NOAA Volcanic SO2 cloud measurement from SNPP and NOAA-20 using LFSO2 algorithm

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Introduction

This poster presents an evaluation of the NOAA operational atmospheric SO_2 retrieval algorithm, the Linear Fit SO_2 algorithm (LFSO2). LFSO2 is used to create estimates from measurements made by the Suomi NPP (S-NPP) Ozone Mapping and Profiler Suite (OMPS). We compare the results to those from a Principal Component Analysis (PCA) algorithm applied to the same measurements. A total of 20 independent volcanic scenarios and one environmental disaster scenario over eight years of time span are selected for this comparison. More than three months of Mount Kilauea volcanic activity in 2018 are monitored and included in this comparison. We found that the current operational LFSO2 retrievals at lower troposphere (TRL), mid-troposphere (TRM), and lower stratosphere (STL) have a discontinuity and a saturation-like relationship with PCA results. The current operational LFSO2 algorithm has been investigated, and a new logic has been introduced. With this, the discontinuity and the saturation appearance in comparisons vanished and a close to linear relationship with the matchup data from the PCA retrieval products is demonstrated. The minimum detectable values for all three SO_2 layer products and the PBL products are estimated with the improved LFSO2 algorithm. Results for a volcanic cloud over Colombia for the updated LFSO2 for OMPS and a Differential Optical Absorption Spectroscopy (DOAS) algorithm for TROPOMI measurements are also compared. Similar SO_2 total mass estimates over the region are obtained from the two instruments.

Data and volcanic scenarios for comparison

Table 1 listed all data sets examined with this study. The operational NRT estimation of global SO_2 from S-NPP OMPS measurements are created by the NOAA S-NPP Data Exploitation (NDE) center. The SO_2 data records (V8TOS) are available for download starting from 24 January 2018. The LFSO2 computes total SO_2 which are assumed to be distributed in the Umkehr layers of 0, 1, 2, and 4. The NASA PCA NMSO2 data are used in this study for inter comparison with LFSO2 retrievals, and are available from the NASA GES DISC site. The SO_2 estimates from DOAS method retrieval measured by TROPOMI on board S5P are collected via the GES DISC site.

Table 1 Data related in this investigation

	platforms	Processing	methods	Source
V8TOS	S-NPP	NOAA NDE	LFSO2 (NRT)	Operational
NMSO2	S-NPP	NASA	PCA	GES DISC
NMEV-L1B	S-NPP	NASA	LFSO2 (off line)	GES DISC
TROPOMI	S5P	ESA	DOAS	Via GES DISC

Table 2 Scenarios selected for inter comparison

Event	days	Date (mm/dd/yyyy)	Volcano	SO2 Cloud height
1	1	05/08/2012	Nyiragongo, DR Congo	TRM
2	2	05/14/2012	Mauna Kea Hawaii USA	TRL
3	3	04/16/2013	Manam, New Guinea	TRM
4	4	02/14/2014	Kelut, Java, Indonesia	STL
4	5	02/16/2014	Kelut, Java, Indonesia	STL
4	6	02/17/2014	Kelut, Java, Indonesia	STL
4	7	02/18/2014	Kelut, Java, Indonesia	STL
4	8	02/19/2014	Kelut, Java, Indonesia	STL
5	9	09/01/2014	Bardarbunga, Iceland	TRL
6	10	09/27/2014	Ontake, Japan	TRM
7	11	11/24/2014	Fogo, Cape Verde Islands	TRM
7	12	11/27/2014	Fogo, Cape Verde Islands	TRM
7	13	11/28/2014	Fogo, Cape Verde Islands	TRM
8	14	04/24/2015	Calbuco, Chile	STL
8	15	04/26/2015	Calbuco, Chile	STL
9	16	12/04/2015	Etna, Sicily, Italy	TRM
10	17	03/28/2016	Pavlof Aleutian Islands, Alaska	TRM
11	18	03/08/2017	Bogoslov, Aleutian Islands, Alaska	TRM
12	19	04/21/2017	Turrialba, Costa Rica	TRL
13	20	05/17/2017	Bogoslov, Aleutian Islans, Alaska	TRM
14	21	09/05/2017	Fernandia Galapogos Islands, Ecudor	TRL
15	22	10/21/2017	Tinakula Solomon Islands	TRM
16	23	11/27/2017	Agung, Bali, Java	TRM
17	24	01/22/2018	Mayon Philippines	TRM
17	25	01/23/2018	Mayon Philippines	TRM
18	26	02/19/2018	Sinabung, Indonesia	STL
18	27	02/20/2018	Sinabung, Indonesia	STL
19	28	06/03/2018	Fuego, Guatemala	TRM
20	29	06/17/2018	Fermandian Galapagos Islands Ecuador	TRL
21	30	06/27/2019	Mosul, Iraq	PBL
21	31	06/28/2019	Mosul, Iraq	PBL

Current Operational LFSO2 vs. PCA

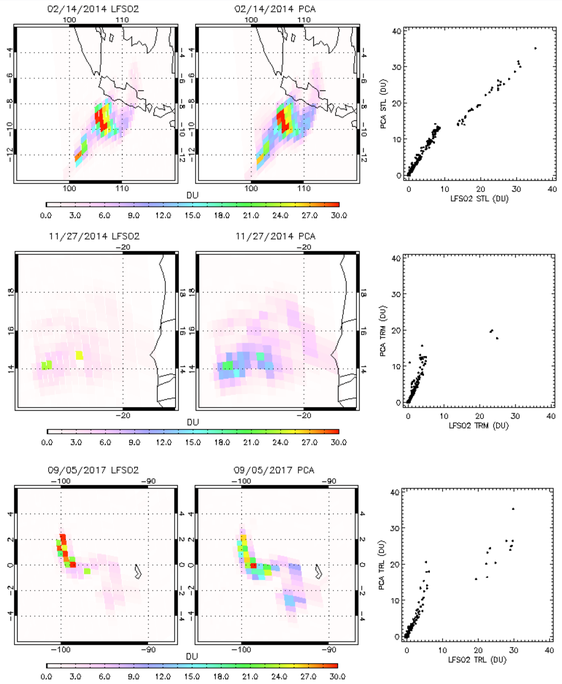

Figure 1 demonstrates the status of current operational LFSO2 product compare with the PCA products for three daily cases. The maps on the left are for LFSO2 retrievals, the maps in the middle are from PCA retrievals, and the scatter plots on the right illustrates the correlations of LFSO2 and PCA retrievals. The first row shows a case where the volcanic clouds were assumed to be distributed in Umkehr layer 4 (STL). The second row shows a case for volcanic clouds estimates for Umkehr layer 2 (TRM). The third row shows a case for the volcanic clouds estimates for Umkehr layer 1 (TRL).

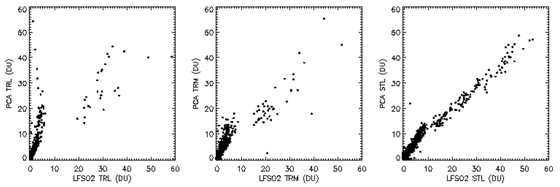

Figure 2. Comparisons between LFSO2 (in current operation) and PCA retrievals for all three volcanic SO2 cloud heights in the 29 selected scenarios in Table 2. From left to right, SO2 estimates are for TRL, TRM, and STL layers.

LFSO2 algorithm

The LFSO2 is a multi-technique combined algorithm. It contains the linear fit technique, the Band Residual Difference (BRD) technique, and the Beer-Lambert law technique. The linear fit technique in conjunction with BRD technique are used to retrieve total amount of SO_2 distributing in the TRL, TRM, and STL layers. The Beer-Lambert law is independently used to retrieve the SO_2 distributed in the boundary layer (PBL). All the three techniques in LFSO2 algorithm are based on the ozone residuals from V8TOZ EDR ozone retrieval. The linear fit technique conducts its retrieval in two steps. In the first step, the SO_2 total amount is initially estimated. In the second step, the retrieval is switched to either the linear fit or the BRD technique based on weather the first initial estimated SO_2 total amount is larger or smaller than 10 DU and on the air mass factor 4. When initial $SO_2 < 10$, the switch turns to BRD technique, otherwise it turns to the linear fit. This is the reason the scatter plots exist discontinuity and a saturation like relation with PCA.

Improvement of LFSO2 Linear Fit technique

Based on the algorithm investigation, we tested a new retrieval logic, in which we turn off the "switch" by tuning the criteria of 10 DU close to the minimum detectable value of about 0.5 DU.

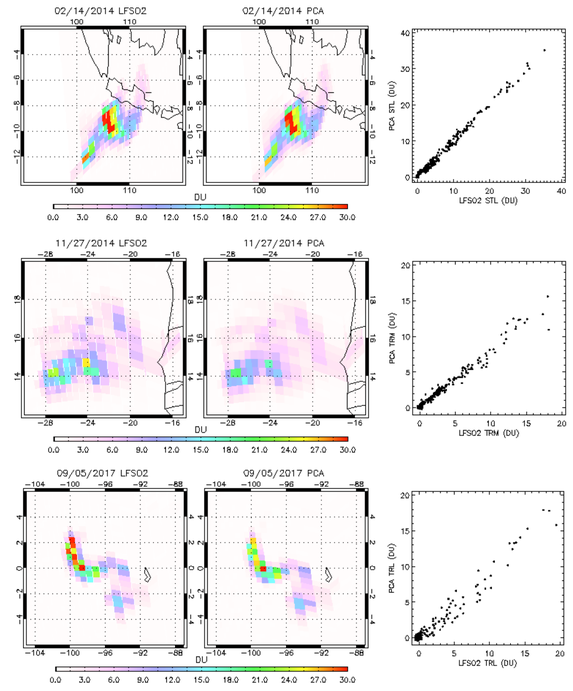

Figure 3 The figure demonstrates the LFSO2 retrievals status after using improved retrieval logic. The figure arrangement is the same as in figure 1.

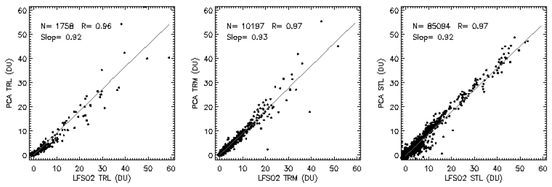

Figure 4. Comparisons between improved LFSO2 and PCA in all three volcanic SO_2 cloud heights in the 29 selected scenarios are illustrated. From left to right are SO_2 appeared in the layers of TRL, TRM, and STL.

LFSO2 vs. PCA over Kilauea Hawaii

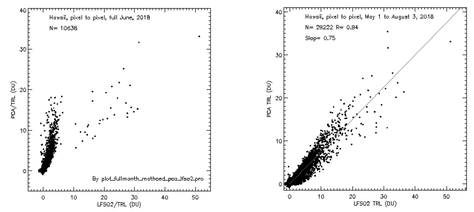

Figure 5. Hawaii Kilauea volcano erupted form May 3 to August 5 in 2018 as measured by S-NPP. We investigated this event in a latitude/longitude box (14°N to 24°N and 150°W to 165°W) for LFSO2 before and after its improvements. The left panel shows the current operational LFSO2 vs. PCA collected over the full month in June 2018. The right panel shows improved LFSO2 vs. PCA for three month data from May 1 to August 3, 2018.

LFSO2 vs. PCA in PBL retrieval

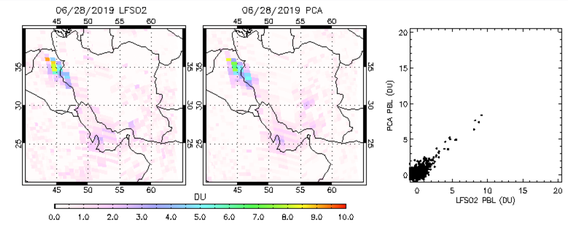

Figure 6. A Sulphur company fire near Mosul in Iraq has been measured by OMPS. LFSO2 results and PCA results are given in the left and middle maps. Their pixel to pixel comparison results are illustrated by the scatter plot on the right panel.

LFSO2 minimum detectable

The minimum detectable amount for both LFSO2 and PCA at PBL, TRL, TRM, and STL layers are estimated in the Equatorial Pacific region. The geographic extent is 120° to 150° west longitude and ±10° in latitude. A total of 76 cases with little or no expected SO_2 contamination were selected in the region from May 1 to August 1, 2018 for the evaluation.

Table 3. Average means and standard deviations over 76 days

	Mean PBL	STD (PBL)	Mean TRL	STD (TRL)	Mean TRM	STD (TRM)	Mean STL	STD (STL)
LFSO2	0.087	0.53	0.019	0.19	0.0077	0.087	0.0064	0.071
PCA	0.077	0.32	0.023	0.16	0.012	0.087	0.01	0.073

S-NPP OMPS and S5P TROPOMI

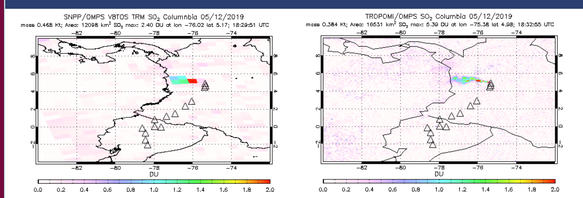

Figure 7. Both satellite witnessed a vary similar SO_2 cloud pattern. The total SO_2 cloud mass estimated by each instrument is similar as expected. The difference in maximum total amount is caused by different spatial resolution.

Summary

1. Current operational LFSO2 retrievals have been compared with PCA retrievals both from S-NPP OMPS NM observations.
2. Discontinuity and nonlinearity are found in operational Linear Fit results in TRL, TRM, and STL layers versus PCA results.
3. Investigation indicated these are caused by two independent retrieval techniques, linear fit and BRD, both are used in the LFSO2 by switch on or off based on a previously determined criteria.
4. We tested the effects of turning off the BRD technique and using the linear fit technique only.
5. We redo the all the same pixel by pixel comparisons, and the results demonstrate that the discontinuity and nonlinearity problem are removed and reduced, respectively.
6. A new updated LFSO2 algorithm is ready for use in operation.
7. LFSO2 PBL retrievals have a close to linear relation with PCA.
8. Except for the noisier PBL retrievals, TRL, TRM, and STL products have similar noise level as those of PCA.

Acknowledgment and contact

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