Development of Ozone Profile and Total Ozone Column Algorithms for GEMS

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Introduction

1. Ozone profile Algorithm based on SAO Optimal Estimation tech.

2. Total Column Ozone Algorithm based on NASA TOMS V9

3. What have we done from both algorithms ?

4. What will we do in the future ?

Ozone Profile Algorithm

- Optimal Estimation (Rodgers, 2000) based ozone profile algorithm
- OMI OE algorithm : **Xiong Liu (Harvard SAO)**
- O3 fitting Windows : **270-330 nm (OMI), 300-330 nm(GEMS)**

$$\chi^2 = \left\| \mathbf{S}_y^{-\frac{1}{2}} \{ \mathbf{K}_i (\mathbf{X}_{i+1} - \mathbf{X}_i) - [\mathbf{Y} - F(\mathbf{X}_i)] \} \right\|_2^2 + \left\| \mathbf{S}_a^{-\frac{1}{2}} (\mathbf{X}_{i+1} - \mathbf{X}_a) \right\|_2^2$$

Spectrum difference
bet. Measurement and simulation

State vector difference
Bet. current solution and a priori

- RTM model(radiance, weighing function matrix) : **VLIDORT**
- A Priori: **Mon/Latitude dependent O3 profile clima. [McPeters et al. 2007]**

  Switch to Tropopause-based O3 profile clim. [Bak et al., 2013]
- Measurement error: **OMI level 1b random-noise error**
- Cloud information : **OMI O2-O2 algorithm**
- Detailed treatments of wavelength and radiometric calibrations

  Soft calibration : correct wav./cross track dependent biases in level 1 radiance

  Correct wavelength shifts: radiance/irradiance, radiance/o3 cross section

  fitting : surface albedo, cloud fraction, scaling parameter for ring effect, mean fitting residuals

Total Ozone column Algorithm

- **TOMS V9 Total ozone algorithm : P. K., Bhartia and David Haffner**
- **RTM model(radiance, weighing function matrix) :** VLIDORT v2.6 (online)
  - A 21 toms standard ozone profile (101 layer)
  - Rayleigh scattering + O_3 gas without aerosol and cloud
  - Brion-Daumont-Malicet (BDM; Malicet et al., 1995)
- **SLER (Simple Lambertian Equivalent Reflectivity model)**
  - Surface pressure (Terrain height -> 1 atm)
- **Linear R-λ correction (follow Dave et al., 1978)**
  - Aerosol, residual errors, Terrain height, calibration and sea glint correction
  - 340/354 nm for reflectivity
- **Wavelength :** 312.61, 317.85 , 331.04 nm (reduce Ring effect)

Total Ozone column Algorithm

- **OE (Optimal Estimation) uses 3 wave for O3 information**

$$\hat{X}_{n+1} = X^a + S_a K_n^T (K_n S_a K_n^T + S_\varepsilon)^{-1} [(Y - Y_n) - K_n (X^a - \hat{X}_n)] \quad \text{(Rodgers, 2000)}$$

  - For now using 216 profile a priori [Lat x Month] (McPeters et al., 2006)
  - Measurement error (Se) is assumed 0.5% for all channel
- **Total O3** calculated by integrating retrieved profile
- Advantage of using **OE** provides error bars, efficiency factors, and DFS
- Not yet applied: Cloud correction & Ring & temperature correction.

Evaluation of ozone profile retrievals from synthetic GEMS measurements

- **Averaging kernels (AK)**

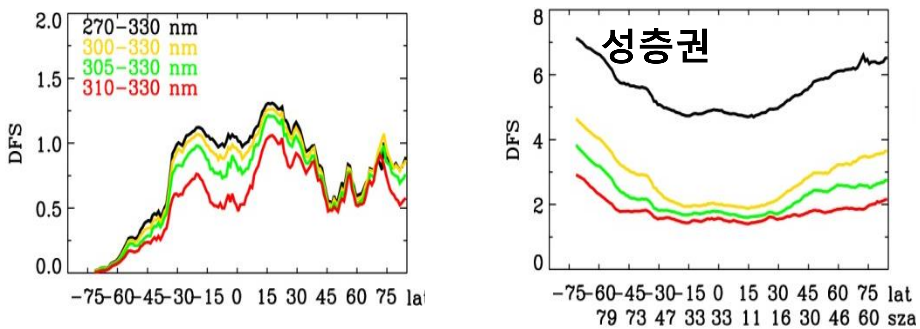
$$\mathbf{A} = \frac{\partial \mathbf{x}_{ret}}{\partial \mathbf{x}_{true}} = (\mathbf{K}^T \mathbf{S}_y^{-1}\mathbf{K} + \mathbf{S}_a^{-1})^{-1}\mathbf{K}^T \mathbf{S}_y^{-1}\mathbf{K}$$

0 (by A priori) < A < 1 (by measurement)

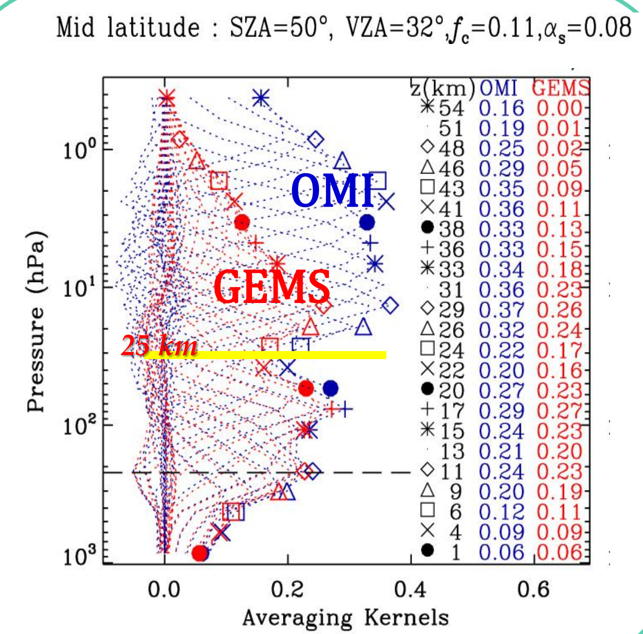
- **Degrees of the Freedoms for Signal (DFS)** : Diagonal element of the Averaging kernel.

  OMI total DFS : 6 -7

DFS as function of LAT/SZA for 4 fitting windows



Comp. OMI and GEMS AK

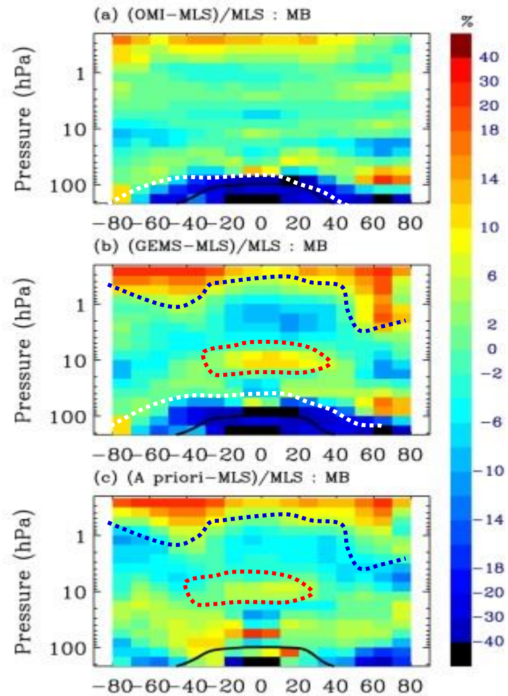


- GEMS keep the spectral information for the trop. O3 comparable to OMI.
- The stra.O3 information decrease two times due to no measurements below **300** nm, especially at alt > 25 km.
- GEMS stratospheric DFS is 2 to 4 depending on SZA

Evaluation of GEMS stratospheric ozone profile retrievals using MLS

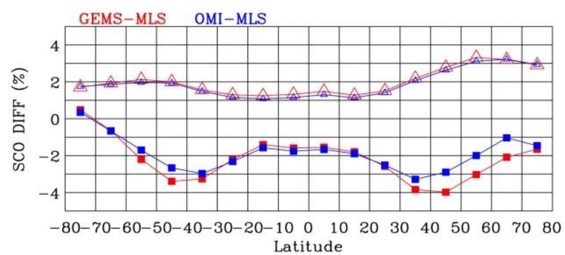
- OMI UV (300-330 nm) ➔ GEMS retrievals, OMI UV(270-330 nm) ➔ OMI retrievals
- Microwave Limb Sounder (MLS v3.3) standard ozone products above 215 hPa.
  VR = ~ 3 km (7-11 km)
- Compare OMI/GEMS retrievals and MLS during April, 2006

Profile comparison

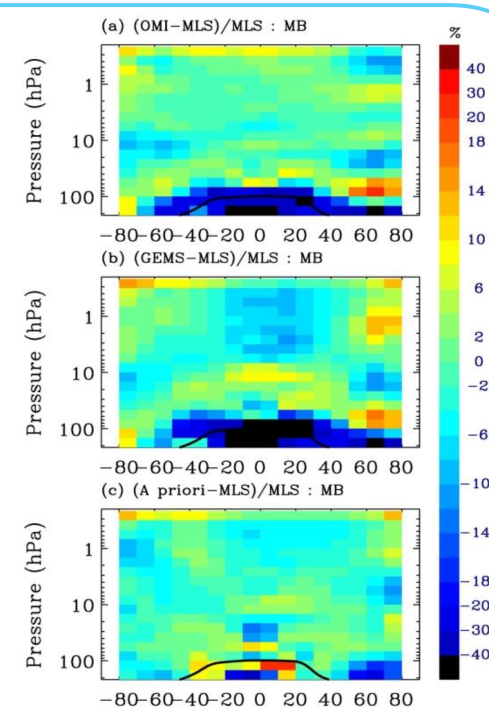


Mean Bias

SCO comparison



- Only 1 % difference at mid latitude



- Tropopause region : large negative bias is found commonly due to coarser VR Of OMI/GEMS than MLS
- High stratosphere above 3 hPa : large positive bias in GEMS due to no information below 300 nm and large influence from a priori

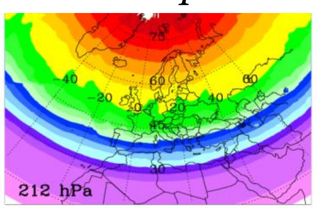
- ML (2012) is updated version of LLM (2007)
- Use of the better a priori data can improve GEMS retrievals above 3 hPa

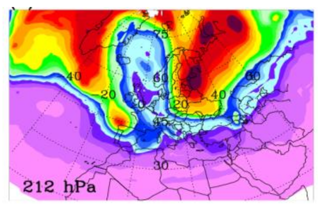
Development of New a priori ozone data

Relatively weak vertical information in UTLS where large O3 gradient occurs: greatly depends on climatological a priori info. Develop a tropopause-based climatology (as a proxy for atmospheric dynamics) for improving OMI retrievals in the UTLS using Ozonesonde profiles from 1983 to 2008. Each individual profile is extended from the climatological stratospheric O3 profiles. The use of TB coordinate is an established method in analyzing the UTLS ozone field, with the advantages; better preserves the sharp gradient across the tropopause and significantly reduces ozone variance due to daily meteorological variabiliy

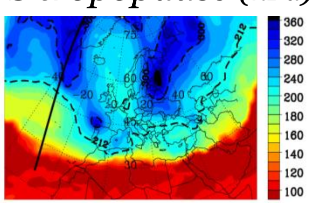
LLM | **TB** | **OMI – ozonesonde (2004-08)**

- *Horizontal a priori*

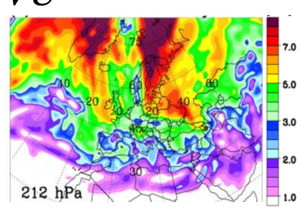




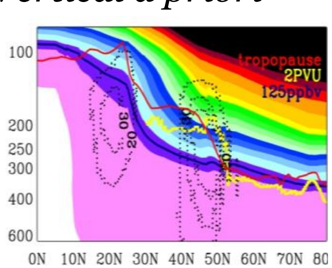
- *GFS tropopause (hPa)*

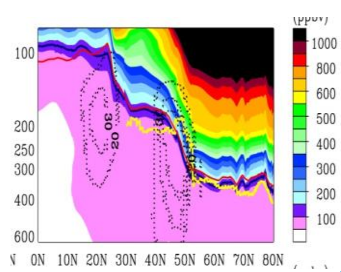


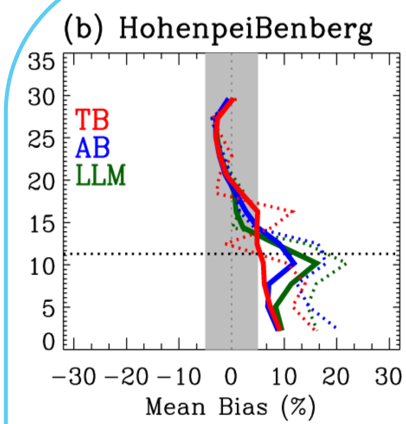
- *PVU*

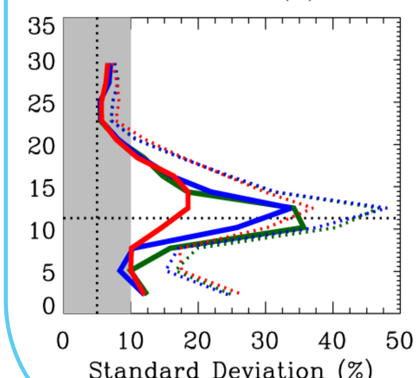


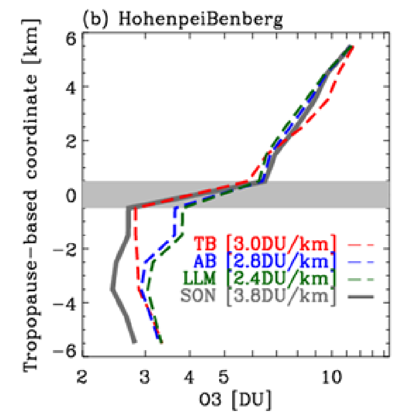
- *Vertical a priori*







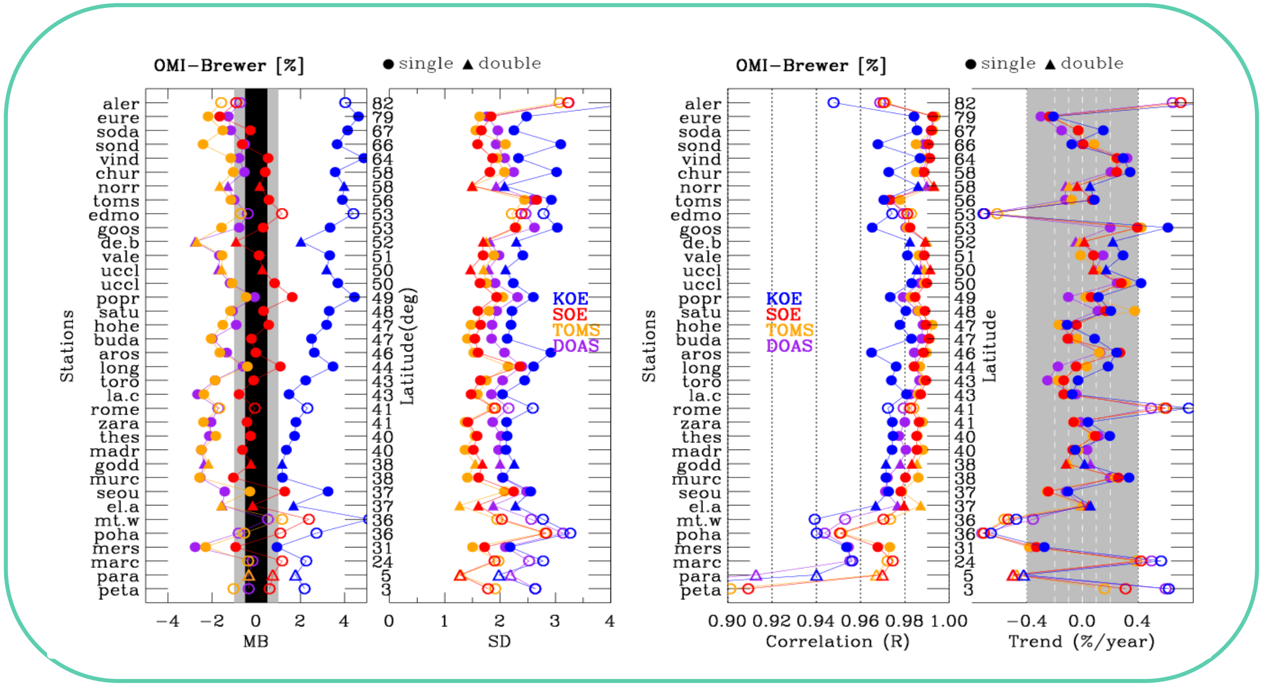




What have we done ?

Validation of SAO ozone profile algorithm on Total O_3

- Evaluate the retrieval performance in total ozone through comparison with four years (05-08) of Brewer data over the NH, collocated from WOUDC network.
- Same comparison with Brewer has been conducted for three operational total ozone for intercomparison against SAO total ozone ; NASA TOMS (v.8.5), KNMI DOAS (v.1.2.3.1), and KNMI OE algorithms (v.1.1.0 before 1-2-2006, v.1.1.1 after)



- We initially selected 36 stations having at least 100 days with Direct Sun Brewer observation every year.
- 28 stations among them were identified as a good reference using the similar selection procedure done by Balis et al. [2007].
- A good reference has **a smooth variation from station to station w.r.t the mean difference, correlation, long-term stability** from station to station

✓ Circle and triangle symbols indicate single and double Brewer stations, respectively.

✓ The filled and opened symbols represent stations selected and rejected, respectively.

❖ The agreement between SOE and Brewer lies within ± 1 % at most stations; the overall difference is 0.02 % with a standard deviation of 1.81 % over the NH.

❖ TOMS and DOAS comparisons with Brewer have the similar negative biases at mid latitude, but -1.65 % and -1.22 % at high latitude

❖ KOE algorithm overestimates Brewer total ozone by from ~ 2 % at mid-latitude to ~ 5 % at high lat. stations.

❖ Standard deviations of KOE/DOAS biases are larger than 2 %. Those of TOMS/SOE biases are ~ 1.8 % over NH

Validation of V9 ozone algorithm using PANDORA

- During DRAGON campaign, 22 AERONETs were established throughout South Korea and 2 PANDORAs also were placed at Busan and Seoul, respectively to monitor air pollution and to validate satellite data, aircraft data, and improve chemistry-transport models.
- Total O_3 derived from V9 were compared with PANDOARA to evaluate and access total O_3 derived from V9. For comparison between Satellite and V9, Pandora data were averaged over ± 1h window of OMI overpass.
- OMI data were selected to keep only those data where the distance from ground-measurement was < 20 km, OMI cloud fraction <0.1 and AI<0.1 to

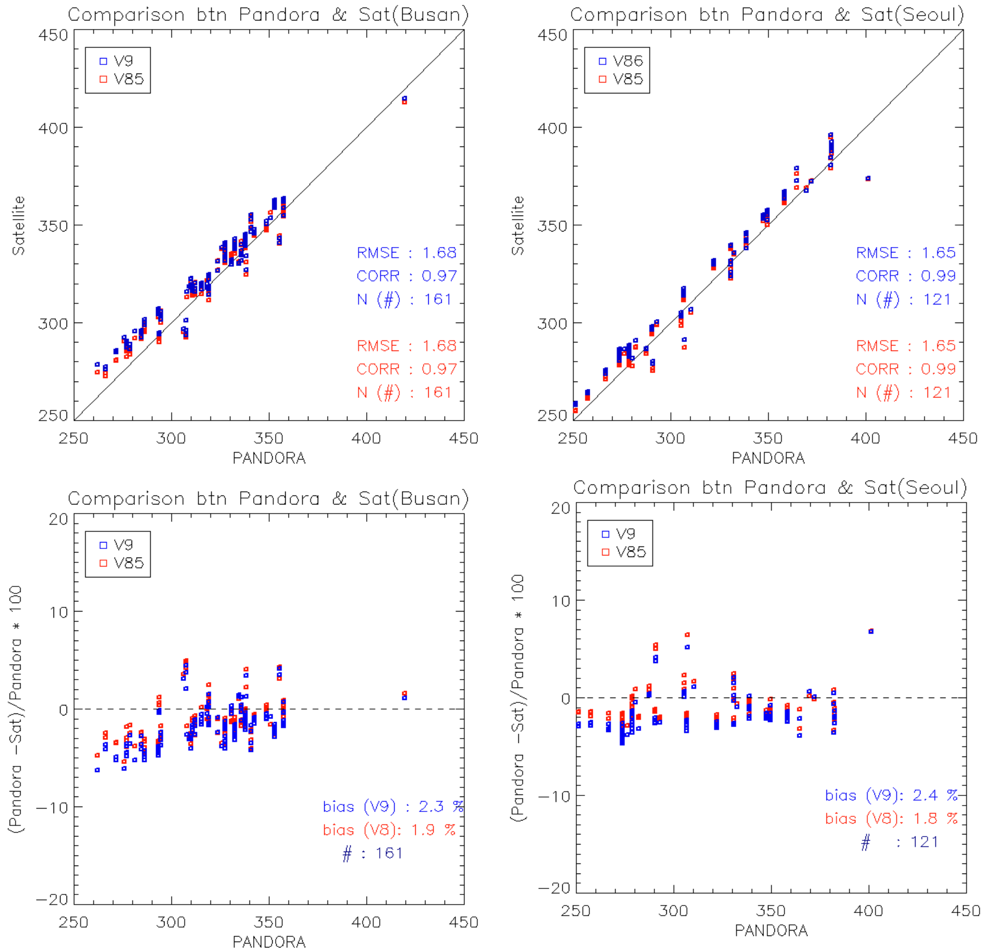
PANDORA

- PANDORA present high precision, high temporal resolution measurement of total column ozone derived from direct-sun irradiance measurement.
- PANDORA uses wavelength range of 270-530nm and a spectral resolution of ~0.5nm (similar to OMI) and measures radiance with a narrow field of view (~1.6°full angle) pointing at the sun, the moon, or the sky.

[J. Herman, 2010]

What have we done ?

Validation of V9 ozone algorithm using PANDORA



- Top : The comparison between Satellite and PANDORA at Busan (left), Seoul (right) during 2012. The result of comparison shows that V8.5 (red) & V9 (blue) results have a good agreement with Pandora.
- Bottom : Relative difference of OMI satellite and PANDORA as a function of Pandora ozone. The blue is V8.5 and the red is V9. Bias is 2~3%

Future Research Plan

1. Evaluation of the OMI SAO and V9 Total column ozone products w.r.t. ground ozone station over Northeast Asia.

2. Analyze the reason that some of tropospheric ozone features from the OE method does not match meteorological flow.

3. Find the best a priori ozone information from LLM, ML, total ozone or tropopause dependent climatology

4. Understand retrieval algorithm related to cloud/aerosol/surface reflectivity /reference spectrum data factors.

5. Complete R-λ correction and cloud correction for V9 algorithm

6. Appreciate your collaboration.