Community Workshop on Air Quality Remote Sensing from Space: Defining an Optimum Observing Strategy

Directly Retrieved Global Distribution of Tropospheric Column Ozone from GOME

X. Liu[1], K. Chance[1], C.E. Sioris[1], T.P. Kurosu[1], R.J.D. Spurr[1,2], R.V. Martin[1,3], M.J. Newchurch[4], M. Fu[5], J.A. Logan[5], D.J. Jacob[5], P.I. Palmer[5], I. Megretskaia[5], R. Chatfield[6]

[1]Atomic and Molecular Physics, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA
[2]RT SOLUTIONS, Inc., Cambridge, MA, USA
[3]Department of Physics and Atmospheric Sciences, Dalhousie University
[4]Atmospheric Science Department, University of Alabama in Huntsville
[5]Division of Engineering and Applied Sciences, Harvard University
[6]Atmospheric Chemistry and Dynamics Branch, NASA Ames Research Center

Abstract Ozone profiles and tropospheric column ozone are derived from back scattered radiance spectra in the ultraviolet measured by the GOME with the optimal estimation technique. The retrievals are capable of capturing the spatiotemporal evolution of TCO in response to regional or short time-scale events such as the 1997-1998 El Niño event and a 10-20 DU change within a few days. The mean biases relative to ozonesonde observations are usually within 3 DU (15%) and the standard deviations are within 3-8 DU (13-27%). The global distribution of TCO displays nearly zonal bands of enhanced TCO of 36-48 DU at 20ºS-30ºS during the austral spring and at 25ºN-45ºN during the boreal spring and summer. The overall structure is very similar to the GEOS-CHEM model simulation with small biases of <±5 DU and consistent seasonal cycles in most regions. This method can be readily applied to observations from current or next generation of nadir-viewing UV/visible instruments such as SCIAMACHY, OMI, GOME-2, and OMPS to derive ozone profiles, total ozone and tropospehric ozone.

Station	TCO A Priori-Sonde			GOME-Sonde			Station	TCO A Priori-Sonde			GOME-Sonde		
Resolute	5.6	5.7	0.56	0.1	6.2	0.46	Ku. Lumpur	9.0	5.0	0.00	3.0	5.4	0.38
Scoresby.	2.4	5.4	0.52	-3.3	5.9	0.39	San Crist.	7.8	2.7	0.74	2.7	3.8	0.62
Sodankylä	2.7	3.8	0.62	-0.5	6.5	0.53	Nairobi	-1.7	5.9	0.29	-0.7	5.4	0.66
Churchill	3.1	5.2	0.56	1.0	4.2	0.62	Java	4.6	7.5	0.50	-0.1	5.0	0.87
Valentia	-0.3	8.0	0.27	0.5	6.5	0.25	Ascension	-6.9	6.3	0.80	0.0	5.9	0.77
Hohenpei.	2.4	5.3	0.59	1.1	5.8	0.56	Am. Samoa	5.0	5.8	0.55	1.5	4.5	0.82
Payerne	2.3	5.6	0.64	-0.1	5.6	0.65	Tahiti	9.6	5.6	0.47	5.1	4.1	0.82
Boulder	3.1	5.7	0.69	1.9	3.9	0.87	Réunion	1.6	5.3	0.78	1.8	3.2	0.85
Ankara	3.4	4.9	0.83	2.6	5.2	0.87	Irene	3.6	5.5	0.79	-0.3	4.6	0.85
Wallop Is.	0.6	6.6	0.69	-3.0	5.4	0.83	Easter Is.	7.2	8.3	0.45	2.6	5.4	0.81
Tateno	3.5	6.6	0.73	0.0	5.2	0.85	Laverton	0.8	3.4	0.68	-2.5	4.7	0.69
Kagoshima	6.2	7.6	0.65	1.7	7.8	0.71	Lauder	2.3	3.5	0.62	1.6	4.0	0.40
Santa Cruz	-4.2	8.2	0.54	1.5	7.4	0.76	Macquarie	2.6	3.2	0.75	-0.3	5.2	0.56
Naha	6.4	7.0	0.56	5.4	6.1	0.70	Marambio	-0.7	5.1	0.76	-0.9	5.0	0.81
Hilo	2.6	6.4	0.67	1.7	6.0	0.79	Syowa	1.0	3.8	0.92	-3.1	5.6	0.80
Paramaribo	2.0	3.7	0.00	-1.8	3.7	0.22	Neumayer	1.7	3.4	0.93	-4.0	5.1	0.89
Kaashidhoo	3.4	5.0	0.27	0.9	6.5	0.27							

Table 1. Comparison statistics (mean bias in DU), 1σ standard deviation in DU, and the Pearson correlation coefficient) between GOME retrieved/*a priori* TCO and ozonesonde measurements at 33 stations from 1996 though 1999.

- **Mean biases are mostly within 3 DU (15%) and the 1σ standard deviations are within 3-8 DU 13-27%.**

1. Algorithm Description

- Optimal estimation with TOMS V8 ozone climatology
- Fitting window: 289-307 and 326-339 nm (couldn't be used in between due to calibration problems).
- 11 layers (2-3 layers in the troposphere, use NCEP tropopause to divide troposphere and stratosphere)
- Wavelength calibrations: variable slit widths, shifts among radiances, irradiances, and cross-sections
- Radiometric calibrations: undersampling correction, a 2nd-order polynomial correction in 290-310 nm and a 2rd-order surface albedo in 325-339 nm,
- Forward modeling with LIDORT; ECMWF/NCEP daily temperature, surface & tropopause pressure, GOMECAT clouds, GOCART

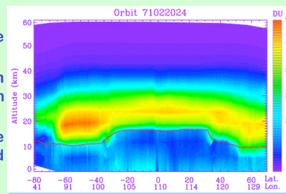

Fig. 1 An orbit of retrieved profiles of partial (layer) column ozone (DU) on 22 October 1997. It shows ozone hole in Antarctic polar vortex and maximum ozone outside the polar vortex, enhanced tropospheric ozone over Indonesia and the Southern India Ocean.

- **Fig. 1** shows an orbit of retrieved profiles. This poster focuses on the retrieved TCO.

2. Retrieval Characterization of Tropospheric Ozone

- Vertical resolution: 9-16 km in the troposphere   DFS: 0.5-1.5 between ±50ºN/S.
- Precision: < 10%   Precision + Smoothing: 15-25%
- Precision in TCO: from <6% (1.5 DU) in the tropics to <12% (3.0 DU) at high latitudes
- Precision + smoothing in TCO: from <12% in tropics to <25% at high latitudes.
- Globally-averaged retrieval accuracy in TCO: 21%.
- A *priori* influence in TCO: from ~15% in the tropics to ~50% at high latitudes.
- Spatial resolution: normally 960×80 km² (320x40 km² is possible after June 1998)

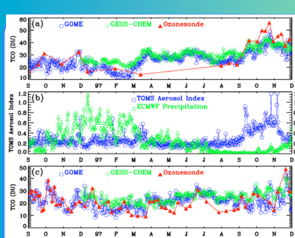

Fig. 2 (a) GOME and GEOS-CHEM daily TCO from Sep.1996 to Nov. 1997 over Indonesia (110º-125ºE,8.6º-6.6ºS) and ozonesonde TCO at Java (112.7ºE,7.6ºS). (b) Same as (a) but for TOMS aerosol index and ECMWF precipitation. (c) Same as (a) but over (180º-158ºW,15.2º-13.2ºS) and at American Samoa (170ºW,14.2ºS).

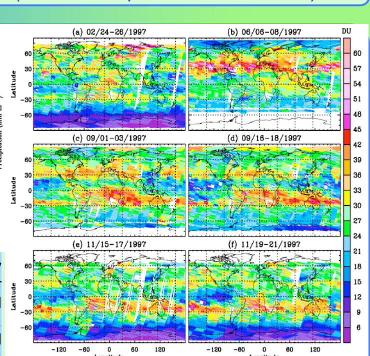

Fig. 3 Three-day composite global maps of TCO.

3. Daily Retrievals and Validation

- Detailed TCO response to the 1997-1998 El Niño event (dry weather and wildfires) over Indonesia (**Fig. 2a-b**).
- Changes of 10-20 DU within a few days (**Fig. 2c**).
- TCO (>40 DU) in Feb. over North Africa (**Fig. 3a**)
- Band of high TCO (40-60 DU) at 25-45ºN in June (**Fig. 3b**).
- Distinct differences at 25-40ºN (**Fig. 3c-d**) between 1-3 Sep. and 16-18 Sep.; a 12 DU increase over Indonesia.
- Transport of southern subtropical high-ozone air to the tropics around American Samoa in Nov. (**Fig. 2c**, **Fig. 3e-f**).
- Capture most of the temporal variability of ozonesonde observations (**Fig. 2a**, **Fig.2c**, **Fig. 4**)

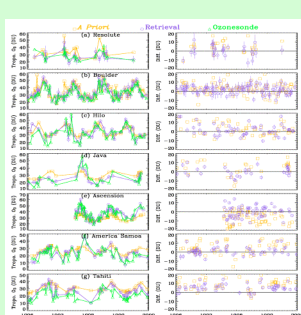

Fig. 4. Comparison with selected ozonesonde observations.

4. Global Distribution of TCO

- Tropical wave-1 during most months especially in the southern hemisphere.
- TCO of 33-39 DU near Gulf of Guinea during North Africa biomass burning season (support the tropical Atlantic paradox).
- Significant spatiotemporal variation over tropical pacific, location of low TCO migrates with ITCZ.
- Wave-1 patterns weakens in the extratropics with nearly uniform bands at ~30ºS/N).
- Enhanced TCO at 25ºN-45ºN in April-July (36-48 DU) and at 25ºS-35ºS in Sep.-Nov. (33-45 DU).
- At ~30ºS and over the tropical south Atlantic, TCO maximizes in Sep.-Nov. and minimizes in Apr.-June.
- 15-30ºN: highest in spring and lowest in Jul.-Sep. 30-45ºN: highest in May-Jul. and lowest in Nov.-Dec.
- TCO of <30 DU uniformly distributed south of 35ºS during all seasons with a large latitudinal

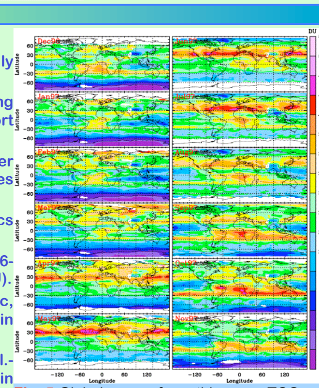

Fig. 5 Global maps of monthly mean TCO from Dec. 1997 to Nov. 1997.

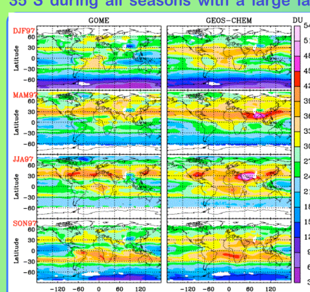

Fig. 6 Comparison of GOME and GEOS-CHEM TCO for four seasons during Dec 1996-Nov 1997 (DJF, MAM, JJA, SON).

5. Comparison with the GEOS-CHEM

- Similar overall structure: tropical wave-1 pattern, more uniform distribution of enhanced TCO at ~30ºN/S, generally similar spatiotemporal variations at middle to high latitudes.
- Seasonal average difference:
  - Global: <2±4 DU, r: 0.8-0.9
  - SH: 1.2±2.1 DU, r: 0.94-0.98
  - NH: 4.3±4.6 DU, r: 0.6-0.8
- Significant discrepancies remain:
  - In GEOS-CHEM, the northern bands are broader and are extended to some subtropical and tropical areas; GOME TCO is consistently smaller by 5-20 DU over these regions.
  - GOME TCO does not show a regional maximum of >42 DU over India and Southeast Asia in MAM and Middle-East maximum in JJA and SON, leading to 5-20 DU differences.

Conclusions and Future Outlook

- Ozone profiles and tropospheric column ozone are derived from GOME data using the optimal estimation technique after detailed wavelength and radiometric calibrations and forward modeling.
- The retrieved TCO captures most of the temporal variability in daily ozonesonde observations with mean biases usually within 3 DU (15%).
- Both GOME and GEOS-CHEM TCO show similar overall structures: tropical wave-1 structure, decline of the wave-1 structure in the extratropics, nearly zonal bands of enhanced TCO of 36-45 DU at 20ºS-30ºS during the austral spring and at 25ºN-45ºN during boreal spring and summer, TCO of <30 DU zonally distributed at southern middle to high-latitudes.
- Significant positive biases of 5-20 DU occur at some northern tropical and subtropical regions.
- Reprocessing of GOME data (July 1995-June 2003) is ongoing with a degradation correction scheme, improvements in trace gas (SO_2, BrO, NO_2, HCHO) fitting (e.g., fitting weighting functions, using model-simulated profiles to represent a priori and derive effect air mass factor), and other minor enhancements.
- Apply this algorithm to SCIAMACHY, OMI and GOME-2 observations.

Acknowledgements This study is supported by NASA and by the Smithsonian Institution. We acknowledge WOUDC, SHADOZ, NOAA-CMDL and their data originators for ozonesonde measurements. We thank NOAA-CIRES CDC and ECMWF projects for reanalysis data. We appreciate the ongoing cooperation with the ESA and the German Aerospace Agency in the GOME program.

See the following papers for more detail:

Liu, X., K. Chance, C.E. Sioris, R.J.D. Spurr, T.P. Kurosu, R.V. Martin, M.J. Newchurch, Ozone Profile and Tropospheric Ozone Retrieval from Global Ozone Monitoring Experiment (GOME): Algorithm Description and Validation, J. Geophys. Res., 110(D20), D20307, 10.1029/2005 JD006240, 2005.

Liu et al., First directly-retrieved global distribution of tropospheric column ozone: comparison with the GOES-CHEM model, J. Geophys. Res., Vol. 111, No. D2, D02308, 10.1029/2005JD006564, 2006.