4, SO_2, HCHO, AI, AOD, SSA, Cloud	O_3,(UV, Vis), NO_2, SO_2, H_2CO, $H_2C_2O_2$, AOD, AI, Cloud	O_3, SO_2, (*BrO*), HCHO, Ring, NO_2, O_4, (*IO CHOCHO*), AAI, AOD, Cloud

		Typical range	Precision	Typical value	Precision	Typical value	Precision
O_3	**0-2 km**	4×10^{17} ~ 2×10^{18} cm^{-2}	20 %	40 ppb	10%		10-25%
	Free Troposp			50 ppb	10%		
	Strato-sphere	230-360 DU	5 %	8×10^3	5%		
	Total	250-400 DU	3 %	9×10^3	3%		
NO_2		3×10^{13} ~ $3\times 10^{17} cm^{-2}$	1×10^{15} cm^{-2}	6	1.00		15-25%
SO_2		6×10^{8} ~ 1×10^{17} cm^{-2}	1×10^{16} cm^{-2}	10	10.0		20-50%
HCHO		1×10^{15}~ 3×10^{16} cm^{-2}	1×10^{16} cm^{-2}	10	10.0		20-50%
AOD		0.2	0.1	0.1-1	0.05		
AAOD				0-0.05	0.03		
AI		-1 ~ +5	0.2	-1 - +5	0.2		
Cloud Fraction		0 ~ 1	0.05	0-1	0.05		
Cloud Top Height		200-900 hPa		200-900 hPa	100 hPa		
CHOCHO				0.2	0.4		
BrO							
Ref.				Kelly Chance		Ben Veihelmann, Cathy Clerbaux	



Before Launch
MET. field
Emission
CTM
RTM
Rλ(Sat.)
Radiance spectrum Sim
After Launch
GEMS_Lv1b Radiance spectrum
Cloud
• Rad Cloud fraction
• Cloud height
YES
Cloud detection
NO
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
NO2
• Trop. NO2 VCD
SO2
• Trop. SO2 VCD
HCHO
• HCHO VCD
O3
• Trop. O3 VCD
• Total O3 VCD
CAL/VAL
Data Assimilation
AQ Forecast
Public Service
Climate Change Policy

Error analysis using the optimal estimation method



Calculation domain & conditions

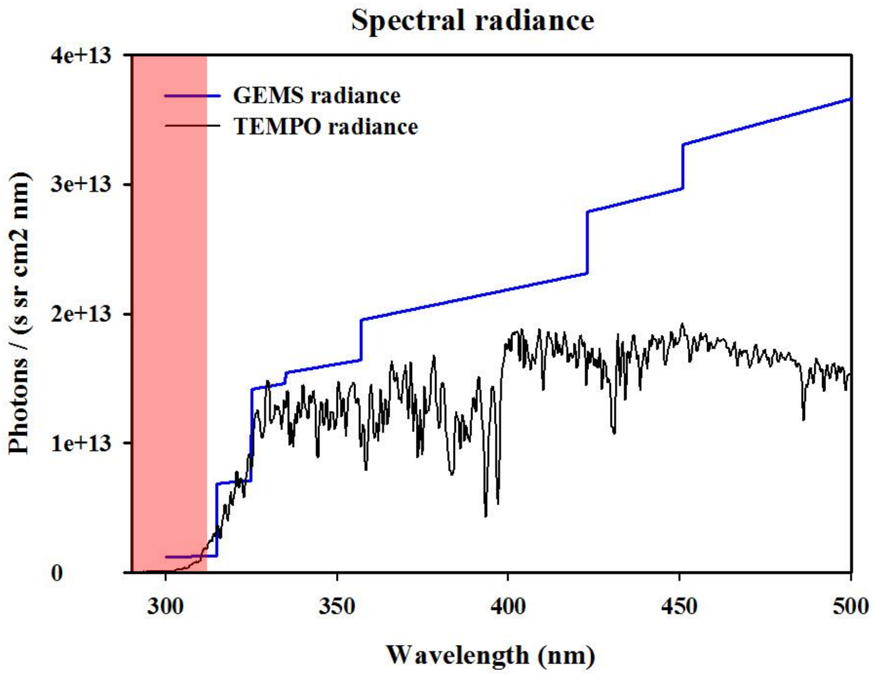
Temporal domain
0 – 7 UTC (every hours) X 12 month

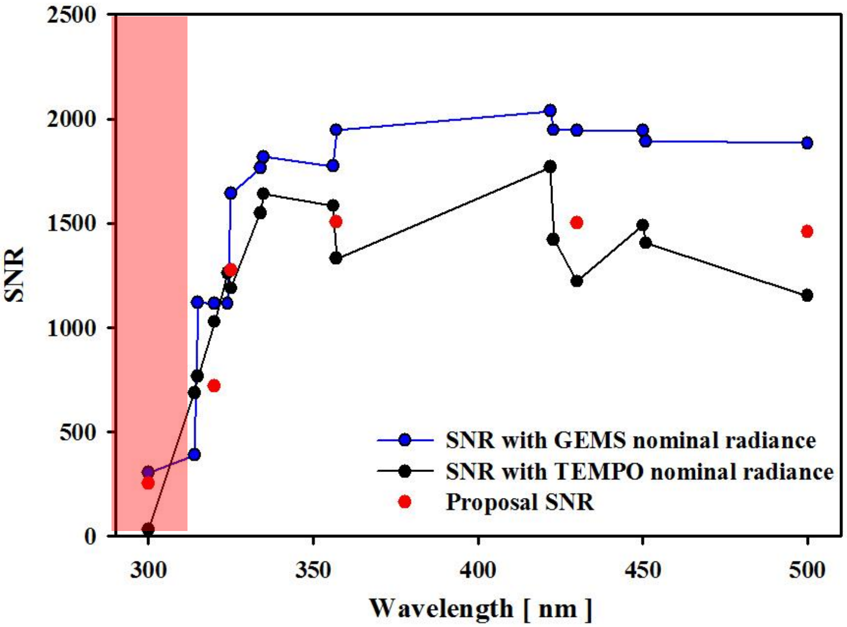
Spatial domain
75 – 145 longitude X 5 – 45 latitude (2 degree resol.)
→ ~ 70,000 runs

Atmosphere profiles
Randomly extracted GEOS-chem US atmosphere (~70,000 profiles)
6 gases (O_3, NO_2, H_2CO, SO_2, $C_2H_2O_2$, H_2O), BrO, OClO, O_4
Actual viewing geometry for a geostationary satellite at 128.2° E
No aerosol and cloud (under consideration)

RTM calculation and sensitivity calculation
300-500 nm at 0.6 nm FWHM, every 0.2 nm
GEMS SNR
Climatology surface reflectance from TOMS at 388nm

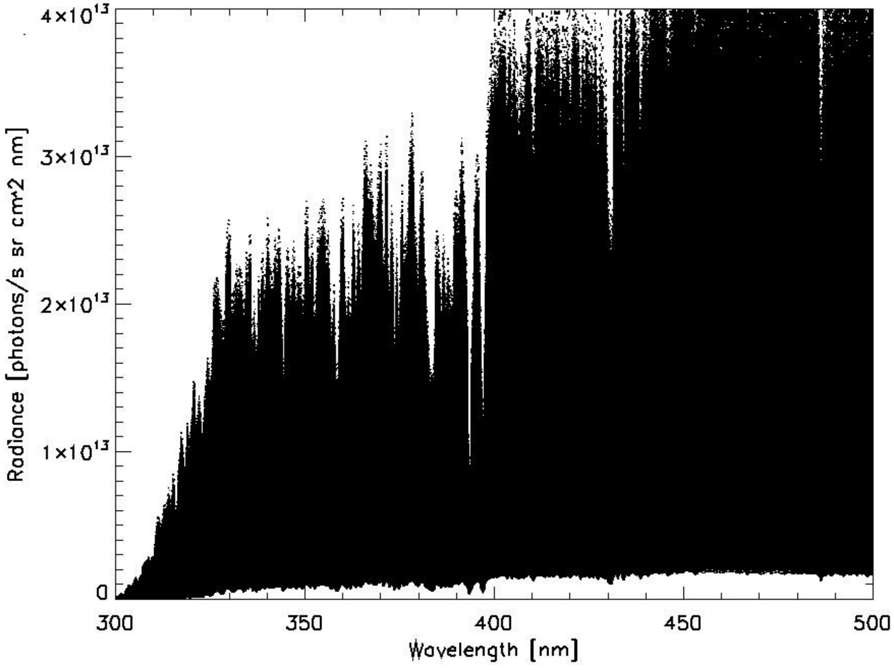
Nominal radiance and SNR

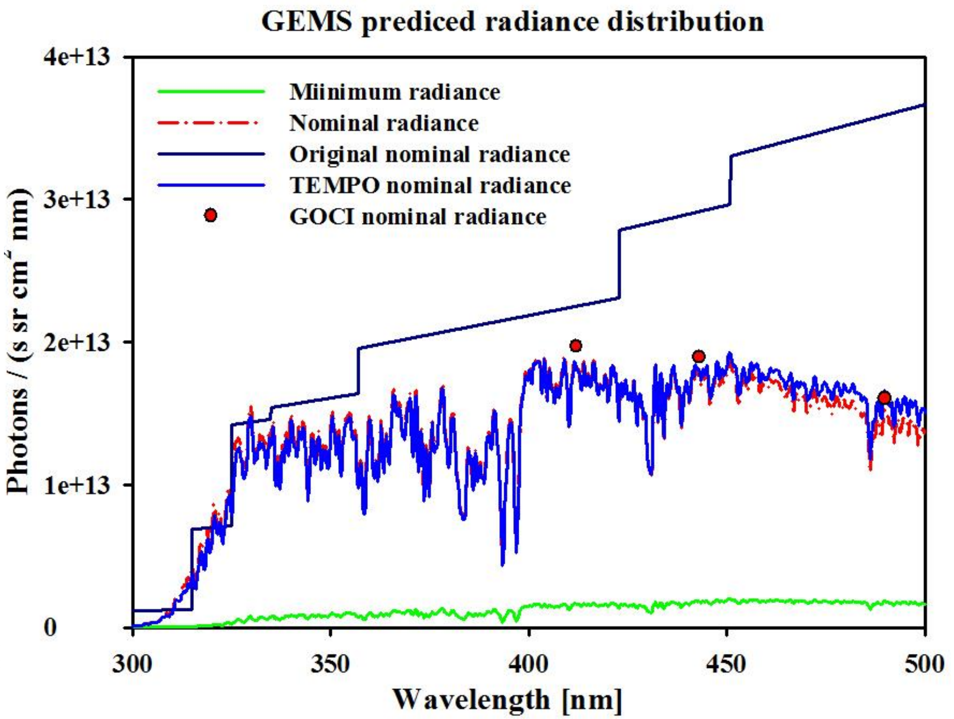




- Overestimation of nominal radiance → decrease of SNR
- Near 300 nm → Important for ozone retrieval (wavelength coverage extension issue)

Nominal radiance issue

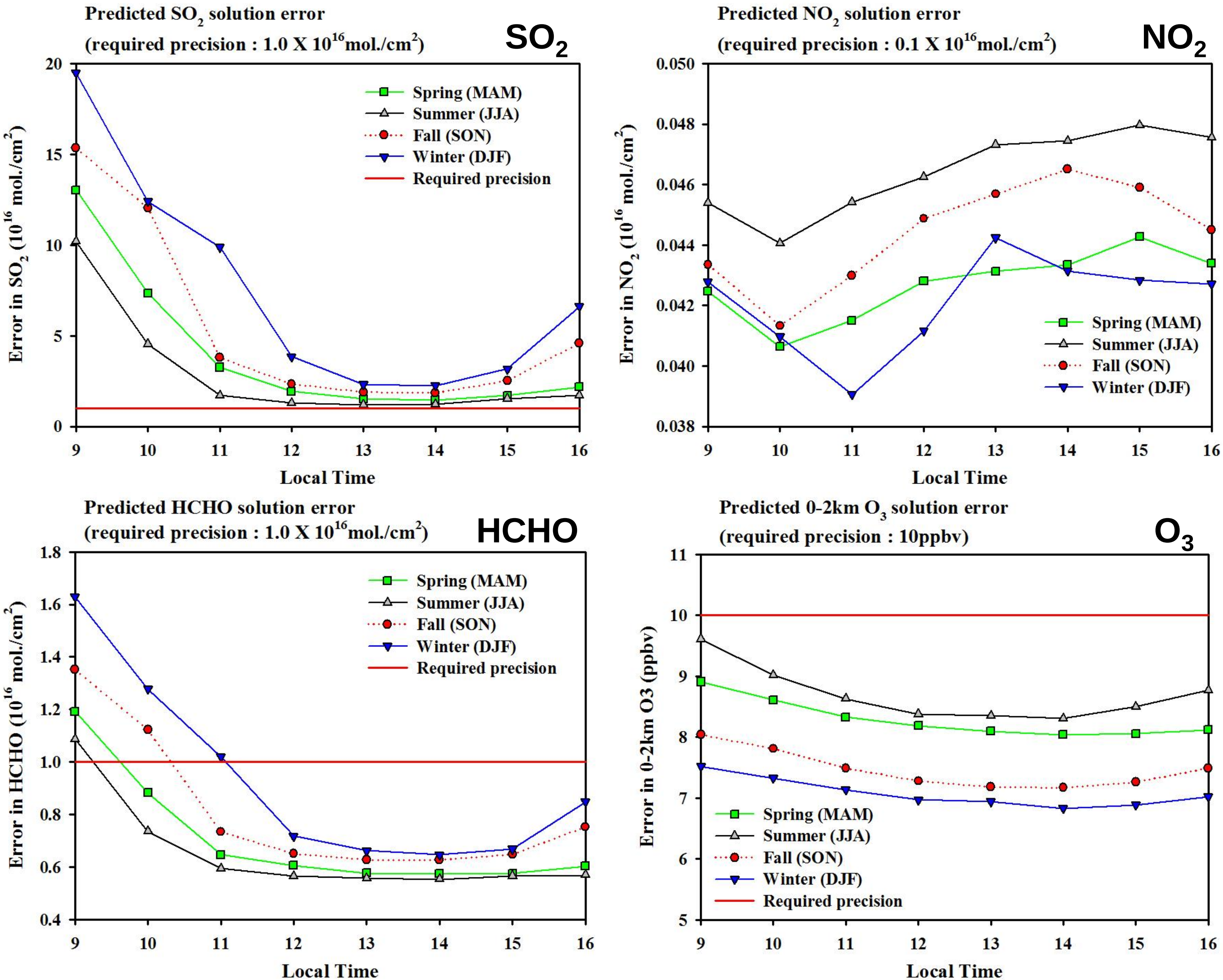




- No aerosols or clouds
- GEMS surface reflectance and viewing geometry
- Randomly extracted GEOCAPE CTM results (~70,000 simulations)
- Scalar calculation
- GOCI most probable measured radiance (all pixels including cloud)

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

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


Predicted SO2 solution error
(required precision : 1.0 X 10^16 mol./cm^2)
SO2
Spring (MAM)
Summer (JJA)
Fall (SON)
Winter (DJF)
Required precision
Error in SO2 (10^16 mol./cm^2)
Local Time
Predicted NO2 solution error
(required precision : 0.1 X 10^16 mol./cm^2)
NO2
Spring (MAM)
Summer (JJA)
Fall (SON)
Winter (DJF)
Error in NO2 (10^16 mol./cm^2)
Local Time
Predicted HCHO solution error
(required precision : 1.0 X 10^16 mol./cm^2)
HCHO
Spring (MAM)
Summer (JJA)
Fall (SON)
Winter (DJF)
Required precision
Error in HCHO (10^16 mol./cm^2)
Local Time
Predicted 0-2km O3 solution error
(required precision : 10ppbv)
O3
Spring (MAM)
Summer (JJA)
Fall (SON)
Winter (DJF)
Required precision
Error in 0-2km O3 (ppbv)
Local Time

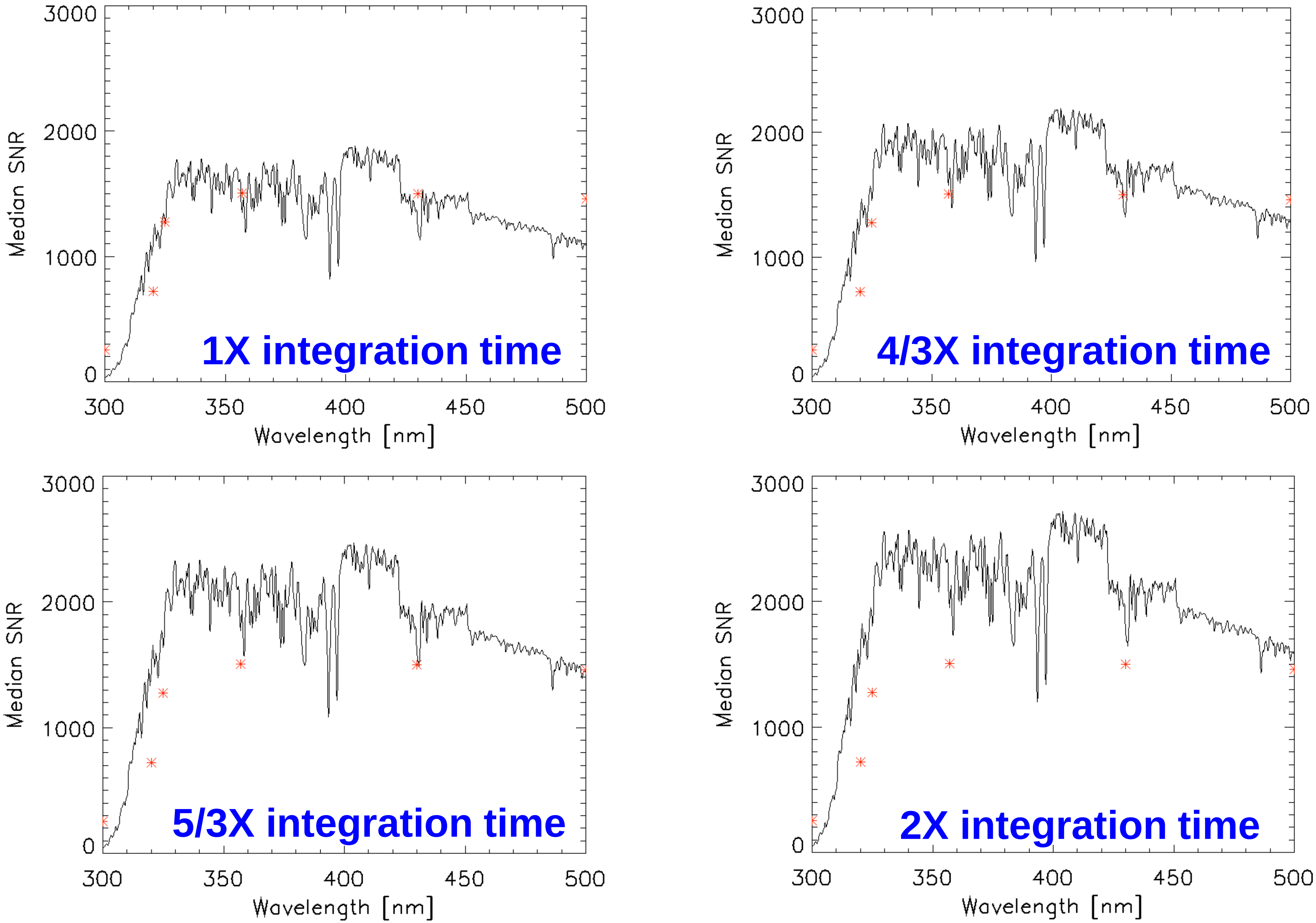
Predicted trace gas retrieval performance of GEMS (w/o cloud & aerosol)

Species	Required Precision	Meet Reqs (%)
O_3	10 ppbv	86.0 % (300-500 nm)
		86.6 % (290-500 nm)
NO_2	$1x10^{14}$	99.8 %
SO_2	$6x10^{14}$	30.8 %
HCHO	$3x10^{15}$	99.8 %

Solution:

- ✓ Coadd spatial pixels (2, 4,…), but only possible in N-S direction
- ✓ Increase integration time by
  - securing longer observation time than 30 minutes
  - reducing E-W scan range

Predicted SNR @ nominal radiance with different integration time



Issues: 1) signal saturation, 2) pointing stability

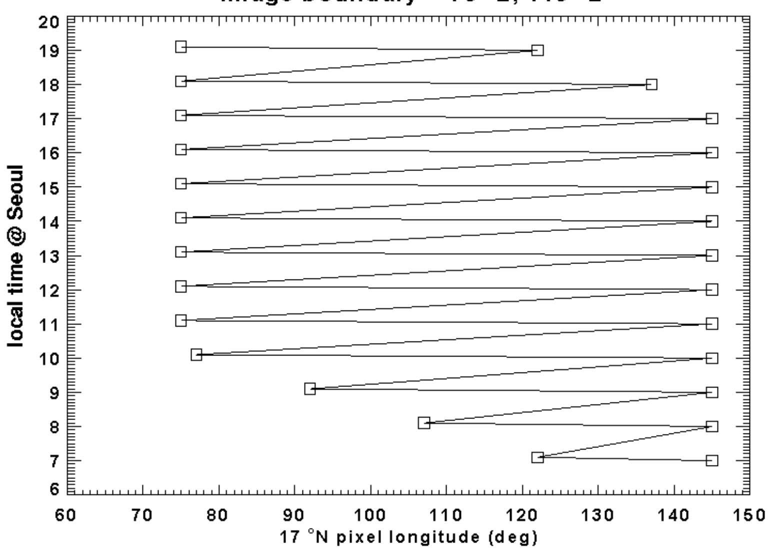
Fraction of predicted SNRs larger than requirements at original nominal radiance of each wavelength bin

Wavelength	SNR Proposed @ original nominal radiance	SNR with median radiance of GEMS / Proposed SNR (%)			
		1x integration time	4/3x integration time	5/3x integration time	2x integration time
300 nm	252	14.6 %	17.4 %	19.8 %	22.0 %
320 nm	720	152.5 %	178.2 %	200.8 %	221.3 %
325 nm	1273	97.8 %	114.2 %	128.7 %	141.7 %
357 nm	1504	89.6 %	104.6 %	117.8 %	129.7 %
430 nm	1500	81.2 %	94.8 %	106.8 %	117.7 %
500 nm	1459	74.4 %	87.0 %	98.1 %	108.1 %

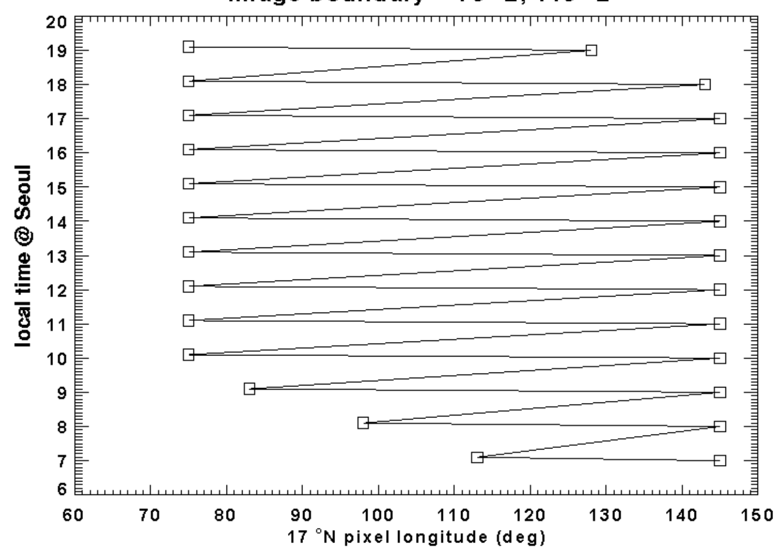
w.r.t GEMS Nominal Radiance

w.r.t New GEMS Nominal Radiance

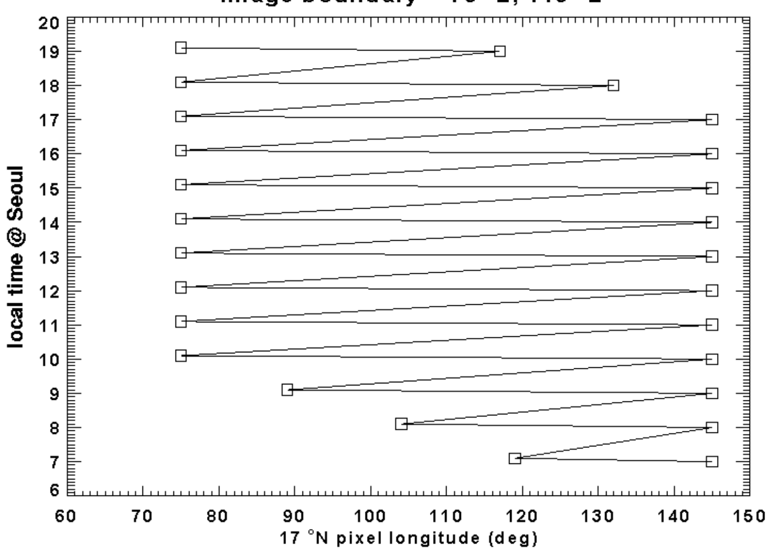
Spring



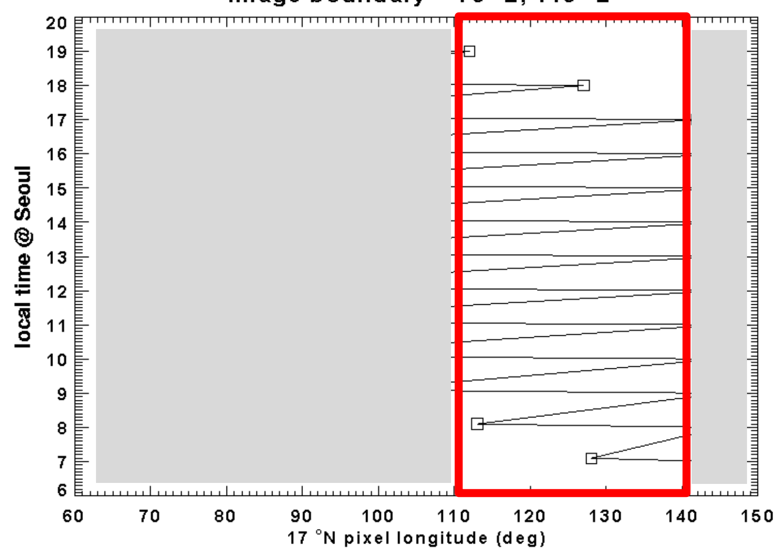
Summer



Autumn



Winter



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

Lessons from OMI

OMI Radiation Test

• Large increase in dark current.
• More ~40% of the pixels showed increased noise (RTS) by more tha
n a factor of 2.
• Estimated decrease in CTE of 4%
.

Measures

• Decrease the detector temperature from +5C to -8C.
• Add 10 kg of shielding around the detectors.(29 mm Al shielding)
• Frequent dark current map updates
.
• RTS detection and flagging algorith
ms.

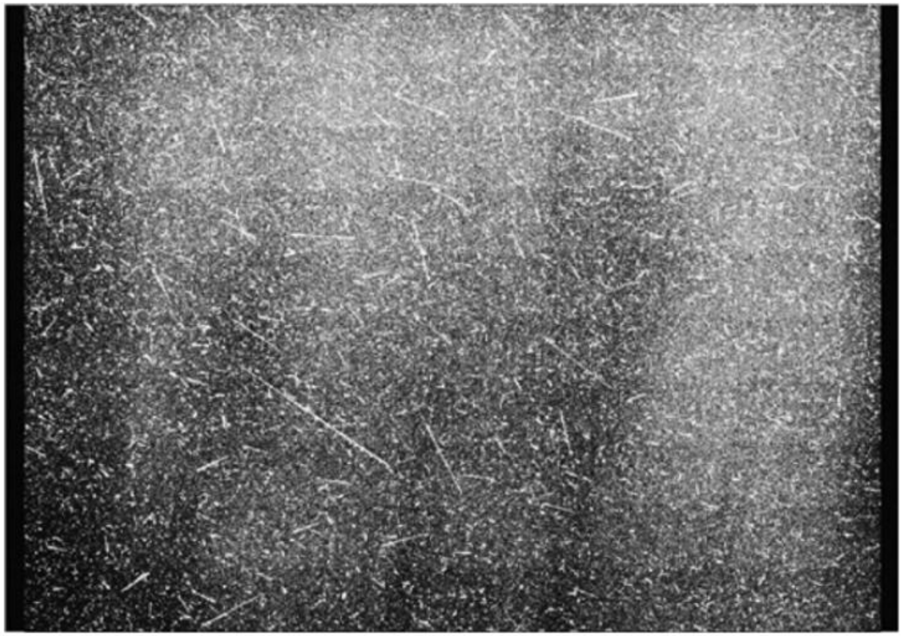


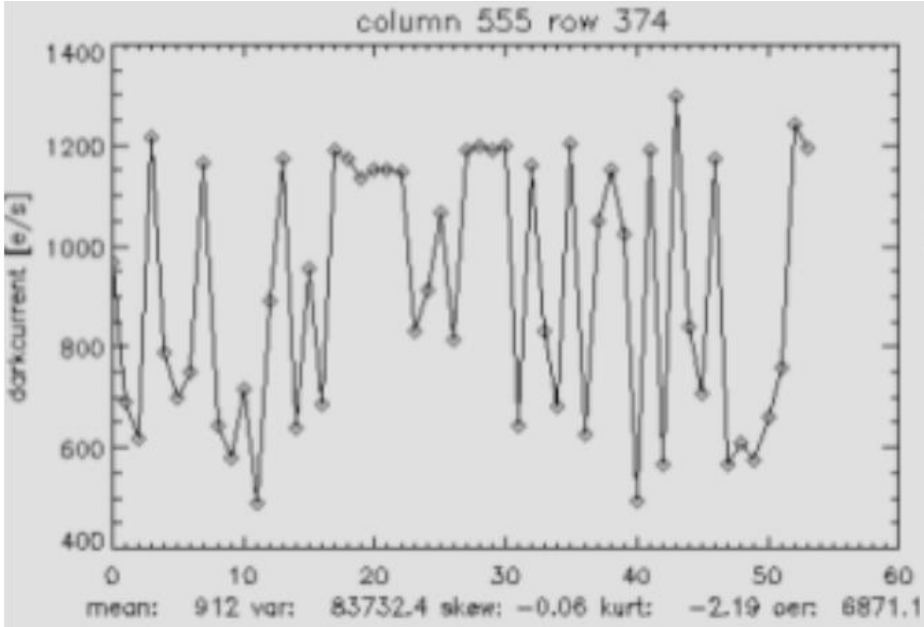
Fig. 43. Dark signal measurement with exposure time 136 s and gain factor 40 in SAA. The increased number of random hits and trails of particles can be observed.

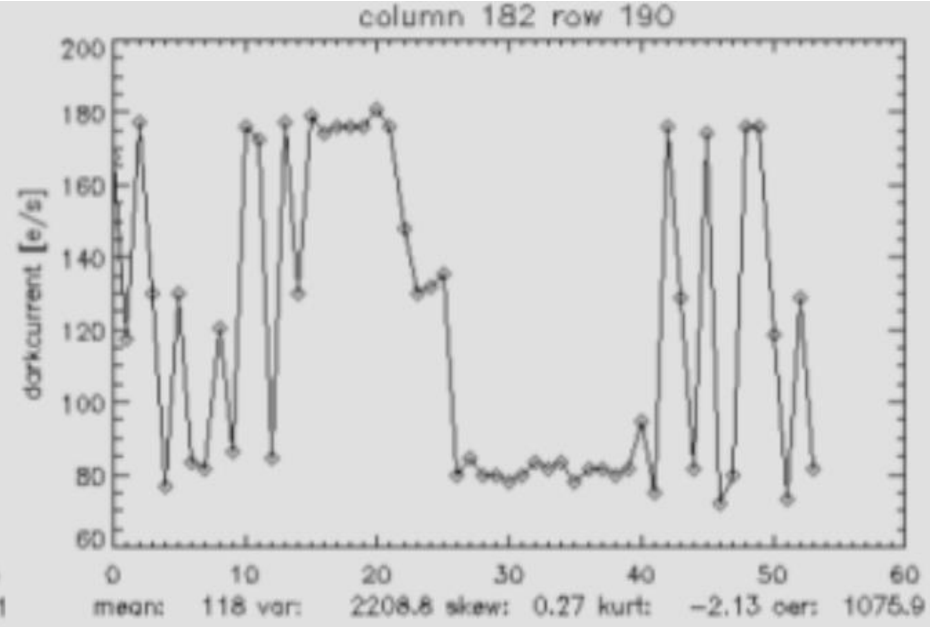
Veefkind and Levelt (2011)

Dobber et al.(IEEE TGRS, 2
006)

Random Telegraph Signals (RTS)

- Randomly changing dark current
- Time scale : seconds ~ week





status sep 2010	tropical			midlatitude			arctic		
	UV1	UV2	VIS	UV1	UV2	VIS	UV1	UV2	VIS
bad	4%	3%	4%	12%	3%	4%	15%	3%	4%
RTS	4%	5%	4%	4%	5%	4%	4%	5%	4%

Veefkind and Levelt (2011)

Data Quality Harmonization with GEO Constellation

- CEOS ACC
  - Harmonizing data quality
    - Sharing basic requirements
    - Comparing algorithm performance
    - Common algorithm standard
  - Cross participating science & review meetings

- Calibration
  - Preflight cal
  - Postflight ground-based Cal/Val
    - Pandora, SAOZ …
    - NDACC activities

Summary

- GEMS is expected to provide information on trace gas and aerosol with their precursors in high spatial and temporal resolution
  - O_3 NO_2 HCHO SO_2 AOD (possibly CO, CH4, and CO2 ?)
  - Clouds, surface reflectance, UV radiation.
- The predicted performance of trace gases from the initial design of GEMS satisfies the product accuracy requirements of NO_2, HCHO, O_3. Meanwhile, the estimated accuracy of SO_2 product seems to be questionable, thus requires the increase of SNR. Revisiting nominal radiance issue, together with the consideration of spatial coadding (lowering resolution), longer observation time, or more frequent operation (or reduced E-W scan range) needs to be taken.
- To avoid the RTS, it is required to lower the detector temperature with appropriate shield.
- Effects of aerosols and clouds on the trace gas retrieval performance should be examined in more detail with realistic data within the GEMS domain.
- The data assimilation between CTM and GEMS data is important with the air quality forecast in operation.

Acknowledgement

GEMS Science Team

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

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