中国科学院遥感与数字地球研究所
Institute of Remote Sensing and Digital Earth ,CAS

Environmental trace gas Monitoring Instrument (EMI) Onboard the GaoFen-5 satellite

Liangfu CHEN, Jianbin GU, Yapeng WANG, Liangxiao CHENG, Huanhuan YAN
State Key Laboratory of Remote Sensing Science, RADI/CAS, Beijing 100101, China

Cheng LIU
School of Earth and Space Sciences, University of Science and Technology of China, Hefei 230026, China

CEOS AC-VC-14
College Park, MD, USA
2-4 May 2018

AC-VC / CEOS

The Atmospheric Composition Virtual Constellation (AC-VC) of the Committee on Earth Observation Satellites (CEOS) strives to coordinate existing and future international space assets and to bring about technical/scientific cooperation and collaboration among space agencies

Key parameters of the Geo-AQ missions GEMS, Sentinel-4, and TEMPO

	GEMS	Sentinel-4	TEMPO
Orbit	Geostationary	Geostationary	Geostationary
Domain	Asia-Pacific	Europe and surrounding	North America
Revisit	1 hour	1 hour	1 hour
Status	update	Detailed Design Phase, CDR completed	update
Host satellite	GEO-KOMPSAT-2B	MTG-S	TBD
Expected Launch	2019	2021 (Flight Acceptance Review first instrument)	No earlier than 11/2018
Payload	UV-Vis 300-500 nm	UV-Vis-NIR 305-500, 750-775 nm	UV-Vis 290-490, 540-740 nm
Key Products	O_3, NO_2, SO_2, HCHO, CHOCHO, aerosol	O_3, NO_2, SO_2, HCHO, CHOCHO, aerosol	O_3, NO_2, SO_2, HCHO, CHOCHO, aerosol
Spatial Sampling	3.5 km N/S x 8 km E/W @38N	8 km x 8 km @45N	2.1 km N/S x 4.7 km E/W @35N
Nominal product resolution	7 km N/S x 8 km E/W @38N (gas), 3.5 km N/S x 8 km E/W @38N (aerosol)	8.9 km N/S x 11.7 km E/W @45N	8.4 km N/S x 4.7 km E/W or better @35N (with 100W orbit)
Notes	Synergy with AMI and GOCI-2 instruments w.r.t. aerosol and clouds.	Two instruments in sequence on MTG-S. Synergy with IR sounder on MTG-S w.r.t. O_3. Synergy with FCI imager on MTG-I w.r.t. aerosol and clouds.	GEO-CAPE precursor or initial component of GEO-CAPE. Synergy with GOES-R/S ABI w.r.t. aerosol and clouds.

Key parameters of the LEO missions Sentinel-5P, Sentinel-5, OMPS and EMI

	Sentinel-5P	Sentinel-5	OMPS	EMI
Orbit	Low-Earth	Low-Earth	Low-Earth	Low-Earth
Domain	Global	Global	Global	Global
Revisit	1 day	1 day	1 day	1 day
Status	Commissioning phase	PDR completed	Operational	
Host satellite	Free flyer with only one instrument	MetOp-SG	Suomi-NPP and JPSS series	GaoFen-5
Expected Launch	Launched in October 2017	2021 (Flight Acceptance Review first instrument)	2011 (Suomi-NPP), 2017 (first JPSS)	May, 2018
Payload	UV-Vis-NIR-SWIR 270-500, 675-775, 2305-2385 nm	UV-Vis-NIR-SWIR 270-500, 685-773, 1590-1675, 2305-2385 nm	0.3-0.38 µm (nadir mapper), 0.25-0.31 µm (nadir/limb profiler)	UV-Vis 240-315,311-403、401-550、545-710nm
Key Products	O_3, NO_2, SO_2, HCHO, CO, CH_4, aerosol, spectral UV solar irradiance	O_3, NO_2, SO_2, HCHO, aerosol, CO, CH_4, aerosol,	O_3, NO_2, SO_2, aerosol (nadir mapper), O_3 (limb)	O_3, NO_2, SO_2, HCHO aerosol
Spatial Sampling	28x7 km^2 in the UV-1, 3.5x7 km^2 in the UV-2 to NIR, 7x7 km^2 elsewhere, @nadir	7 km x 7 km @nadir	50 km (mapper), 250 km (profiler), @nadir	48 km x 13 km @nadir
Nominal product resolution	See above	7 km x 7 km @nadir	50 km (mapper), 250 km (profiler), @nadir	
Notes	In formation with S-NPP for synergy w.r.t. clouds and O_3.	Three instruments in sequence on MetOp-SG. Synergy with IR sounder and with imager on same platform.		

EMI on board GF-5 and GF-5 02/03

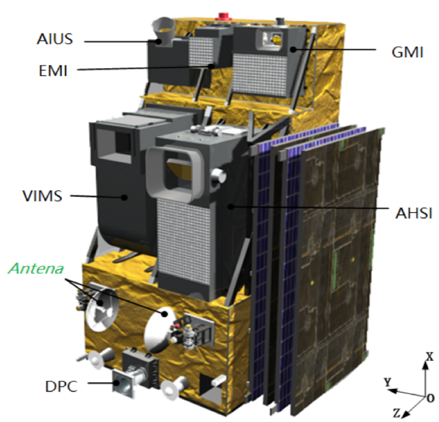
Expected mission lifetimes of the Geo-AQ missions (red) and the complementing LEO missions (blue)

Year [20**]	15	16	17	18	19	20	21	22	23	24	25	26	27	28	...
GEMS															
Sentinel-4															
TEMPO															
Sentinel-5 Precursor															
Sentinel-5															
OMPS															
EMI /GF-5				9th May				8 years							
EMI /GF-5 02	HazeSat					middle					>8 years				
EMI /GF-5 03	Atmospheric Environmental Sat					end of 2020					>8 years				

GF-5 Sat and EMI

- **GF-5 satellite will be launched on next Tuesday (9th May)**

Orbital Type	Sun synchronous orbit
Nominal orbital altitude	708.45km
Dip angle	98.218
Orbital flat period	98.805min
Eccentricity ratio	E<0.0001
Flight cylinder number every day	14.57
Orbital intercept	24.731
Local time of descending node	1:30



- Advanced Hyperspectral Imager (AHSI)
- Visual and Infrared Multispectral Sensor (VIMS)
- Greenhouse-gases Monitoring Instrument (GMI)
- Atmospheric Infrared Ultraspectral (AIUS)
- **Environment Monitoring Instrument (EMI)**
- Directional Polarization Camera (DPC)

Design specifications of EMI

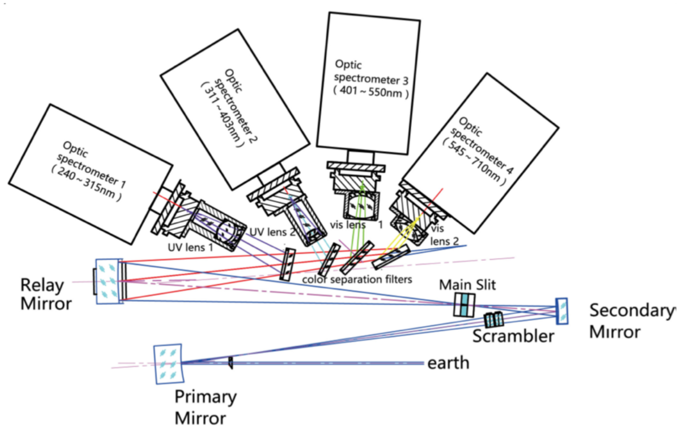
technical parameter	Technical index
Spectrum range	240－315nm、311－403nm、 401－550nm、545－710nm
SNR	>200@UV>312nm（Radiance=1.27μW/$cm^2 \cdot sr^{-1} \cdot nm^{-1}$） >2000@VIS（Radiance=10.89μW/$cm^2 \cdot sr^{-1} \cdot nm^{-1}$）
Spectral resolution	0.3-0.5nm
Radiometric calibration accuracy	absolute accuracy<5%，relative accuracy<3%
Spectral calibration accuracy	>0.05nm
Stray light	$<10^{-3}$
Work mode	Nadir push broom、calibration mode
FOV	114° （cross track）
Spatial resolution	48km（perpendicular to track）×13km（along track） 8km × 13km(UV, binning factor 4) 12km × 13km(VIS, binning factor 4)
Digitalizing bit	14 bits
Bit rate	48Mbps

Outline

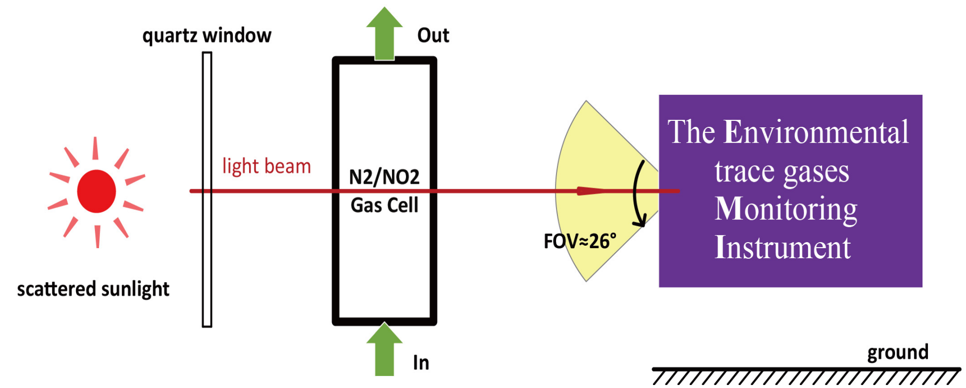
1. EMI Preflight Evaluation in AIOFM
2. L1b data flow map
3. L2 products retrieval algorithms
4. L2 products validation
5. Summary

1.Preflight Evaluation in AIOFM

- The preflight calibration phase is essential to characterize the properties and performance of the EMI in order to provide information for data processing and trace gas retrievals.
- Cheng Liu presented the first EMI measurement of NO_2 from a gas absorption cell using scattered sunlight as the light source by the differential optical absorption spectroscopy technique.
- The measurement was carried out in Anhui Institute of Optics and Fine Mechanics (AIOFM), Chinese Academy of Sciences, Hefei, China.



Optical layout of the EMI fore-optics system, and the Offner convex grating imaging spectrometer

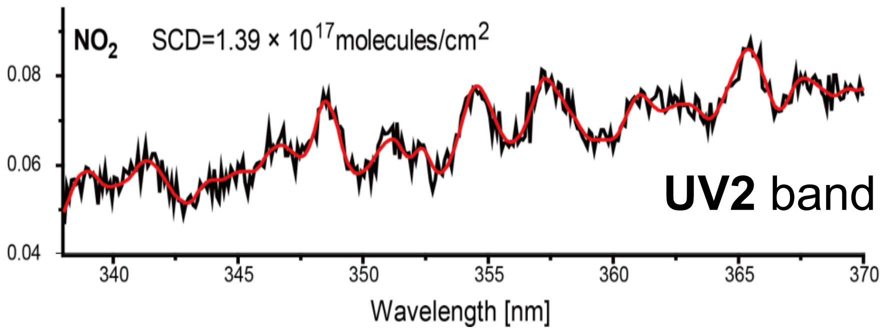


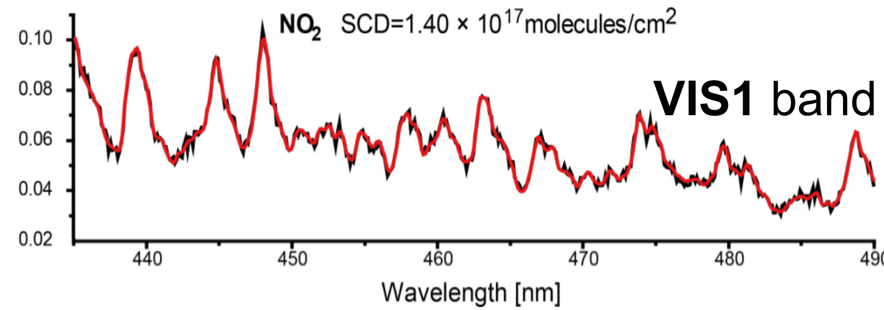
Schematic of the experimental setup

Zhang C. and C.Liu et al., 2018

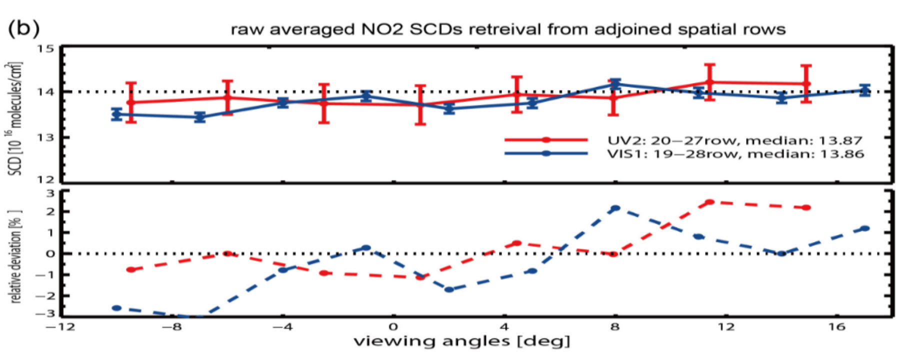
1.Preflight Evaluation in AIOFM

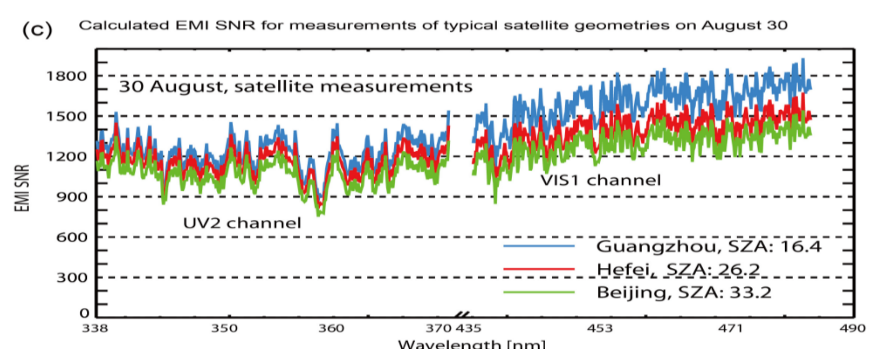
- The differences between measured and DOAS fit result were **smaller than 2%.**
- NO_2 SCDs(1.39±0.04)×10^{17}molecules/cm^2 in the UV2 band;(1.37±0.01)×10^{17} molecules/cm^2 in the VIS1 band.





- The differences among adjoining spatial rows was **less than 3%.**
- Based on the results, Liu concluded that the EMI is capable of measuring the global distribution of the NO_2 column with the retrieval precision and accuracy better than 3% for the tested wavelength ranges and viewing angles.





Zhang C. and C.Liu et al., 2018

2.1 L1b Data Flow Map: data receiving system

- A team from RADI is responsible for GF-5 satellite data receiving, there are four ground stations to receive the data, one locates in Kiruna space centre, Sweden.
- In China, all of the meterological satellites data was recieved by China Meterological Administration.

Kiruna Space Centre, Sweden

Data receiving system

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RADI
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2.2 L1b Data Flow Map: data pre-processing centre

中国资源卫星应用中心
中国航天 China Centre For Resources Satellite Data and Application

- China centre for resources satellite data and application is responsible for GF-5 satellite data pre-processing, and in-orbit calibration and data service.
- L1B data will be released to public and to Satellite Environment Center, Ministry of Environmental Protection.

Geometric calibration field

Radiation calibration field

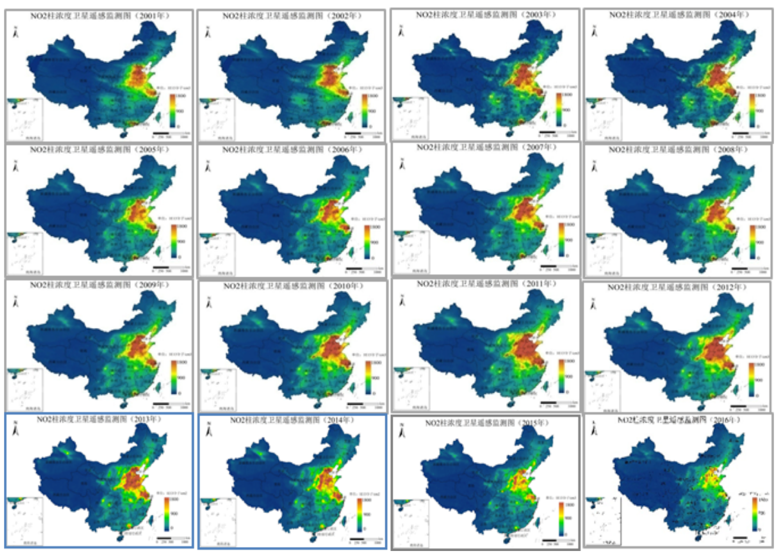
BRDF measuring instrument

2.3 L1b Data Flow Map: data application centre

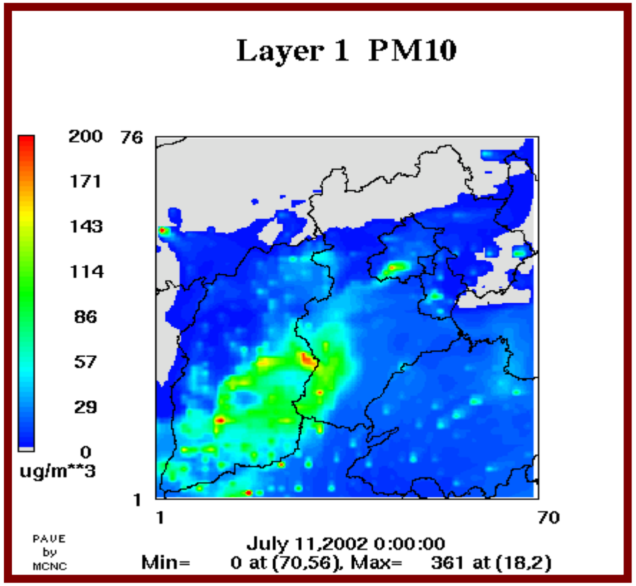
环境保护部卫星环境应用中心

Satellite Environment Center,Ministry Of Environmental Protection

- Satellite Environment Center, Ministry of Environmental Protection is the Primary user of GF-5 satellite in China.
- L2 products: SO_2, NO_2
- L2 products are opened to public



NO_2 products have been used to evaluate the effects of pollution control



To improve model forecast accuracy

ss.cn

2.4 L1b Data Flow Map: L2 product algorithms

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- My team members are responsible for the EMI L2 product algorithms, including O_3, SO_2, NO_2, BrO, HCHO, CHOCHO etc.
- L1 EMI data and L2 products
- L2 products validation activities

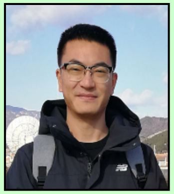

Zhang Ying


Zou Mingmin


Yu Chao

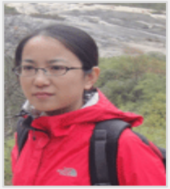

Yu Chao


Wang Yapeng


Cheng Liangxiao


Yan Huanhuang

Trace gases and GHG retrieval from satellite measurements


Tao Jinghua


Wang Zifeng


Fan Meng


Tao Minghui


Si Yidan


Wang Yang

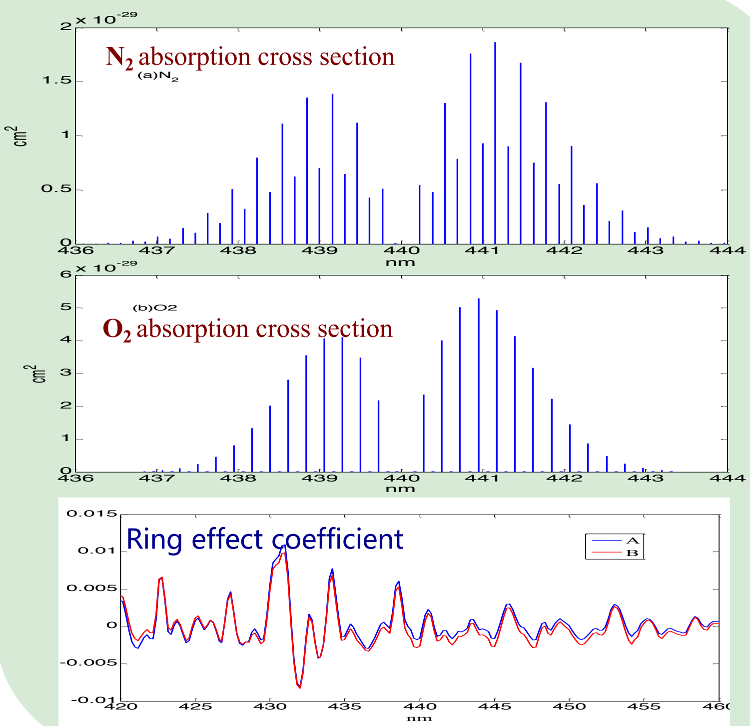
Aerosol optic depth, PM concentration, Particle component, Microphysics of particle

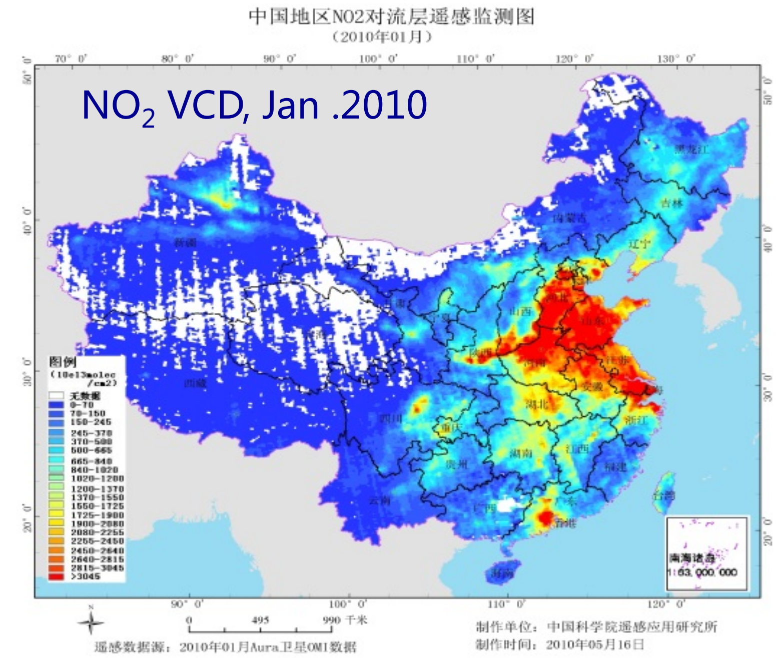
2.4 L1b Data Flow Map

3.1 EMI L2 product algorithms

- **NO_2 vertical column density retrieval**

- **Improving the accuracy of Ring effect calculation by applying a Convolution Method**
  （Convolution of solar spectrum and oxygen scattering cross section）
- **Greatly accelerating the calculation of Ring effect by using two fixed wavelengths**





Differential optical absorption spectroscopy (DOAS)

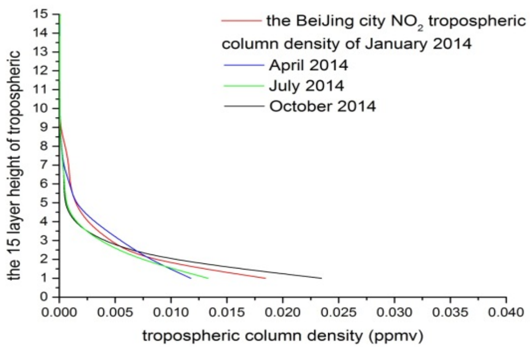
- Han Dong, Chen Liangfu, et al. A Convolution Algorithm of Differential Cross Sections of Ring Effect in Earth's Atmosphere Based on Rotational Raman Scattering, *Science in China Series D: Earth Sciences,* 2011(9) : 1407-1412.

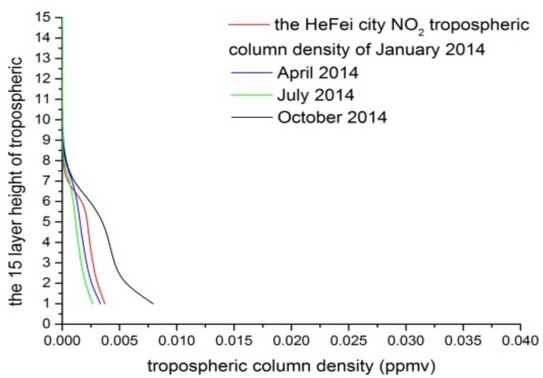
3.1 EMI L2 product algorithms

- **Surface NO_2 concentration**

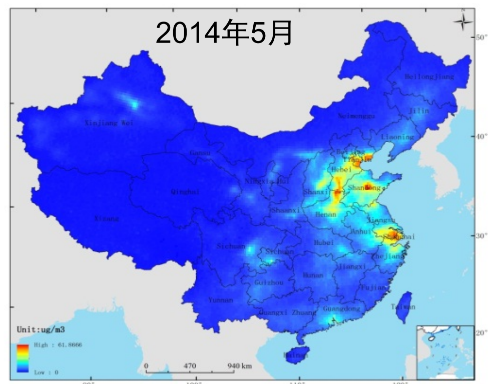
- The surface NO_2 concentration retrieved by assimilation of NO_2 vertical column density and profile from CMAQ model.

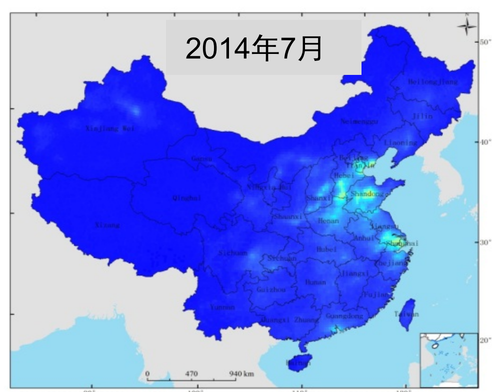
NO_2 profile from CMAQ



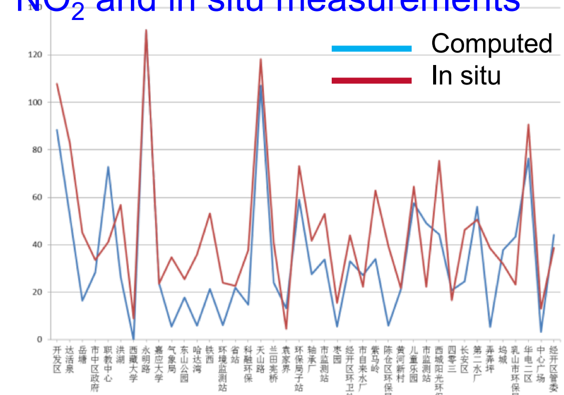


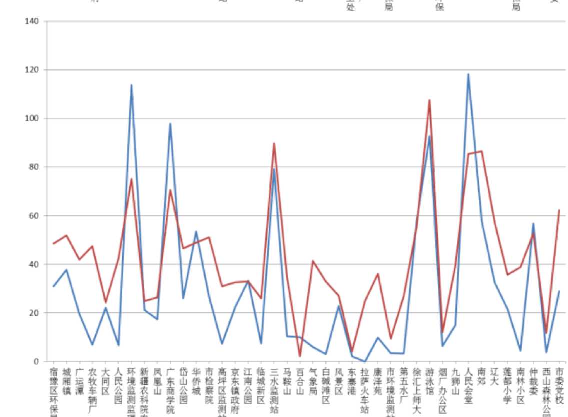
Surface NO_2 from OMI data





Comparison of retrieved surface NO_2 and in situ measurements



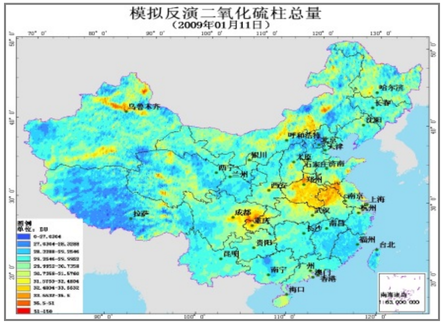


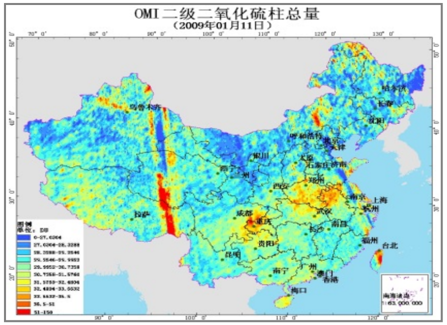
- Jianbin Gu, Liangfu Chen et al. 2017, Remote Sensing.

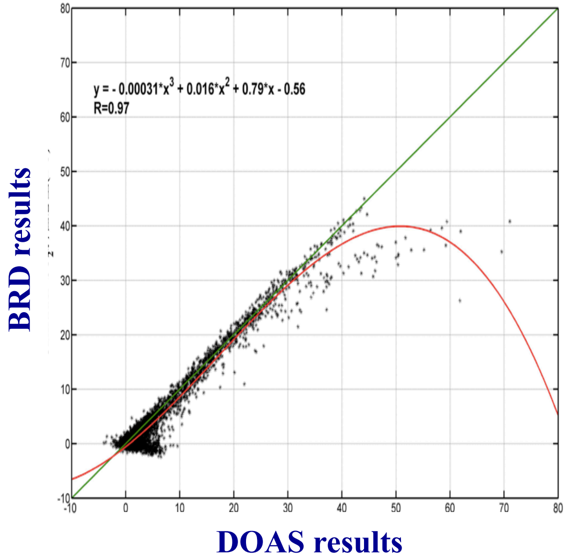
3.1 EMI L2 product algorithms

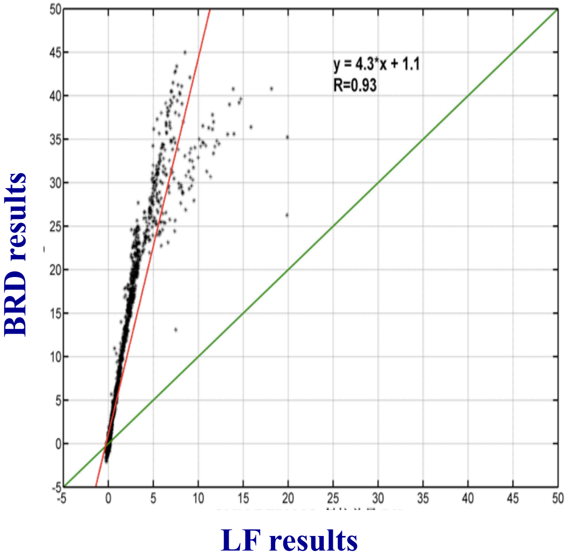
- **SO_2 vertical column density retrieval**

- **Retrieve SO_2 Vertical Column Density using multiple algorithms, including DOAS** (Eisinger and Burrows, 1998)**, BRD (band residual difference,** Krotkov et al., 2006) **and LF （Linear fit algorithm,** Yang et al., 2007) **methods**
- **Successfully correct OMI data row anomalies by comprehensively considering the ozone column and Lambertian effective reflectivity errors**





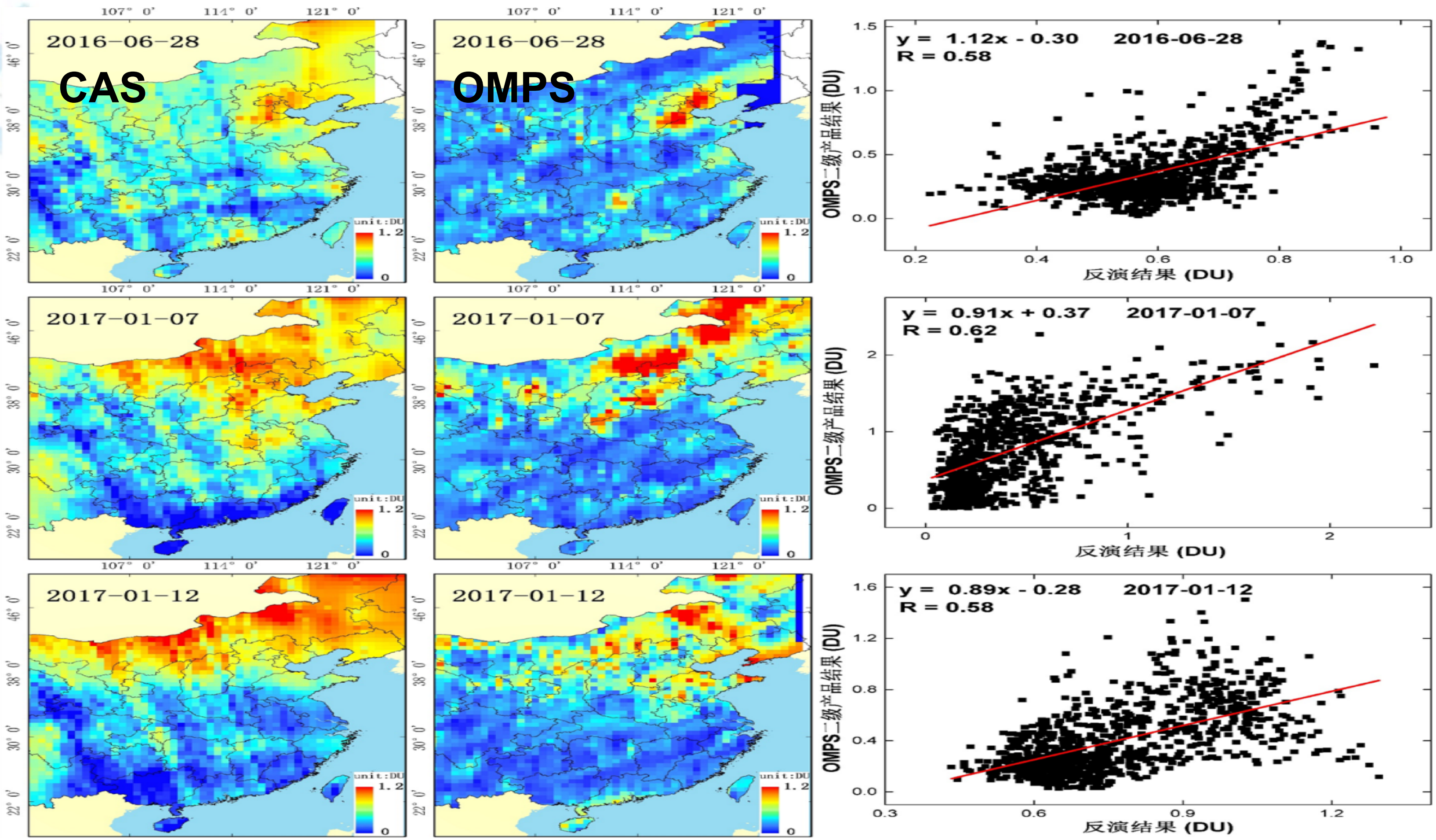




- H.Yan, L.Chen et al.(2012). Corrections for OMI SO_2 BRD retrievals influenced by row anomalies. ***Armos. Meas. Tech.***,5,2635-2646

3.1 EMI L2 product algorithms

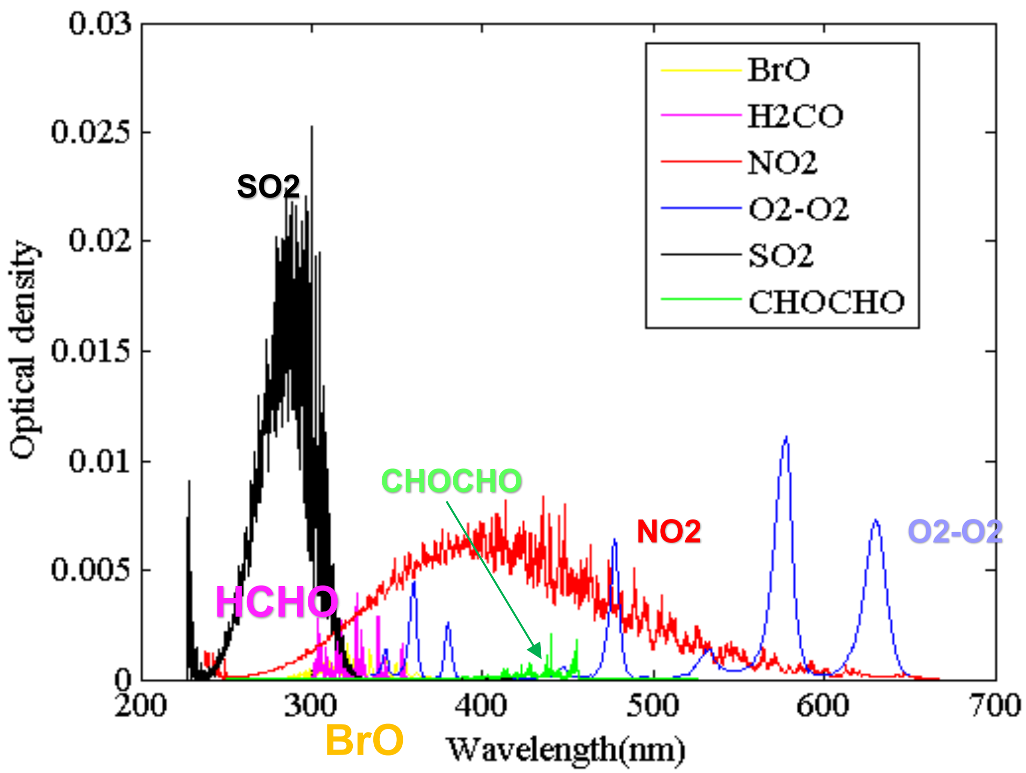
- SO_2 VCD comparison between our PCA algorithm product with OMPS L2 product



- **Better matched in High value area, Higher than OMPS product in some region, R = 0.58，0.62**
- Can Li,J.Joiner, N.A.Krotkov,and P.K.Bhartia,2013, *Geophysical Research Letters*

3.2 EMI L2 NMVOCs product algorithms

- **Trace gas cross sections(300-700nm)**



- **The O2-O2,BrO and HCHO absorptions cross section have correlation effects.Three steps are adopted**
  - **Step1:O_4 SCD**
  - **Step2:BrO SCD**
  - **Step3:HCHO SCD**

- **De Smedt et al., 2015**, *Atmos. Chem. Phys.*

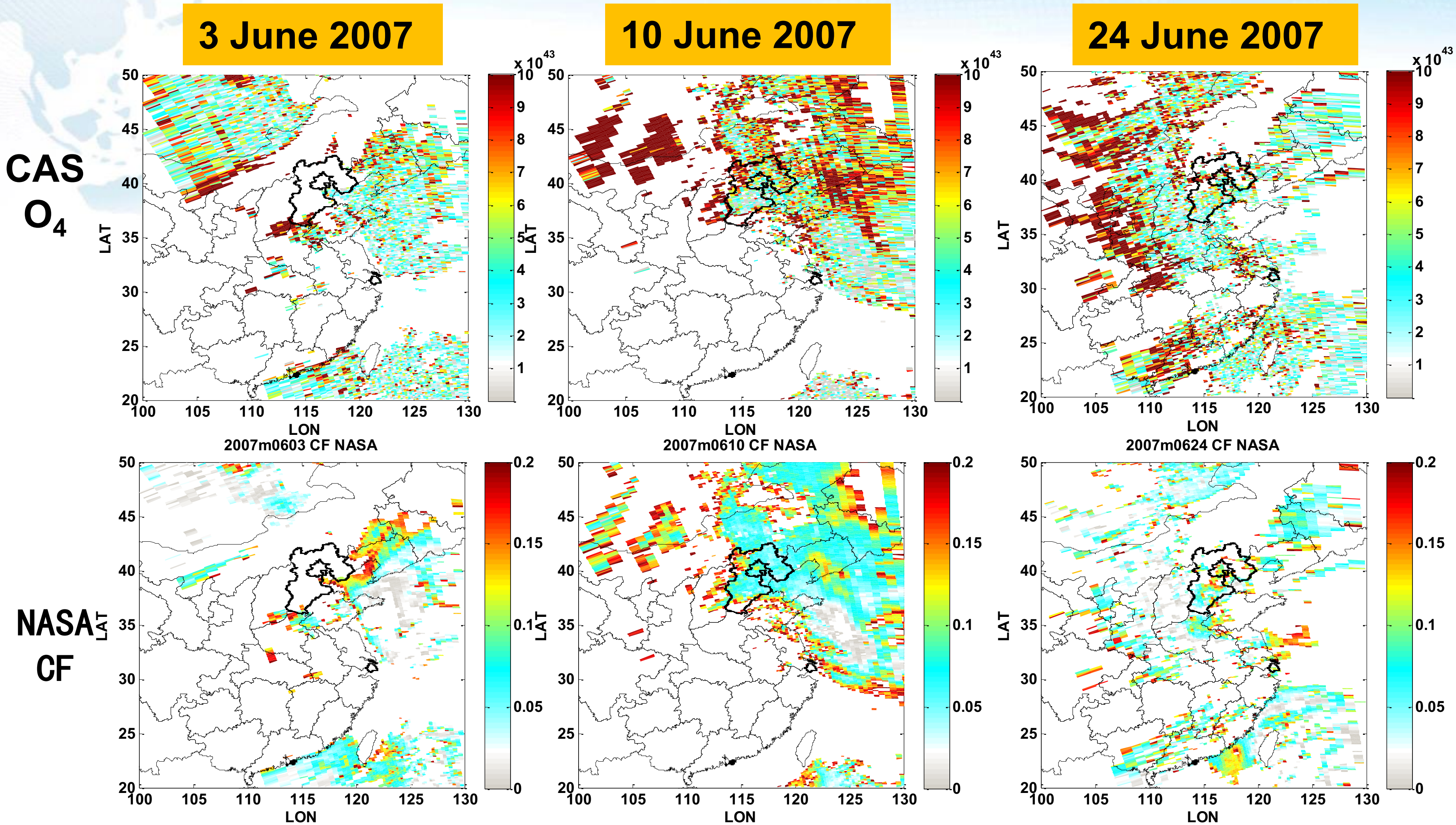
- **NO_2 optical density is much stronger than CHOCHO and their cross sections are overlapping**
  - **Step1:NO_2 SCD**
  - **Step2:CHOCHO SCD(not fitted NO_2)**

- **C. Chan Miller etc. 2014,** *Atmos. Meas. Tech*

EMI HCHO algorithm retrieval parameters

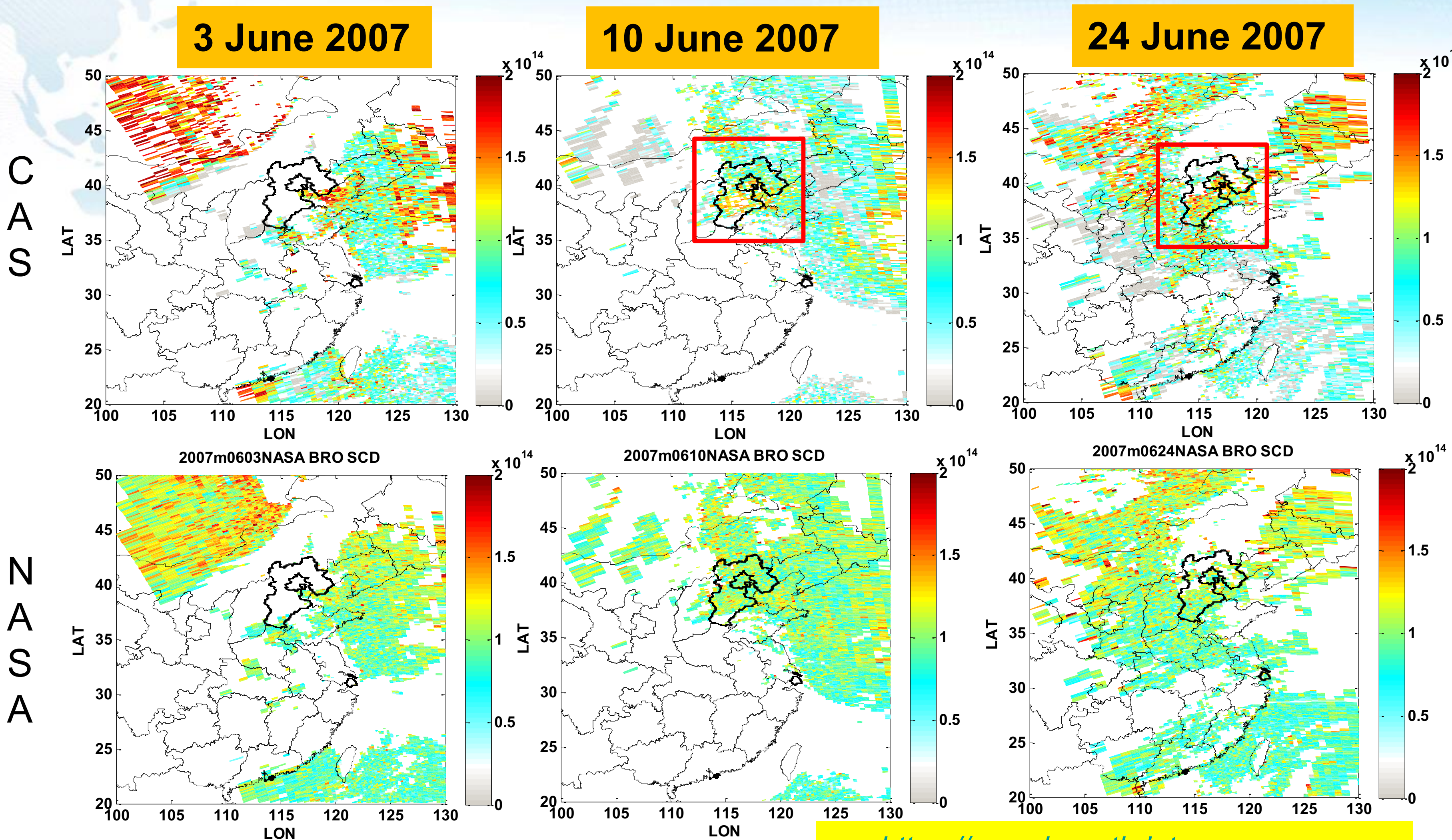
<table>
<tr><th>Parameters</th><th>O_4</th><th>BrO</th><th>HCHO</th></tr>
<tr><td>Fitting window</td><td>339-364 nm</td><td>328.5–359 nm</td><td>328.5-346 nm</td></tr>
<tr><td>Reference spectrum I_0</td><td colspan="3">Daily average of radiances, per row,
selected in a pacific region.(30° N-30° S)</td></tr>
<tr><td>Polynomial</td><td>5th- order</td><td>4th- order</td><td>3th- order</td></tr>
<tr><td rowspan="5">Included cross sections</td><td colspan="3">H_2CO (Chance and Orphal, 2011), 300K</td></tr>
<tr><td>O_3(Malicet et al., 1995), 228K</td><td colspan="2">O_3(Malicet et al., 1995), 228 and 295K</td></tr>
<tr><td colspan="3">NO_2(Vandaele et al., 1998), 220K</td></tr>
<tr><td colspan="2">BrO (Wilmouth et al., 1999), 228K</td><td>BrO (Wilmouth et al., 1999), 228K,not fitted</td></tr>
<tr><td>O_4(Thalman and Volkamer, 2013), 293K</td><td colspan="2">O_4(Thalman and Volkamer, 2013), 293K,not fited</td></tr>
<tr><td>Ring Effect</td><td colspan="3">Calculated based on the SAO2010 solar atlas</td></tr>
<tr><td>Cloud Fraction</td><td colspan="3">OMCLDO2(Acarreta et al., 2004)</td></tr>
<tr><td>HCHO profile</td><td colspan="2"></td><td>GEOS-Chem(0.5(lat)x0.667(lon)) @China region)</td></tr>
</table>

O_2-O_2 product



- *O4 VS CF： O4 Result can reflect the change of Cloud Fraction*
- *Cloud Fraction from https://search.earthdata.nasa.gov*

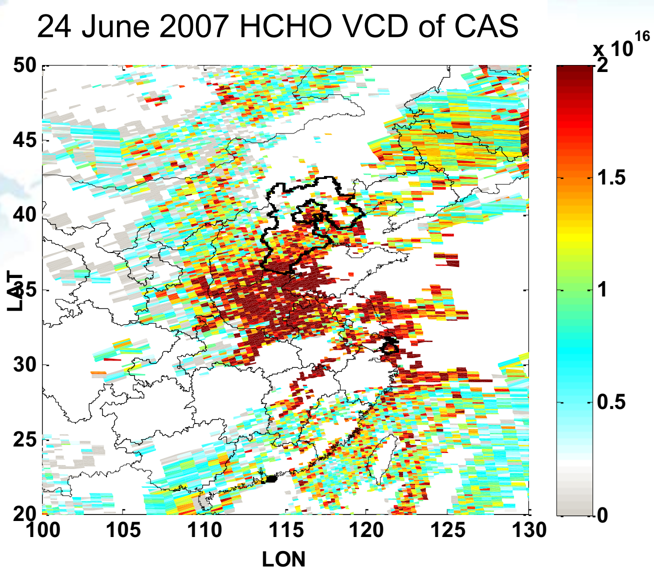
BrO SCD

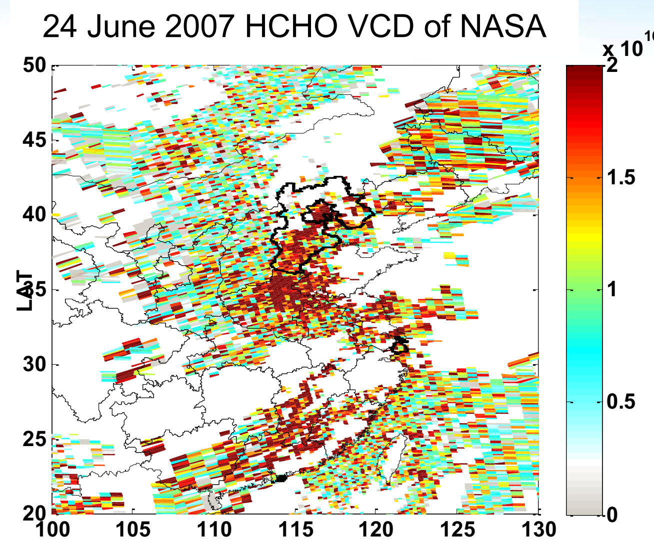


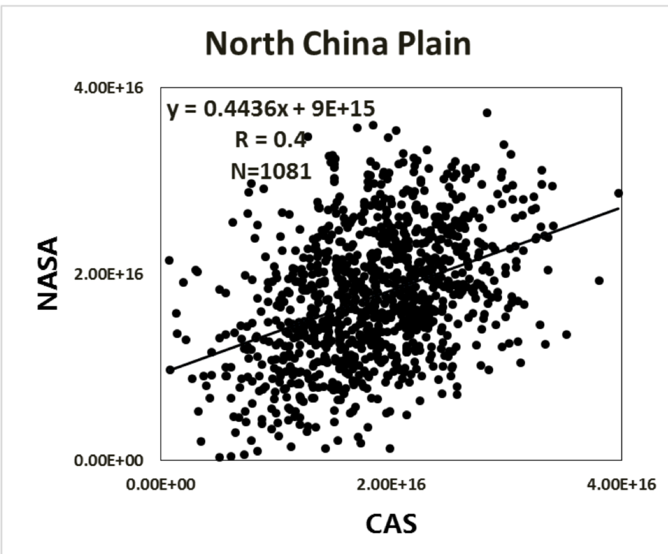
- https://search.earthdata.nasa.gov

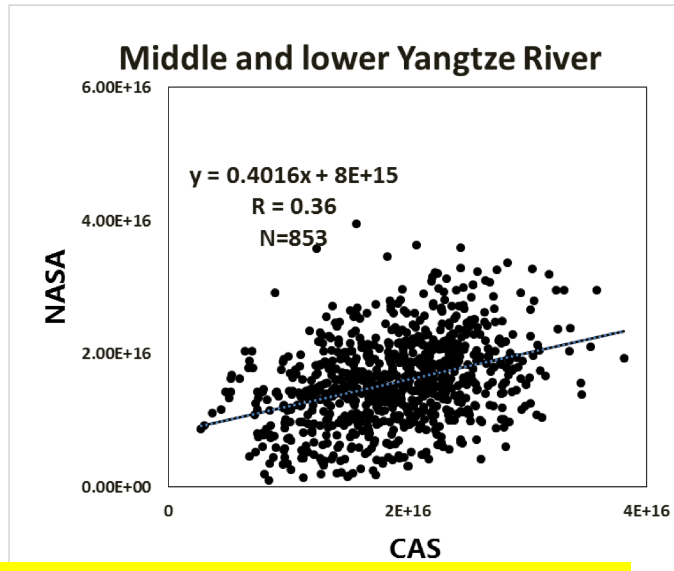
➢ **The changes are more dramatic, higher than the NASA high values,and lower than that low values.**

HCHO VCD









- https://search.earthdata.nasa.gov

NO_2 & CHOCHO retrieval parameters

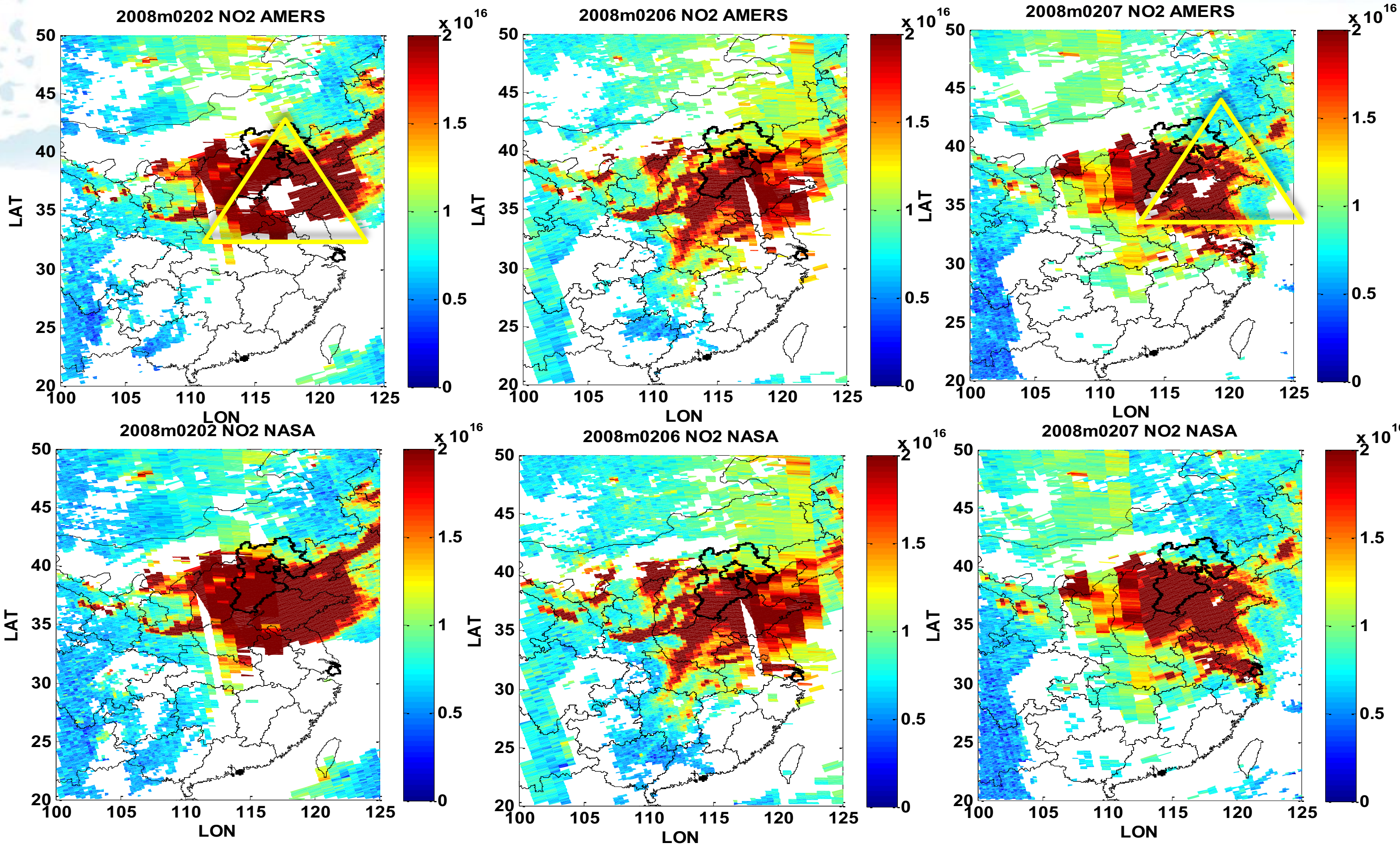
Parameters	NO_2 Setting	CHOCHO Setting
Fitting window	420-455 nm	430-458 nm
Reference spectrum I_0	Daily average of radiances, per row, selected in a pacific region.(30° N-30° S)	
Polynomial	3^{th}- order	4^{th}- order
Included cross sections	Glyoxal (Volkamer et al. 2005), 296K	
	O_3(*Malicet et al. 1995*), 228 K	
	NO_2(*Vandaele et al. 1998*), 220K,294k	NO_2(*Vandaele et al. 1998*), not fitted
	O_4(*Thalman and Volkamer 2013*), 293K	
	H_2O_liquid(Pope and Fry 1997)	
Ring Effect	Calculated based on the SAO2010 solar atlas	
Cloud Fraction	OMCLDO2(*Acarreta et al. 2004*)	

NO_2 SCD

2 Feb 2008	6 Feb 2008	7 Feb 2008

CAS

NASA



- https://search.earthdata.nasa.gov

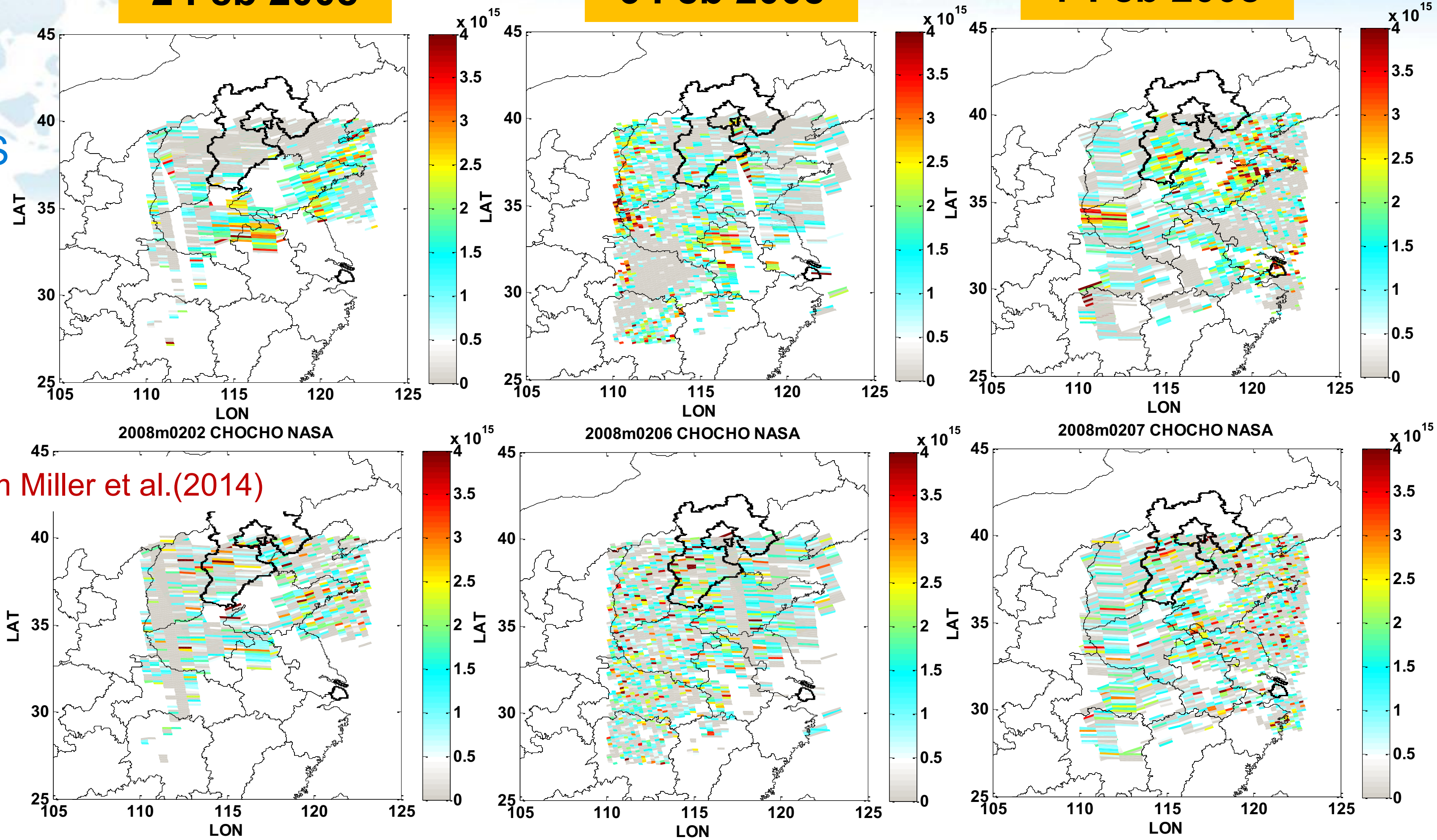
www.slrss.cn

CHOCHO SCD

2 Feb 2008 | **6 Feb 2008** | **7 Feb 2008**

CAS

From Miller et al.(2014)



- https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L2/OMCHOCHO

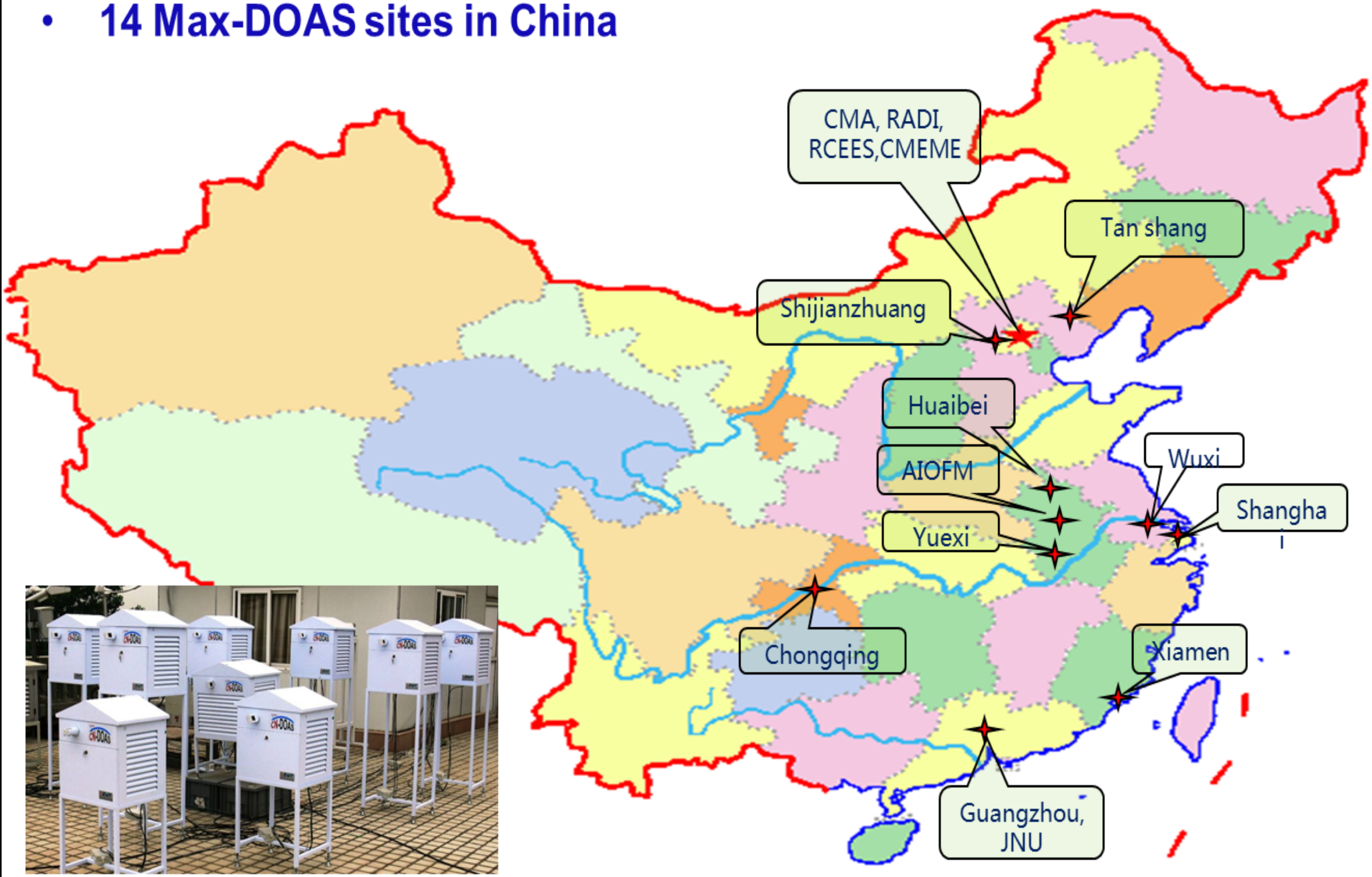
(*Miller et al. 2014*)

4. L2 product validation

- The validation of Air Quality satellite products faces a lot of challenges, the large variability of short-lived species and to remote sensing issues at tropospheric altitudes.
- Cross-validation using products from other low earth orbit instruments, such as OMI, OMPS, S5/UVNS, GOME2 now, and using the products from GEMS(Korea), Sentinel-4 (ESA), and TEMPO(NASA) in near future.
- Using Max-DOAS network measurements to validate EMI trace gas products. There are more then 14 Max-DOAS site China.
- Padora observation network (HAMAQ, Jim).

4. L2 product validation plans

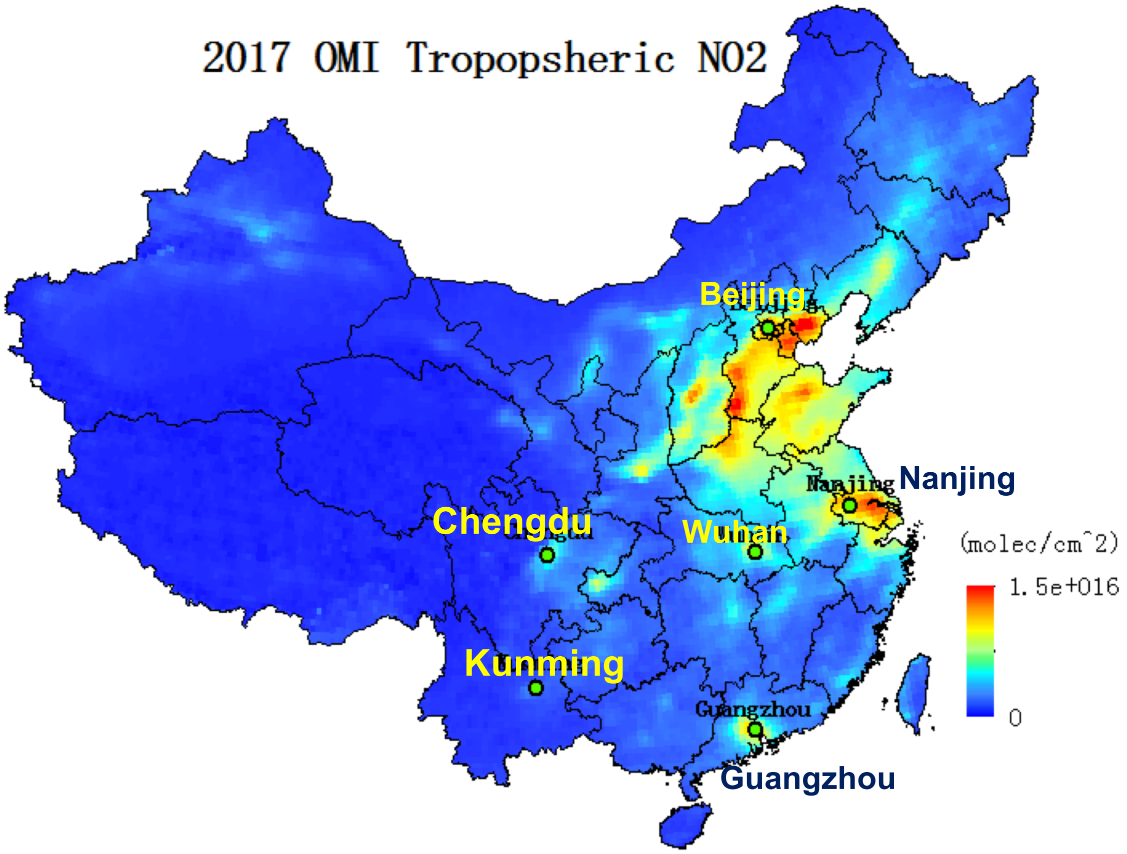
- **14 Max-DOAS sites in China**



One Max-DOAS is operating on the Arctic station.

4. L2 product validation plans

- There will be 8 Pandora sites in China according to Jim's plan.



5.Summary

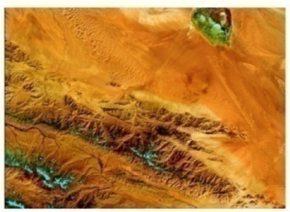
①Preflight evaluation shows that EMI is capable of measuring the global distribution of the NO_2 column with the retrieval precision and accuracy better than 3% for the tested wavelength ranges and viewing angles.

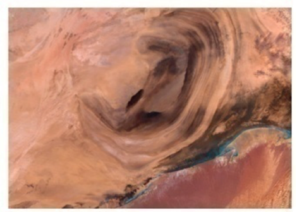
②EMI L1b Data Flow Map presents lots of no scientific challenges my team has to face, it is key problem for all the user to get the EMI products.

③Retrieval algorithms for L2 products such as NO_2, SO_2, CHCO, CHOCHO and BrO have been presented.

④Big challenge for EMI products validation.

谢 谢！






Thanks！

地址：北京市海淀区邓庄南路9号（100094）
电话：86-10-82178008 传真：86-10-82178009
邮箱：office@radi.ac.cn
网址：www.radi.cas.cn

EMI HCHO algorithm——flow chart