Development of NO_2 and SO_2 retrieval algorithm for GEMS

Young J. Kim and Jihyo Chong

Advanced Environmental Monitoring Research Center (ADEMRC)
School of Environmental Science and Engineering
Gwangju Institute of Science and Technology(GIST), Gwangju, Korea

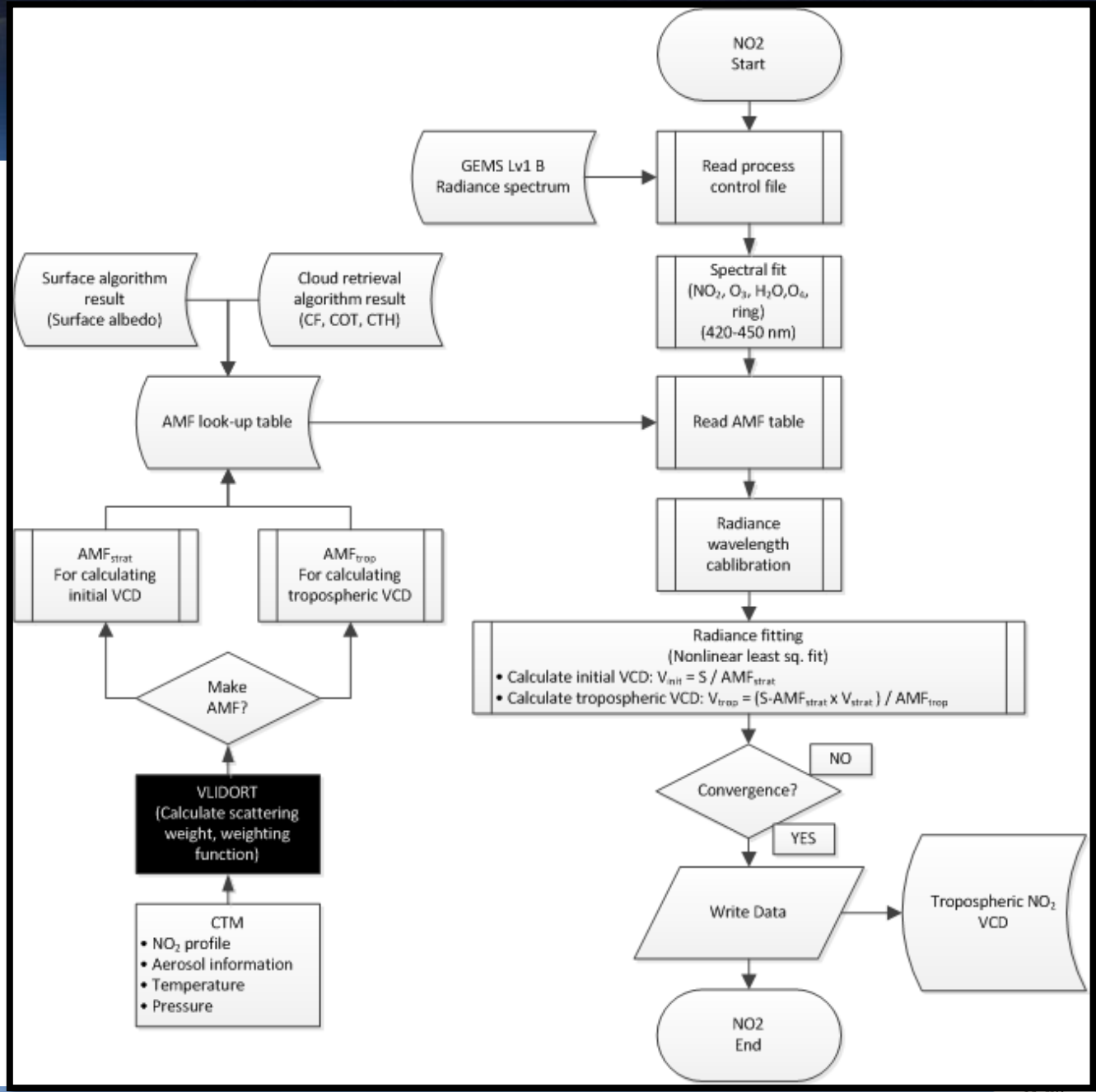
October 14-17, 2013

Hotel Seokyo, Seoul, Korea

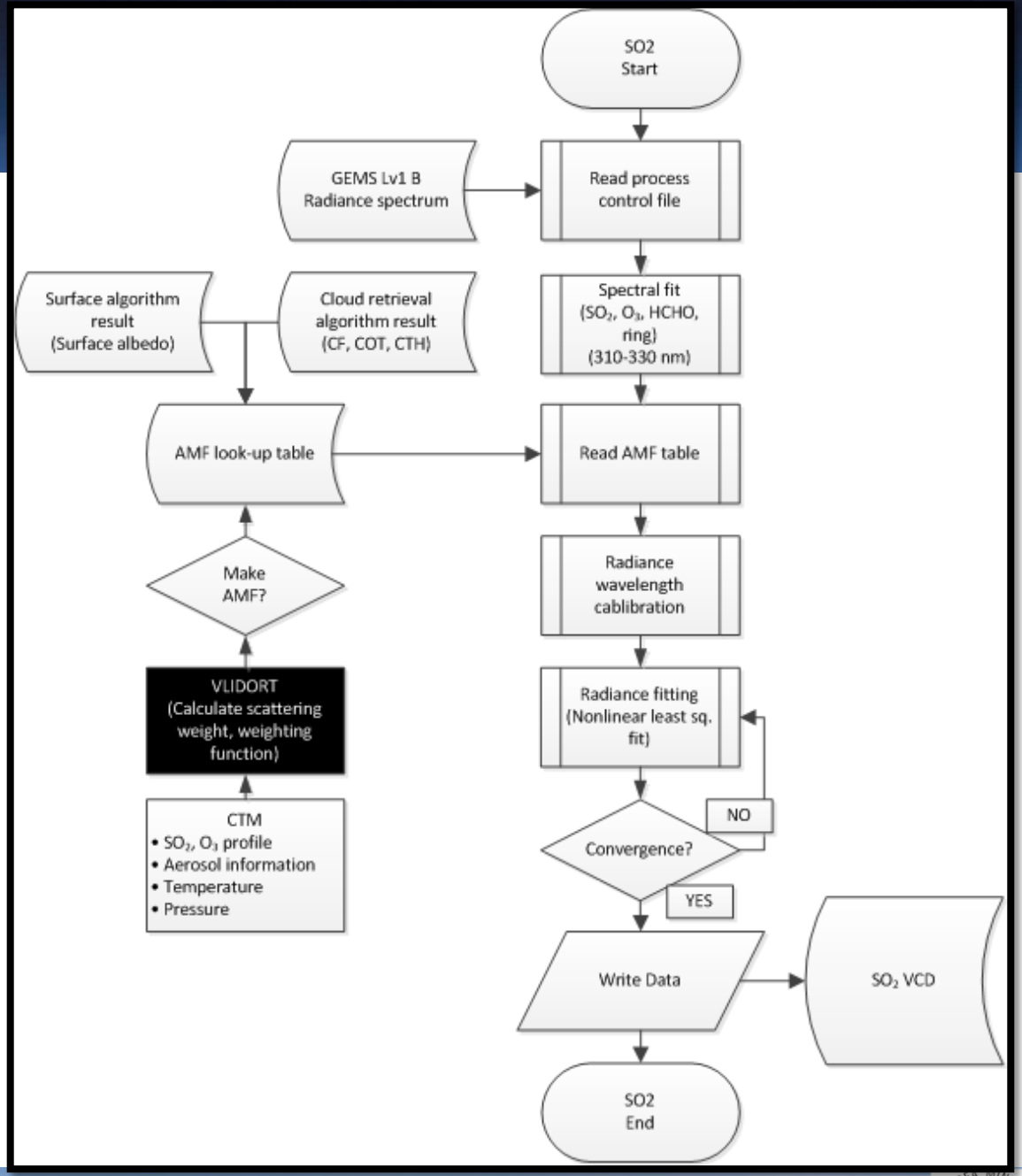
Study areas

- Develop algorithms for NO_2 and SO_2 retrieval for GEMS: flowchart
- SO_2 sensitivity simulation (290-500 nm)
- Airborne I-DOAS measurements

NO_2


NO2
Start
GEMS Lv1 B
Radiance spectrum
Read process
control file
Surface algorithm
result
(Surface albedo)
Cloud retrieval
algorithm result
(CF, COT, CTH)
Spectral fit
(NO_2, O_3, H_2O,O_4,
ring)
(420-450 nm)
AMF look-up table
Read AMF table
AMF_{strat}
For calculating
initial VCD
AMF_{trop}
For calculating
tropospheric VCD
Radiance
wavelength
cablibration
Radiance fitting
(Nonlinear least sq. fit)
• Calculate initial VCD: $V_{init} = S / AMF_{strat}$
• Calculate tropospheric VCD: $V_{trop} = (S-AMF_{strat} \times V_{strat}) / AMF_{trop}$
Make
AMF?
NO
Convergence?
YES
VLIDORT
(Calculate scattering
weight, weighting
function)
Write Data
Tropospheric NO_2
VCD
CTM
• NO_2 profile
• Aerosol information
• Temperature
• Pressure
NO2
End

SO_2


SO2
Start
GEMS Lv1 B
Radiance spectrum
Read process
control file
Surface algorithm
result
(Surface albedo)
Cloud retrieval
algorithm result
(CF, COT, CTH)
Spectral fit
(SO_2, O_3, HCHO,
ring)
(310-330 nm)
AMF look-up table
Read AMF table
Make
AMF?
Radiance
wavelength
cablibration
VLIDORT
(Calculate scattering
weight, weighting
function)
Radiance fitting
(Nonlinear least sq.
fit)
CTM
• SO_2, O_3 profile
• Aerosol information
• Temperature
• Pressure
NO
Convergence?
YES
Write Data
SO_2 VCD
SO2
End

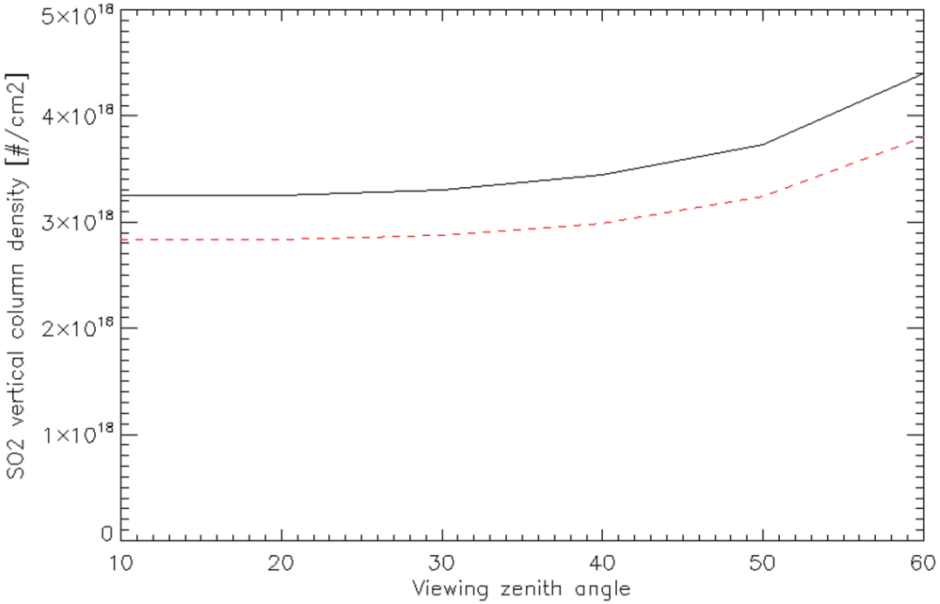
Comparison with GEMS and TEMPO

	GEMS	TEMPO
Wavelength (nm)	300-500	290-490
Sample ratio (1 K detector)	3 sample (0.2 nm)	3 sample (0.2 nm)
Fitting window for SO_2 (nm)	310- 330	305-345
Spectral resolution (nm)	0.6	0.6
	If wavelength is between 290 and 500, SO_2 sensitivity?	

(A) 0.6 nm (2.8 sampling)

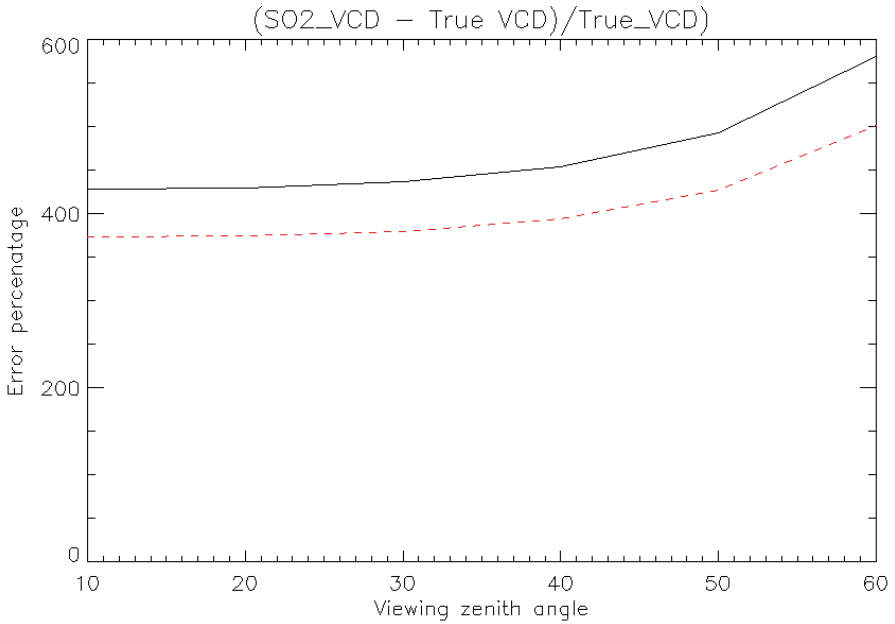
(B) 0.63 nm

SO_2 vertical column density



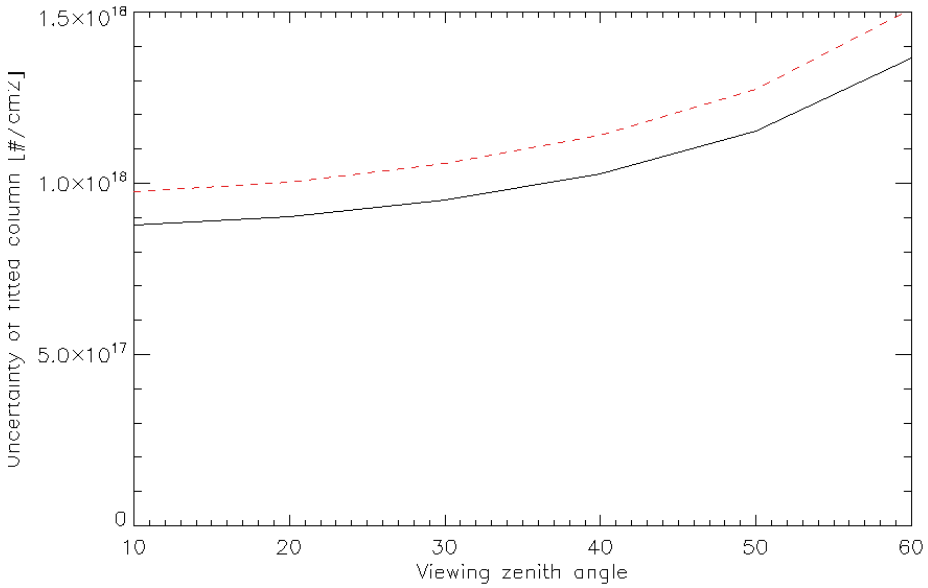
Black bold line : 3 sampling
Red dash line : 2.8 sampling
True value : 7.56774e+15

- SZA : 12.51
- RAA : 46.20
- True value : 7.56774e+15
- Used NY12 profile of GSFC



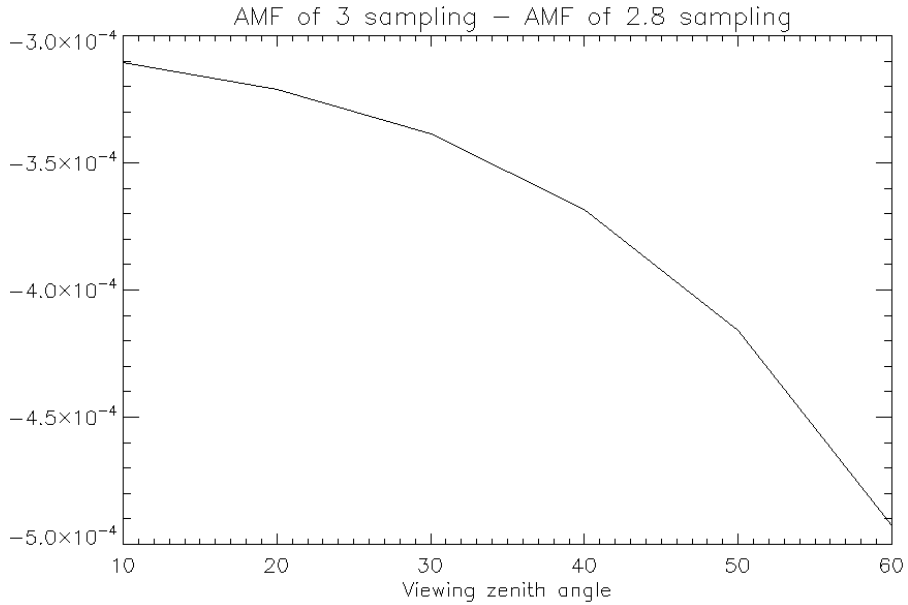
Courtesy of Hyeong A. Kwon

Uncertainty of fitted column



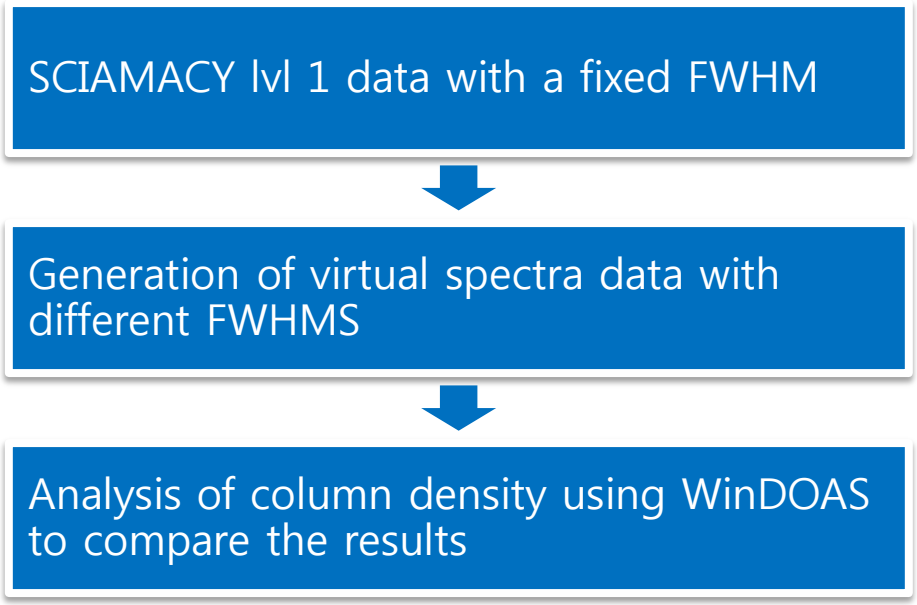
Black bold line : 3 sampling
Red dash line : 2.8 sampling

- Uncertainty is relatively low in case of 3 sampling
- No difference of ΔAMF



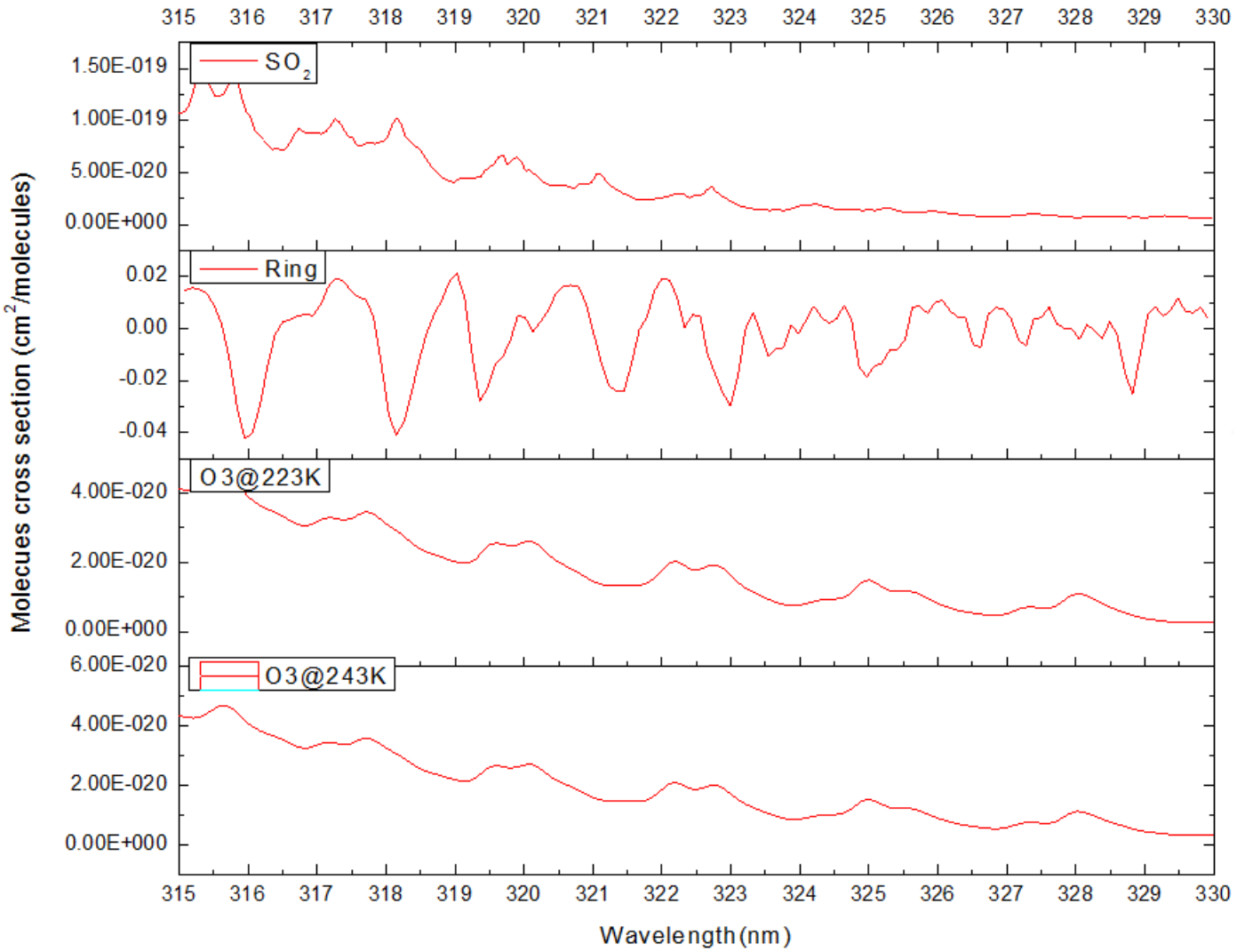
Courtesy of Hyeong A. Kwon

Simulation for SO_2

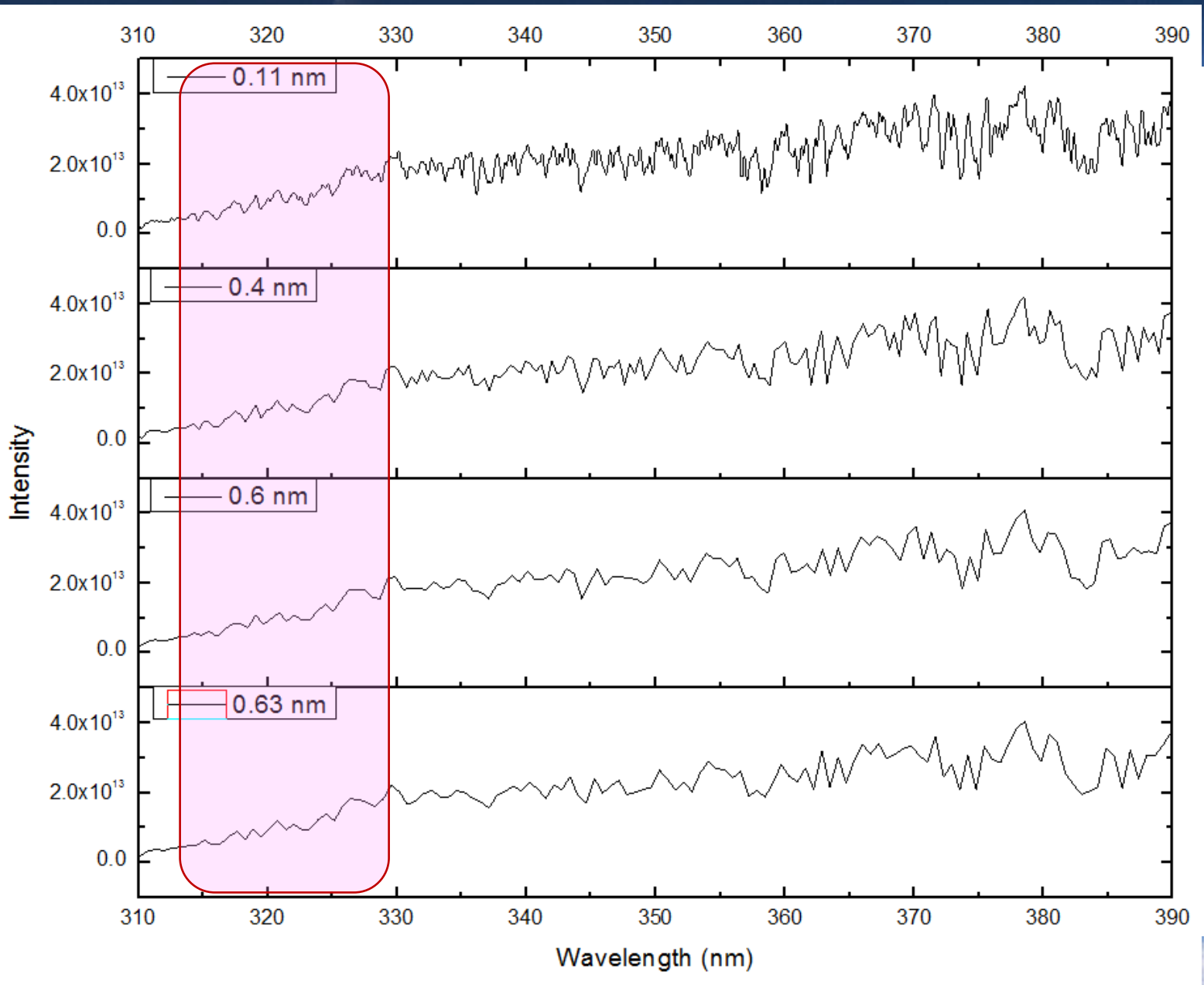


Methodology for simulating measurement accuracy for different FWHMs(0.63 nm)

Molecular cross section for SO_2 analysis (315-330nm)

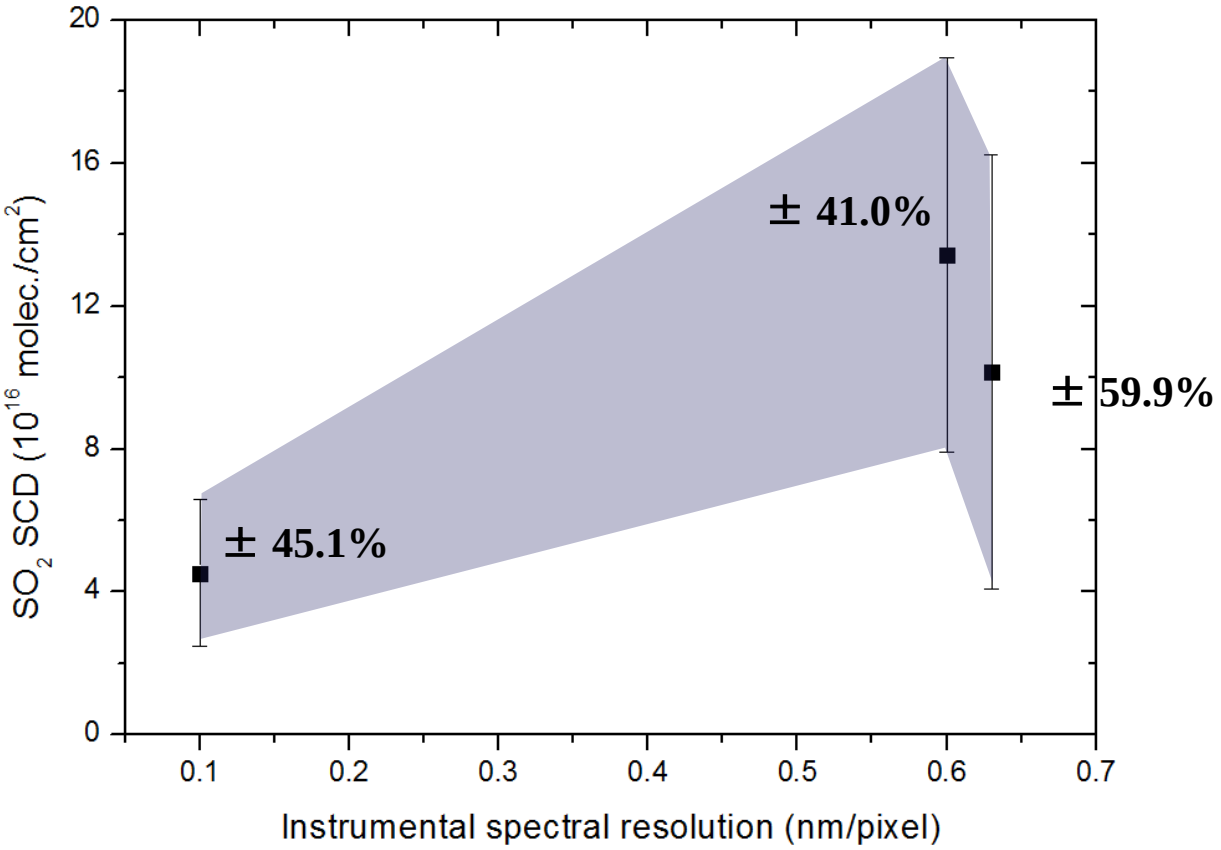


Case 1: Southern China (Feb. 28, 2007)



0.11 nm: original satellite spectra (SCIAMACHY) **0.4, 0.6, and 0.63 nm:** Virtual spectra

SO_2 slant column density and Uncertainty
(310-330 nm)

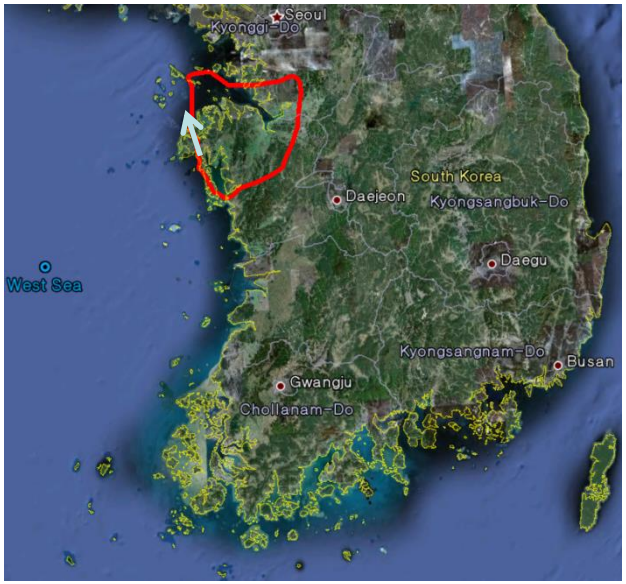


	SCD	fitting error	relative fitting error	min.	max.
0.1 nm	4.53E+16	2.04E+16	45.0%	2.49E+16	6.57E+16
0.6 nm	1.34E+17	**5.50E+16**	**41.1%**	7.90E+16	1.89E+17
0.63 nm	1.02E+17	**6.08E+16**	**59.9%**	4.02E+16	1.62E+17

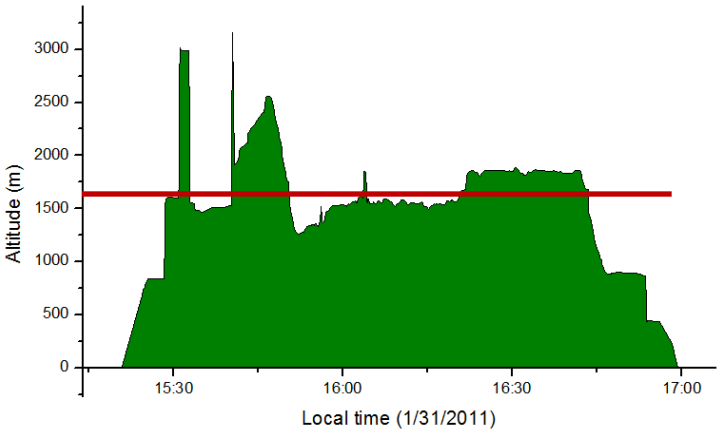
Instrument set-up: airborne Imaging DOAS

Airborne I-DOAS measurement test

Cessna



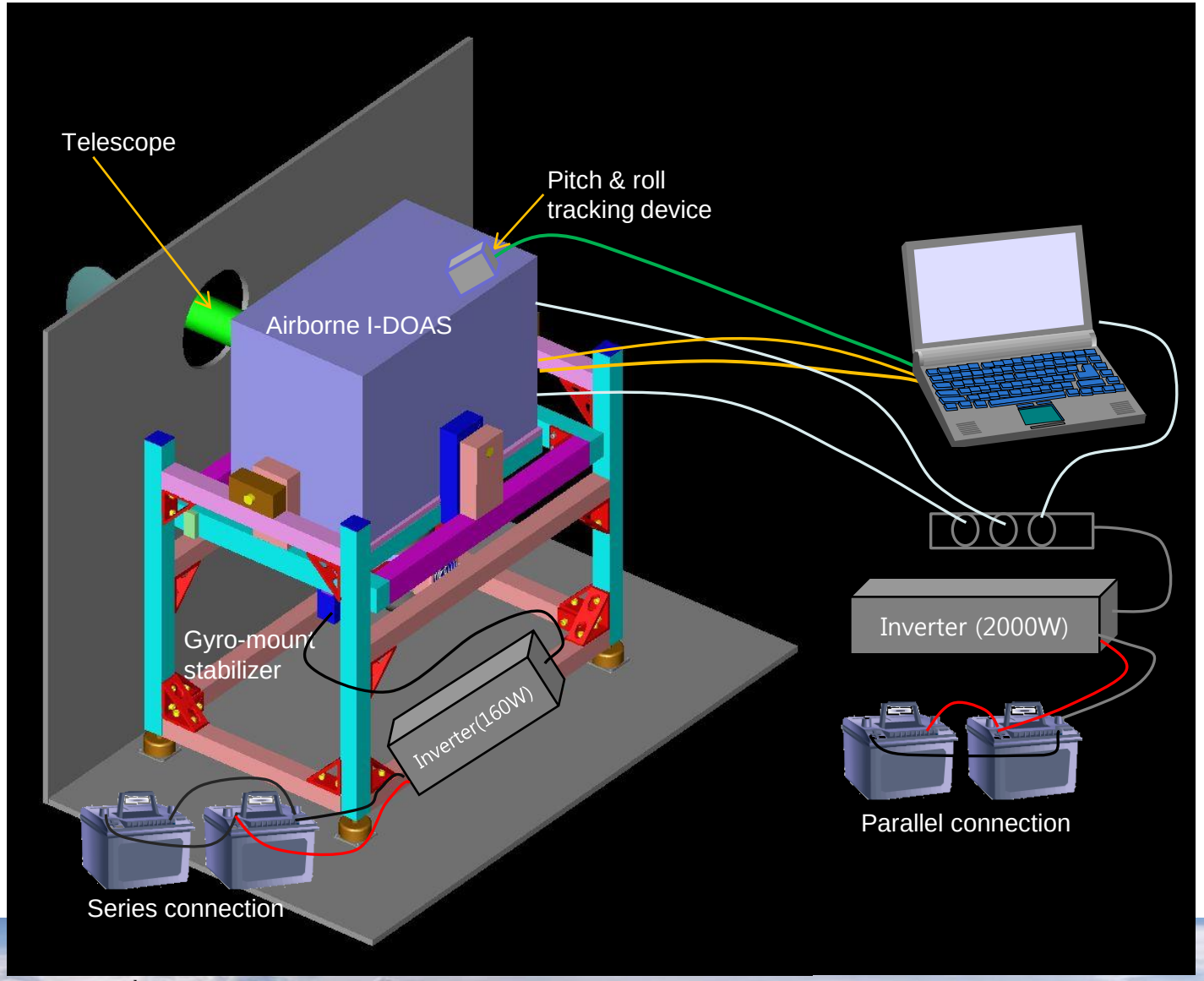
(Aircraft measurement flight route)



- Test measurement days: Jan. 31, 2011
- Measurement species: trace gases (NO_2, SO_2, O_4, HCHO)
- Integration time: 20 ms
- Flight time: ~ 2 hr

Schematic of Airborne I-DOAS

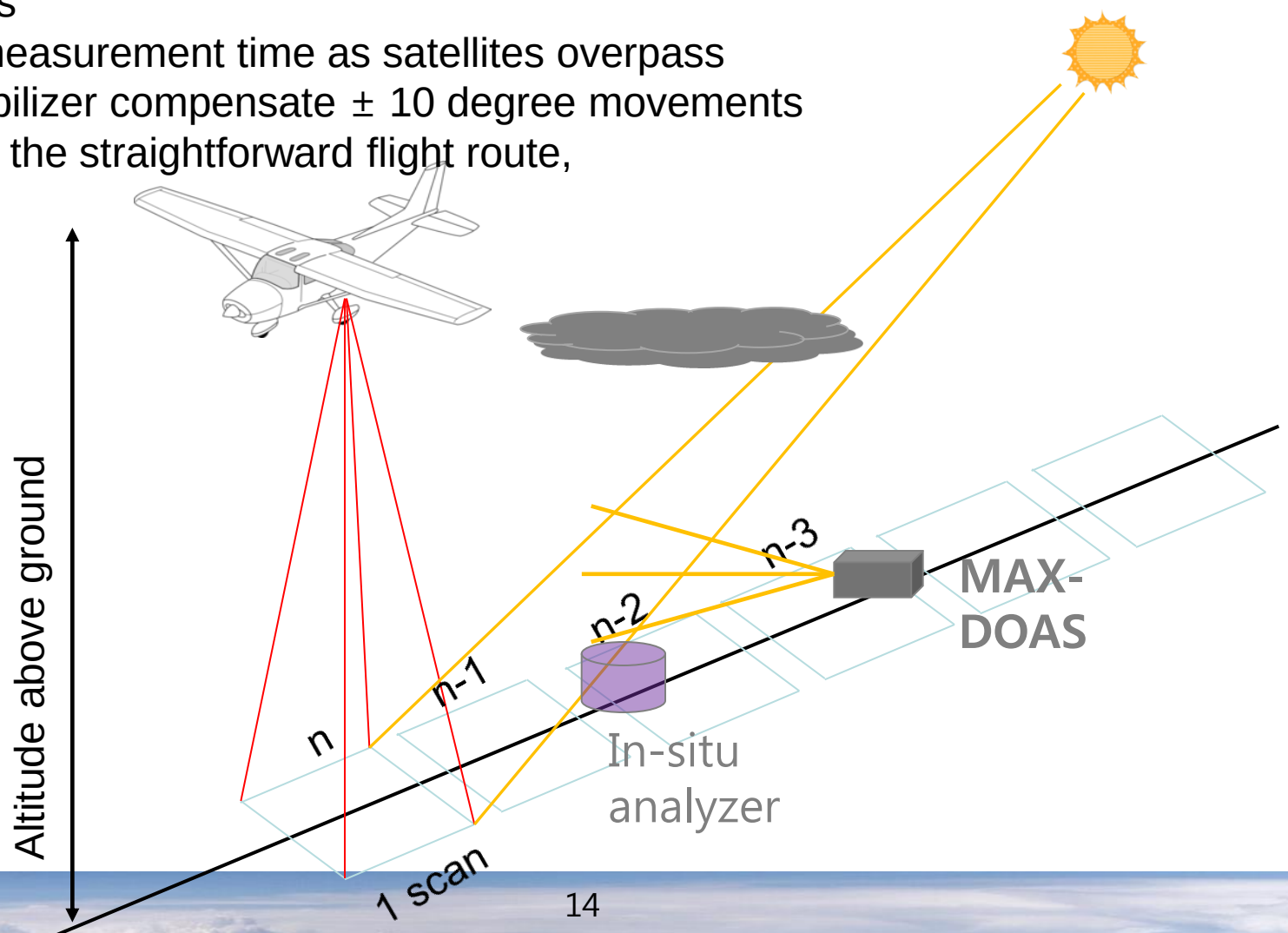
GPS



Airborne Imaging DOAS principle

Ideal measurement conditions:

1. No clouds
2. Similar measurement time as satellites overpass
3. Gyro stabilizer compensate ± 10 degree movements
4. Consider the straightforward flight route,

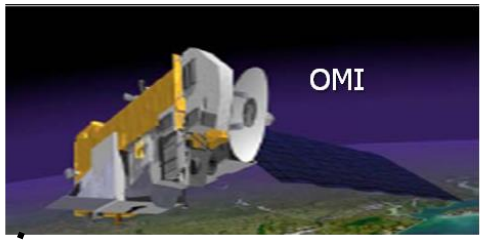


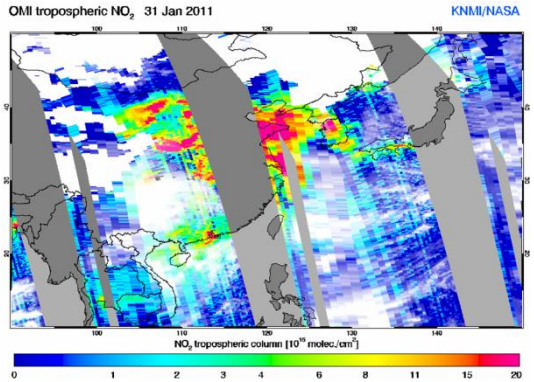
Methodology: airborne I-DOAS

Geometry of trace gases' measurements

Date	start time	end time
Jan. 31, 2011	12:04:35	13:43:28

Satellite

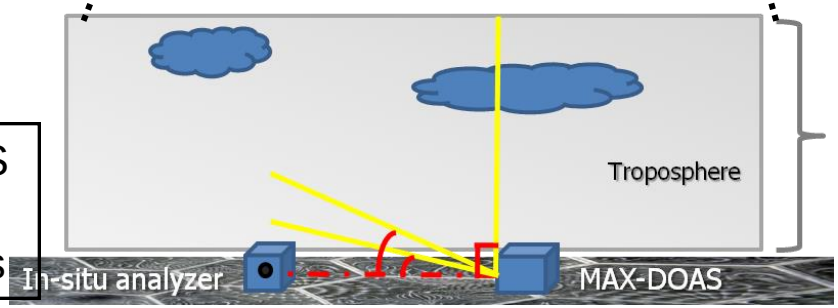




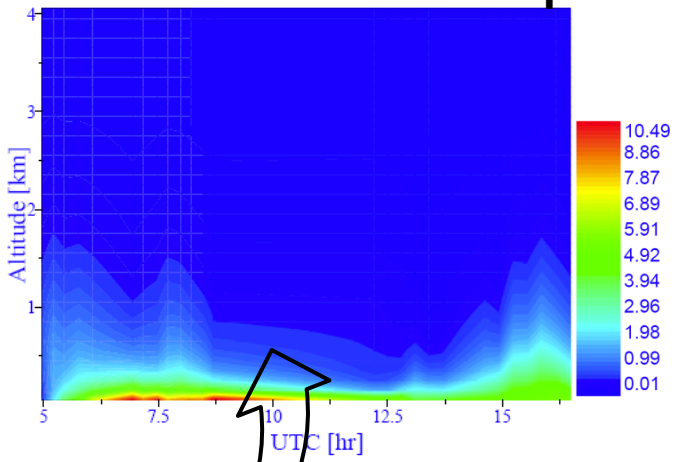
Airborne I-DOAS

Cessna

MAX-DOAS and in-situ instruments



Comparison



Instruments

RTM to get AMF

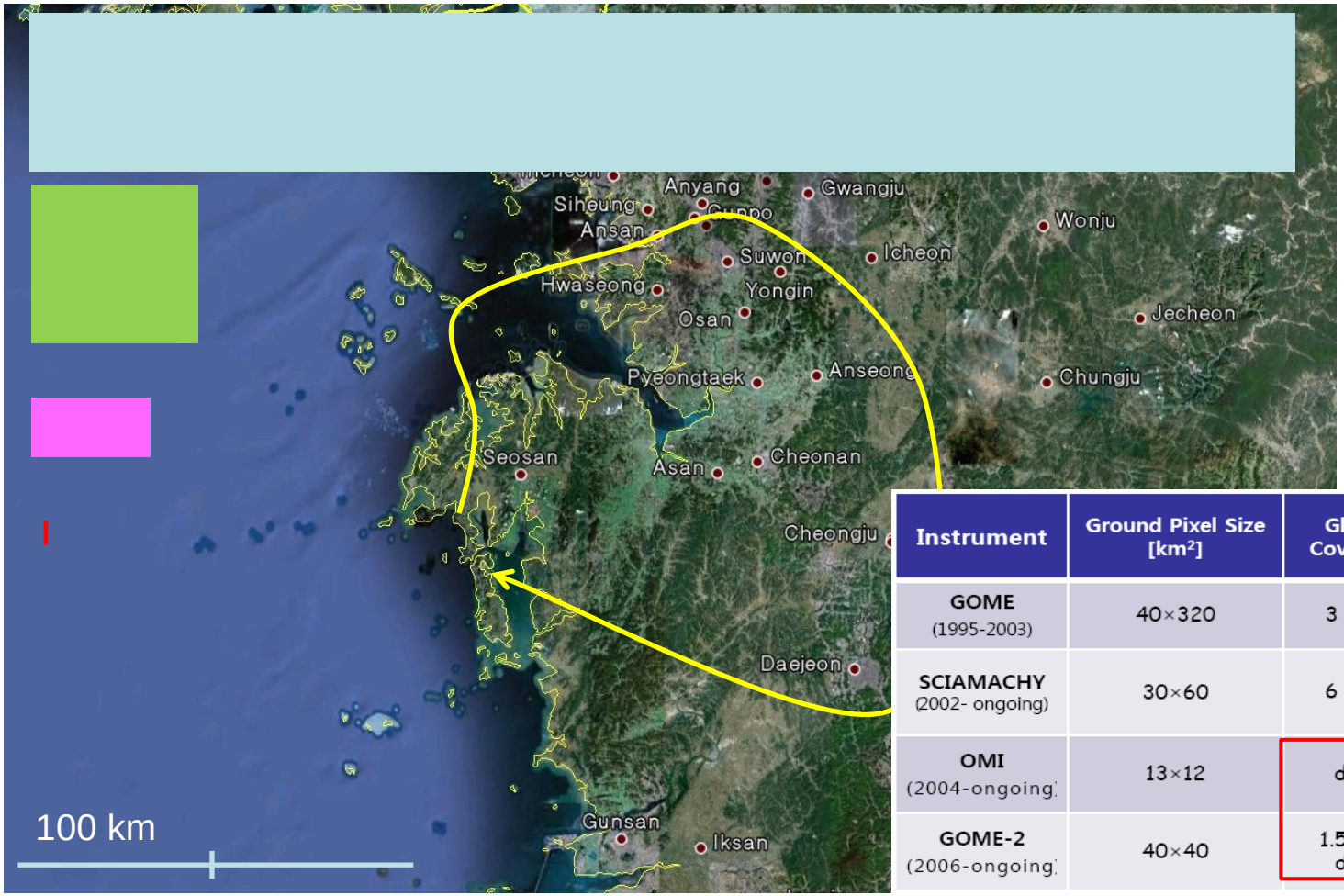
Spatial Resolution of flight route

GOME
(40X320)

GOME2
(40X40)

OMI
(15X30)

Airborne I-DOAS
(0.01X0.2)



Instrument	Ground Pixel Size [km²]	Global Coverage
GOME (1995-2003)	40×320	3 days
SCIAMACHY (2002- ongoing)	30×60	6 days
OMI (2004-ongoing)	13×12	daily
GOME-2 (2006-ongoing)	40×40	1.5 to 3 days

SCIAMACHY validation (Fix et al., 2005)

Comparison for airborne DOAS

	Previous study	This study
Visualized trace gas	NO_2[(1)], OClO[(2)] and SO_2[(3)] (volcano)	NO_2
Measurement method	Airborne MAX-DOAS[(1-3)]	Airborne Imaging DOAS[(4)]
Telescope	variable	Nadir mode (0 degree)
Altitude	variable	< 3 km
Objectives	SCHIMACHY Validation[(2)] NO_2 Profile retrieval[(1, 5)]	Validation for OMI & GEMS validation in the future

(1) Retrieval of Profile Information from Airborne Multi Axis UV/visible Skylight Absorption Measurements, Bruns et al., Applied Optics 43, 4415, 2004

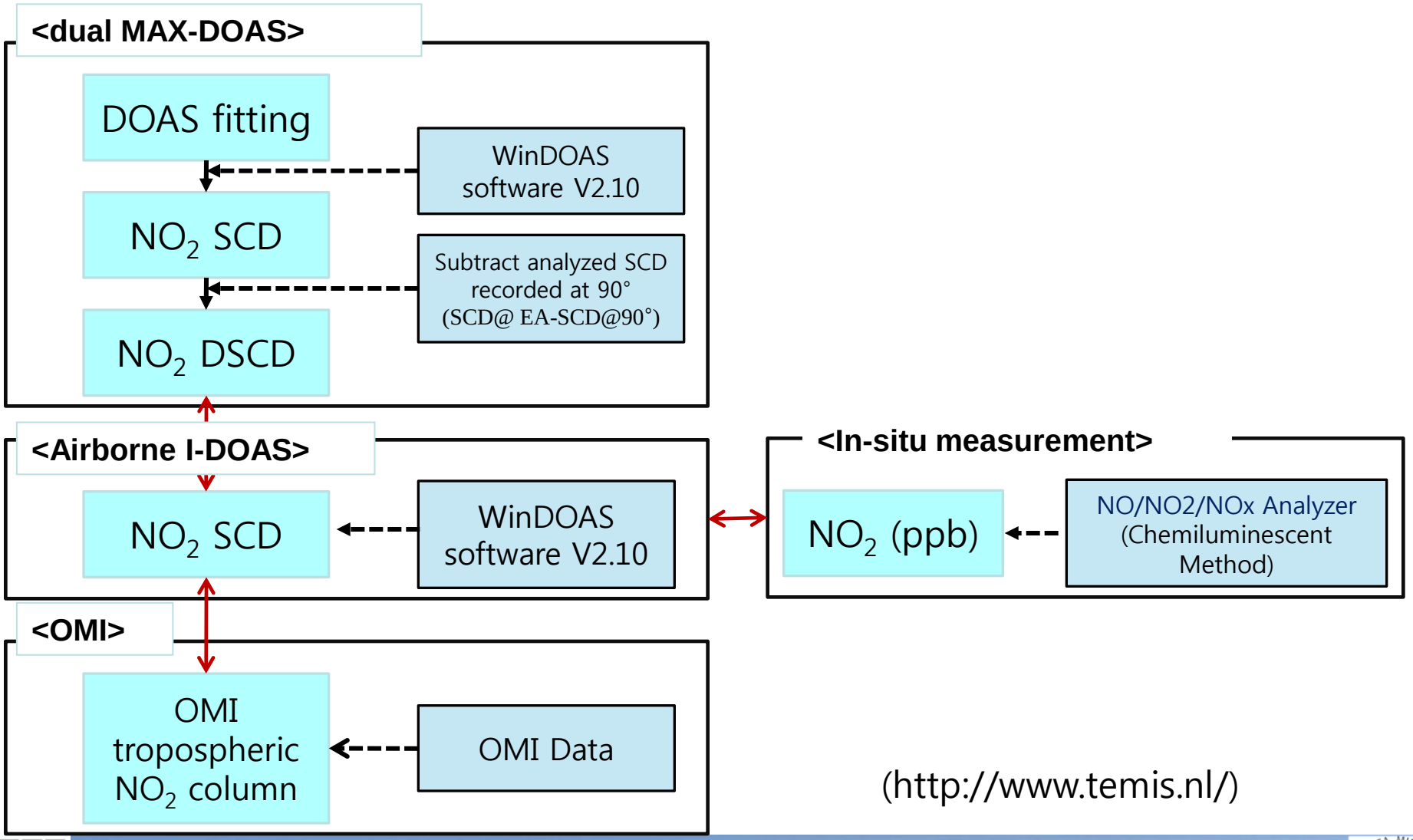
(2) SCIAMACHY validation by aircraft remote sensing: design, execution, and first measurement results of the SCIA-VALUE mission, Fix et al., ACP 5, 1273, 2005

(3) Airborne multi-axis DOAS measurements of tropospheric SO_2 plumes in the Po-valley, Italy, Wang et al., ACP 6, 329, 2006

(4) Direct observation of two dimensional trace gas distribution with an airborne Imaging DOAS instrument, Heue et al., Atmos. Chem. Phy. Discuss., 2008

(5) NO_2 Profile retrieval using airborne multi axis UV-visible skylight absorption measurements over central Europe, Bruns et al., ACP 6, 3049, 2006

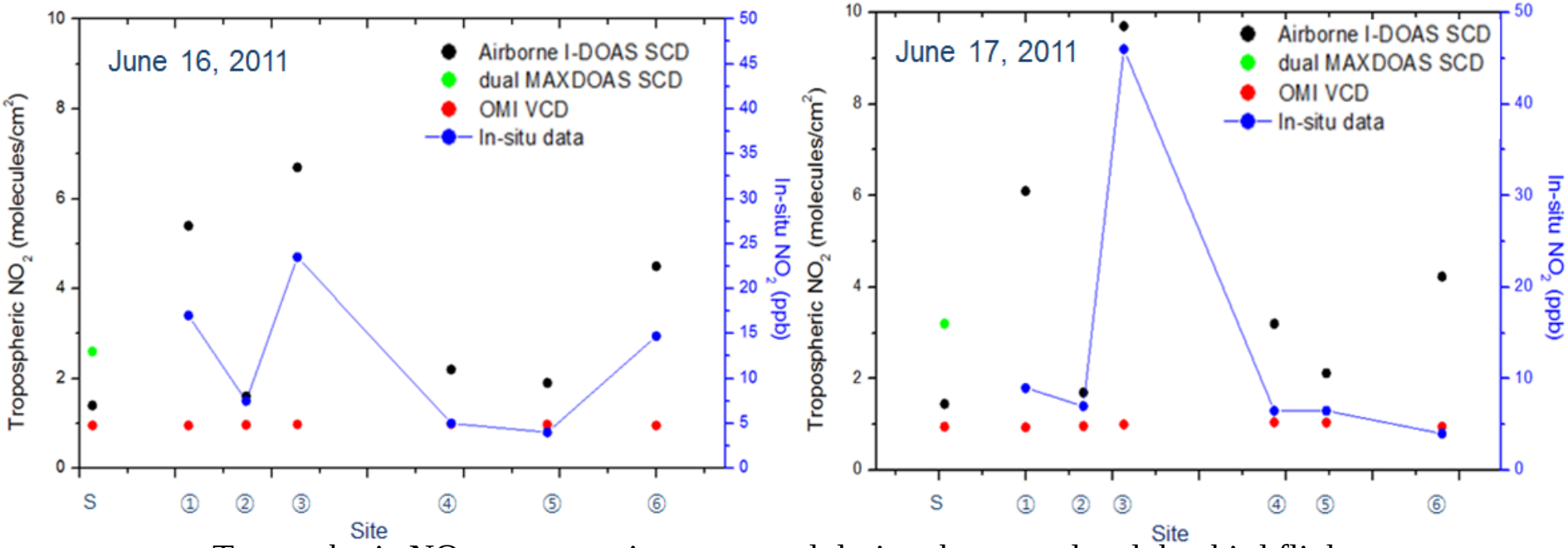
Analysis flowchart



(http://www.temis.nl/)

Comparison with each instruments

Over the power plants pollution plume high column densities were observed. The enhanced local concentrations also lead to an increase in both I-DOAS and satellite's NO_2 data. Due to the large field of view of OMI, the data are affected by the low column densities outside the pollution sources.



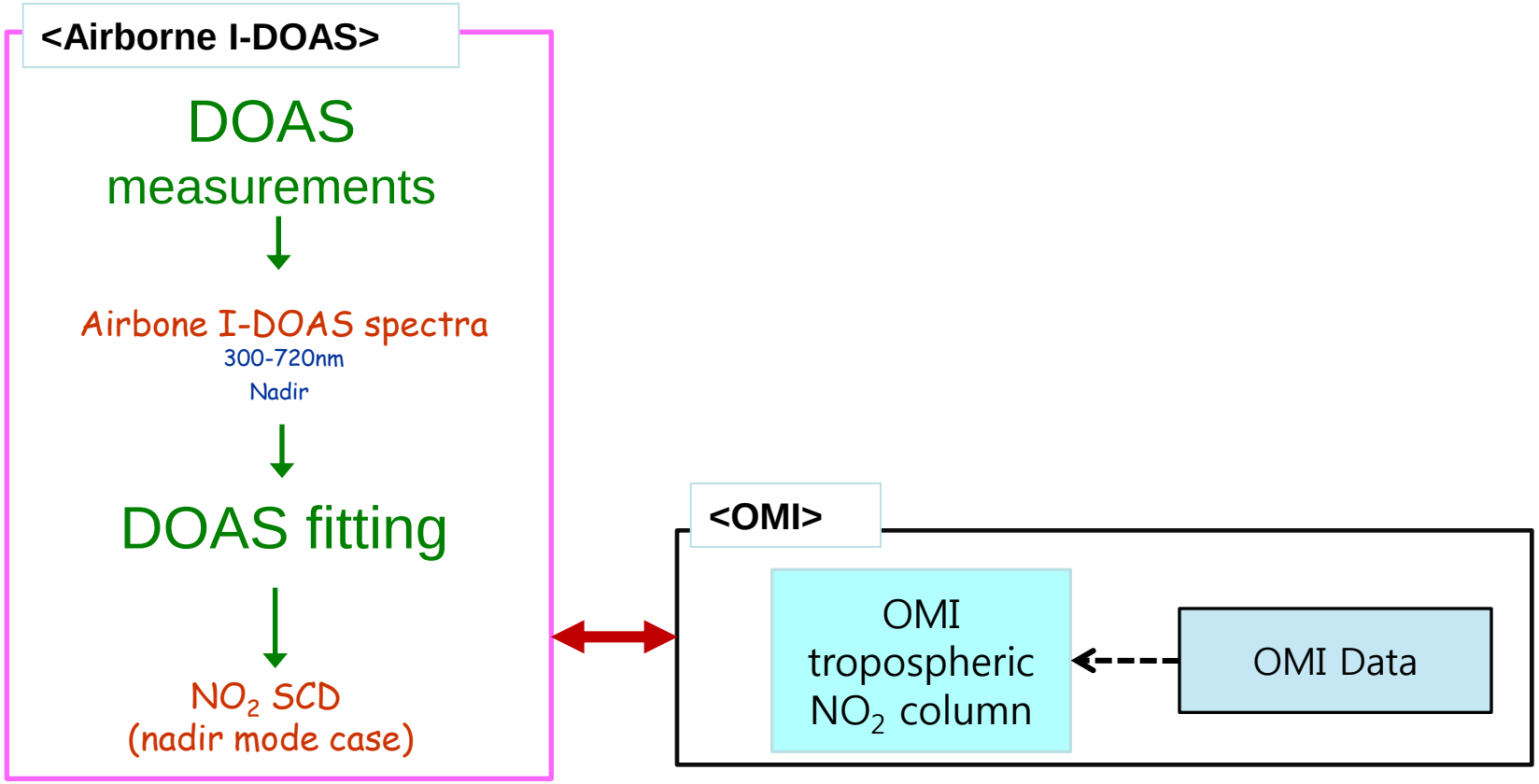
Tropospheric NO_2 concentration measured during the second and the third flights
(S:starting point, ①: Taean power plant ②: Dejeok Island ③: Pyeongtaek power plant
④: Cheoan city ⑤: Gonju city ⑥: Boreung power plant)

Airborne I-DOAS measurement information

Date		Time	ground MAX-DOAS	Flight pathway	note
2011	1/31	PM	mini MAX-DOAS	1	test flight
	12/5	PM	dual MAX-DOAS	2	
	12/6	PM	dual MAX-DOAS	2	
2012	3/8	PM	no	2	test flight
	4/26	PM	mini MAX-DOAS	2	DRAGON Campaign
	4/27	PM	mini MAX-DOAS	2	DRAGON Campaign
	11/10	AM	mini MAX-DOAS	2	
	11/10	PM	mini MAX-DOAS	1	
	11/15	PM	mini MAX-DOAS	2	

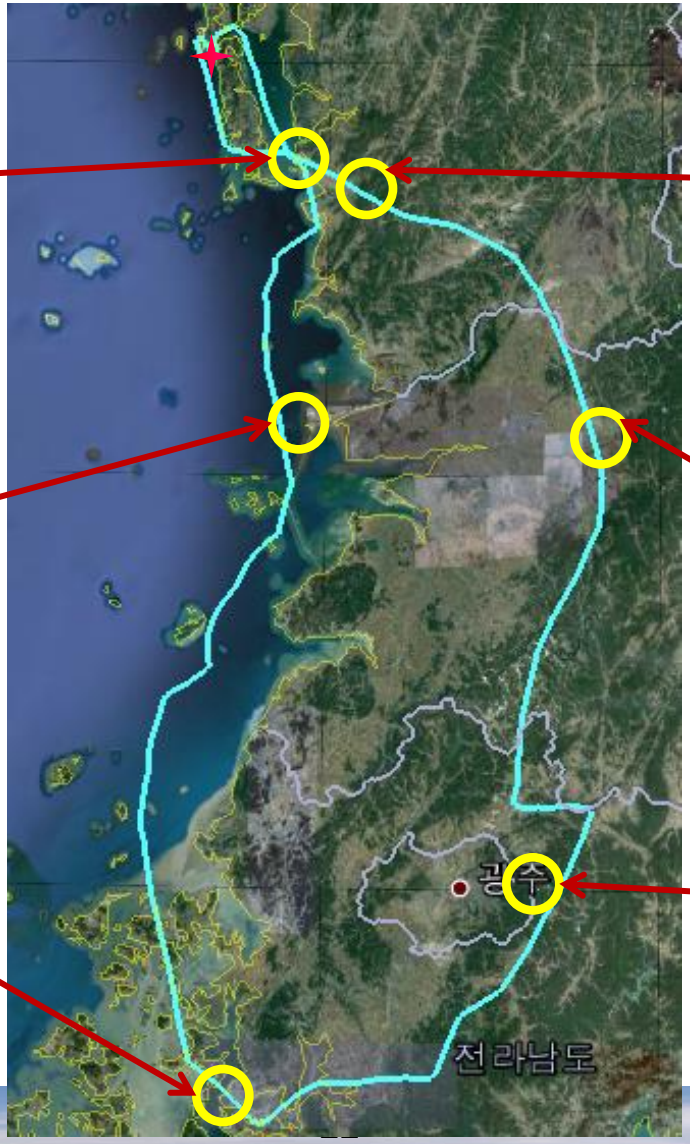
1: clockwise pathway from starting point
2: count clockwise pathway from starting point

The analysis flowchart



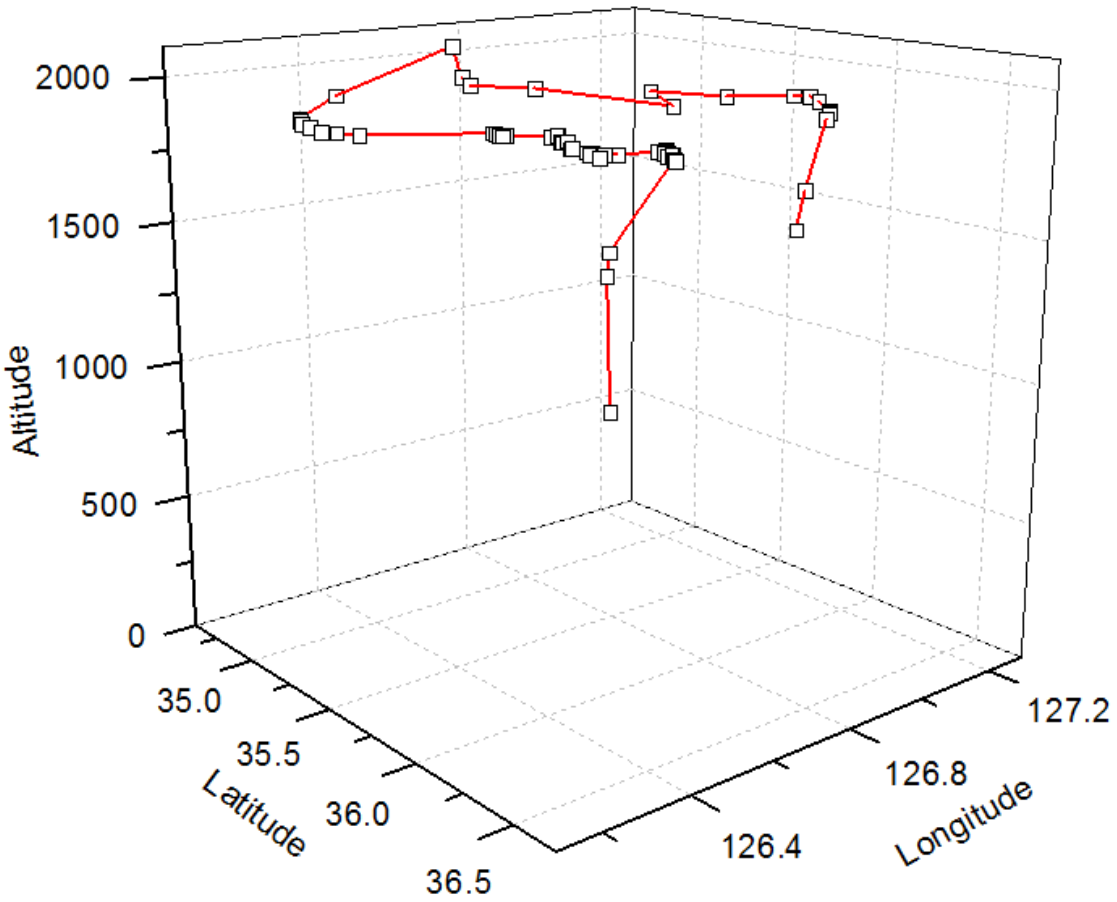
(http://www.temis.nl/)

2011/12/05_Aircraft measurement pathway

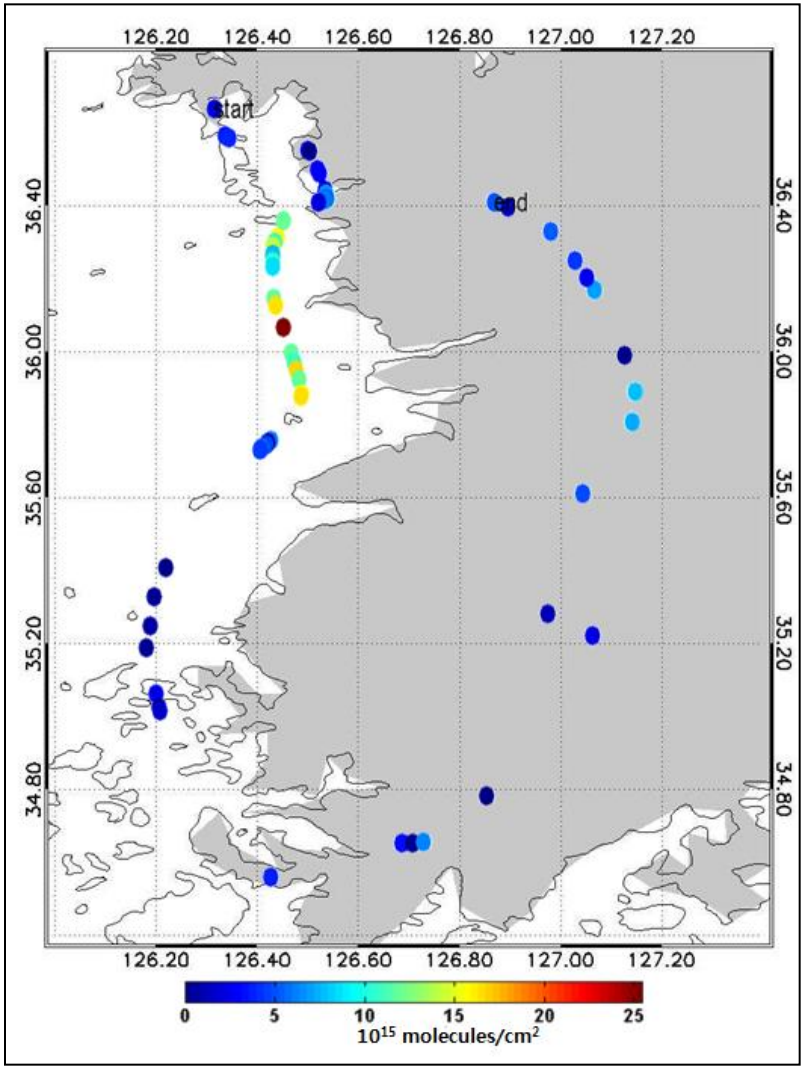


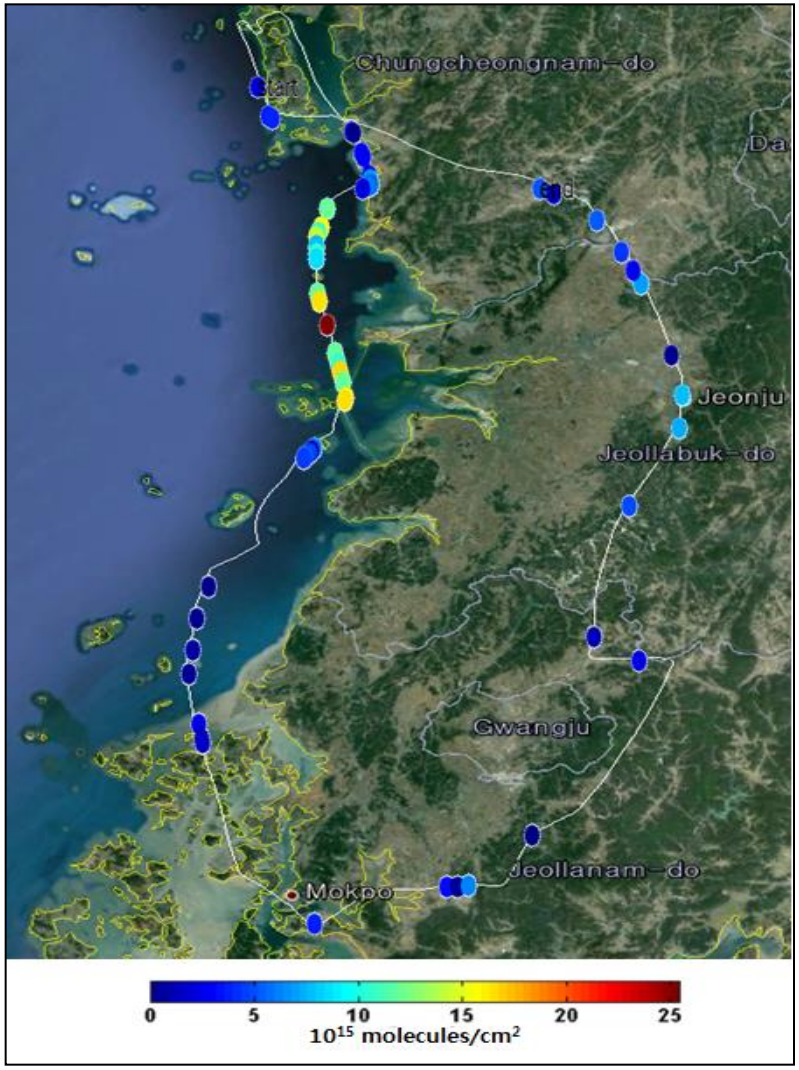
✦: Starting point

2011/12/05_Aircraft measurement pathway

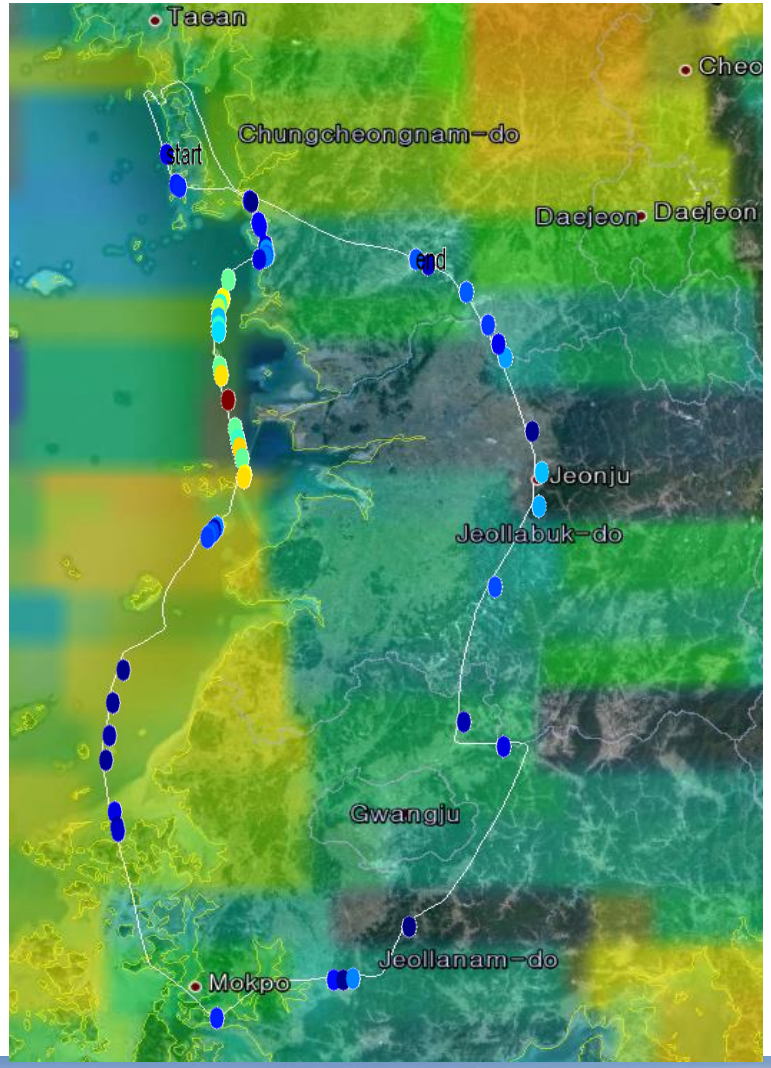


2011/12/05_Aircraft measurement

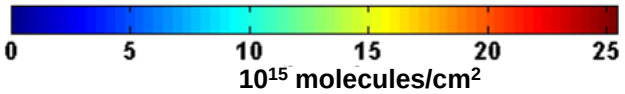




OMI vs. A I-DOAS: 2011/12/05_Aircraft measurement

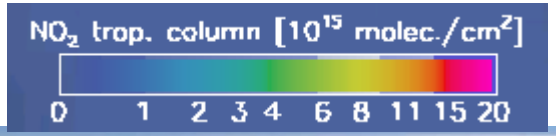


A I-DOAS

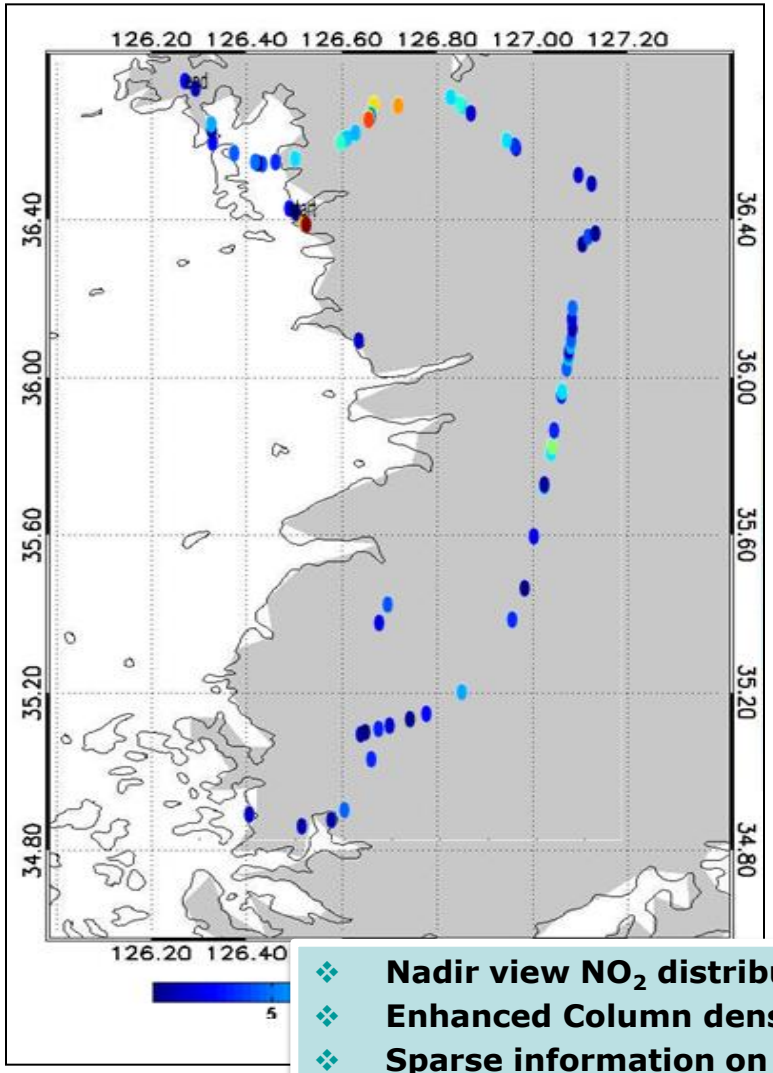


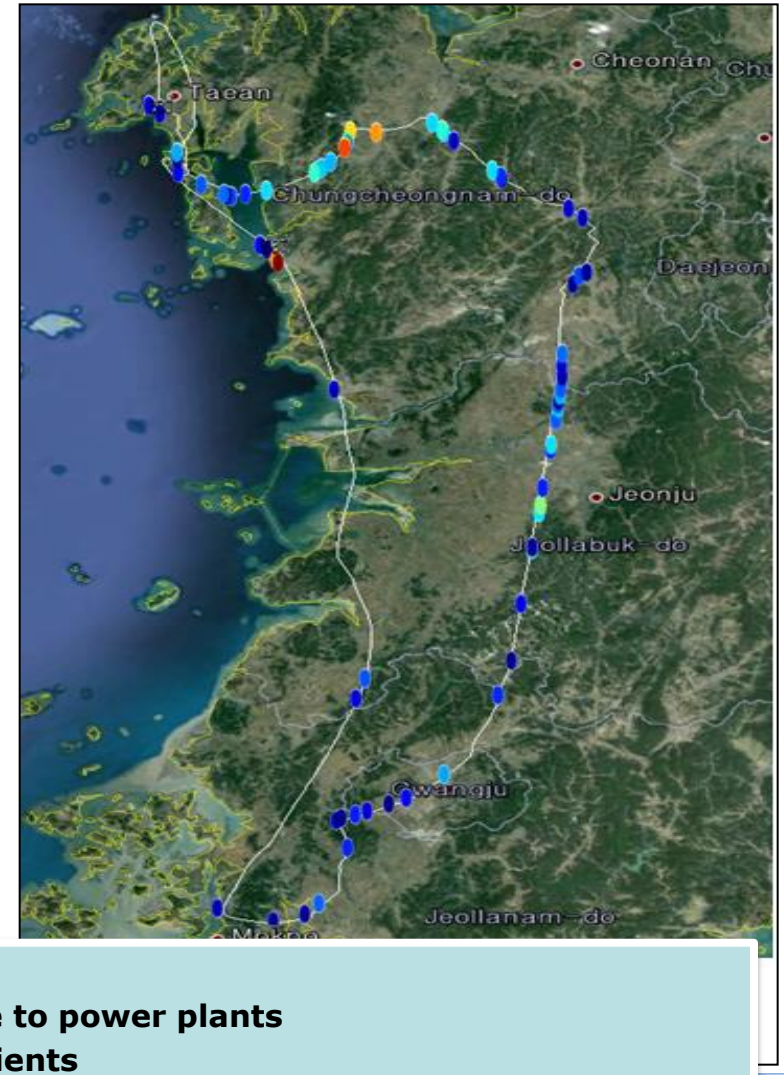
	Overpass time
A I-DOAS	13:03~15:22
OMI	13:16~14:55

OMI



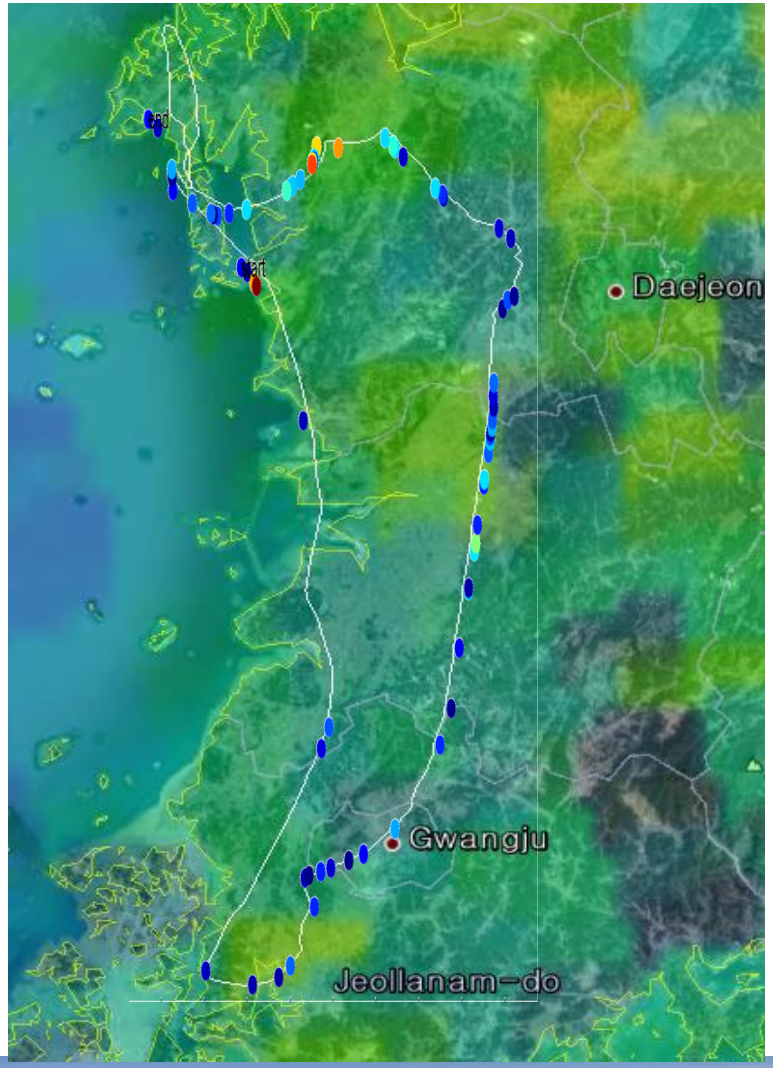
2012/04/26_Aircraft measurement





- Nadir view NO_2 distribution
- Enhanced Column densities close to power plants
- Sparse information on local gradients

OMI vs. A I-DOAS: 2012/04/26_Aircraft measurement

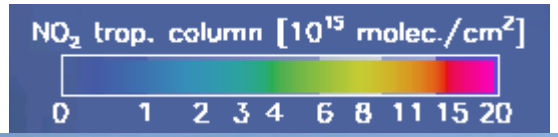


A I-DOAS

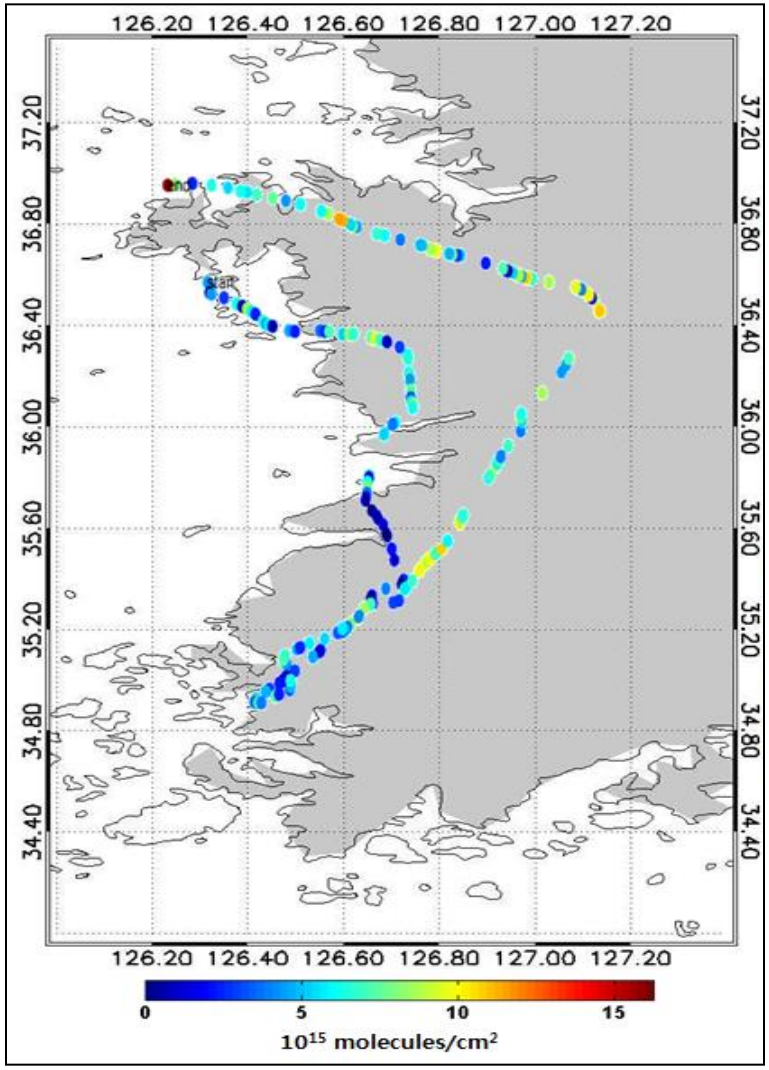
10^{15} molecules/cm^2

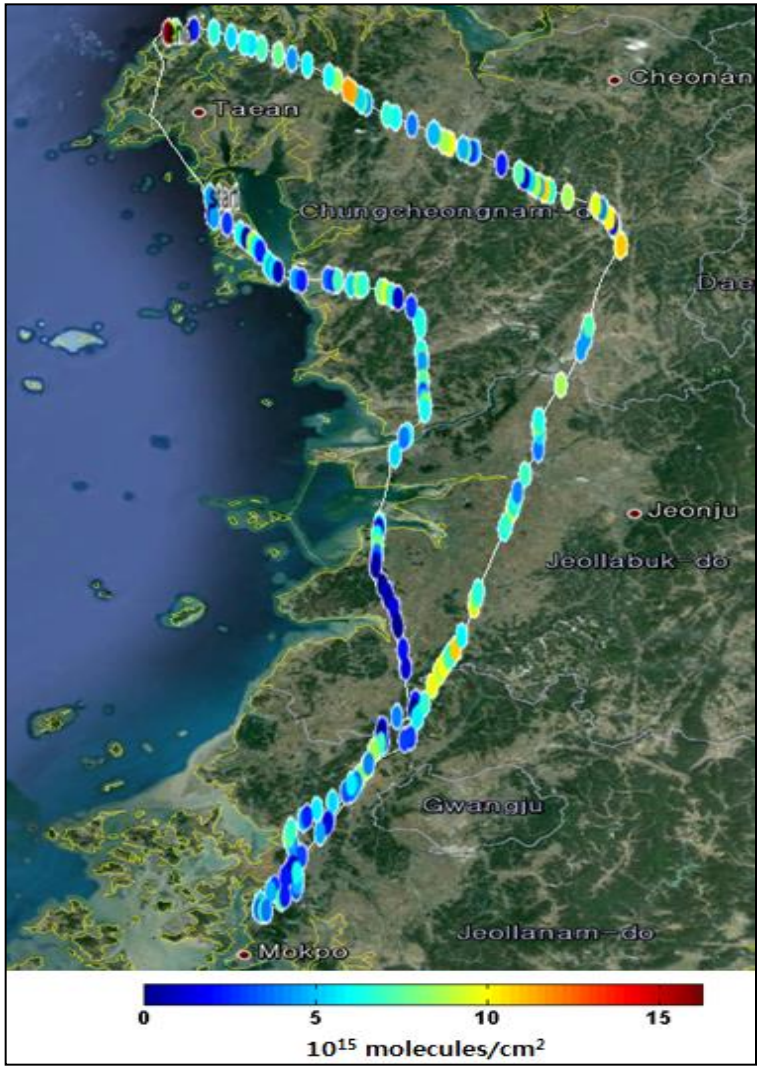
	Overpass time
A I-DOAS	11:24~14:17
OMI	12:45~14:24

OMI

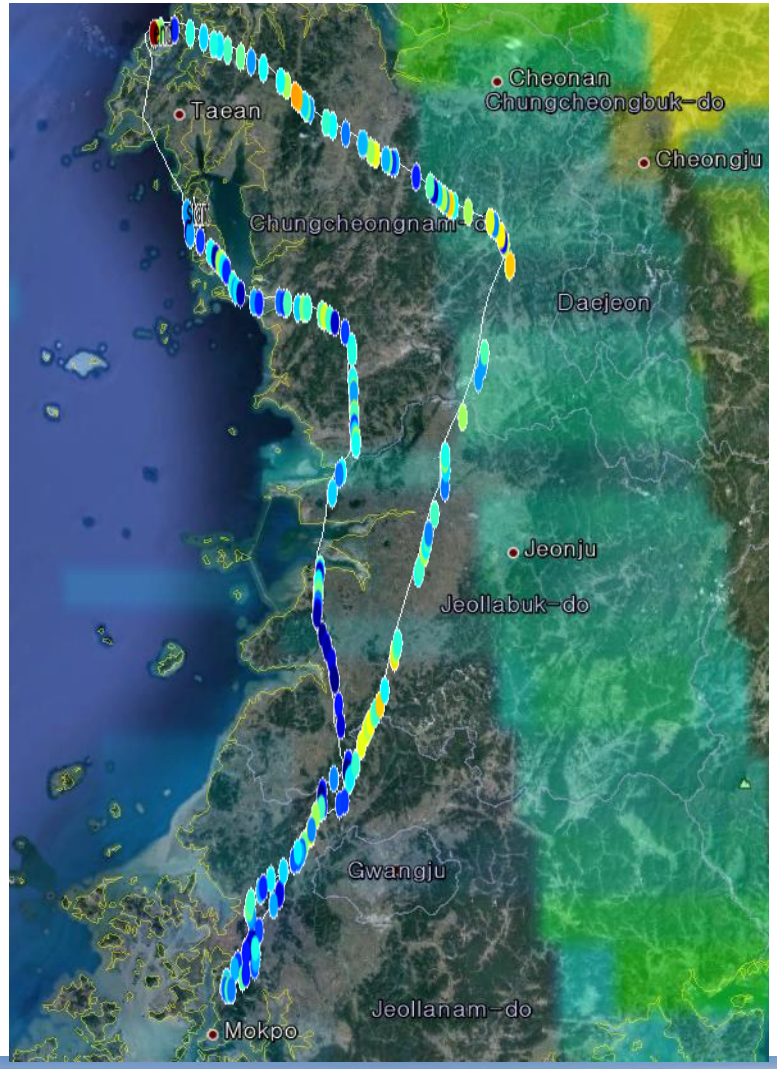


2012/04/27_Aircraft measurement





OMI vs. A I-DOAS: 2012/04/27_Aircraft measurement

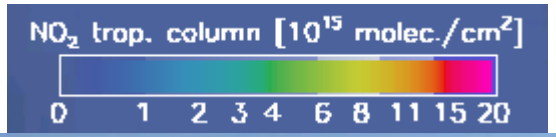


A I-DOAS

10^{15} molecules/cm^2

	Overpass time
A I-DOAS	10:30~13:00
OMI	11:49~13:28

OMI



Summary & future works

- **NO_2 & SO_2 retrieval algorithms are still under development, based on BOAS or DOAS technique.**

- **For SO_2 sensitivity test, 3 sampling case was simulated better than 2.8 sampling in terms of fitting column, however, there was no different AMF value for 2 cases.**

- **For 0.6 nm & 0.63 nm spectral resolution, fitting error was relatively low in case of 0.6 nm.**

- **On the first aircraft measurement day (31 Jan, 2011), the retrieval of airborne I-DOAS was not analyzed due to the much cloud. The results of airborne I-DOAS was relatively higher than that of satellite due to the spatial resolution.**

- **We'll Investigate the airborne I-DOAS application to validate satellite data and to compare GEMS with high spatial resolution with in-situ instruments.**

Future works

- **Blind inter-comparison**

CTM

Concentration, N_i (t,x,y,z)

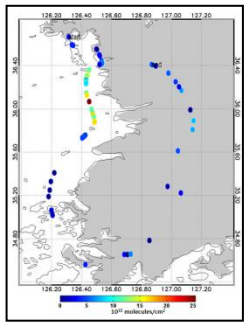
Blind Intercomparison

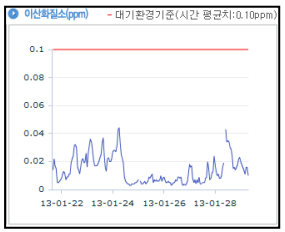
GEMS-retrieved Concentration N'_i (t,x,y)

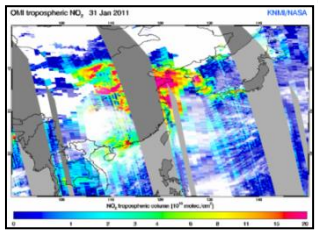
NO_2, SO_2 Retrieval Algorithm

- **Intensive measurements for comparison and validation**

Airborne↔Surface or ground-based ↔ Satellite





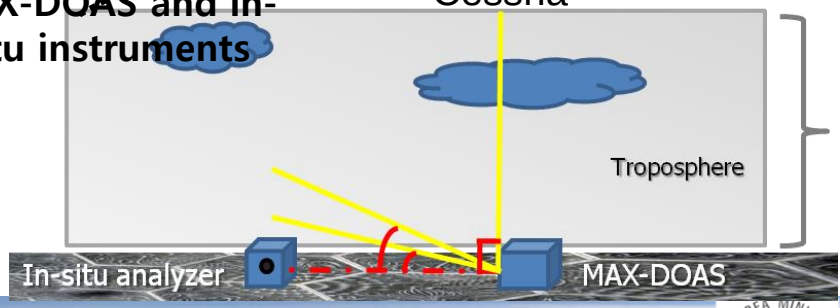


Satellite

Airborne I-DOAS

Cessna

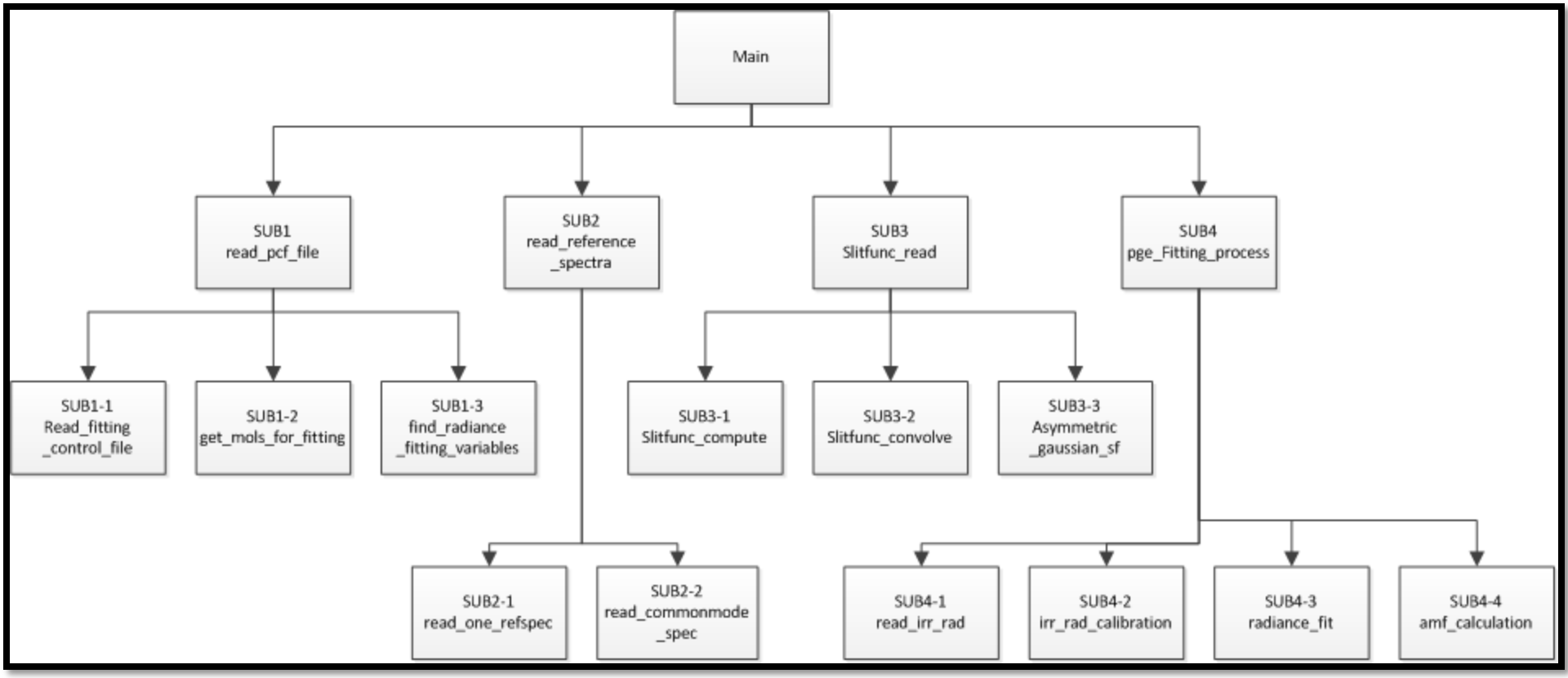
MAX-DOAS and in-situ instruments



Thanks for your attention!

yjkim@gist.ac.kr or
jihyojung@gist.ac.kr

SO_2


Main
SUB1
read_pcf_file
SUB2
read_reference
_spectra
SUB3
Slitfunc_read
SUB4
pge_Fitting_process
SUB1-1
Read_fitting
_control_file
SUB1-2
get_mols_for_fitting
SUB1-3
find_radiance
_fitting_variables
SUB3-1
Slitfunc_compute
SUB3-2
Slitfunc_convolve
SUB3-3
Asymmetric
_gaussian_sf
SUB2-1
read_one_refspec
SUB2-2
read_commonmode
_spec
SUB4-1
read_irr_rad
SUB4-2
irr_rad_calibration
SUB4-3
radiance_fit
SUB4-4
amf_calculation