Update on mini-satellite for air quality observation with 1x1 horizontal resolution and NICT project for air pollution

HAPIEST project: Health care Assist by air PollutIon ESTimation

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Motivation

PM2.5 prediction 12:00 JST 10 Oct 2016

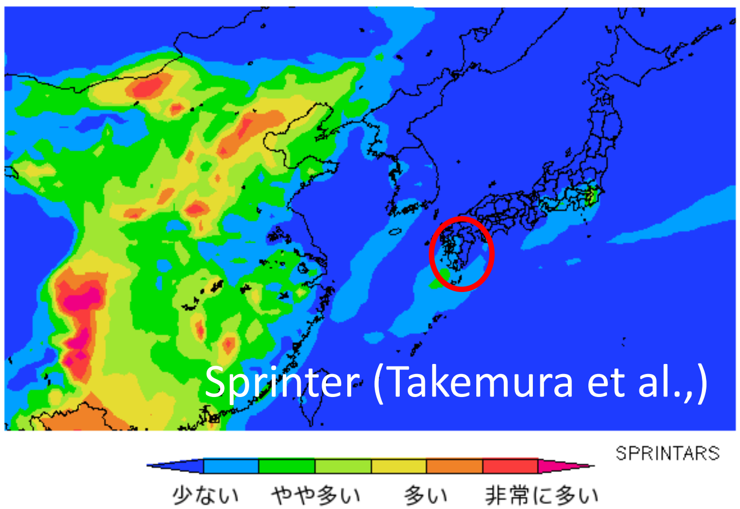
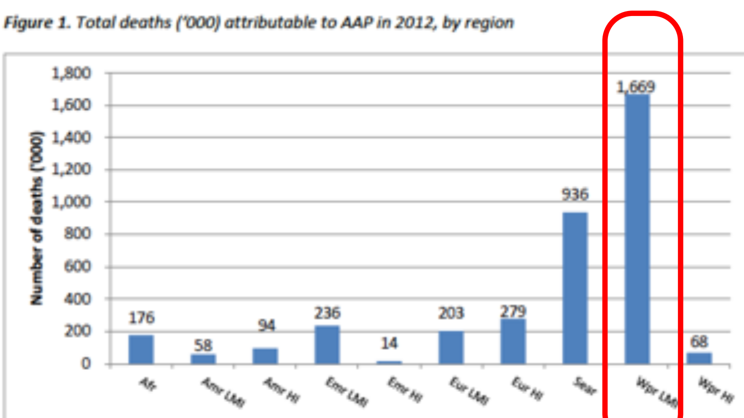


Figure 1. Total deaths ('000) attributable to AAP in 2012, by region



AAP: Ambient air pollution; Amr: America, Afr: Africa; Emr: Eastern Mediterranean, Sear: South-East Asia, Wpr: Western Pacific; LMI: Low- and middle-income; HI: High-income.

In Kyusu iland, more than 70% of pollution come from outside of Japan.

WHO report (2014): Globally, 3.7 million deaths were attributable to ambient air pollution (AAP) in 2012. <u>The Western Pacific and South East Asian regions bear most of the burden with 1.67 million and 936'000 deaths</u>, respectively. About 236'000 deaths occur in the Eastern Mediterranean region, 200'000 in Europe, 176'000 in Africa, and 58'000 in the Americas. The remaining deaths occur in high-income countries of Europe (280'000), Americas (94'000), Western Pacific (67'000), and Eastern Mediterranean (14'000).

<u>Serious damage: How about to provide a prediction of detail health index for Fukuoka-city in 1km level?</u>

HAPIEST project: Health care Assist by air PollutIon ESTimation

A Pollution prediction system in Fukuoka, Kyushu, Japan

In Kyusu iland, more than 70% of pollution come from outside of Japan.

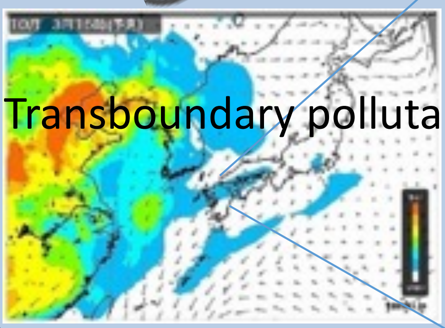
There are many ground-based observation base for pollution species.

HAPIEST project: Health care Assist by air PollutIon ESTimation

A Pollution prediction system in Fukuoka, Kyushu, Japan

Satellite data sets
HIMAWARI-8
GEMS

Other datasets
(Soramame, Sky-net, DOAS, Lidar etc)



Model Assimilation

Stretch NICAM-Chem
[Goto et al., 2015]

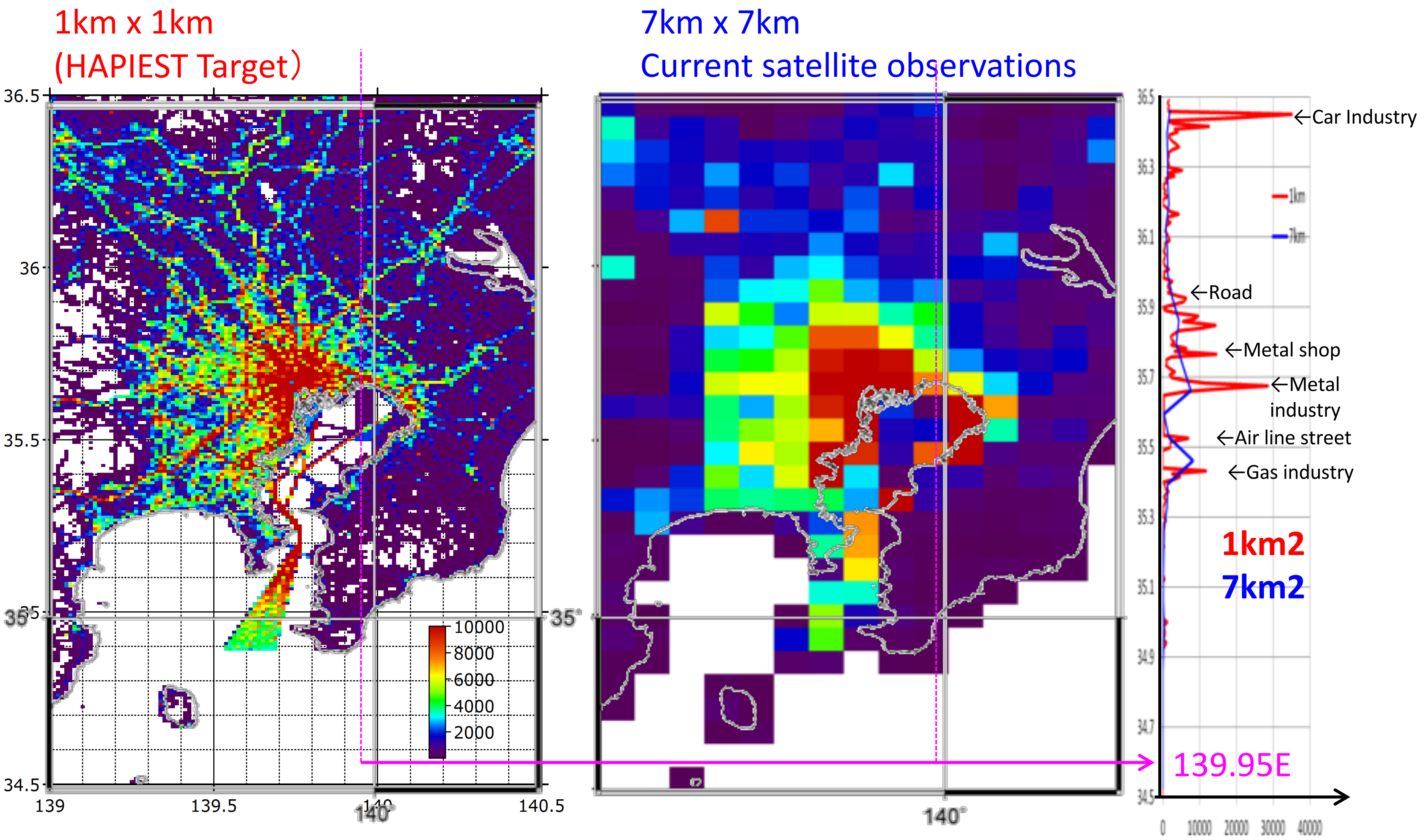
Optimal Satellite data(mini satellites constellation)
For 1x1km order air quality observation

New optimal satellite observations

Fukuoka Distribution of Air Quality Health Index：AQHI

$$AQHI = \left(\frac{1000}{10.4}\right) \times [(e^{0.000537 \times O_3} - 1) + (e^{0.000487 \times PM_{2.5}} - 1) + (e^{0.000871 \times NO_2} - 1)]$$

HAPIEST project: Health care Assist by air PollutIon ESTimation



NOx emission data by Kannari et al.,EAGrid2000, JCAP

Status of Model Simulation

Plan of the air pollution prediction system for Fukuoka City

Using the Stretch NICAM-Chem

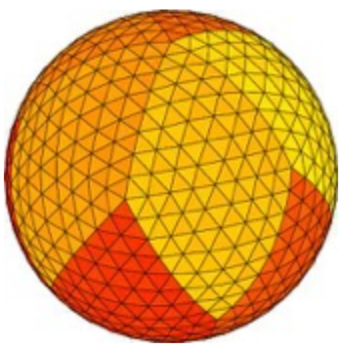
[Goto et al., 2015]

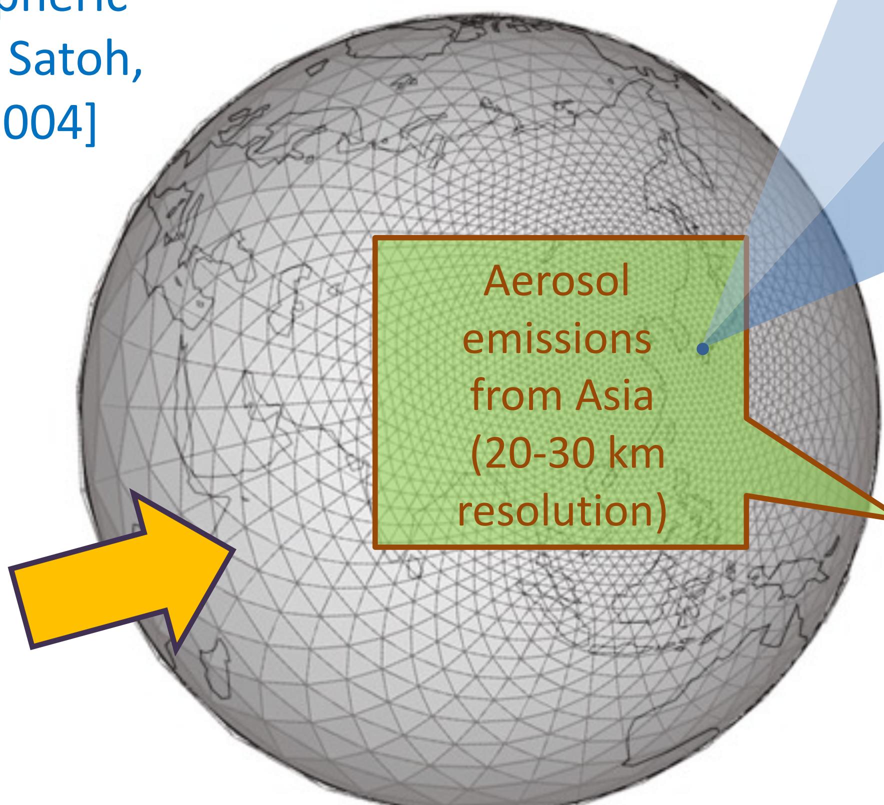
NICAM: Nonhydrostatic ICosahedral Atmospheric Model [Tomita and Satoh, 2004; Satoh et al, 2004]

Scalable simulation: covering global and also with a few km resolution at the target place, with smaller calculation resources

Fukuoka City

(a few km resolution)

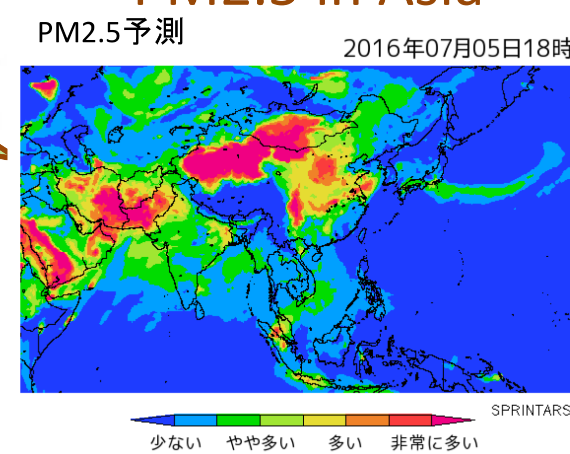




Outside Asia: Put climate parameters monthly

[Stretch grid coordinate：Tomita, 2008]

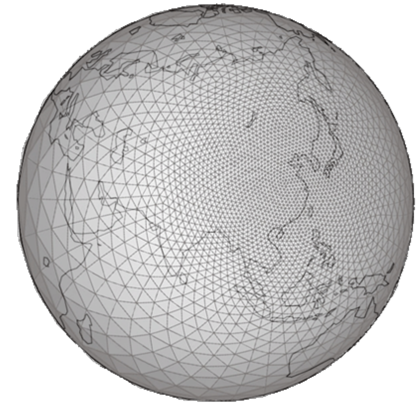
PM2.5 in Asia



[SPRINTARS, Kyushu Univ.]

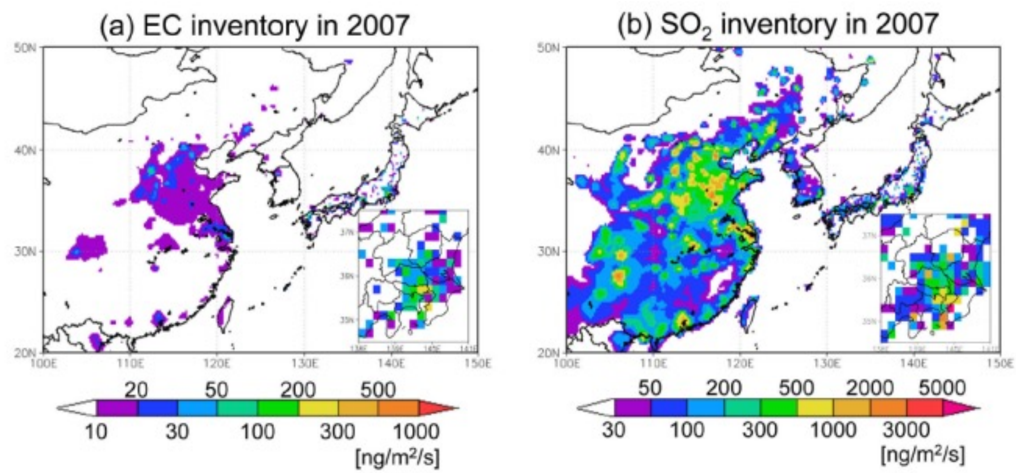
Achievements of the Stretch NICAM-Chem

[Goto et al., 2015]

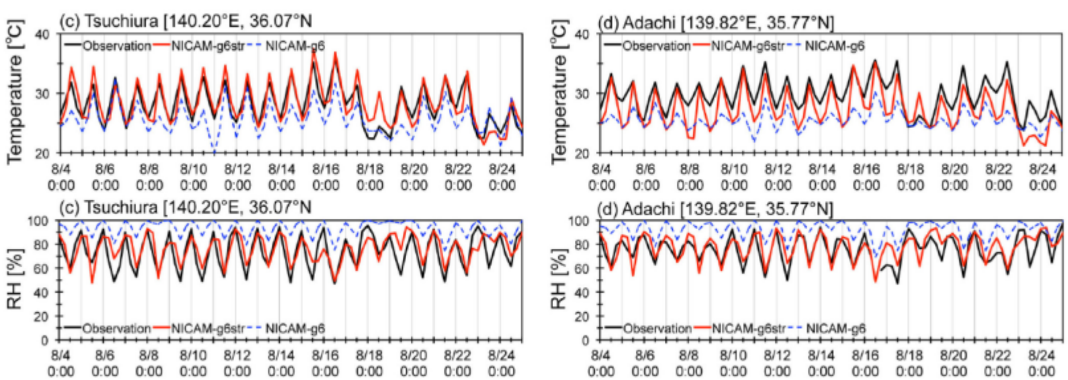


- glevel=6, stretch ratio=100
(minimum horizontal resolution of ~11km around Tokyo [140°E, 35°N])
- Aerosol model (SPRINTARS) [Takemura et al., 2000 and later] has been implemented.
- Very well validated
by the observations.

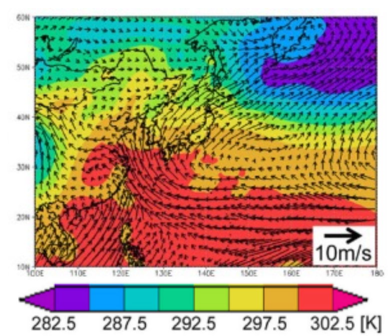
EC: elemental carbon



2m temperature and relative humidity

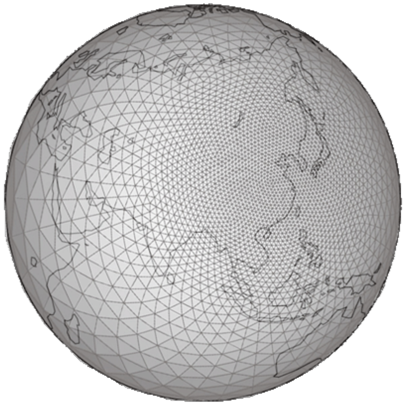


Surface temperature and wind velocity



Demonstration of the ~5km horizontal resolution simulation on/around Fukuoka

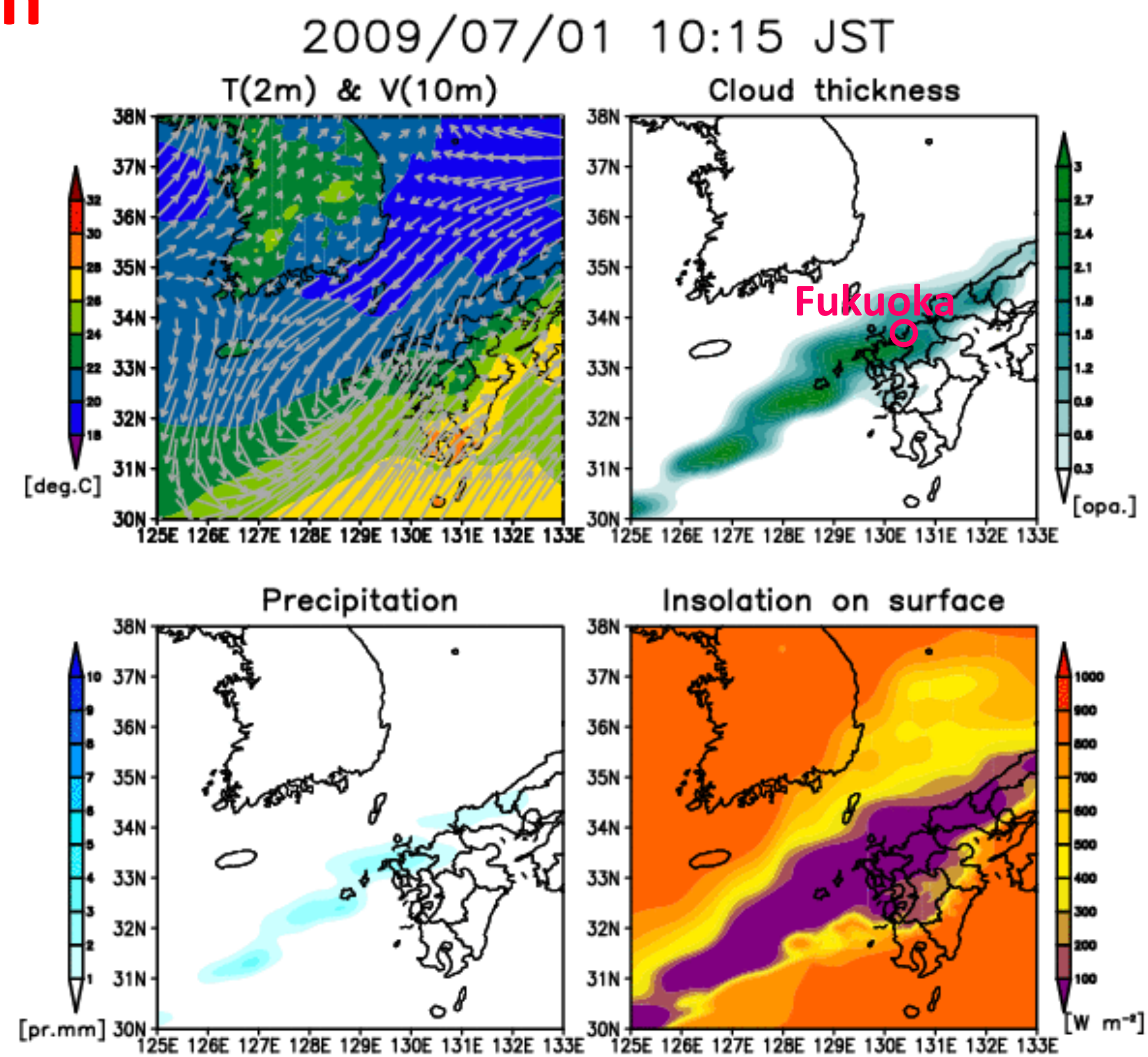
- Stretch NICAM-Chem (with SPRINTARS) with **glevel=7, stretch ratio=100** (minimum horizontal resolution of **<u>~5.5km</u>**)
- Minimum horizontal resolution is centered at 127°E, 31°N.
- 11-hour simulation from 2009/07/01 0:00 UTC (9:00 JST) using the NCEP FNL dataset as the initial state
- Forward run from the initial state (no nudging of atmospheric data during the run)
- Calculation time step of 3-10 seconds



127°E, 31°N [Google map]

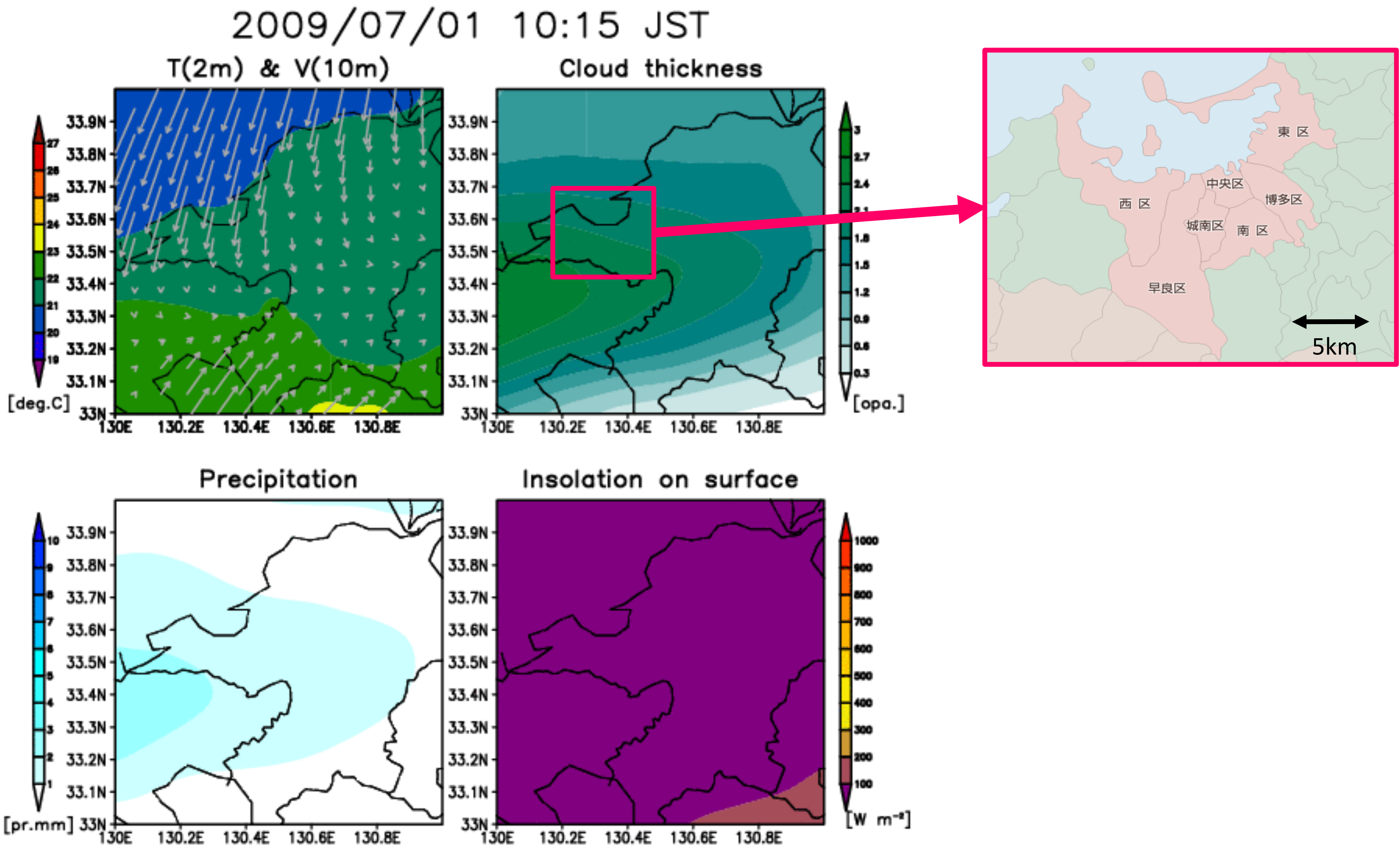
Demonstration of the ~5km horizontal resolution simulation on/around Fukuoka

Animation



Demonstration of the ~5km horizontal resolution simulation on/around Fukuoka

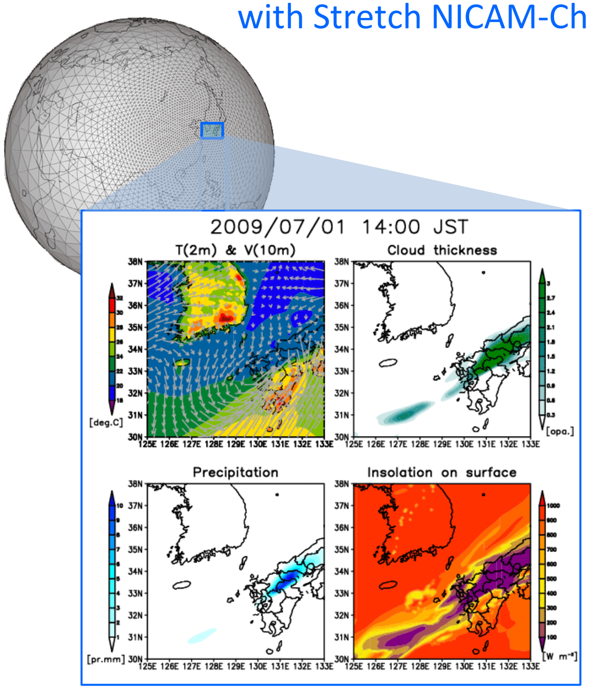
Animation (focused in Fukuoka Pref.)



Future plan: Stretch global simulation for prediction

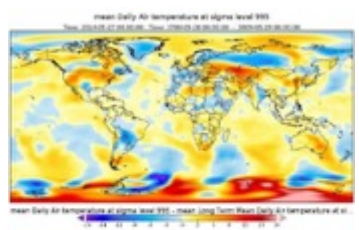
- Simulation of aerosol/oxidant distributions in/around Fukuoka City with Stretch NICAM-Chem with SPRINTARS module (nudging the recent climate data of NCEP/FNL, 2014-2016)
- Comparison with observational data (Himawari 8, NASA/CALIPSO) and assimilation →Feasibility study of prediction, with ~5 km horizontal resolution and 2-3 days in advance

Simulation in/around Fukuoka
with Stretch NICAM-Chem

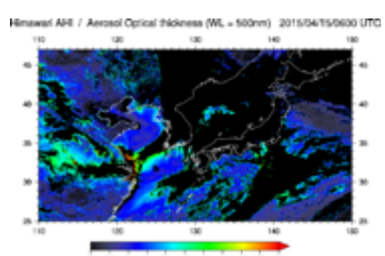


+

NCEP/FNL
climate data



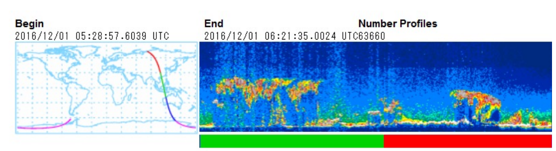
Himawari 8
aerosol distribution

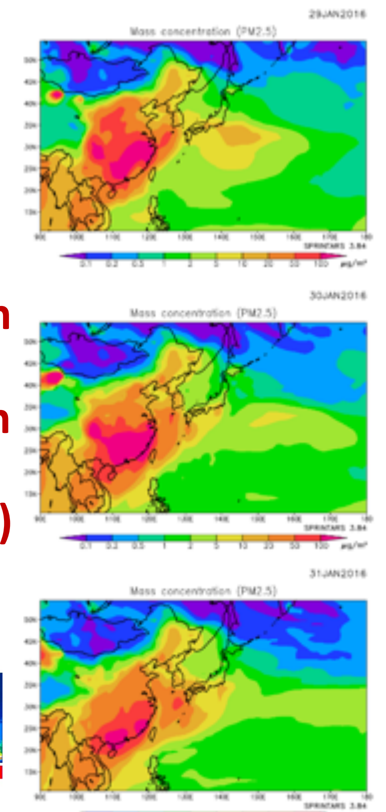


Day-mean PM2.5 distributions
in 29-31 January 2016
(SPRINTARS, Kyushu Univ.)
which can't be higher than
~35km horizontal resolution

Try the prediction of aerosol distributions with higher horizontal resolution (~5km)

NASA/CALIPSO





A concept of mini-satellite for air quality observation

- a possibility after the GEMS satellite-

Mission Concept

Mission concept: A microsatellite with high horizontal resolution

Scientific requirement

Products	Standard: NO_2,O_4
Detection limit (**NO_2 total column density**) [molecules/cm^2]	**3.0×10^{15} (5%)** (about 0.6ppb in boundary layer)
(ex) Tropospheric NO_2 column amount [molecules/cm^2]	6.0×10^{16} (Boundary layer 4.7×10^{16})
IFOV	1 km x 1km (2 km x 2 km)
Vertical resolution	Tropospheric column
Swath width	approx. 200 km

In this study, we performed a feasibility study for observation precisions of NO_2

→Synthetic spectra are calculated using SCIATRAN (RTM) with two geometries.

→Slant column densities (SCDs) are derived by DOAS method and converted to vertical column densities (VCDs) by division with air mass factor (AMF) derived from SCIATRAN.

Instrumental parameters in this study

These parameters made with A. Kuze (JAXA)

Setup of each parameter

Parameters	The number of parameters	Elements of parameters
Wavelength range	2	Reference : 425 -450 nm(conventional region) 460-490 nm
Area	2	Seoul (as polluted area) Hokkaido (as clean area)
Season	1	Winter(Jan.)
Altitude of satellite	1	300 km
Spectral resolution (FWHM)	1	0.4 nm
Sampling step	1	0.1 nm
Detector size	1	0.064 mm
Aperture size	1	0.74 cm
Read noise	1	10 e
IFOV	2	1 x 1 km^2 2 x 2 km^2

Error analysis

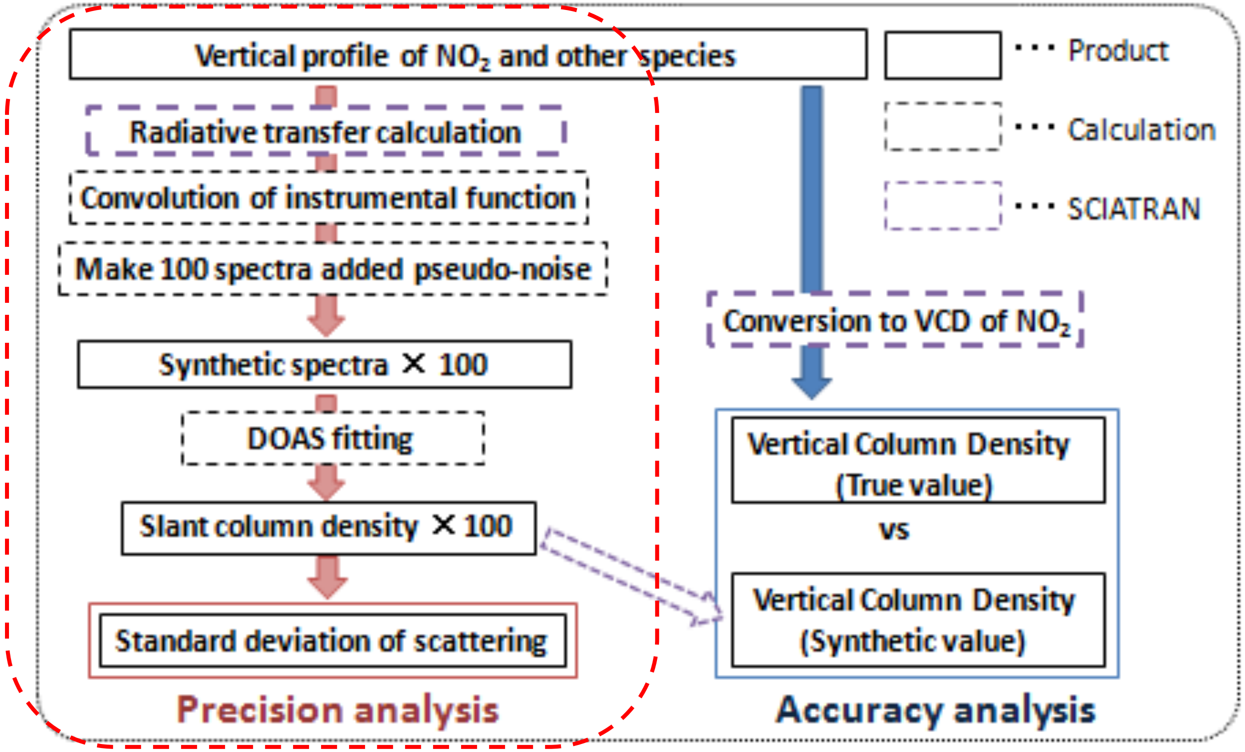
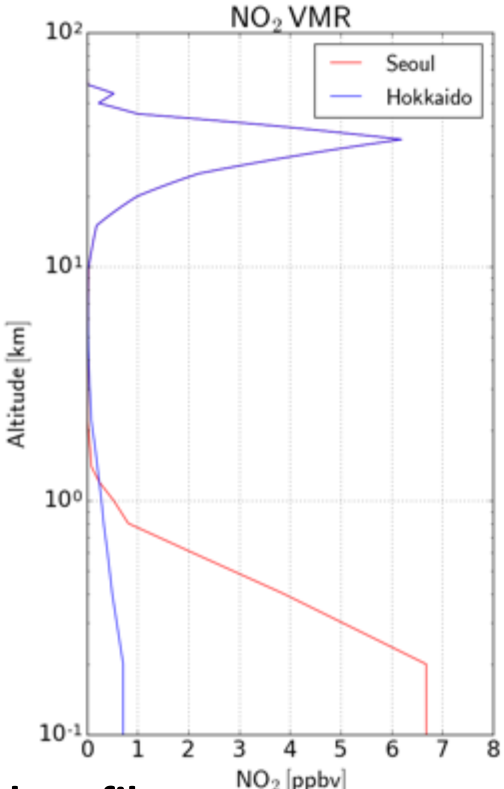


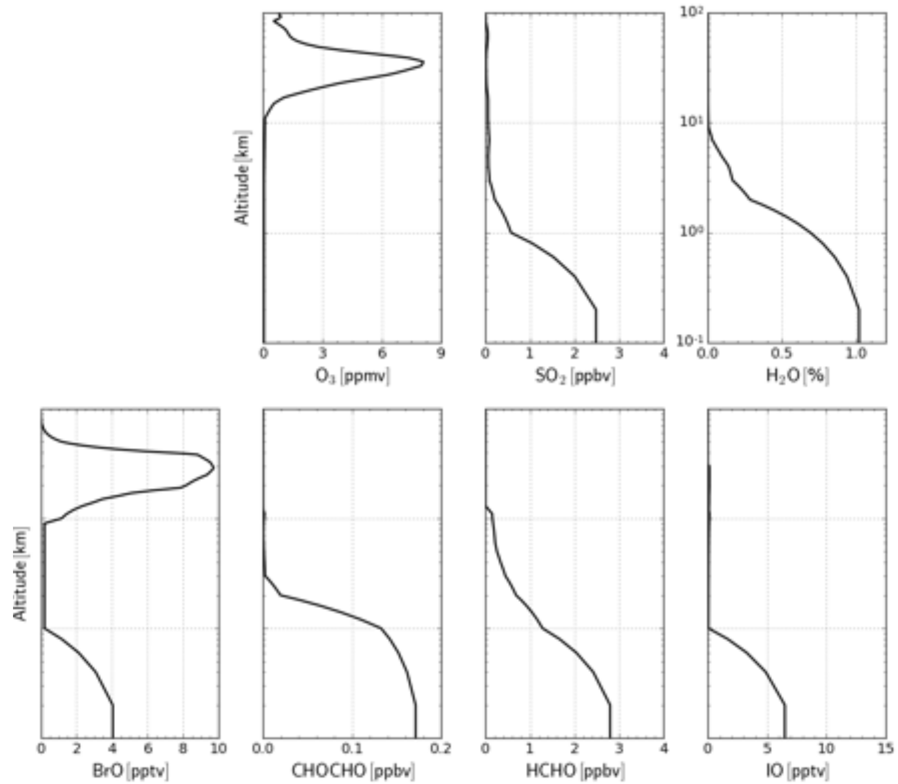
Fig. Flow of algorithm for estimation of precisions and accuracies of retrieved NO_2 (*Noguchi et al.*, 2011)

Precision analysis :

- Prepare the vertical profile of NO_2 and the other species as input data into RTM (SCIATRAN)
- Convolute with Gaussian slit function and make 100 spectra added the pseudo-noise
- Conduct DOAS fitting and retrieve SCDs from each spectrum
- Estimate precisions of retrieval NO_2 column as 1σ standard deviation of 100 SCDs.

Input profile data - preparation of vertical profile





<u>NO_2 vertical profile</u>

<u>Troposphere</u> : surface – 10 km CHASER model, monthly mean, Jan. 2005 (2.8 ×2.8° gridded cell)

<u>Stratosphere</u> : 10 km – 100 km SOCRATES model , annually mean (from *Aeronomy of the middle atmosphere ver.2* by *G.P. Brasseur and S. Solomon*)

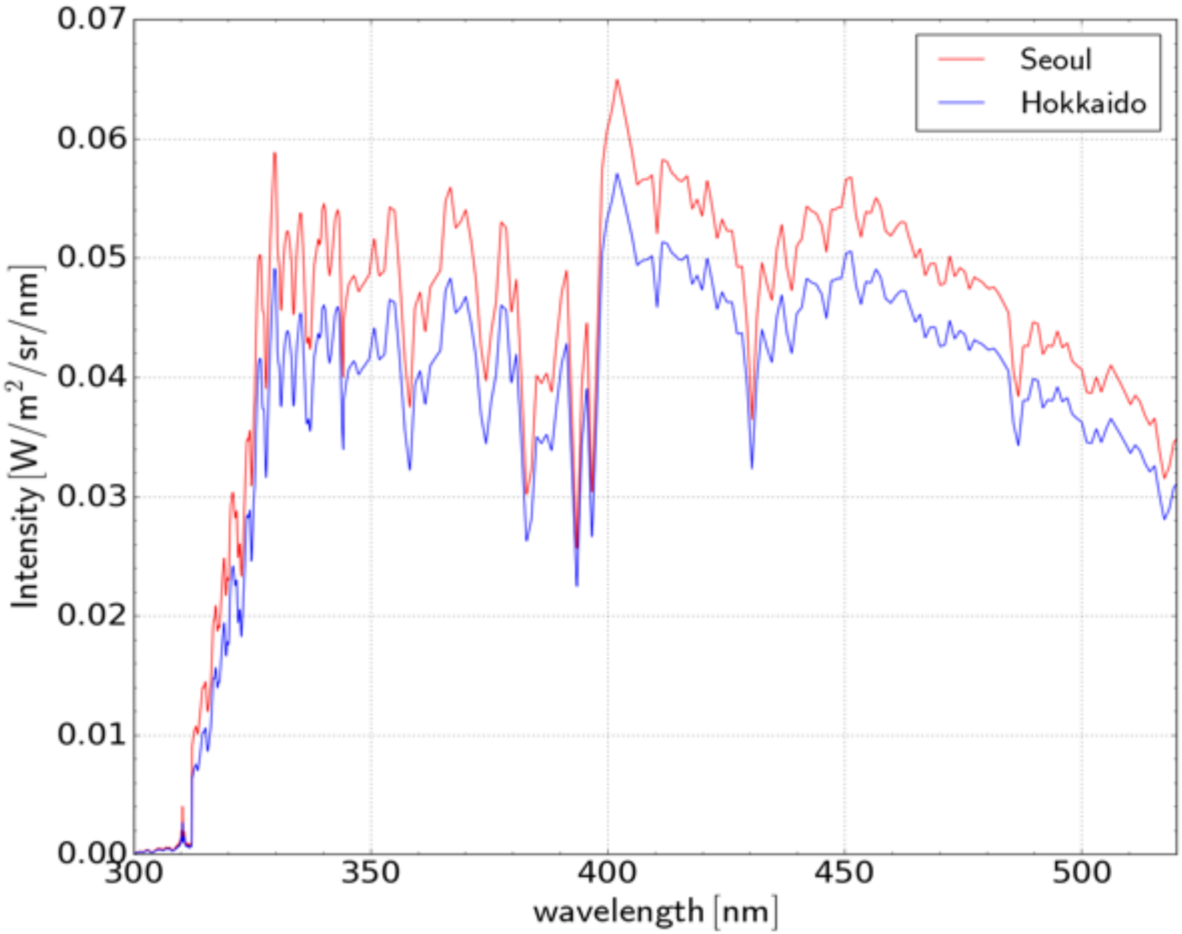
<u>Other gases</u>

Provided by GMAP-Asia science team (*Noguchi et al*., 2011)

<u>Pressure, Temperature</u>

U.S. standard atmosphere

Results - Synthetic spectra from SCIATRAN



・This figure shows a example of radiance spectra at 300 km of altitude by SCIATRAN.

・Spectra convolved with Gaussian slit function with an FWHM of 0.4 nm were plotted in steps of 0.1 nm.

・The radiance at Seoul was larger than that at Hokkaido because SZA assumed at Seoul in this simulation was lower than that at Hokkaido.

Expected SNRs for each IFOV case

SNRs expected in each wavelength and spatial resolution

Wavelength [nm]	Spatial resolution [km^2]	Expected SNR (Electronics)	Expected SNR (Shot)	Dark current SNR	Expected SNR (all)
480 (460 - 490)	**1x1**	1642	691	2806	**621**
	2x2	9287	1954	11222	**1885**
450 (425 - 450)	**1x1**	1411	620	2518	**554**
	2x2	7983	1753	10073	**1688**

・We assumed that the detector was Si-CMOS 2D array sensor and the optical efficiency and quantum efficiency was 0.43.

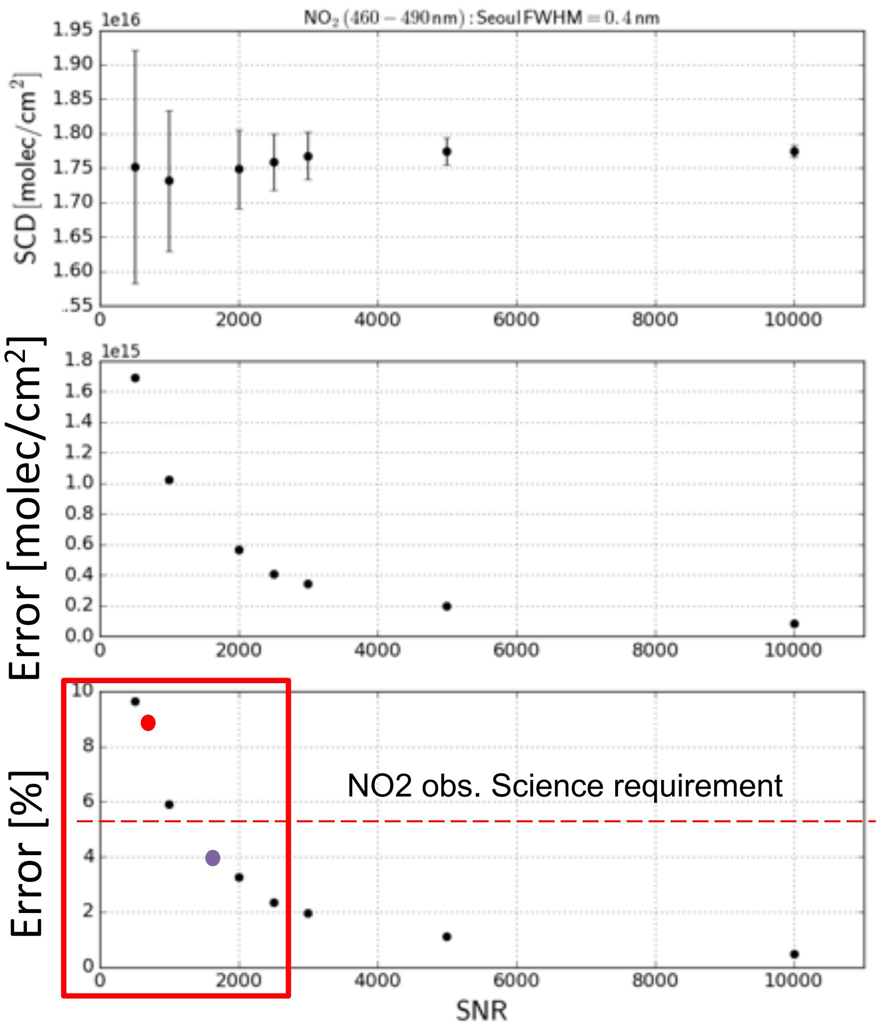
・In both cases of wavelength, expected SNRs of 2 x 2 km^2 became about three times larger than them of 1 x 1 km^2.

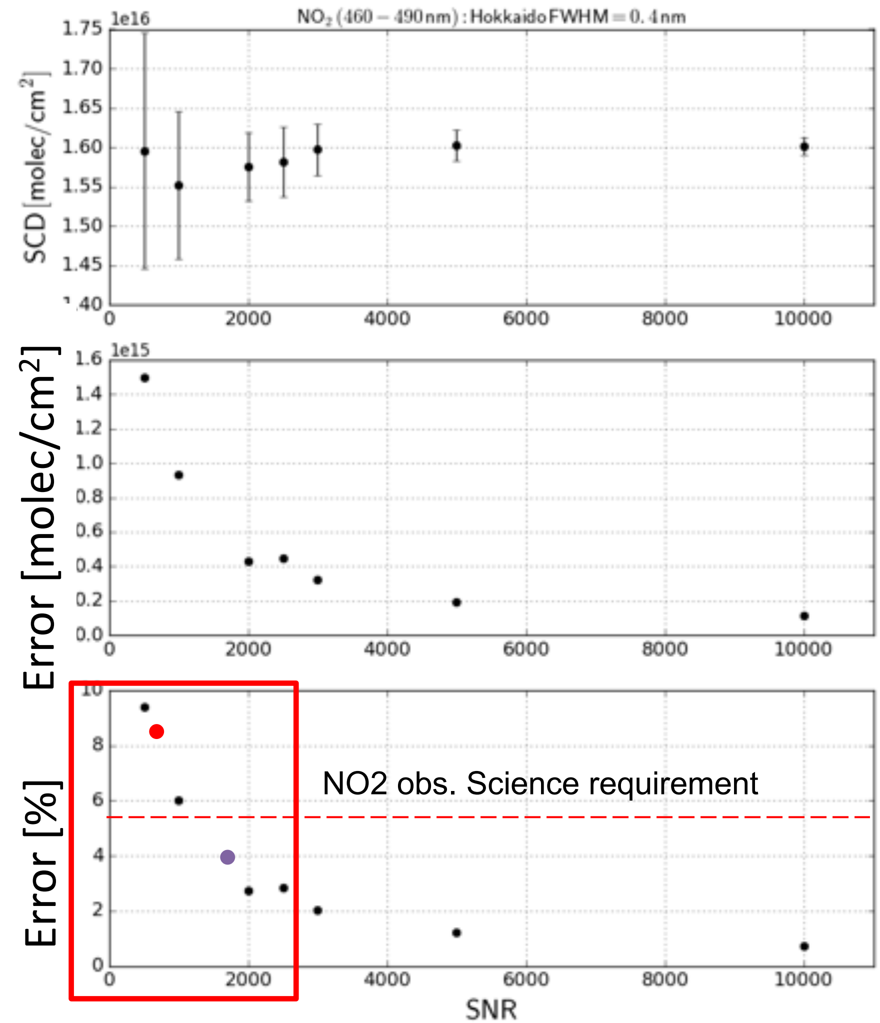
NO2 observation error vs Instrumental SNR

Winter (Jan.), Alt. of satellite = 300 km, FWHM = 0.4, 460-490 nm, Δλ =0.1 nm

Left : Seoul

Right : Hokkaido





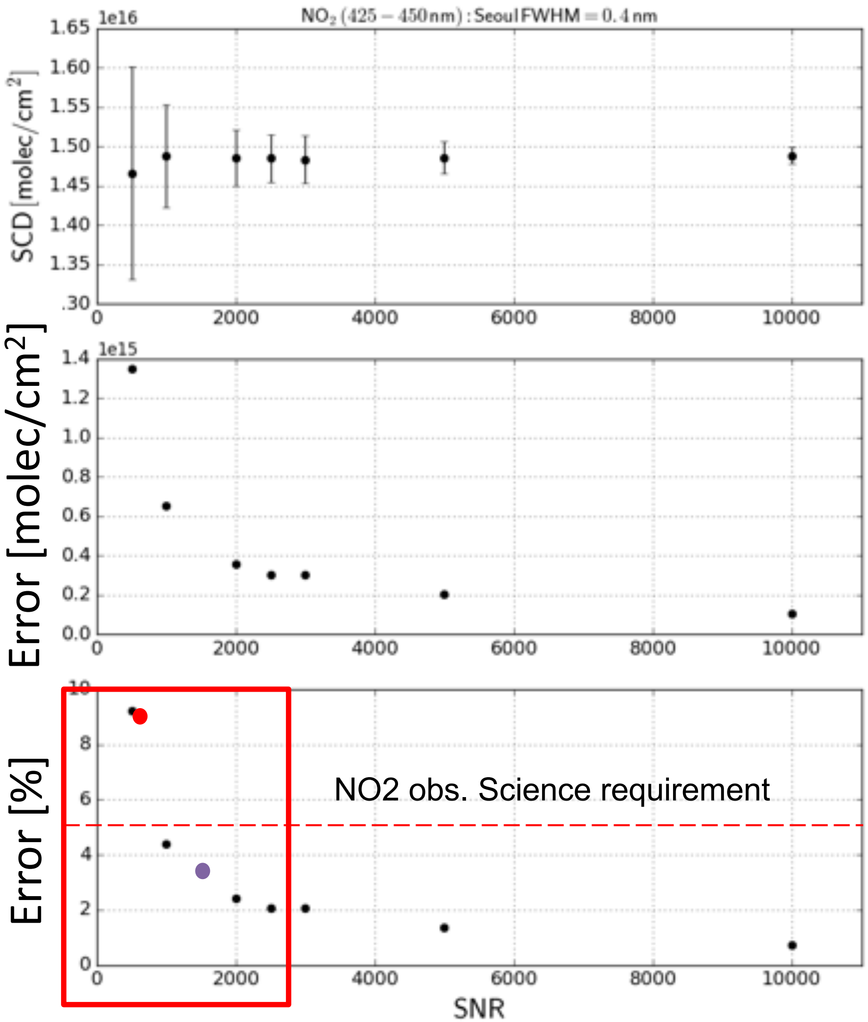
1x1 km^2 → SNR=621 @ 480 nm (red), 2x2 km^2 → SNR=1885 @ 480 nm (purple)

Upper figure : SCD (total = tropo. + strato.), Middle figure : Error [molec/cm^2], Lower figure : Error [%]

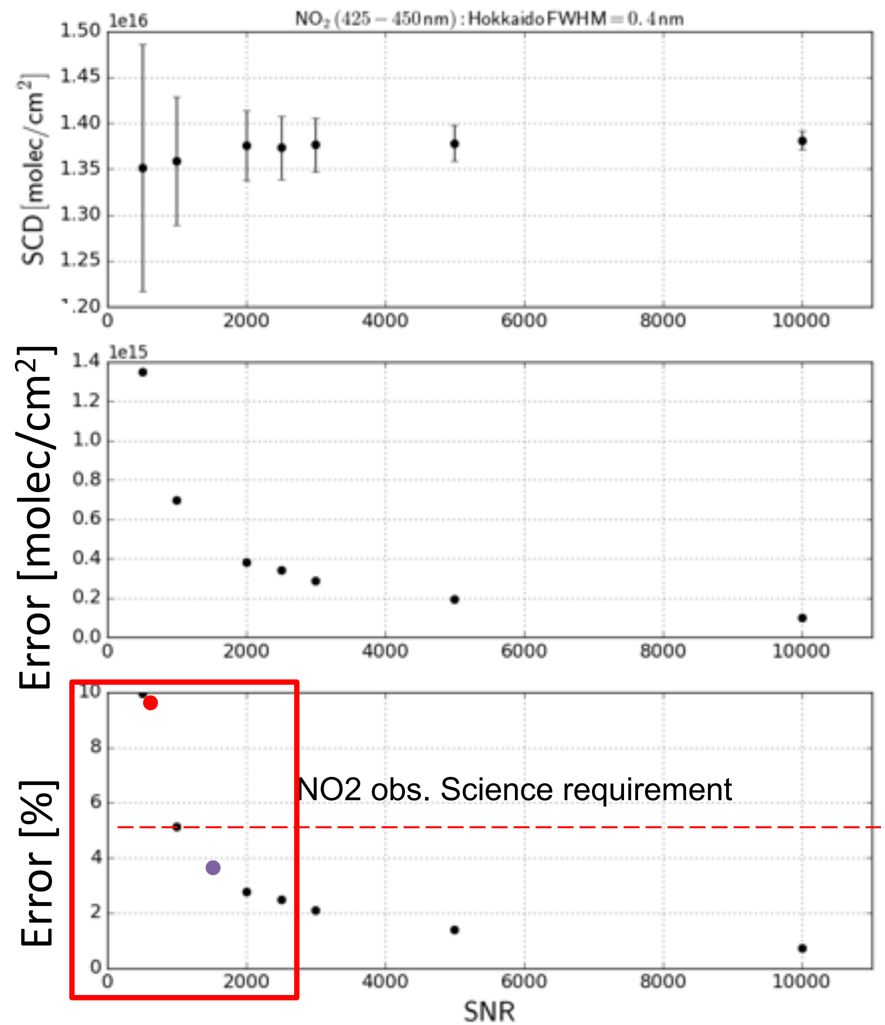
NO2 observation error vs Instrumental SNR

Winter (Jan.), Alt. of satellite = 300 km, FWHM = 0.4, 425-450 nm, Δλ =0.1 nm

Left : Seoul



Right : Hokkaido



1x1 km^2 → SNR=554 @ 450 nm (red), 2x2 km^2 → SNR=1688 @ 450 nm (purple)

Upper figure : SCD (total = tropo. + strato.), Middle figure : Error [$molec/cm^2$], Lower figure : Error [%]

Summary for instrumental feasibility study

- Instrumental SNR is better for 460 – 490 nm than 425 – 450 nm. This difference is critical for the choice of 1x1 km^2 / or 2x2 km^2 resolution.

- Spatial resolution of 1x1 km^2, NO2 total column error 6%, provided SNR about 500 is feasible with 460 – 490 nm setup.

HAPIEST project: Health care Assist by air PollutIon ESTimation

A Pollution prediction system in Fukuoka, Kyushu, Japan

Thank you very much for your attention!
We are happy for any international collaboration ☺
ykasai@nict.go.jp

Satellite data sets
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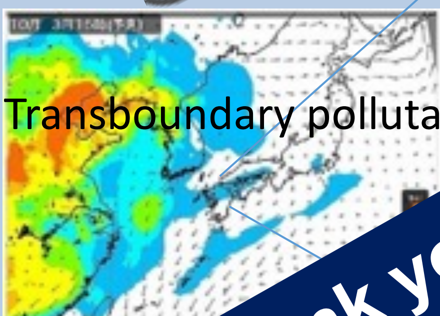
GEMS

Other datasets
(Soramame, Sky-net, DOAS, Lidar etc)



M-Chem
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Optimal Satellite data(mini satellites constellation)
For 1x1km order air quality observation

New optimal satellite observations

Fukuoka Distribution of Air Quality Health Index：AQHI

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