Feasibility study of tropospheric ozone retrieval using multi-spectral synergetic approach with UV, TIR and microwave measurements from space

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Published in:
T. O. Sato et al., *AMT*, **11**, 1653-1668, 2018.

Atmos. Meas. Tech., 11, 1653–1668, 2018
https://doi.org/10.5194/amt-11-1653-2018

Atmospheric Measurement Techniques

Vertical profile of tropospheric ozone derived from synergetic retrieval using three different wavelength ranges, UV, IR, and microwave: sensitivity study for satellite observation

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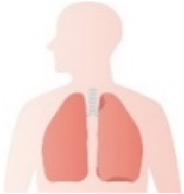
Received: 5 April 2017 – Discussion started: 29 May 2017
Revised: 26 January 2018 – Accepted: 29 January 2018 – Published: 26 March 2018

Introduction

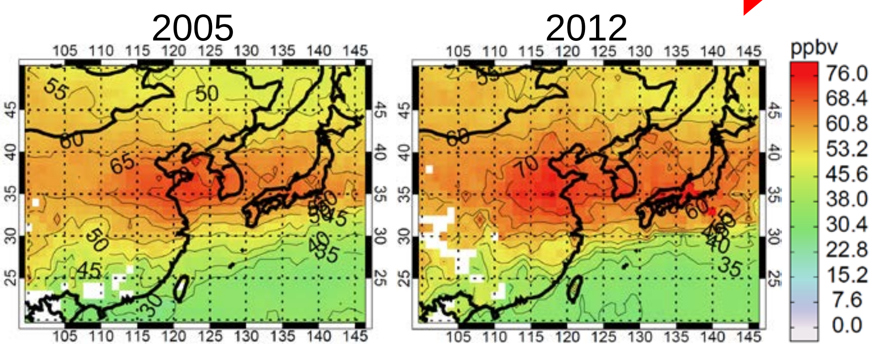
- 7 million people died as a result of effects of air pollution in 2012 [WHO, 2014].
- Tropospheric ozone:
  - One of major air pollutants



Our health

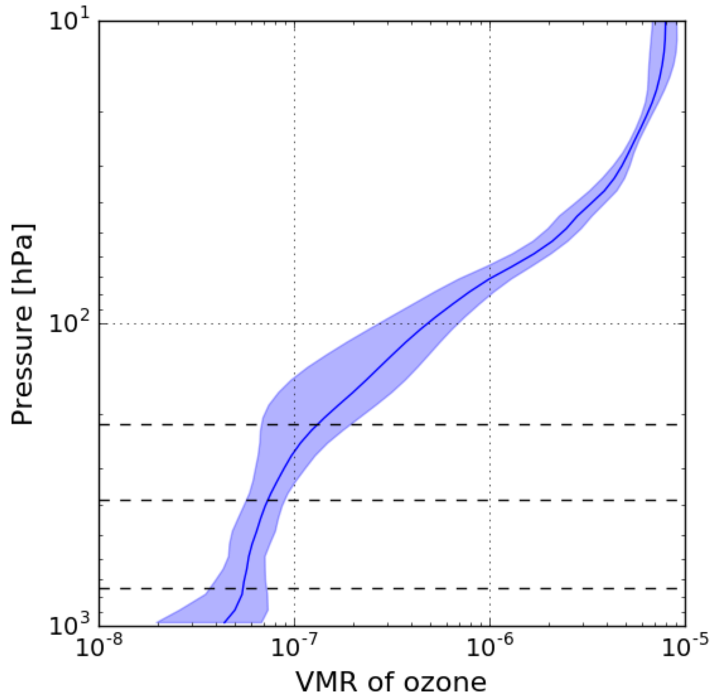
Crops

Increasing / keep high level



Ozone distribution at 0-3 km in June [Hayashida et al., 2015]

- Monitoring of ***vertically resolved*** ozone amount is required.



Stratosphere:
- Absorption of solar UV radiation
- Central role of stratospheric chemistry

Troposphere:
- The third largest global warming gas

Lowermost Troposphere:
- Harmful pollutant

Objective

- Our idea = Adding MW limb measurement to the multi-spectral synergetic retrieval using satellite observations
- We performed a sensitivity study of synergetic retrieval of tropospheric ozone profile using UV, TIR and MW measurements.

Single measurement

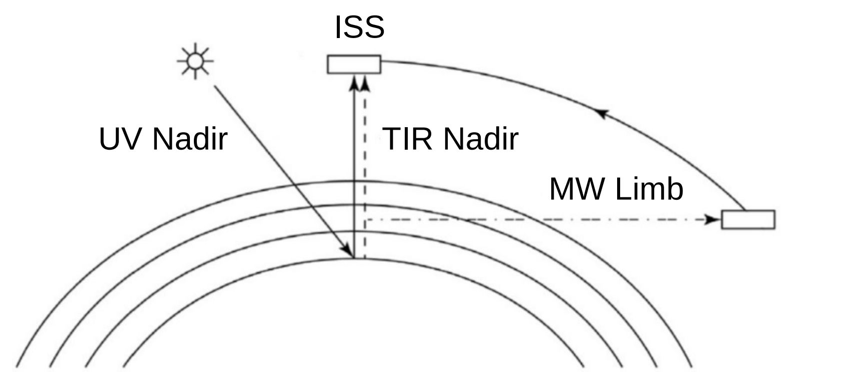
	UV-vis Nadir	TIR Nadir	MW Limb
Strato.	Resolve to several layers	Resolve to several layers	Profile
Upper Tropo.			
Middle Tropo.	Tropo. column	Tropo. column	×
Lower most Tropo.			×

Multi measurements

UV-vis Nadir +MW Limb	UV-vis Nadir +TIR Nadir	UV-vis Nadir +TIR Nadir +MW Limb
Profile	Resolve to several layers	
		?
Tropo. column	Resolve to 2 – 3 layers	
	*DFS < 0.3	
OMI + MLS [Ziemke et al., 2006]	OMI + TES [Fu et al., 2013] GOME2+IASI [Cuesta et al., 2013]	Our work

Observation scenario

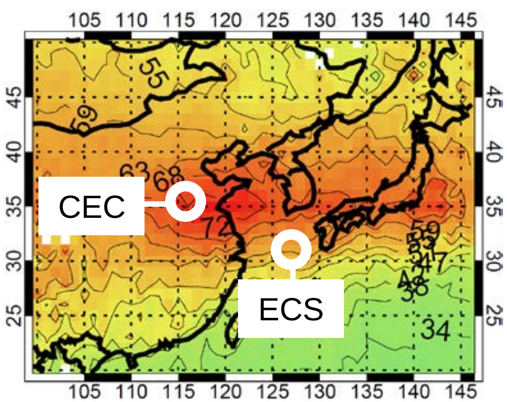
- Follows the concept of the Japanese mission, Air POLLution Observation (APOLLO).
  - Platform = ISS (300 km height)
  - UV Nadir + TIR Nadir + MW Limb



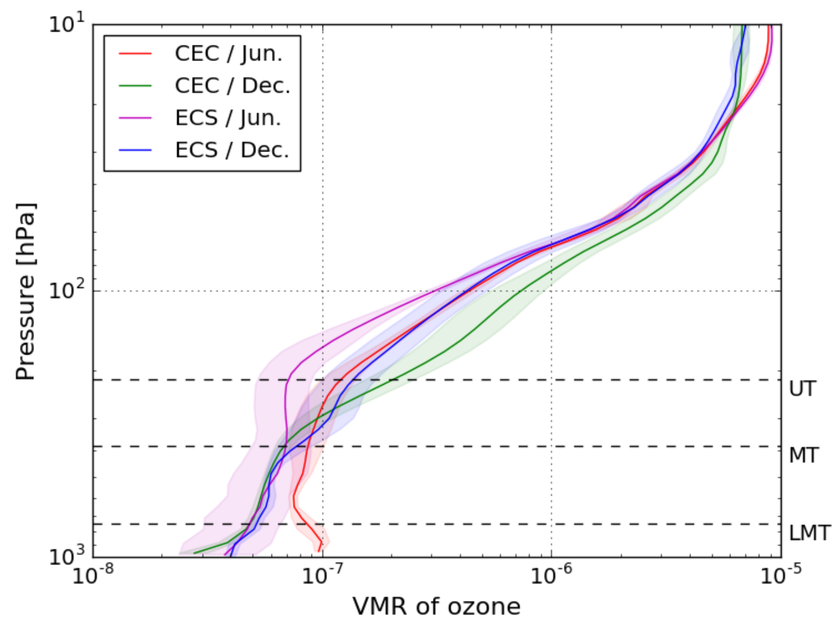
Observation geometry of nadir (UV, TIR) and limb (MW)

- Target area: East Asia
  - One of the most serious ozone polluted area
  - 4 cases (2 sites X 2 seasons) were assumed. (Total 20 atmospheric profiles)

Sites:	CEC (Central-East China)	35°N, 116.5°E
	ECS (East China Sea)	31°N, 127.3°E
Season:	Summer (Jun.) and Winter (Dec.) in 2009	



Simulation points
(Background: Ozone at 0-3 km in June, 2009 [Hayashida et al., 2015])



Vertical ozone profiles used in this study
Surface – 65 hPa: Air quality forecasting system
985 – 0.01 hPa: MERRA data

Radiative transfer calculation setting

	UV Nadir	**TIR Nadir**	**MW Limb**
Forward model	SCIATRAN	LBLRTM	AMATERASU
Wavelength	305 – 340 nm	980 – 1080 cm^{-1}	345 – 357 GHz, 639 – 651 GHz
Spectral resolution	0.6 nm	~0.12 cm^{-1}	25 MHz
Sampling step	0.2 nm	~0.12 cm^{-1}	25 MHz
Sensitivity	S/N ~90 (300 nm), S/N ~2600 (340 nm)	S/N ~300	T_b~0.7 K (350 GHz band), T_b~1.7 K (645 GHz band)
Cloud	No	No	No
Aerosol	Basic background	No	No
Scattering	Yes	No	No
Emission	No	Yes	Yes

Assumption:
- No bias between the three forward models (to investigate potential advantage)
- Spherically homogeneous atmosphere along the line-of-sight of MW measurement
- Thermal contrast (surface/atmosphere) < 1 K
- Time difference between the nadir and limb measurement was ignored.

Retrieval method

- Optimal estimation method (OEM) [Rodgers, 2000] for the synergetic retrieval and the error estimation

DFS: Degree of freedom for signal

The number of useful independent quantities there are in a measurement

$$\mathrm{DFS} = \sum_{\mathrm{i}=\mathrm{i}_{\mathrm{min}}}^{\mathrm{i}_{\mathrm{max}}} \mathrm{A}[\mathrm{i},\mathrm{i}]$$

PMS: Pressure of maximum sensitivity

$$\mathrm{PMS}[\mathrm{i}] = \mathbf{p}[\text{where } \mathrm{A}[\mathrm{i},:] \text{ is maximum.}]$$

RRE: Reduction rate of error (from a priori error)

$$\mathrm{RRE} = 1 - \mathrm{PCE}_{\mathrm{retrieved}}/\mathrm{PCE}_{\mathrm{a\ priori}} \quad [\%]$$

A: Averaging kernel

Characterizing the sensitivity of the retrieved state ($\mathbf{x}$) to the true state ($\hat{\mathbf{x}}$)

$$\mathrm{A}[\mathrm{i},\mathrm{j}] = \frac{\partial \hat{\mathbf{x}}[\mathbf{i}]}{\partial \mathbf{x}[\mathbf{j}]}$$

Comparison with previous studies

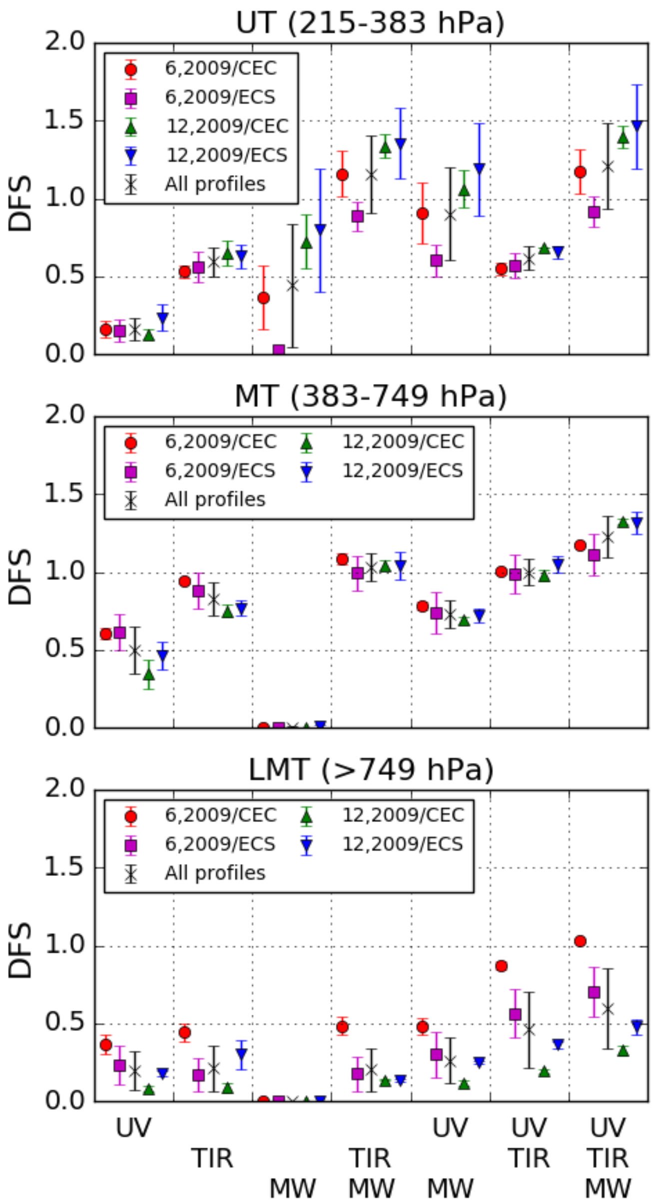
- Values of DFS for UV, TIR and their combination were compared.

	DFS_{UV}	DFS_{TIR}	DFS_{UV+TIR}	ΔDFS	Def. LMT
Our simulation	0.20	0.21	0.46	+128%	> 749 hPa
OMI+TES [Fu et al., (2013)]	0.10	0.21	0.37	+139%	> 700 hPa
GOME-2+IASI [Cuesta et al., (2013)]	0.08	0.20	0.29	+104%	< 3 km
Simulation [Natraj et al., (2011)]	0.26	0.27	0.57	+115%	> 800 hPa

Good agreement in relative DFS increase

Results: Degree of Freedom for Signal (DFS)

MW increased DFS in UT, MT and LMT. (MW alone has less sensitivity in MT and LMT.)



Upper Troposphere (UT)

- TIR, MW: dominant (MW depends on amount)
- For all profiles averaged,
  DFS (UV+TIR) = 0.62±0.08
  DFS (UV+TIR+MW) = 1.21±0.28
- DFS was increased ~100% by adding MW.

Middle Troposphere (MT)

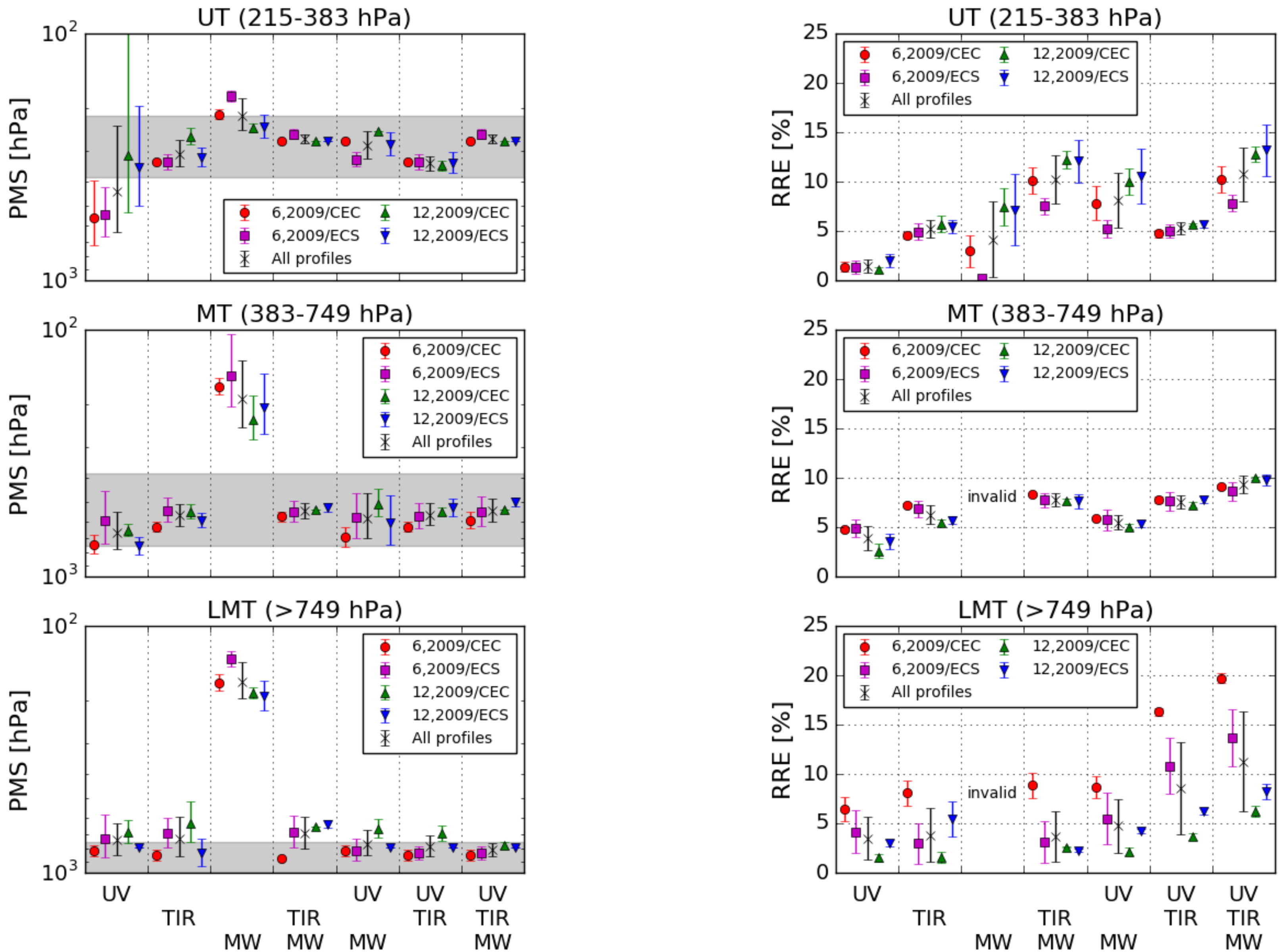
- DFS: TIR > UV >> MW (less information)
- For all profiles averaged,
  DFS (UV+TIR) = 1.00±0.09
  DFS (UV+TIR+MW) = 1.23±0.13
- DFS was increased ~20% by adding MW.

Lowermost Troposphere (LMT)

- Same as the case in MT
- DFS was increased ~30% by adding MW.

Results: Pressure of maximum sensitivity (PMS) and reduction rate of error (RRE)

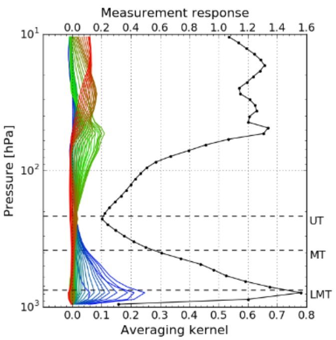
Improvements in PMS and RRE are observed by adding MW measurement.



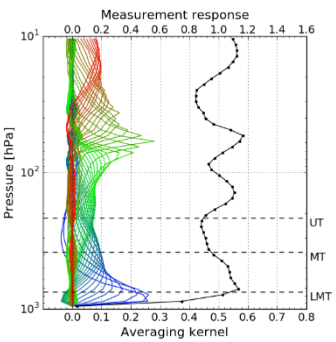
Results: Averaging kernel

- Calculated for profile with enhanced ozone in LMT (CEC / Summer)

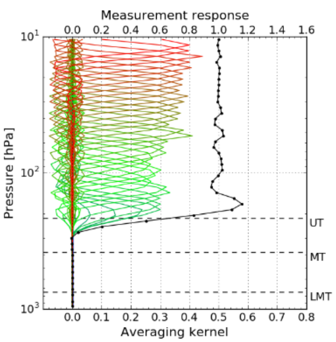
UV



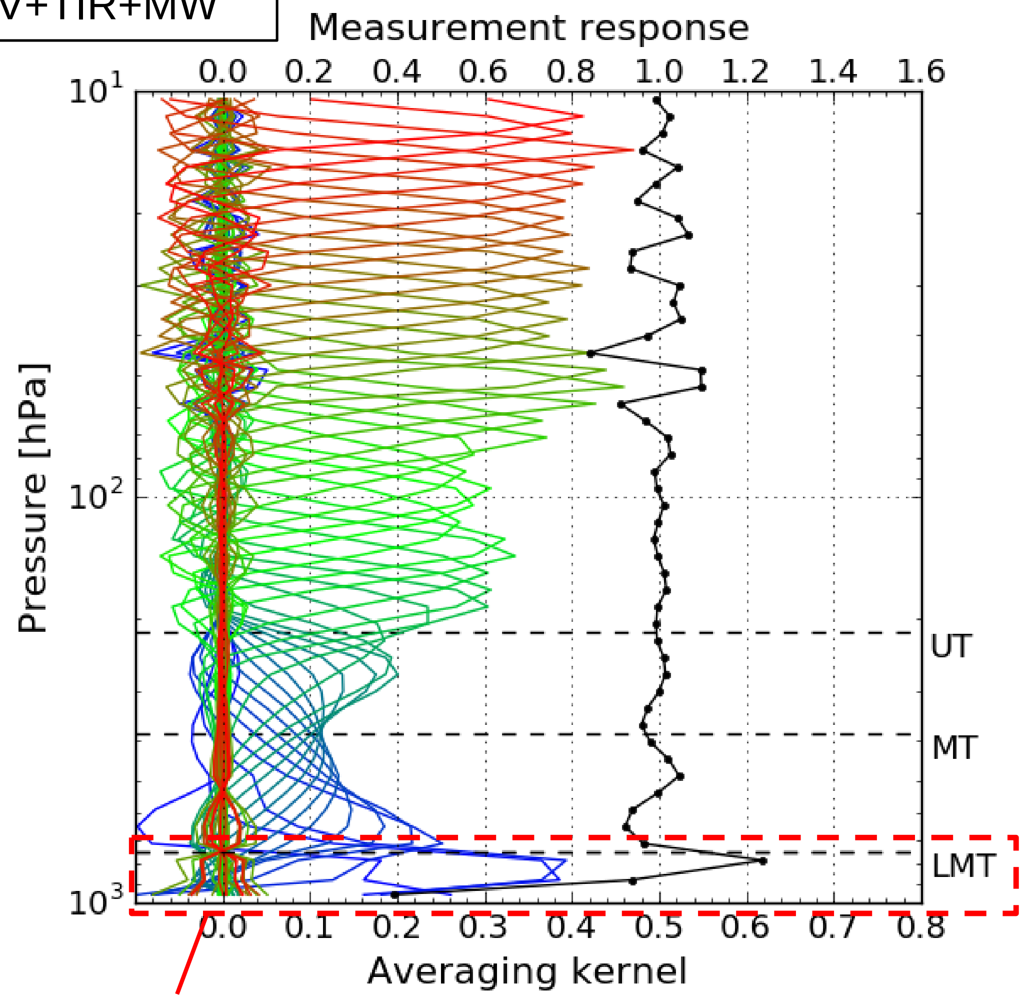
TIR



MW



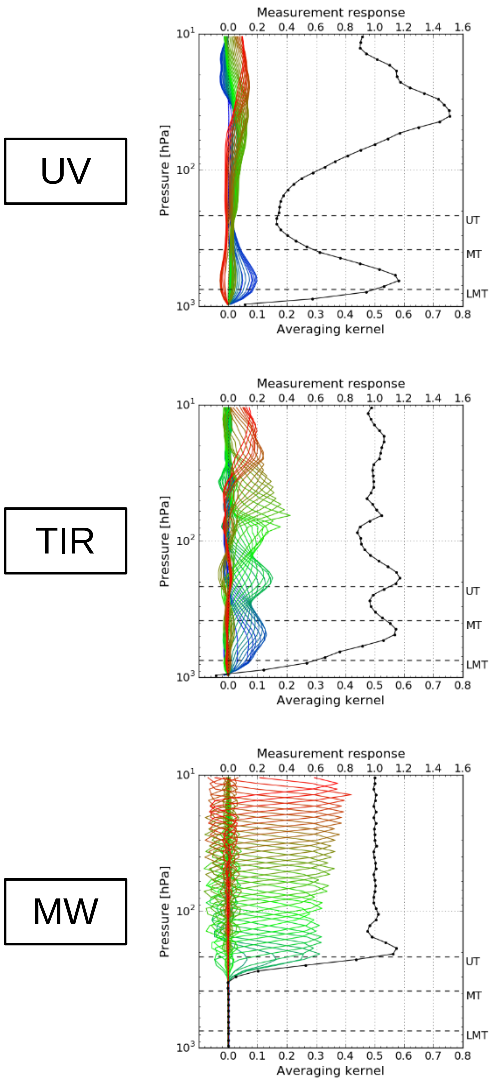
UV+TIR+MW

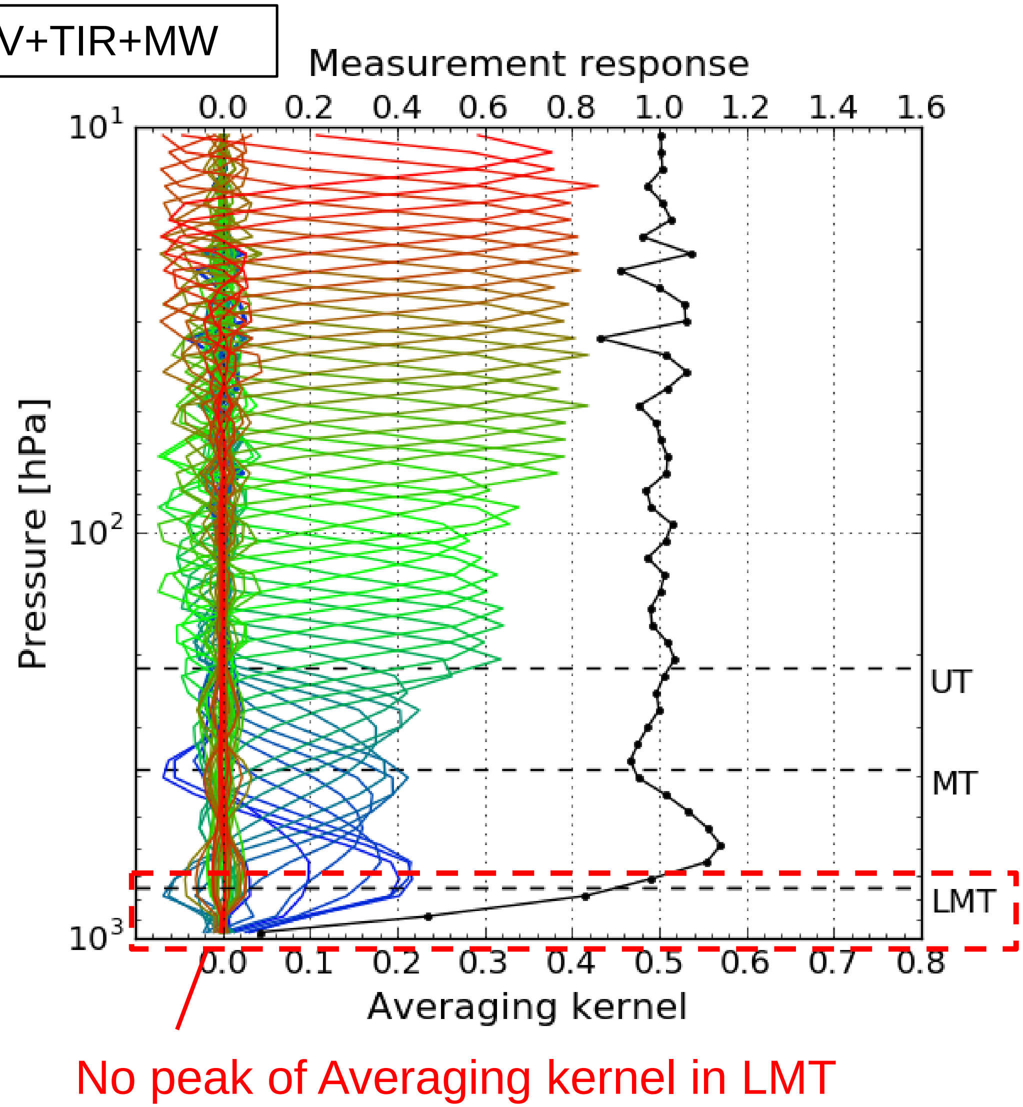


Enhanced peak of Averaging kernel in LMT

Results: Averaging kernel

- Calculated for profile with low ozone amount in LMT (CEC / Winter)





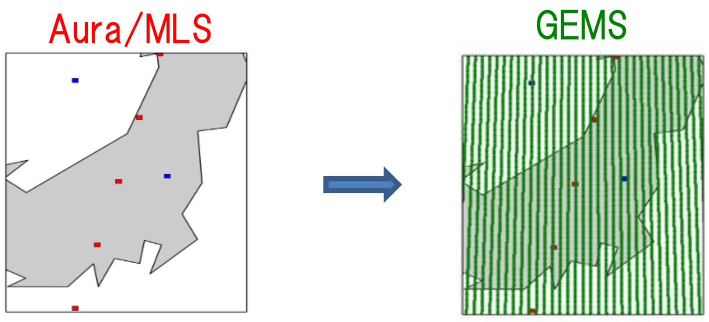
Implementation to real measurements

Possibilities:

- Adding MW measurement: 30% increase in DFS of the LMT ozone
- Simulation for IASI-NG+UVNS shows: DFS of the LMT ozone = 0.75 (over land) [Constantino et al., 2017]

⇒ Possibility to derive the LMT ozone with DFS larger than 1 from space

- GEMS+MLS combination derives the surface ozone distribution from space over Asia with high spatial-temporal resolution.



Problems:

- Discrepancy in the forward model
  - Error in spectroscopic parameters (3~5% in MW, ~4% in UV/TIR)
  - Tangent height correction error for MW causes a discrepancy between the atmospheric layers in simulation and the true.

- Coincidence of MW limb measurement and UV/TIR nadir measurement

Summary and perspectives

Our feasibility study to obtain vertically resolved tropospheric ozone profiles by synergetic retrieval using a combination of UV, TIR, and MW ranges shows:

- Increase of DFS values by ~100% (UT), ~20% (MT) and ~30% (LMT) by adding the MW measurements to the UV+TIR measurements
- Constraint of the stratospheric vertical ozone profile could be important for accurate estimate of the tropospheric ozone profile.
- Improvements in DFS, PMS and RRE were observed in several a priori settings (σ_a = 100%, 50%, 30%, 20%, 10%).
- Improvement in the LMT ozone retrieval by adding MW measurement is obvious for the case of ozone enhancement in the LMT (as large as approximately 5×10^{21} m^{-2}).

Contribution to Japanese missions (e.g., Air POLLution Observation (APOLLO) and air pollution prediction project in NICT).

High spatial-temporal resolution of GEMS observation potentially overcomes the coincidence problem.