

Explicit and Observation-based Aerosol Treatment in Tropospheric Retrieval of NO₂ and Other Tracers

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in collaboration with

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Ministerie van Infrastructuur en Milieu

Retrieving Tropospheric NO₂ Vertical Column Density

Step 1: SCD from DOAS calc.

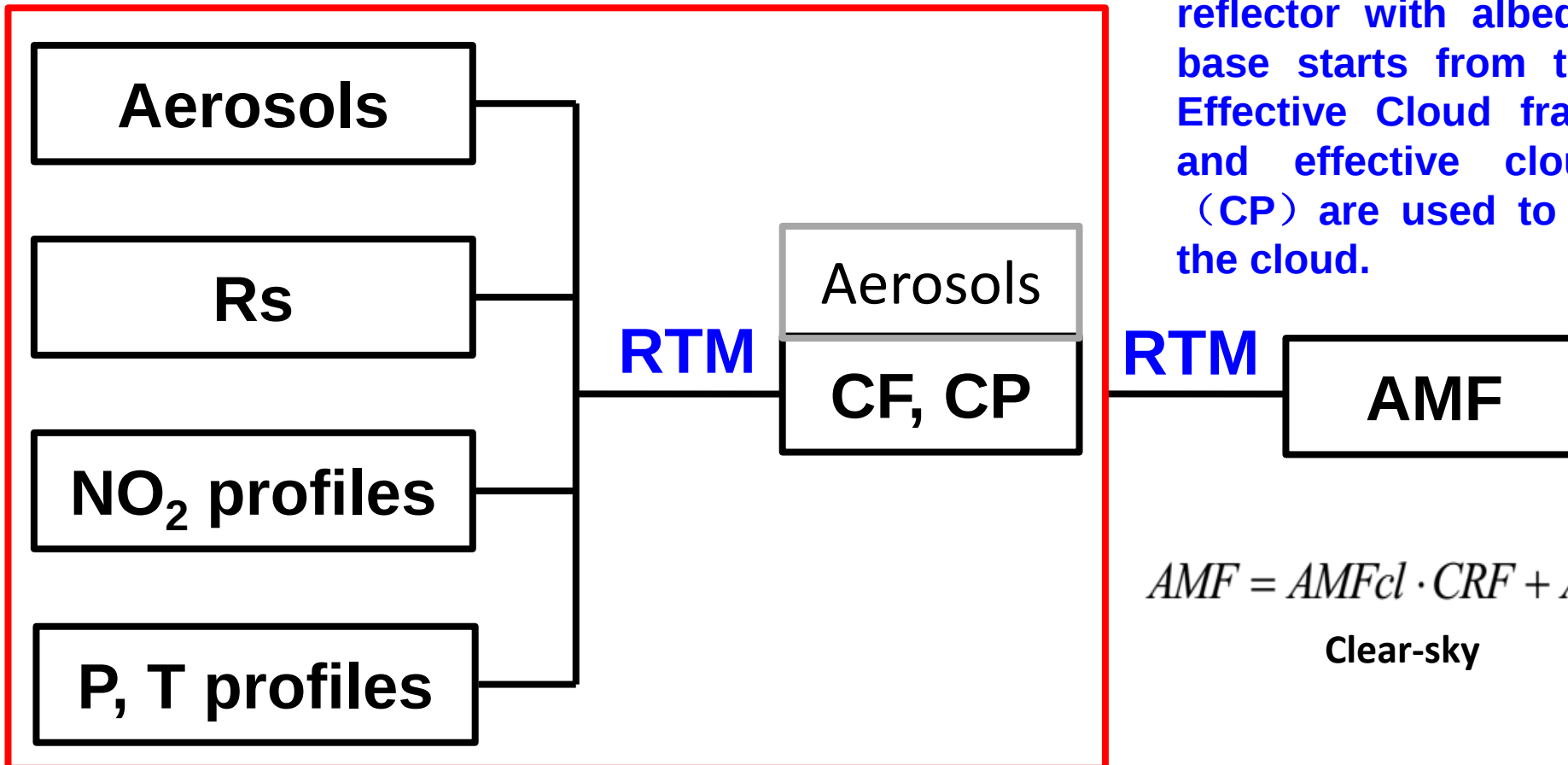
Step 2: Tropospheric and stratospheric SCD

Step 3: Tropospheric AMF – *error pool*

$$\blacksquare \text{SCD} = F(\text{radiance})$$

$$\blacksquare \text{SCD}_T = \text{SCD} - \text{SCD}_S$$

$$\blacksquare \text{VCD}_T = \text{SCD}_T / \text{AMF}$$

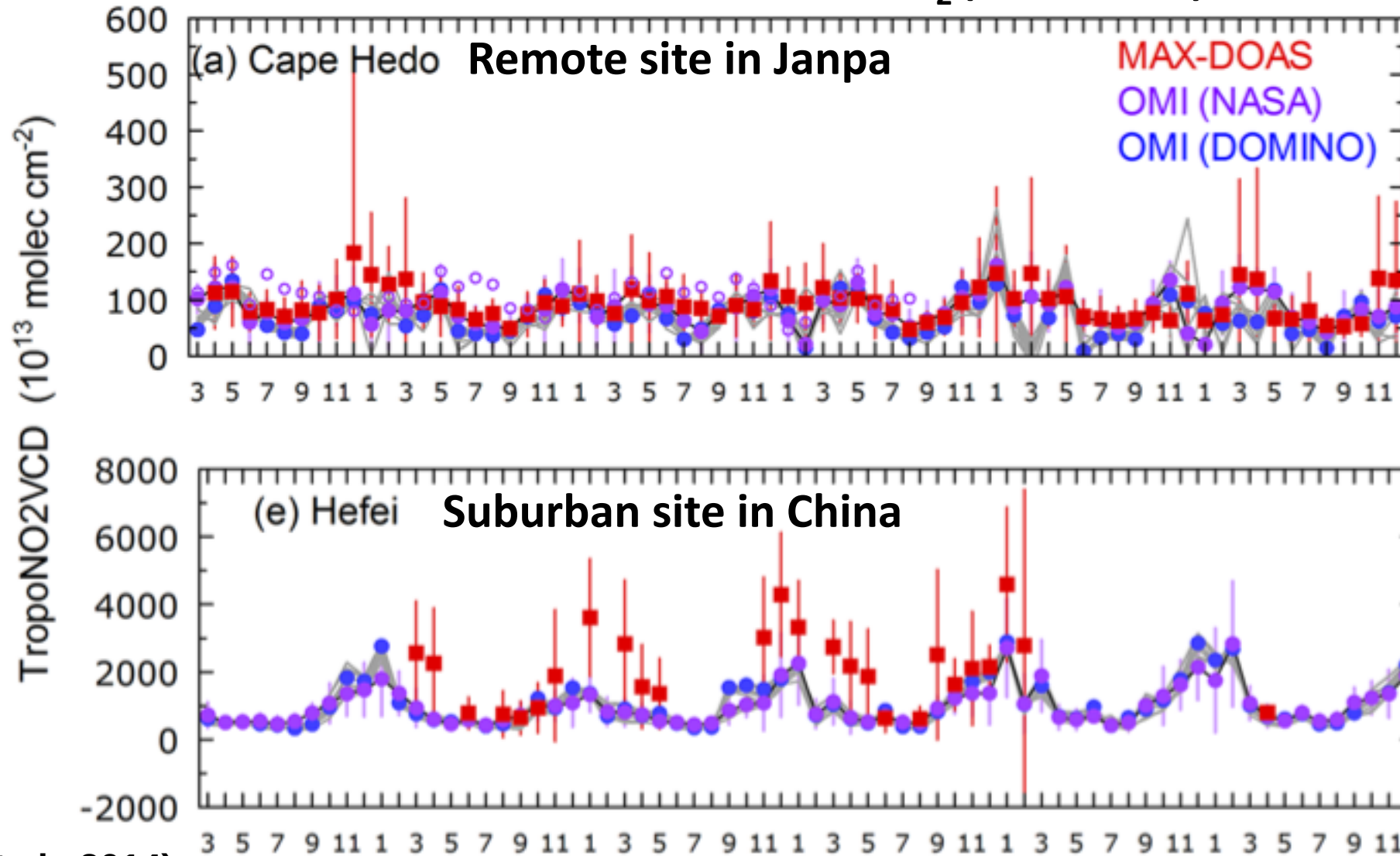


**** “ effective cloud” is Lambert reflector with albedo 0.8. cloud base starts from the ground. Effective Cloud fraction (CF) and effective cloud pressure (CP) are used to parameterize the cloud.**

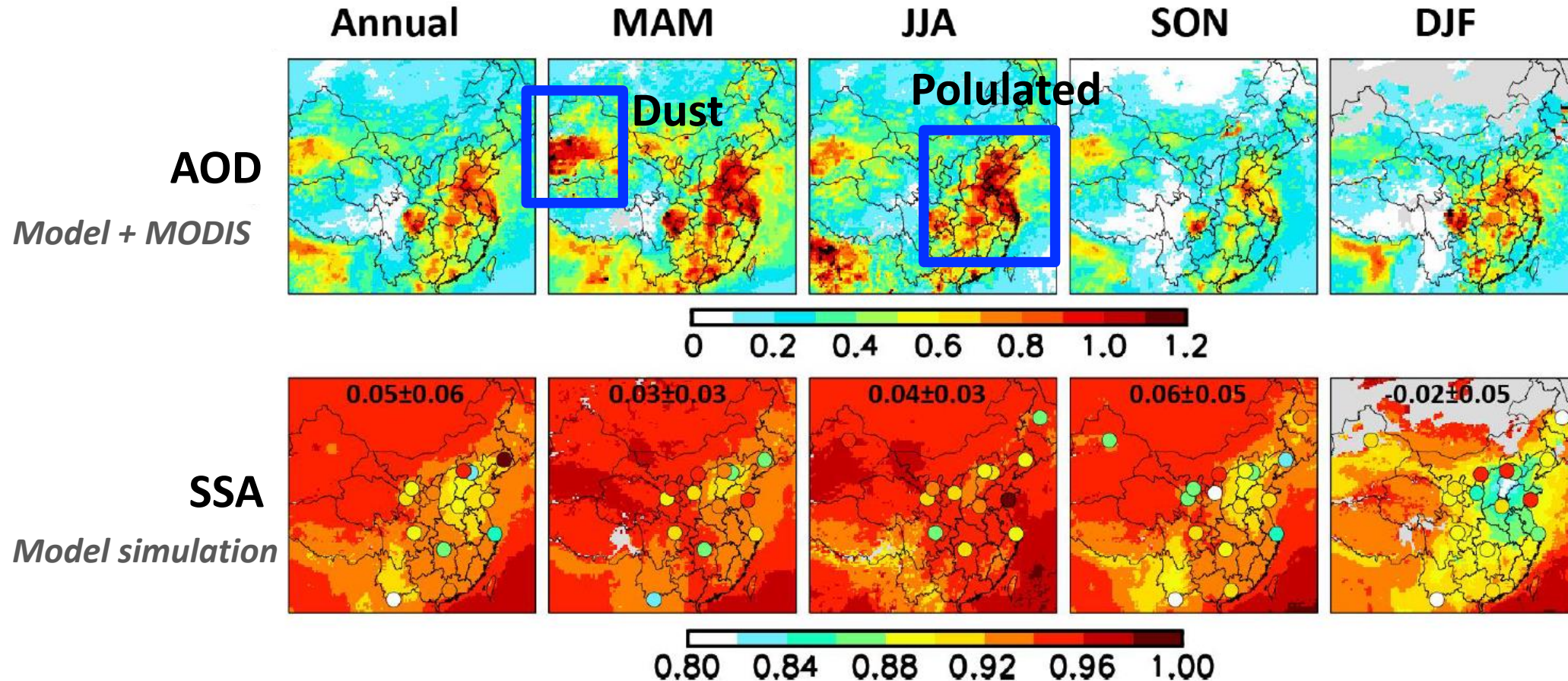
$$\text{AMF} = \underbrace{\text{AMF}_{cl} \cdot \text{CRF}}_{\text{Clear-sky}} + \underbrace{\text{AMF}_{cr} \cdot (1 - \text{CRF})}_{\text{Cloudy-sky}}$$

Satellite NO₂ VCD Have High Bias in Aerosol-Polluted Areas

MAX-DOAS .vs. satellite NO₂ (2007-2012)



Aerosol Treatment is Critical over China



Characteristics of Chinese aerosols:

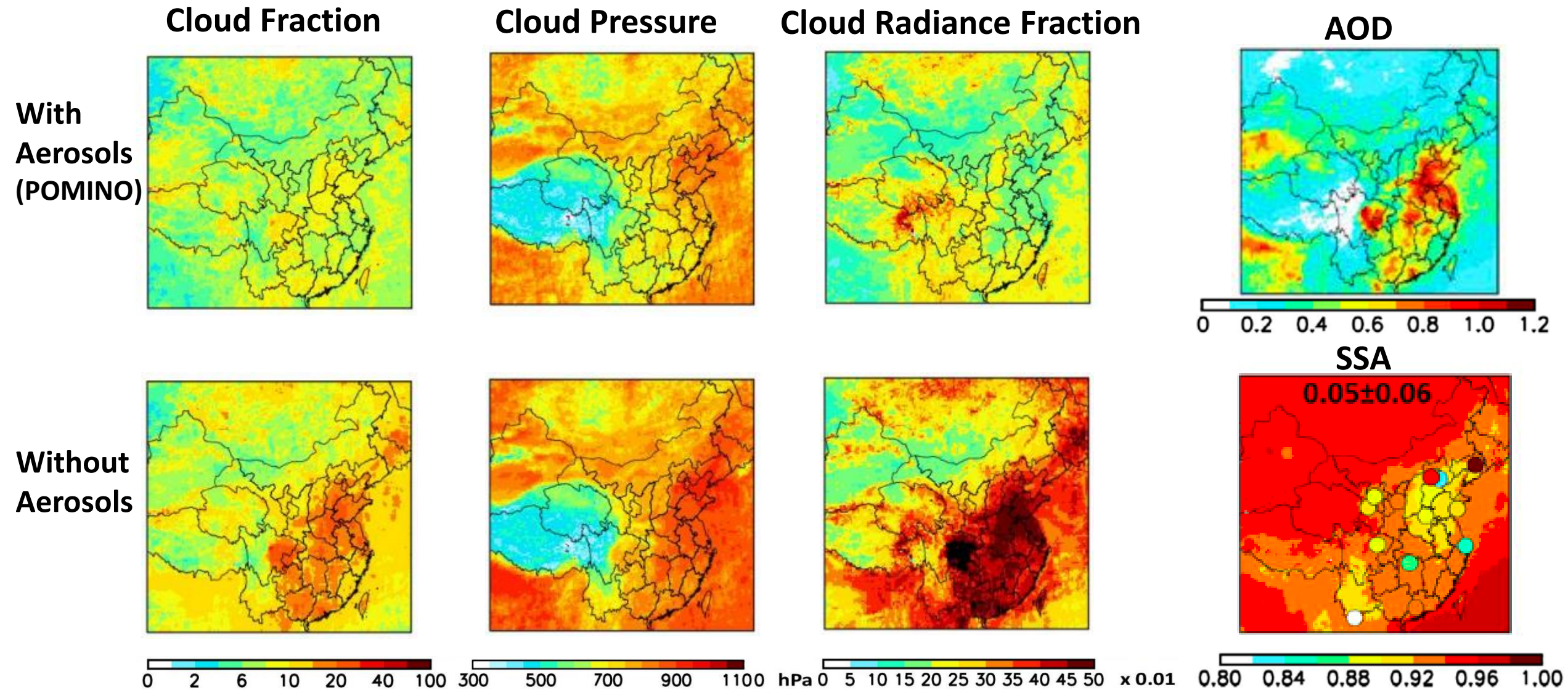
- Large amounts in key areas
- Highly absorbing in many areas
- Considerable spatiotemporal variability

(Lin and Liu et al., 2015, ACP)

Issues in current NO₂ products & improvements of POMINO:

- Not fully accounting for aerosol optical effects (implicit aerosol treatment)
 - **Daily aerosols info from GEOS-Chem, with AOD adjusted by monthly MODIS AOD**
- No geometric dependence of surface reflectance
 - **Account for surface reflectance anisotropy (BRDF; daily MCD43C2 collection 5 (0.05°)**
- Coarse-resolution NO₂ profile (200 km)
 - **High-resolution NO₂ profile (25–50 km)**
- Inconsistent ancillary assumptions between NO₂ and cloud products
 - **Consistent ancillary assumptions in retrieving NO₂ and clouds**
- Use of look-up table, often with insufficient layers affecting interpolation/extrapolation
 - **Parallelized RTM calc. for each pixel**

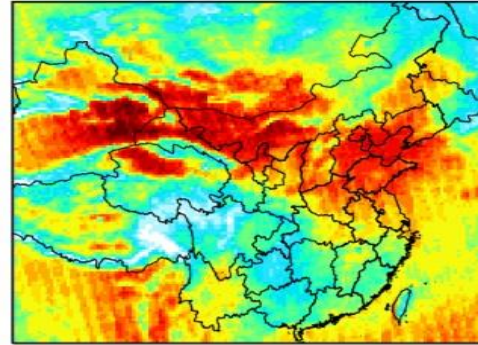
Aerosols Complexly Affect Cloud Retrieval



Explicit Aerosol Treatment Reduces Sampling Low Bias

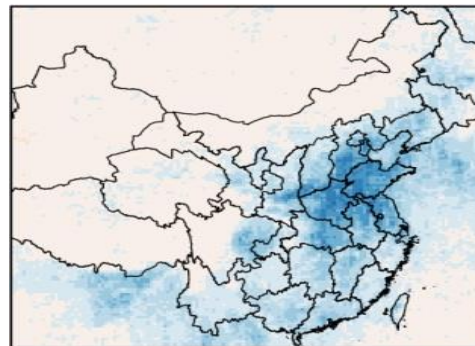
Days per month w/ valid data in POMINO

Valid pixels:
 $\text{CRF} \leq 50\%$

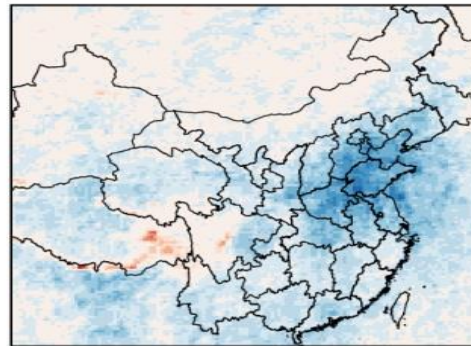


0 2 4 6 8 10 12 14 16 18 20 days

noAER – POMINO



DOMINO – POMINO

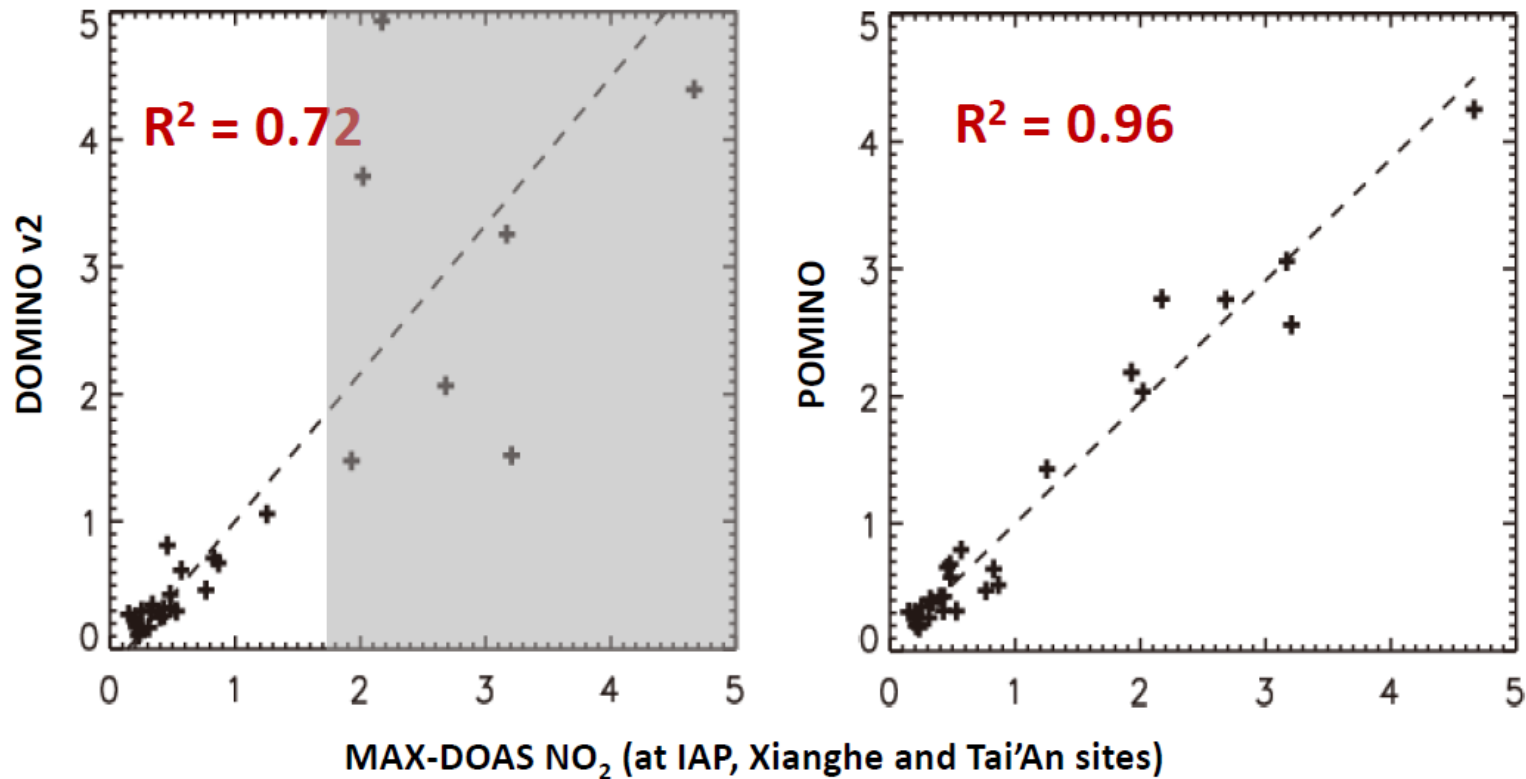


-10 -8 -6 -4 -2 0 2 4 6 8 10 days

- An explicit treatment better accounts for high-pollution days

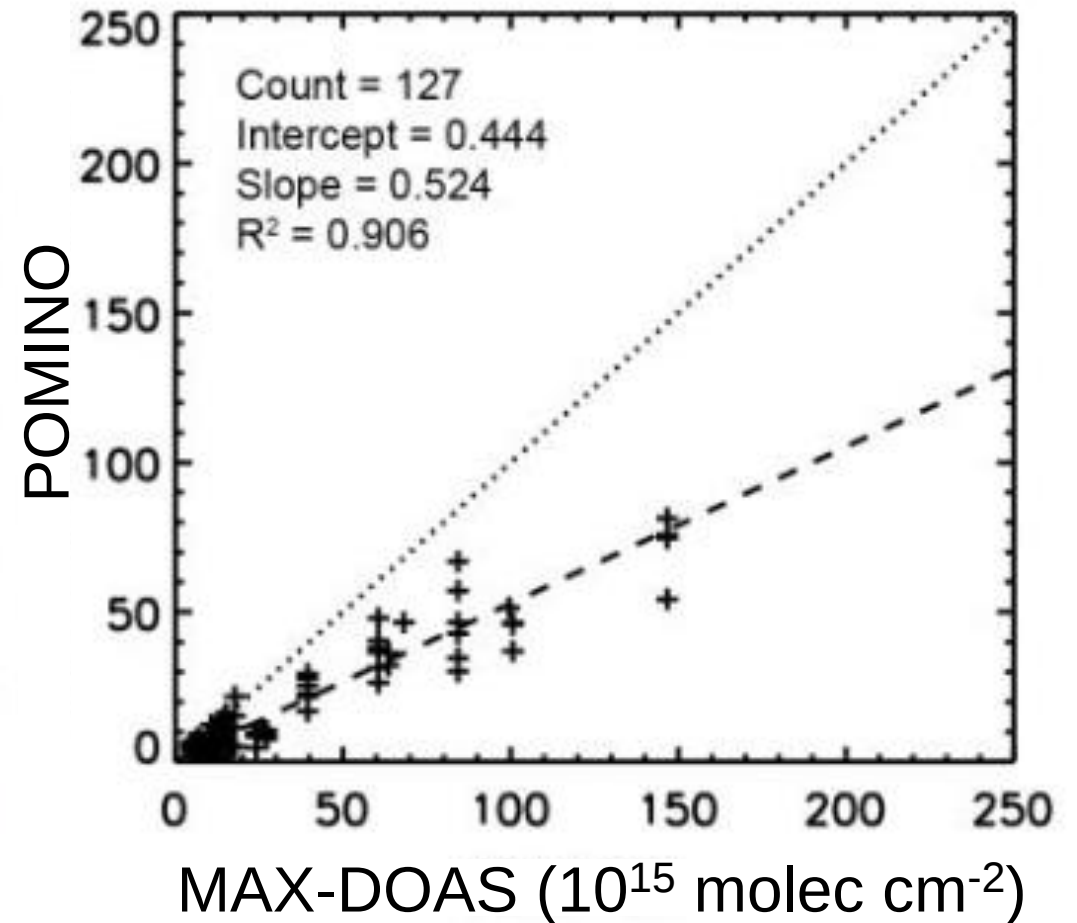
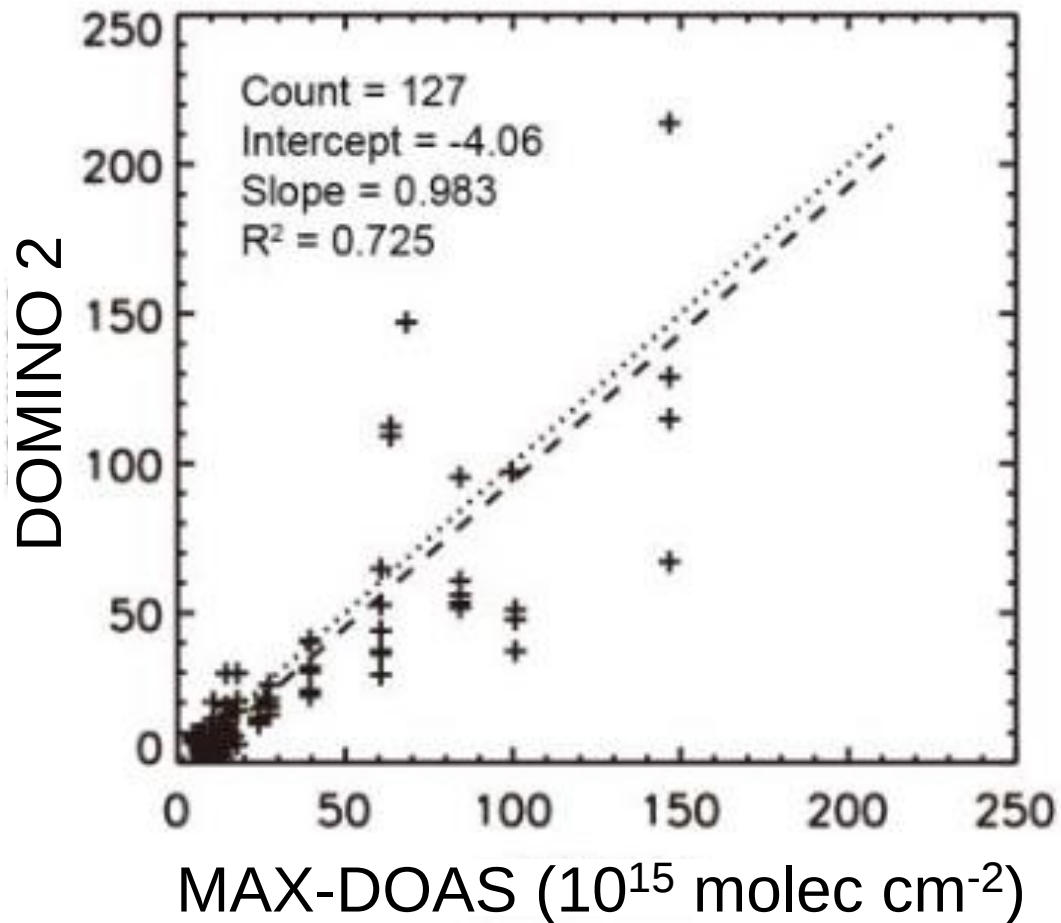
POMINO Better Captures NO₂ Day-to-day Variability

Evaluation of OMI NO₂ data using MAX-DOAS NO₂
(daily data; multiple years and seasons; data normalized to mean)



POMINO Underestimates MAX-DOAS

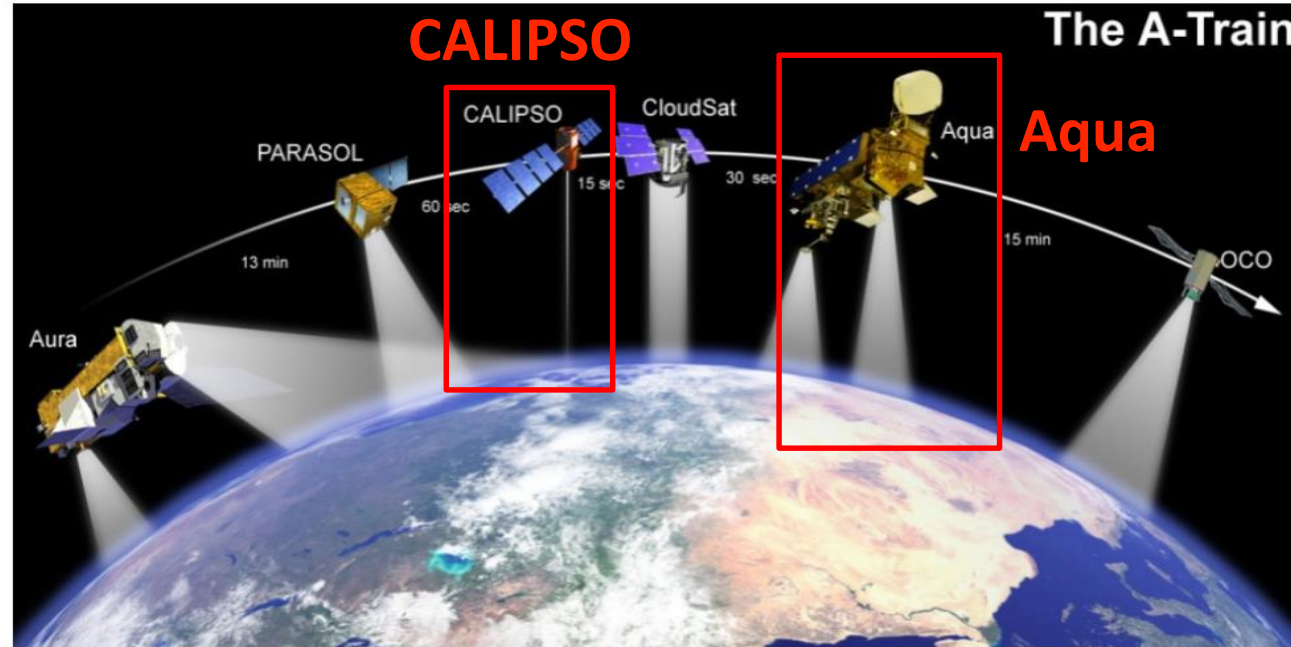
*[At least 60% of underestimate
is due to sampling difference]*



Using CALIOP Aerosol Profiles to Improve Cloud and NO₂ Retrievals

CALIOP Global Coverage:
16 day
~0.2% land coverage

Pasttime of CALIPSO :
45 sec. later than Aqua



Spatial resolution of CALIOP

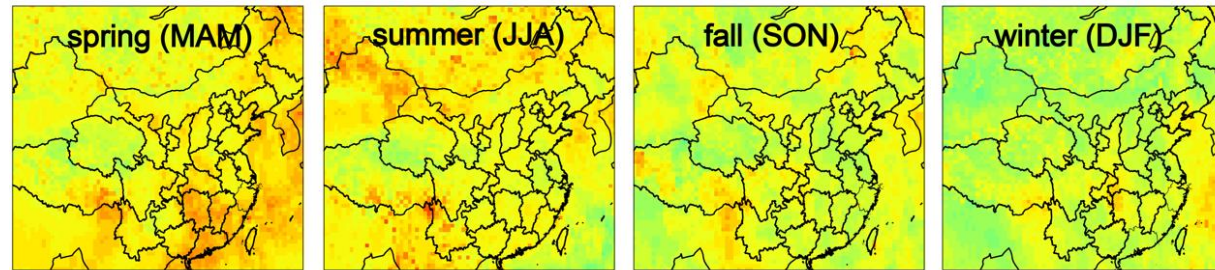
Altitude (km)	Horizontal res. at 532nm (m)	Vertical res. at 532nm (m)
-2.0 ~ -0.5	330	300
-0.5 ~ 8.2	330	30
8.2 ~ 20.2	1000	60
20.2 ~ 30.1	1670	180
30.1 ~ 40.0	5000	300

Model Captures Spatiotemporal Variation in Aerosol Layer Height

$$ALH = \frac{\sum h(l)\sigma(l)}{\sum \sigma(l)}$$

$h(l)$ -height above the ground
 $\sigma(l)$ -extinction of layer l

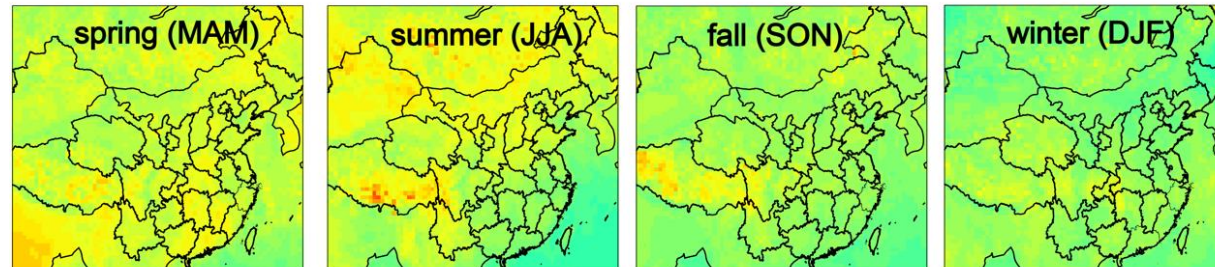
(a) All-sky Level-2 CALIOP based climatology



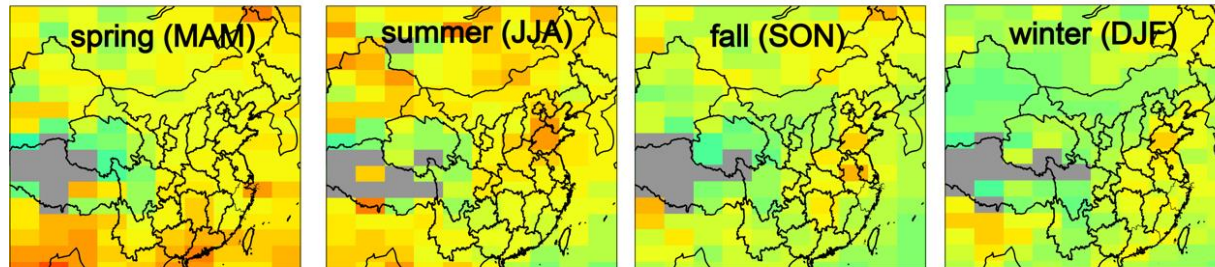
Horizontal res.:
0.5° lat. X 0.667° lon.

Vertical res:
36 layers in troposphere

(b) correspondent GEOS-Chem simulation based climatology



(c) NASA all-sky monthly Level-3 CALIOP based climatology

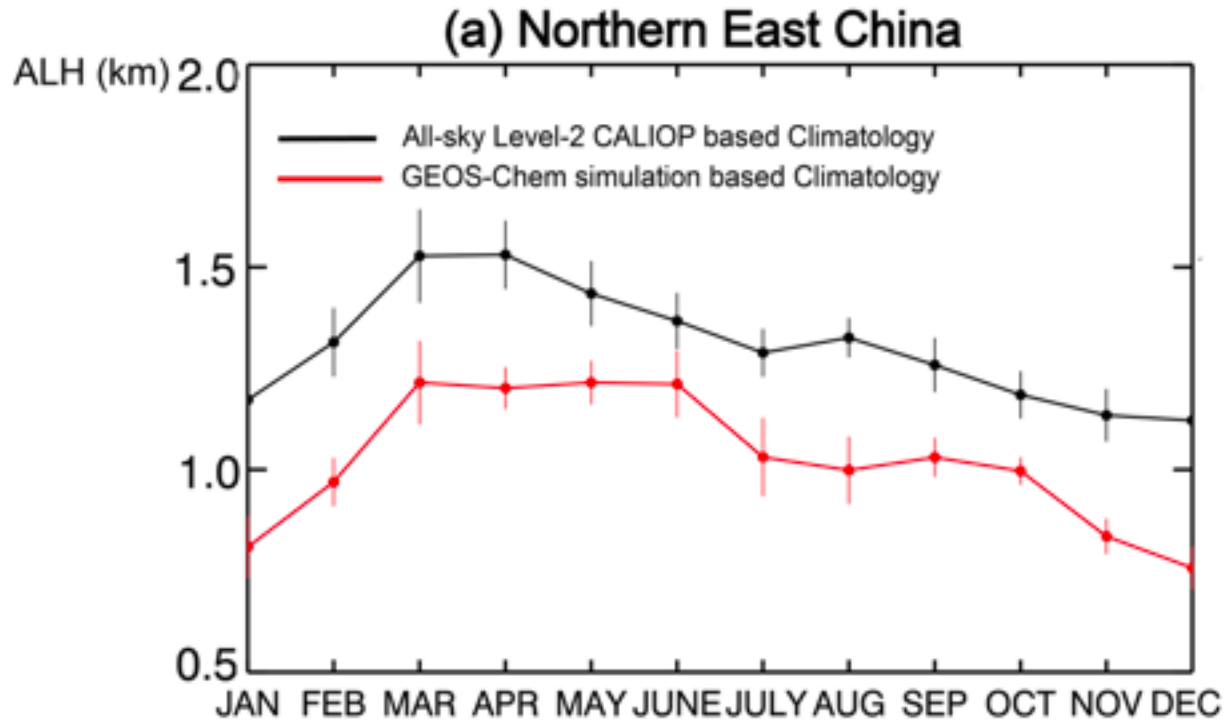


Horizontal res.:
2° lat. X 5° lon.

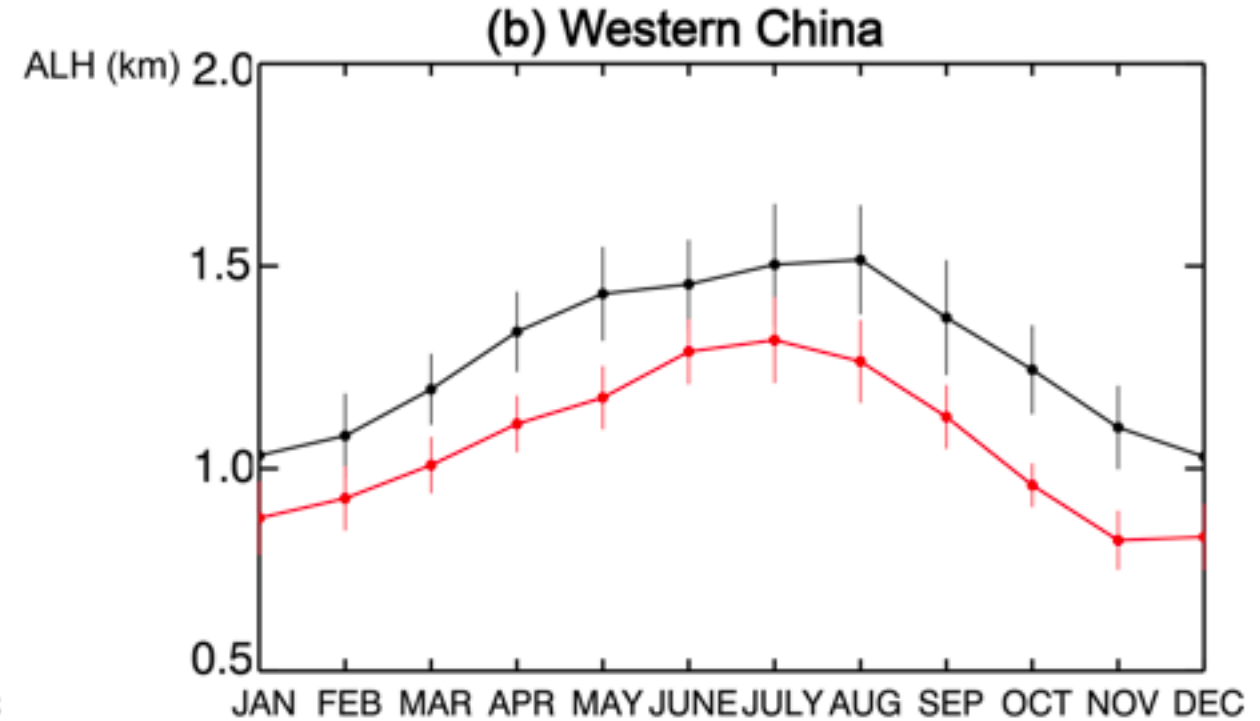
Vertical res:
50 m; from -0.2~80km



GEOS-Chem Underestimates CALIOP Aerosol Layer Height



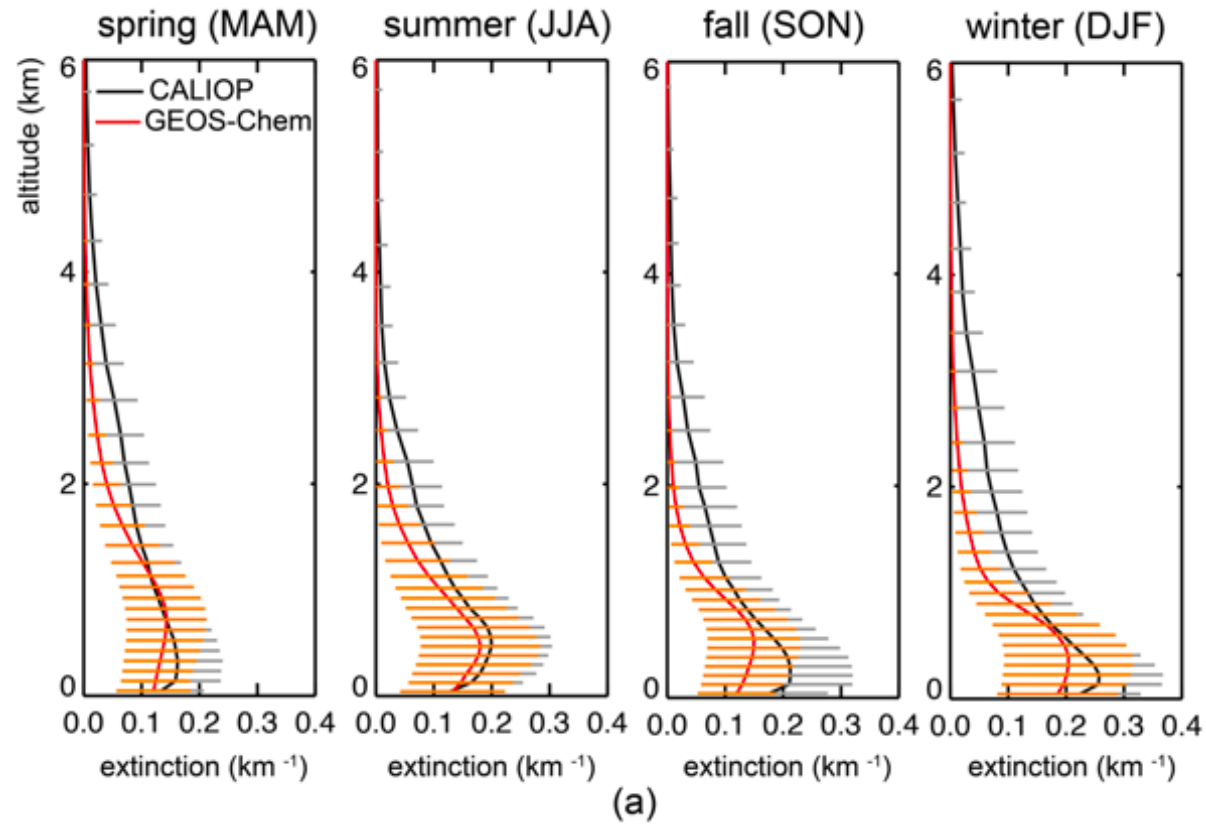
Populated area



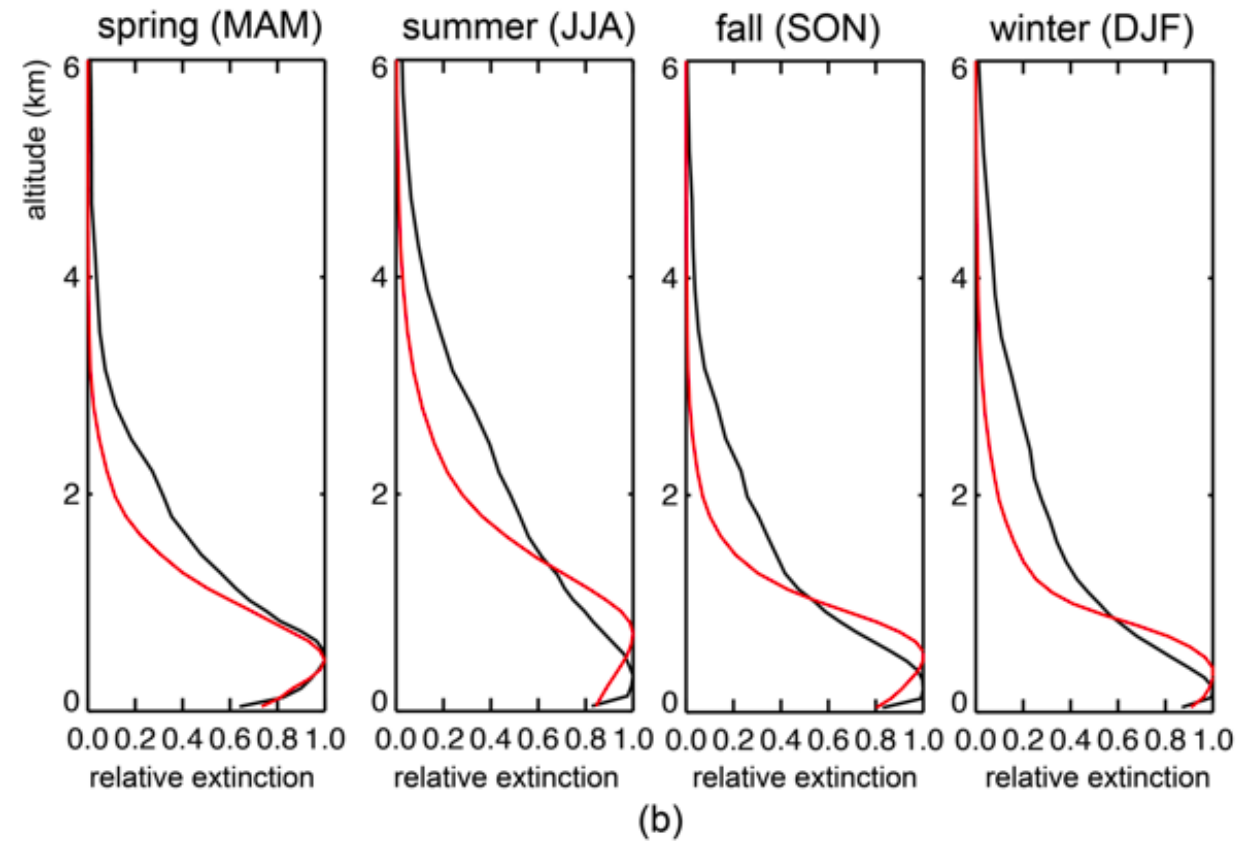
Dust area

Negative (Positive) Bias in Aerosol Extinction Gradient Below (Above) 0.6 km

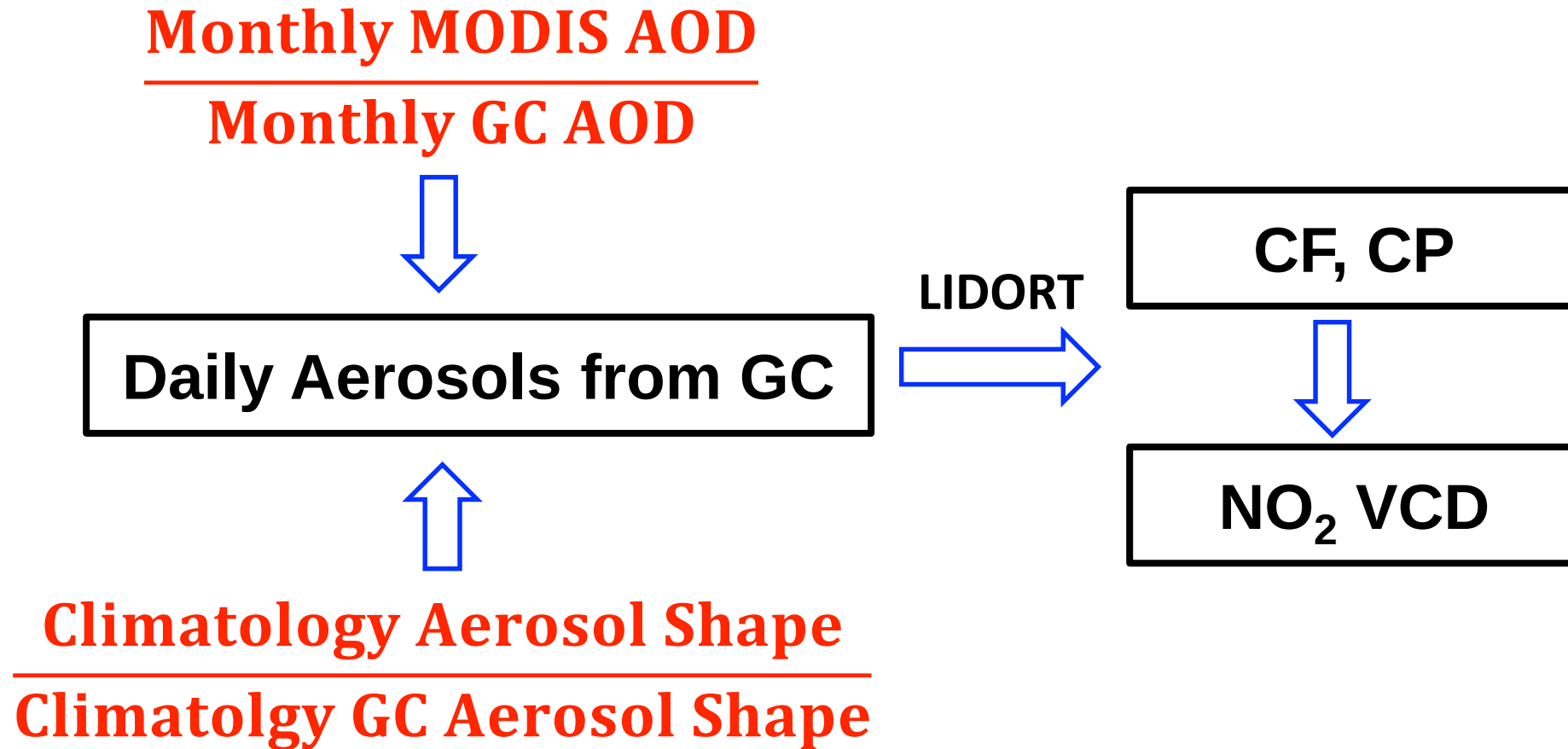
Absolute aerosol extinction profile over NEC



Aerosol extinction profile standardized by maxima of the profile

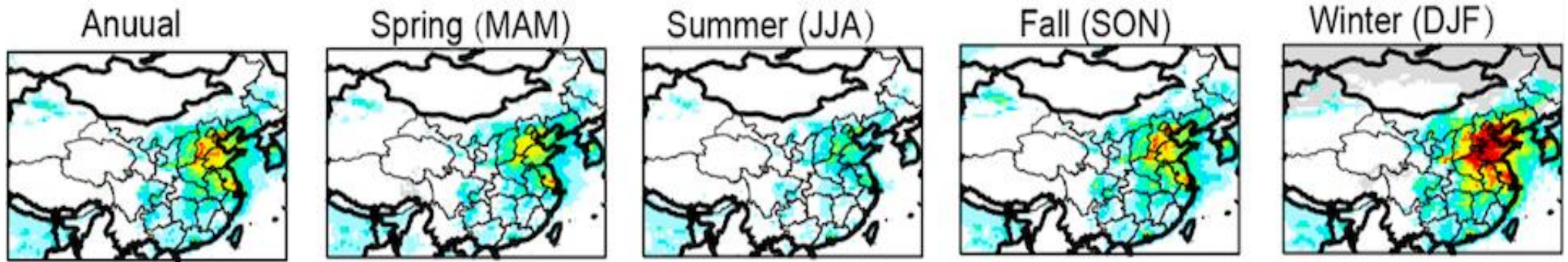


Use CALIOP Monthly Climatology (2007–2015) to Constrain Model

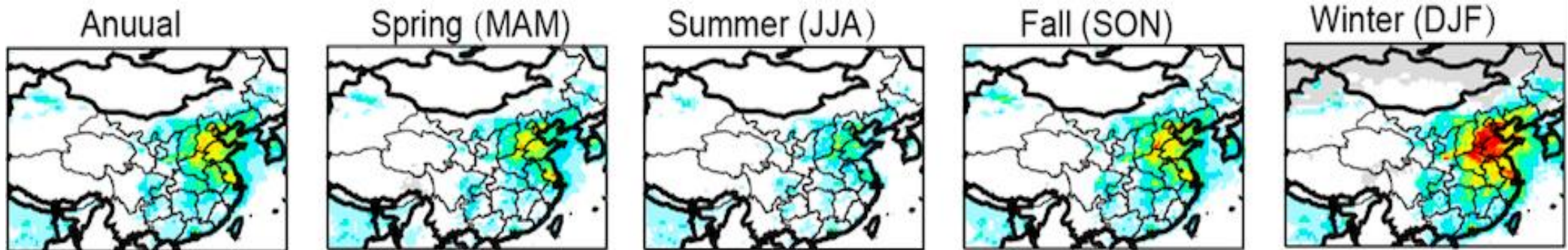


POMINO v1.1 Increase NO₂ VCD by ~15% Averaged over East China

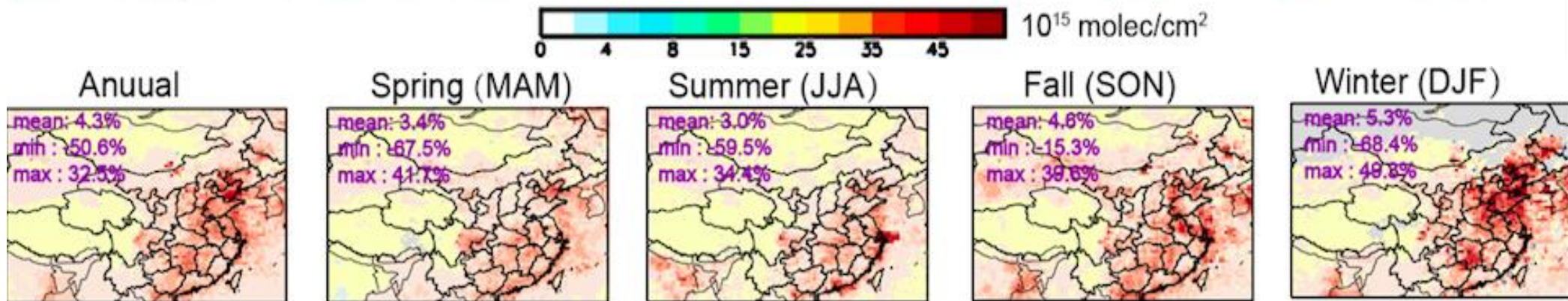
POMINO v1.1



POMINO



Diff (%)



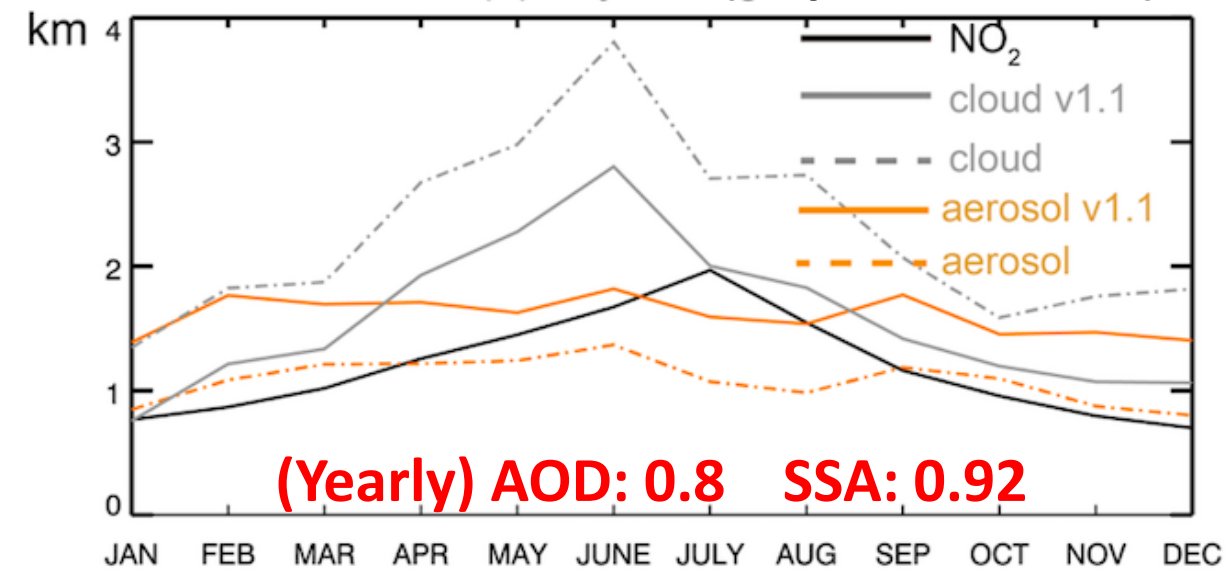
(POMINO v1.1-POMINO) / POMINO



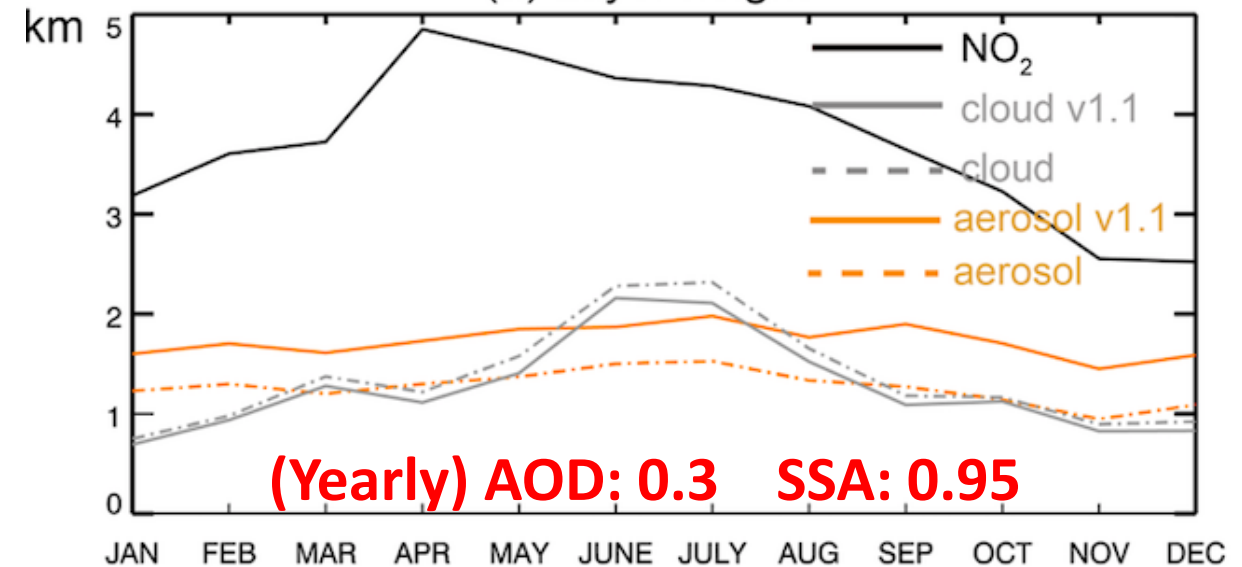
(Liu et al., paper in prepare)

Cloud Top Height Decreases to Compensate for Increased Aerosol Layer

Northern East China (Populated area)



Western China (Dust area)

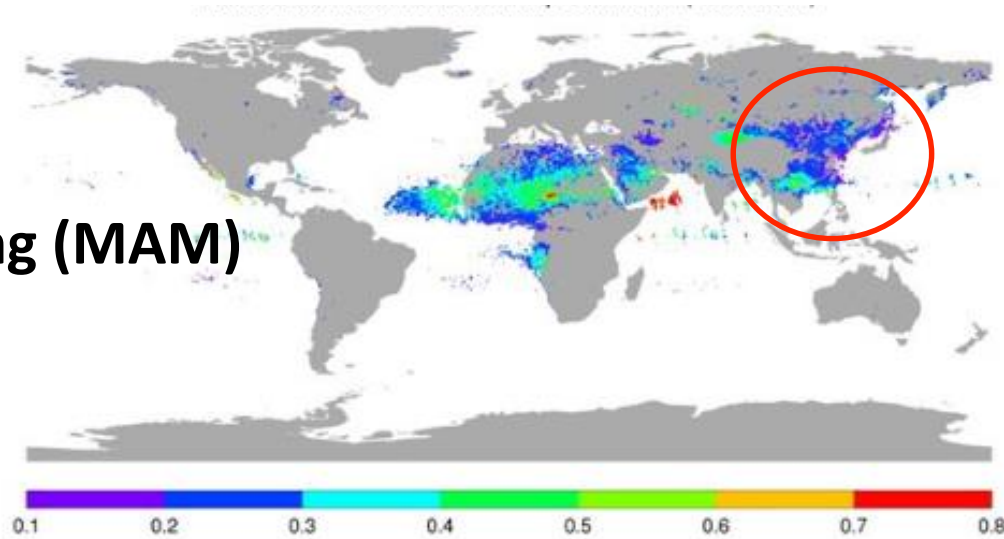


- Nonlinear compensation between ΔALH and ΔCTH
- Improved aerosol layer height is above cloud top in fall and winter

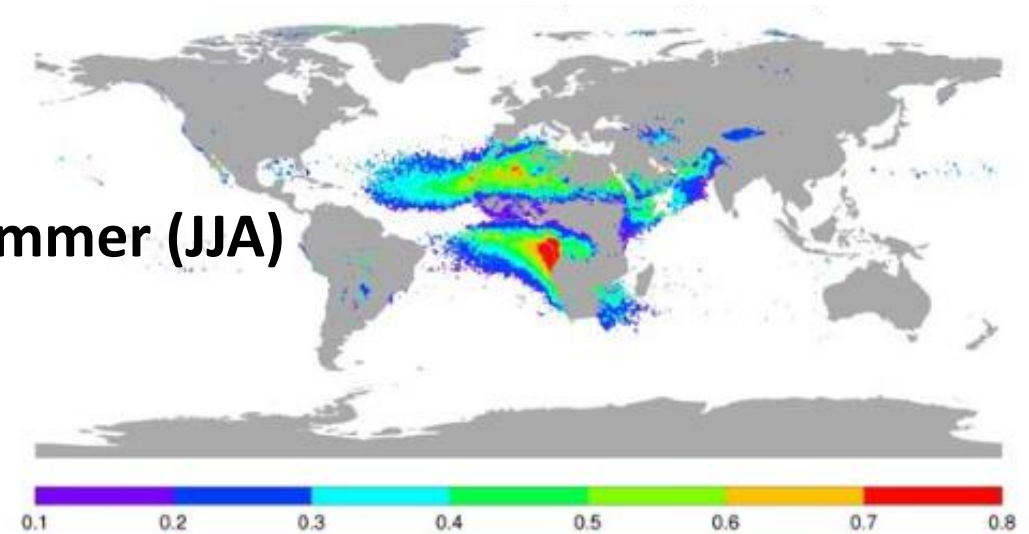
China has Frequent Above-cloud Absorbing Aerosol Events

Above-cloud Abs. Aerosol frequency (2005-2014) derived from OMI's near-UV observations

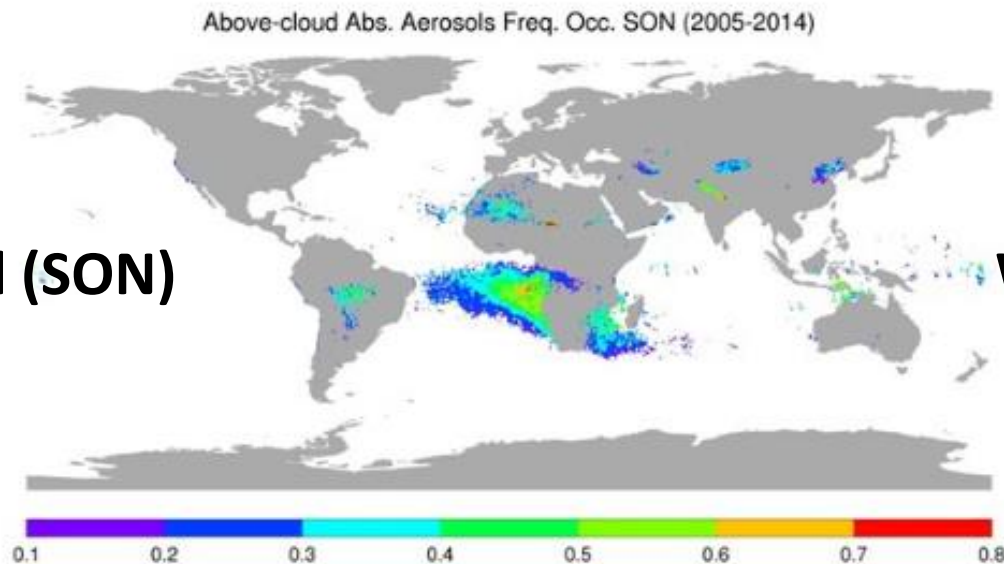
Spring (MAM)



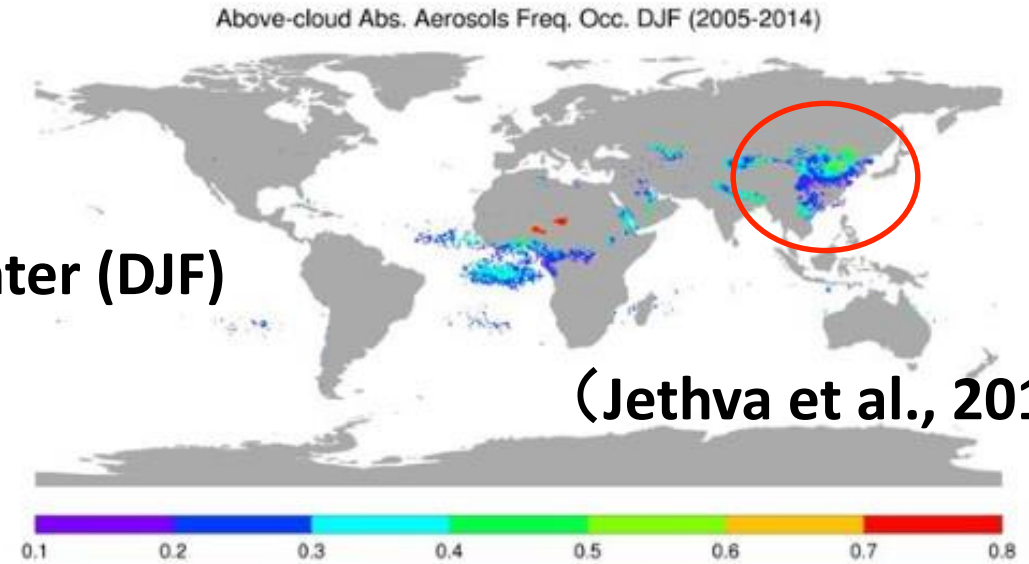
Summer (JJA)



Fall (SON)



Winter (DJF)

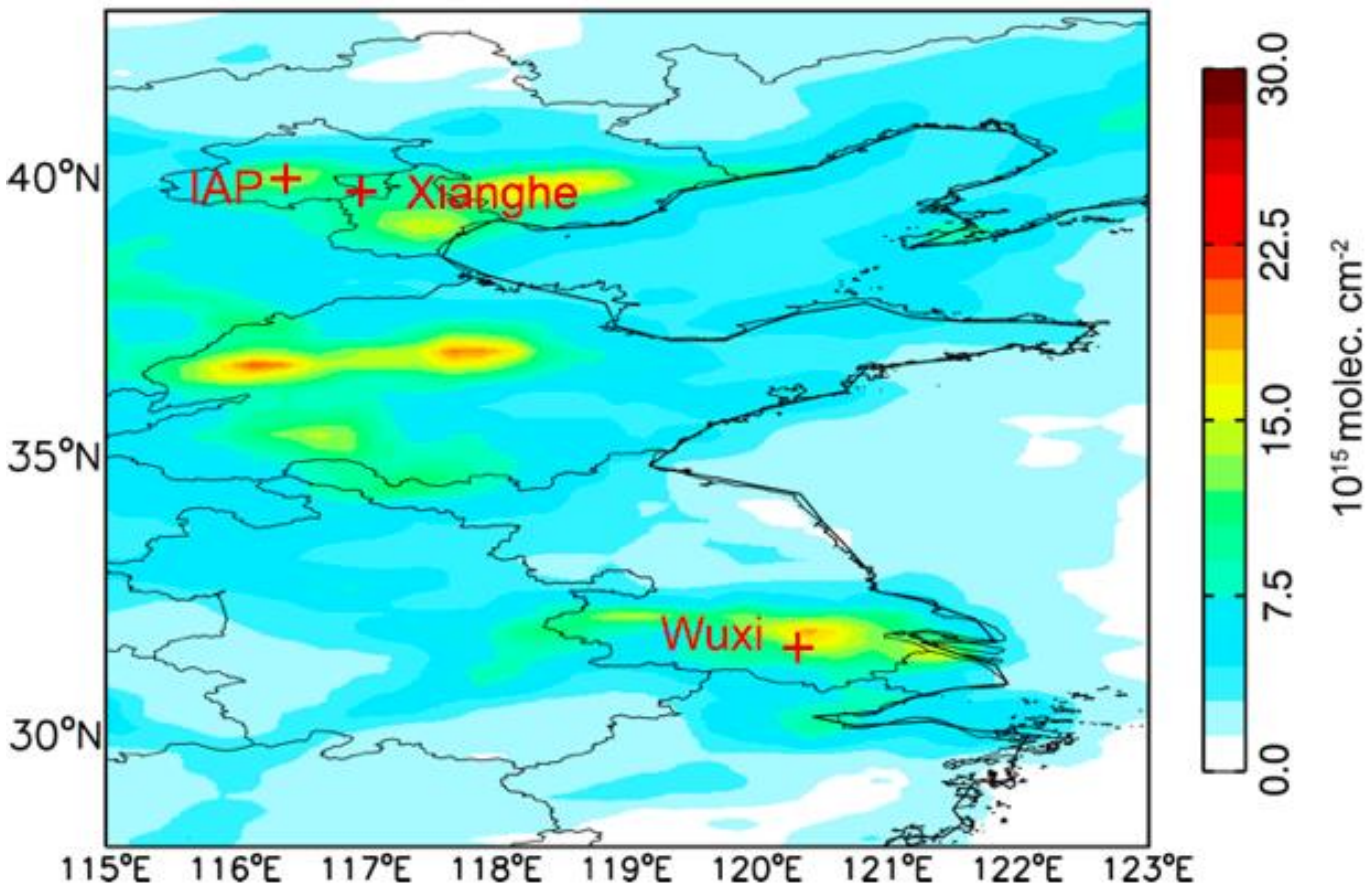


(Jethva et al., 2016)

Comparisons to the MAX-DOAS measurements

<http://www.phy.pku.edu.cn/~acm/acmProduct.php>

POMINO v1.1



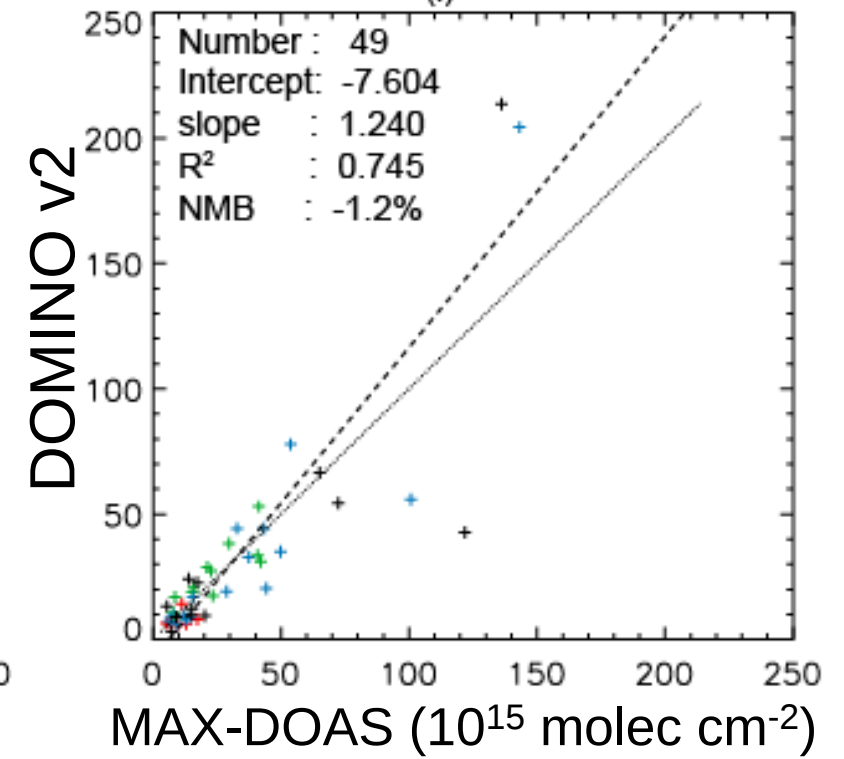
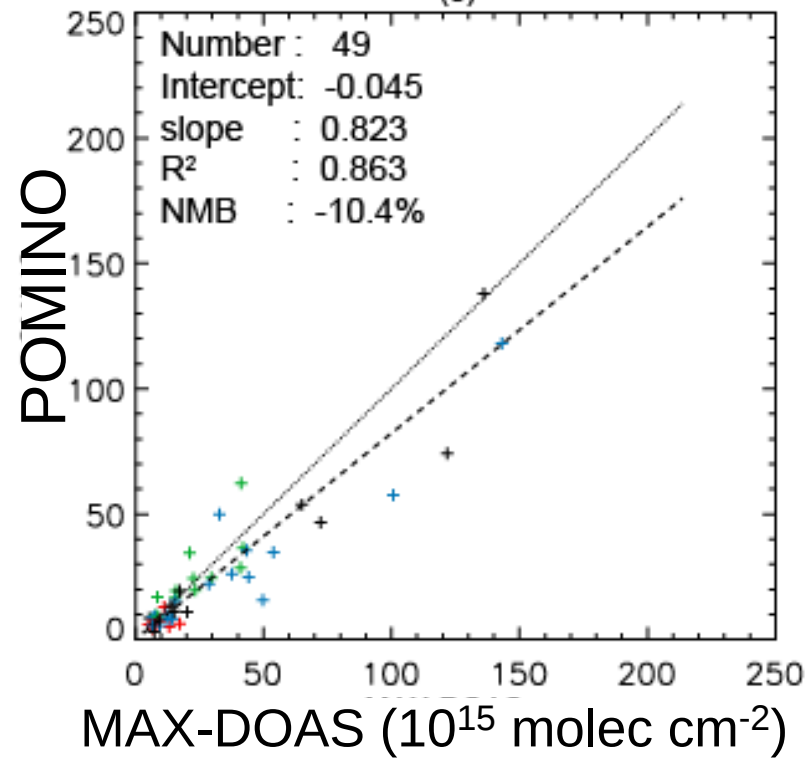
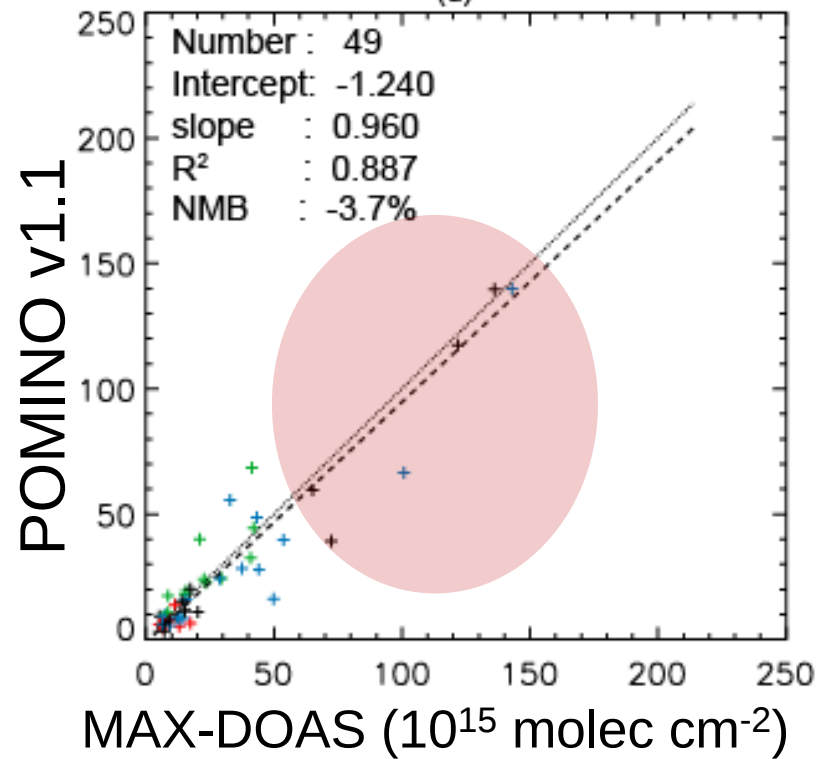
MAX-DOAS Station Information

station	location information	time
Xianghe	116.96°E, 39.75°N, 36m suburban	2012/01/01-2012/12/31
IAP	116.38°E, 39.98°N, 92m urban	2008/06/22-2009/04/16
Wuxi	120.31°E, 31.57°N, 20m urban	2012/01/01-2012/12/31

POMINO v1.1 Decrease Low Bias

Daily OMI Retrievals .vs. MAX-DOAS at 3 Stations

+ spring + summer + fall + winter



POMINO v1.1 performance better in Haze Days

OMI retrievals versus MAX-DOAS on haze days (27 samples)

Product	POMINO v1.1	POMINO	DOMINO
slope	1.07	0.80	1.11
intercept	-3.58	1.76	-11.79
R ²	0.76	0.68	0.38
NMB (%)	4.4	-9.4	-5.0

****haze day ---- selected by checking ground metrological weather records and corrected reflectance of MODIS/Aqua**

Summary

- Including daily aerosol information better captures day-to-day variation of NO₂ VCD
- Explicit aerosol treatment increases the number of valid days, reducing sampling bias
- Using CALIOP climatological aerosol extinction profile to adjust model leads to more realistic relationship between cloud and aerosols
- POMINO v1.1 reduces the low bias in POMINO
- POMINO v1.1 algorithm can be applied to retrievals of SO₂, HCHO and other tracers.

Reference

Lin, J.-T., Liu, M.-Y., Xin, J.-Y., Boersma, K. F., Spurr, R., Martin, R., and Zhang, Q.: Influence of aerosols and surface reflectance on satellite NO₂ retrieval: seasonal and spatial characteristics and implications for NO_x emission constraints, Atmos. Chem. Phys., 15, 11217-11241, <https://doi.org/10.5194/acp-15-11217-2015>, 2015.

Lin, J.-T., Martin, R. V., Boersma, K. F., Sneep, M., Stammes, P., Spurr, R., Wang, P., Van Roozendaal, M., Clémer, K., and Irie, H.: Retrieving tropospheric nitrogen dioxide from the Ozone Monitoring Instrument: effects of aerosols, surface reflectance anisotropy, and vertical profile of nitrogen dioxide, Atmos. Chem. Phys., 14, 1441-1461, <https://doi.org/10.5194/acp-14-1441-2014>, 2014.