DSCOVR EPIC O_3 and Volcanic SO_2 : Algorithm and Product Status

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Algorithm Overview

- The Direct Vertical Colum Fitting (DVCF) algorithm: find retrieved state ($\boldsymbol{x}$) so that the modeled radiance spectra (I_{TOA}) match the satellite-measured spectra (I_m)
- Radiance matching -> minimization of the cost function:

$$\Upsilon = \left\| \Delta \boldsymbol{y}\, \boldsymbol{S}_y^{-1/2} \right\|^2 + \left\| (\boldsymbol{x} - \boldsymbol{x}_a) \boldsymbol{S}_a^{-1/2} \right\|^2$$

where $\Delta \boldsymbol{y} = \{ \ln I_m - \ln I_{TOA}(\boldsymbol{x}) \}$, column vector for four EPIC UV bands

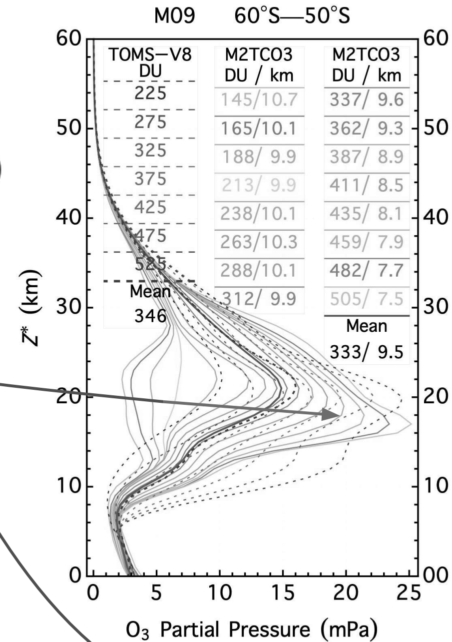
- Iterative solution

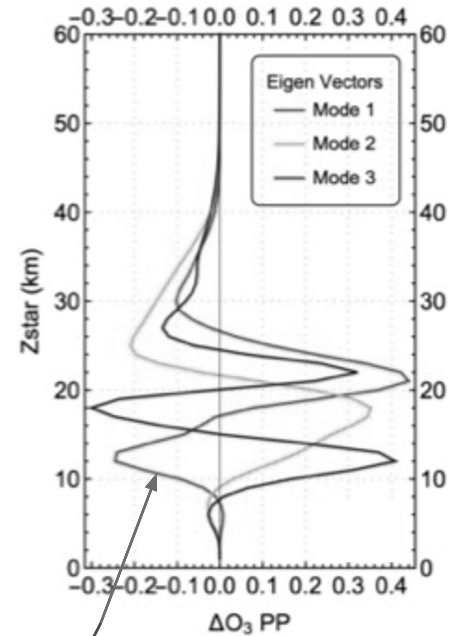
$$\boldsymbol{x}_{i+1} = \boldsymbol{x}_i + \left(\mathbf{K}_i^{\mathrm{T}} \mathbf{S}_{\mathrm{y}}^{-1} \mathbf{K}_i + \mathbf{S}_{\mathrm{a}}^{-1} \right)^{-1} \left\{ \mathbf{K}_i^{\mathrm{T}} \mathbf{S}_{\mathrm{y}}^{-1} \left[\boldsymbol{y} - \ln I_{TOA}(\boldsymbol{x}_i) \right] \right\}$$

Algorithm Overview

O_3 Profile:

$$\boldsymbol{X} = \boldsymbol{X}_m(\upsilon) + \sum_{k=1}^{N} \gamma_k \boldsymbol{e}_k(\upsilon)$$





State vector:

$$\boldsymbol{x} = \{\, \Omega, \gamma_1, \Xi, R_1, R_2 \}$$

O_3 VCD, O_3 $\Delta\boldsymbol{X}$, SO_2 VCD,

R_1 and R_2 are MLER parameters.

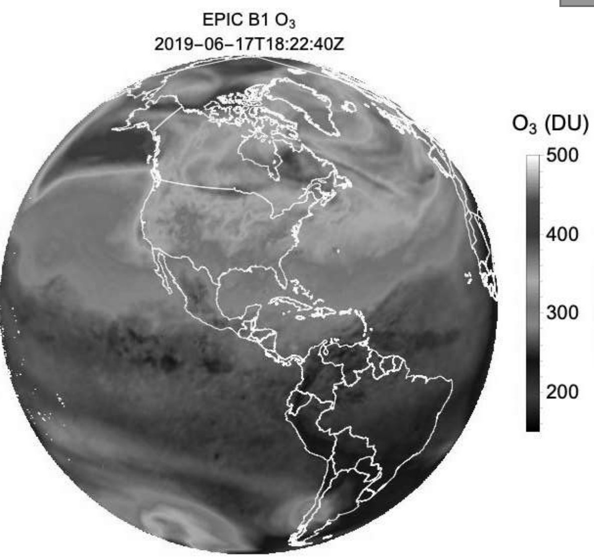
O_3 Profile Reference:
Yang and Liu, 2019
doi: 10.5194/amt-12-4745-2019

DVCF vs. Heritage Algorithm (TOMSv8)

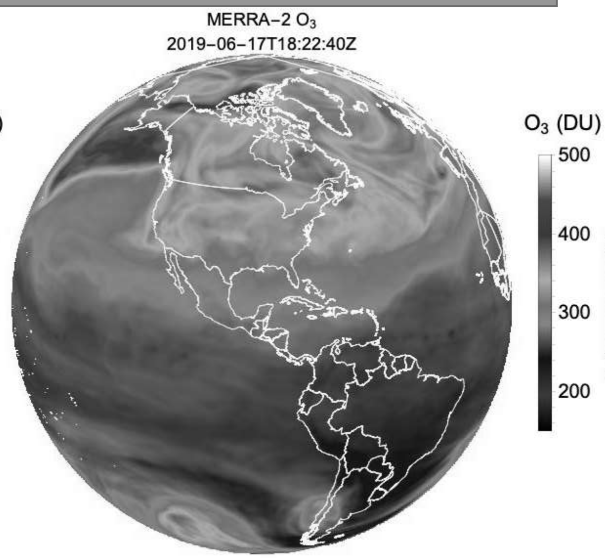
TOMSv8 : use single O_3 sensitive band

DVCF: use all (two for EPIC) O_3 sensitive bands

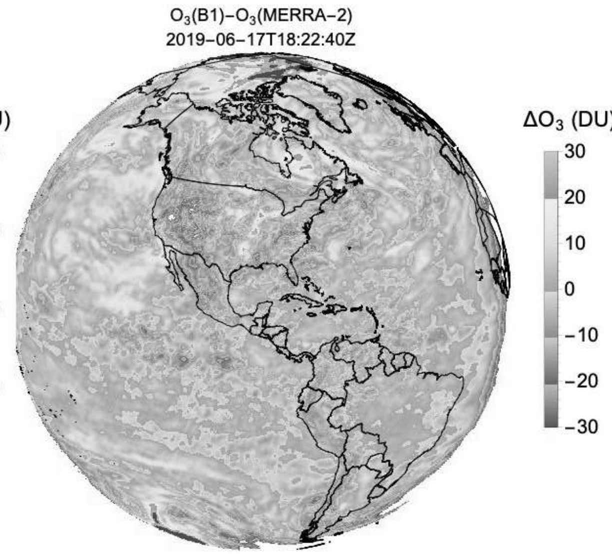
EPIC B1 vs MERRA-2



EPIC B1 O_3



MERRA-2 O_3



DVCF vs. Heritage Algorithm (TOMSv8)

TOMSv8 : use single O_3 sensitive band

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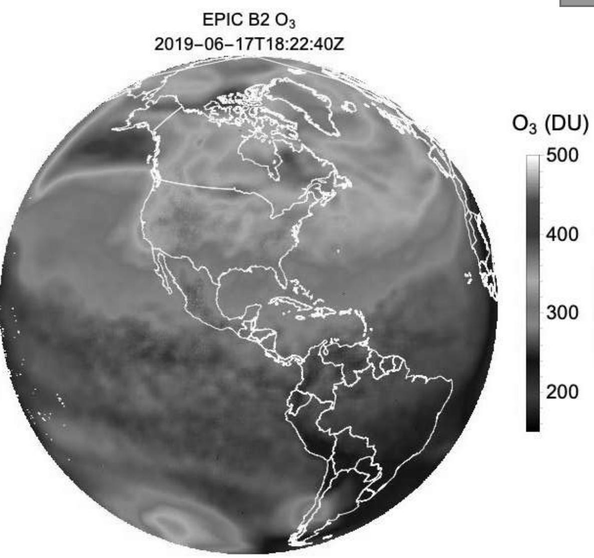
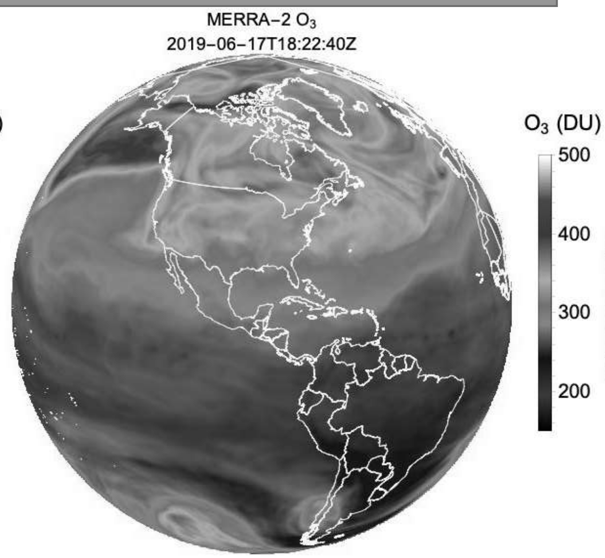
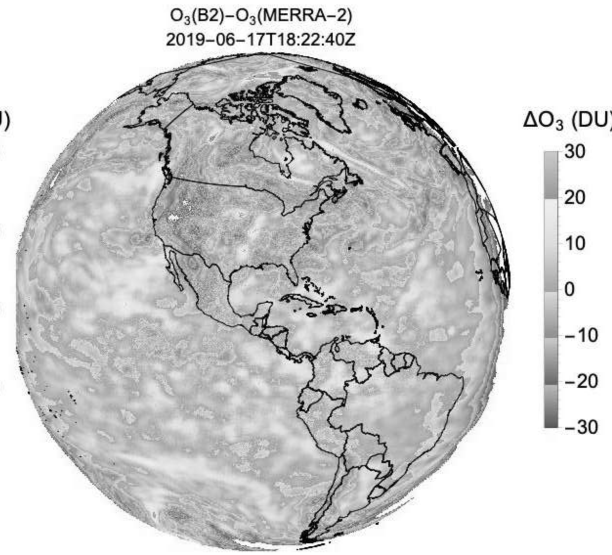
EPIC B2 vs MERRA-2



EPIC B2 O_3



MERRA-2 O_3

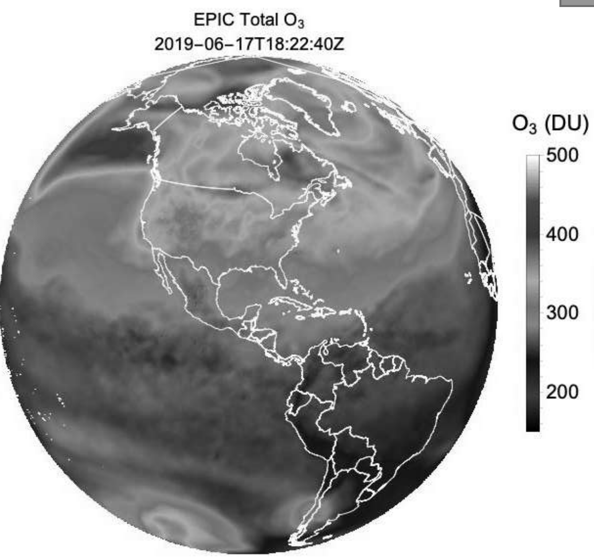


DVCF vs. Heritage Algorithm (TOMSv8)

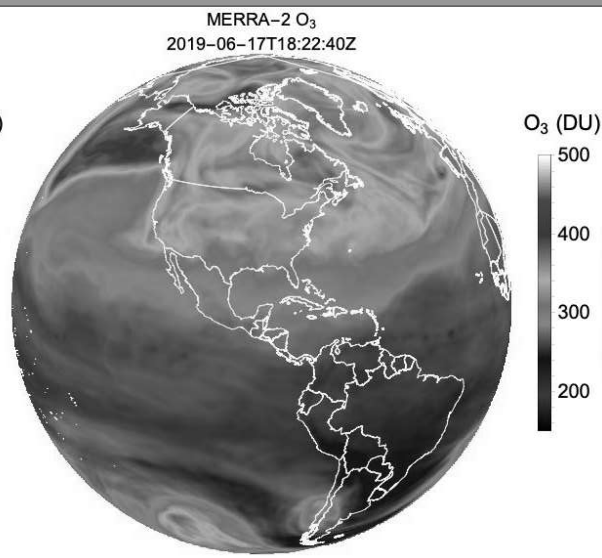
TOMSv8 : use single O_3 sensitive band

DVCF: use all (two for EPIC) O_3 sensitive band

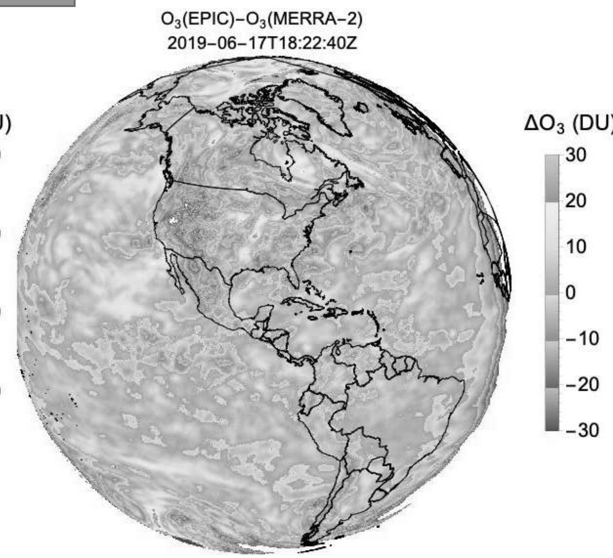
EPIC B1&B2 vs MERRA-2



EPIC B1&2 O_3



MERRA-2 O_3



Accuracy Improvement

ΔO_3 (B1 - MERRA2)

mean. : μ_1=0.50 (DU)

stdDev : σ_1=6.66 (DU)

Correlation : R_1^2=0.9747

ΔO_3 (B2 - MERRA2)

mean. : μ_2=0.81 (DU)

stdDev : σ_2=6.83 (DU)

Correlation : R_2^2=0.9739

ΔO_3 (EPIC - MERRA2)

mean. : μ=0.64 (DU)

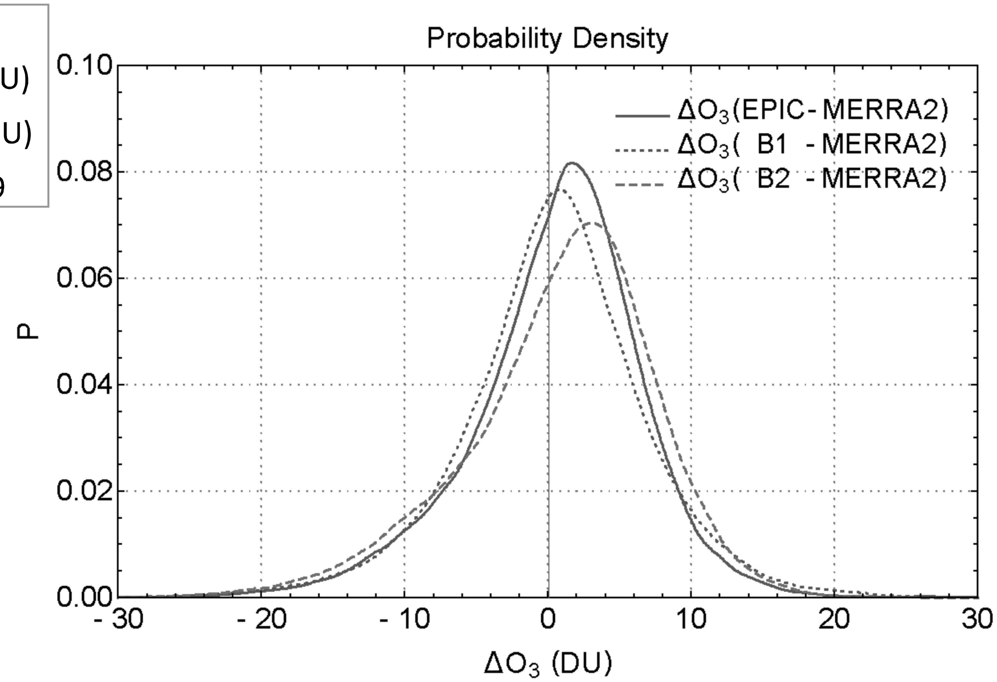
stdDev : σ=6.13 (DU)

Correlation : R^2=0.9768

Improvements

$$\sqrt{\sigma_1^2 - \sigma^2} = 2.61\ (DU)$$

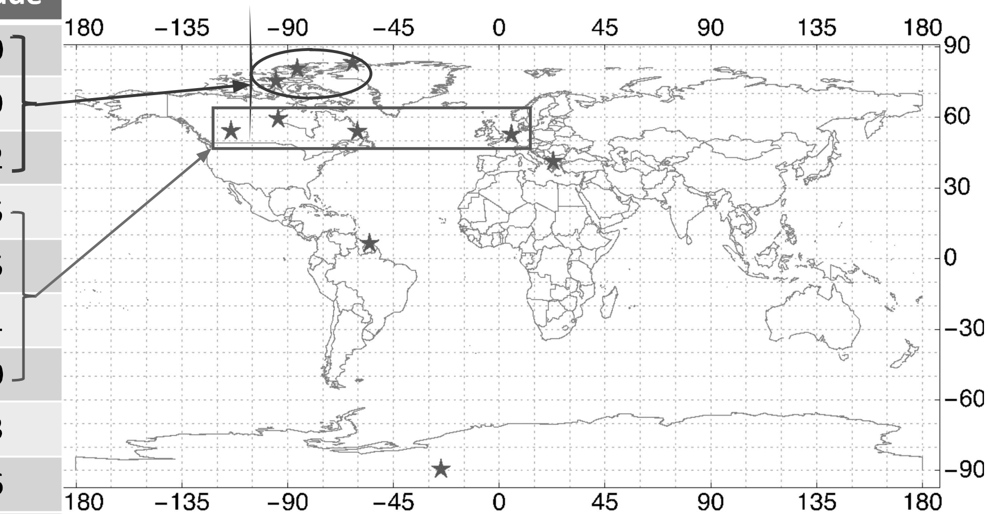
$$\sqrt{\sigma_2^2 - \sigma^2} = 3.01\ (DU)$$



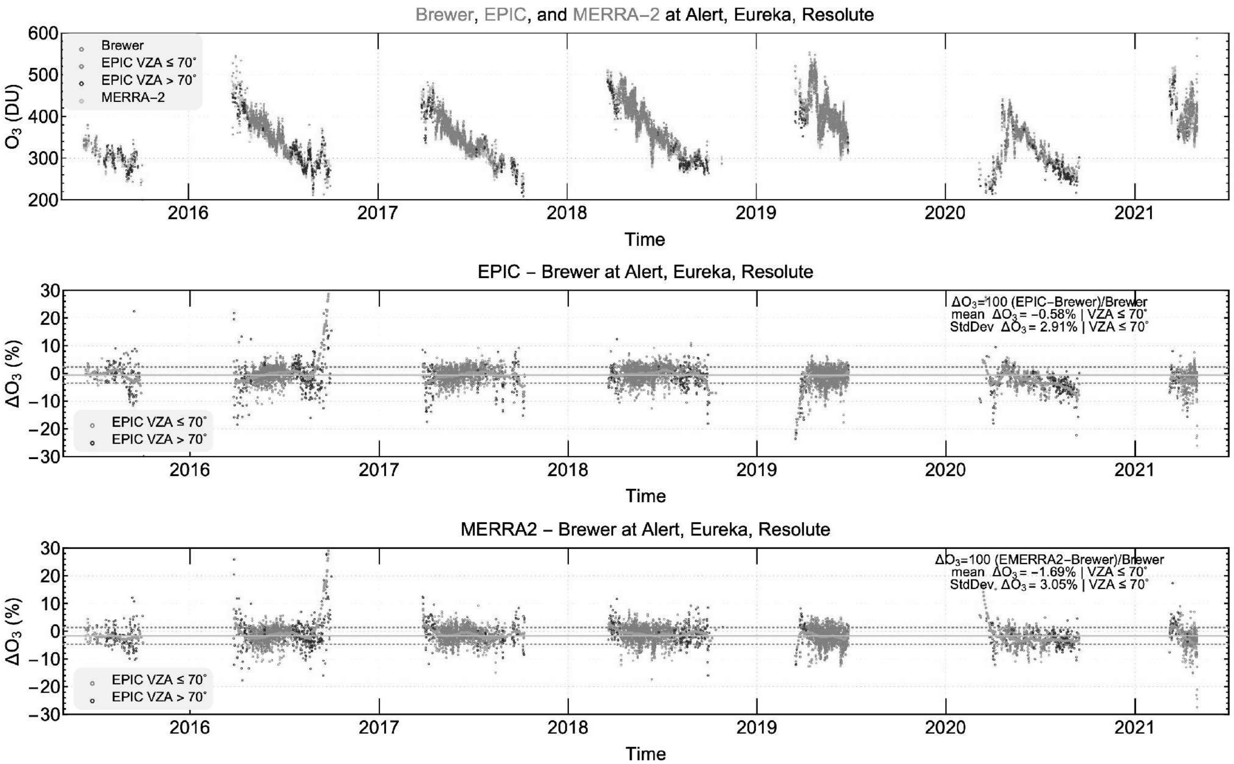
Including more O_3 sensitive bands improves retrieval accuracy significantly

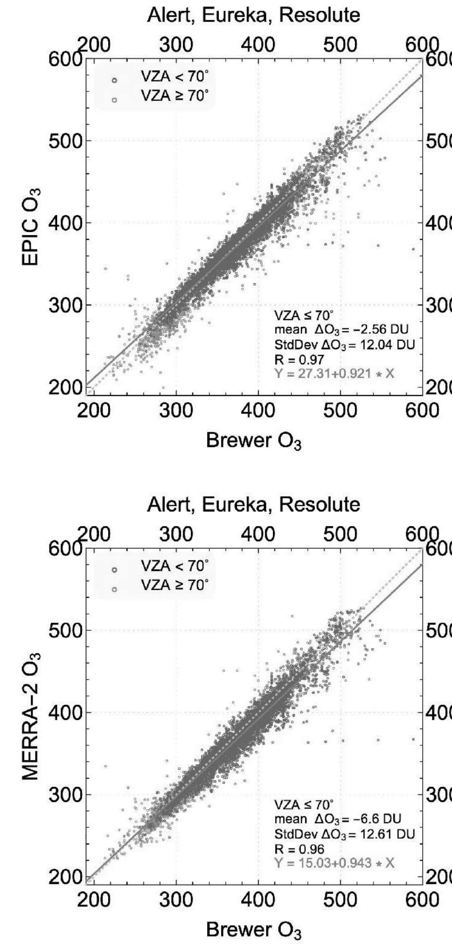
Ozone Validation with Brewer Measurements

Station Name	Latitude
Alert	82.50
Eureka	79.99
Resolute	74.72
Churchill	58.75
Edmonton	53.55
Goose Bay	53.31
De Bilt	52.10
Thessaloniki	40.63
Paramaribo	5.806
South Pole	-89.99

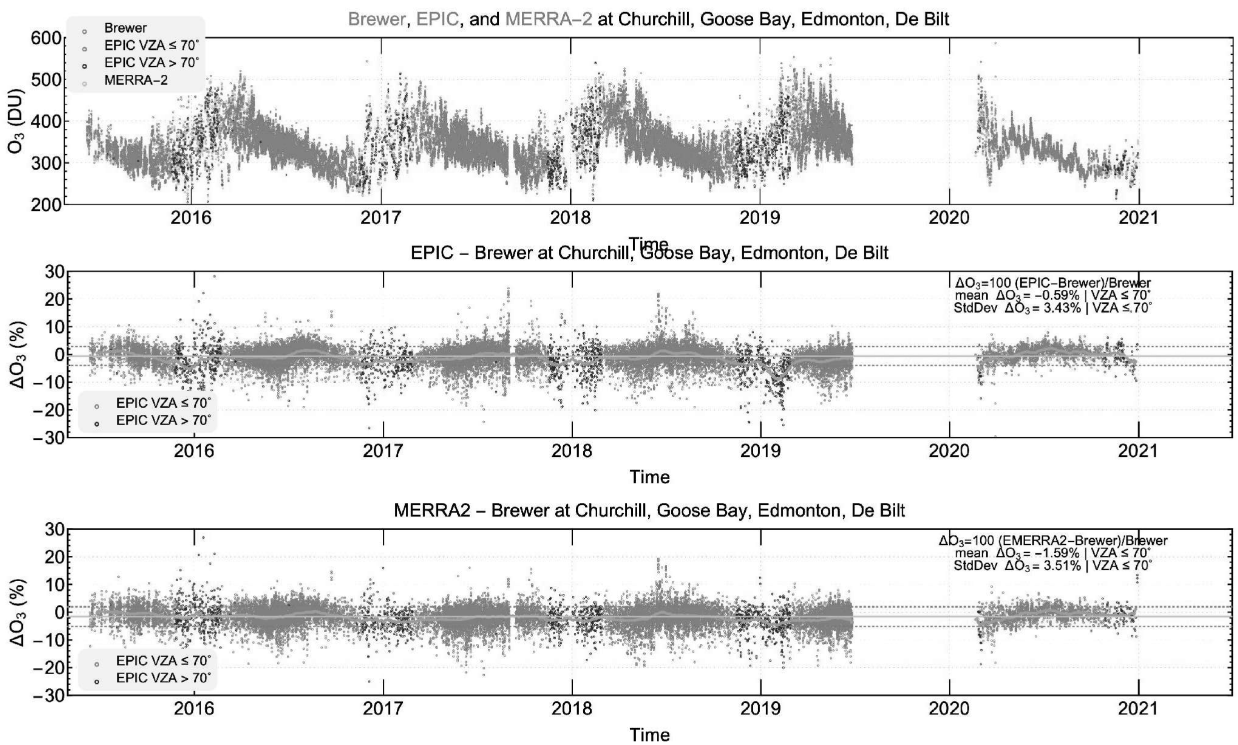


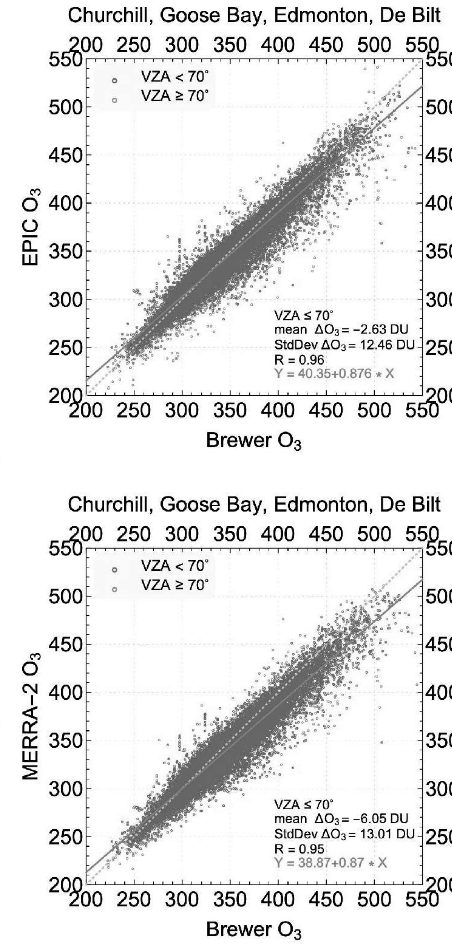
High Northern Latitude



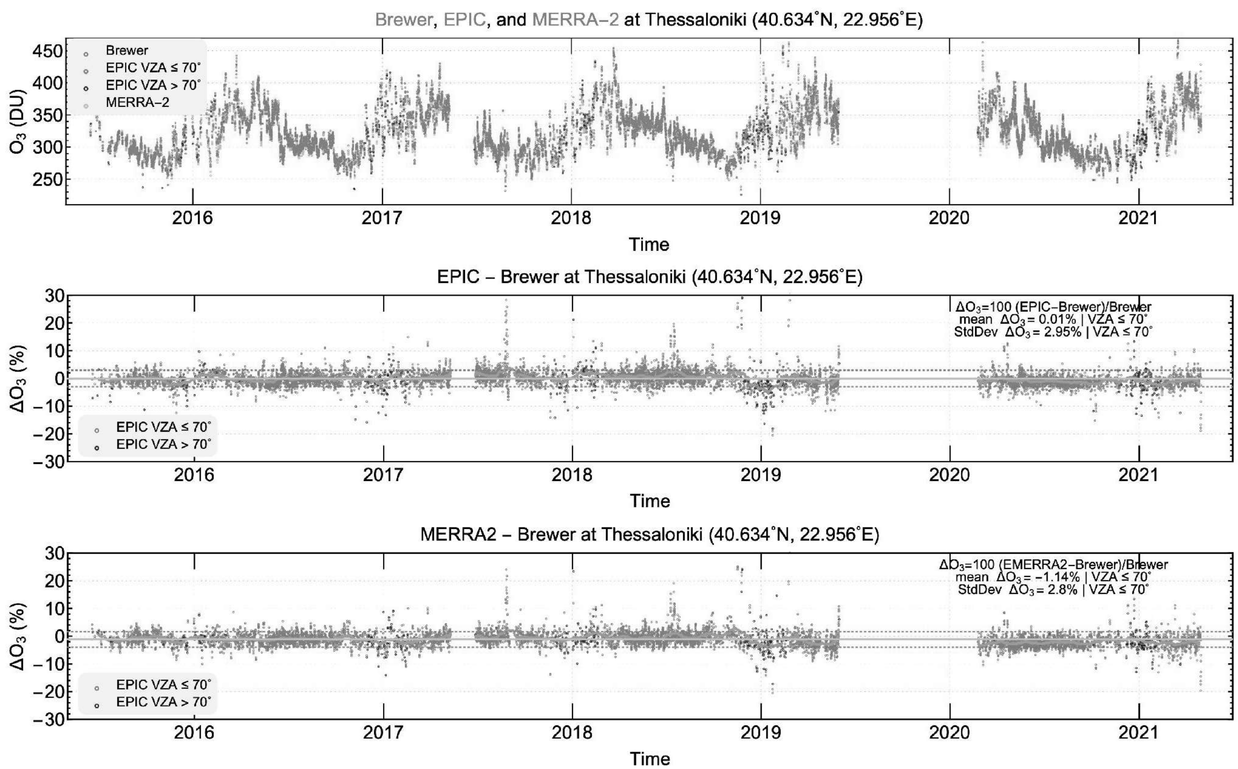


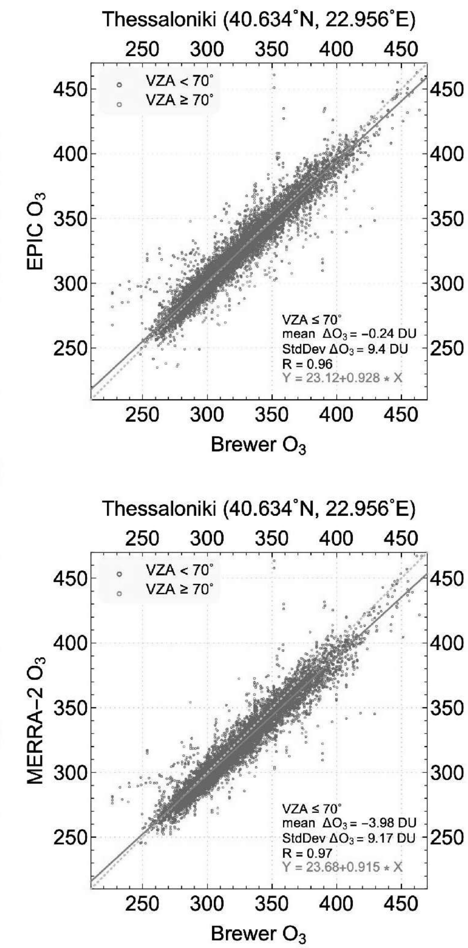
High-Mid Northern Latitude



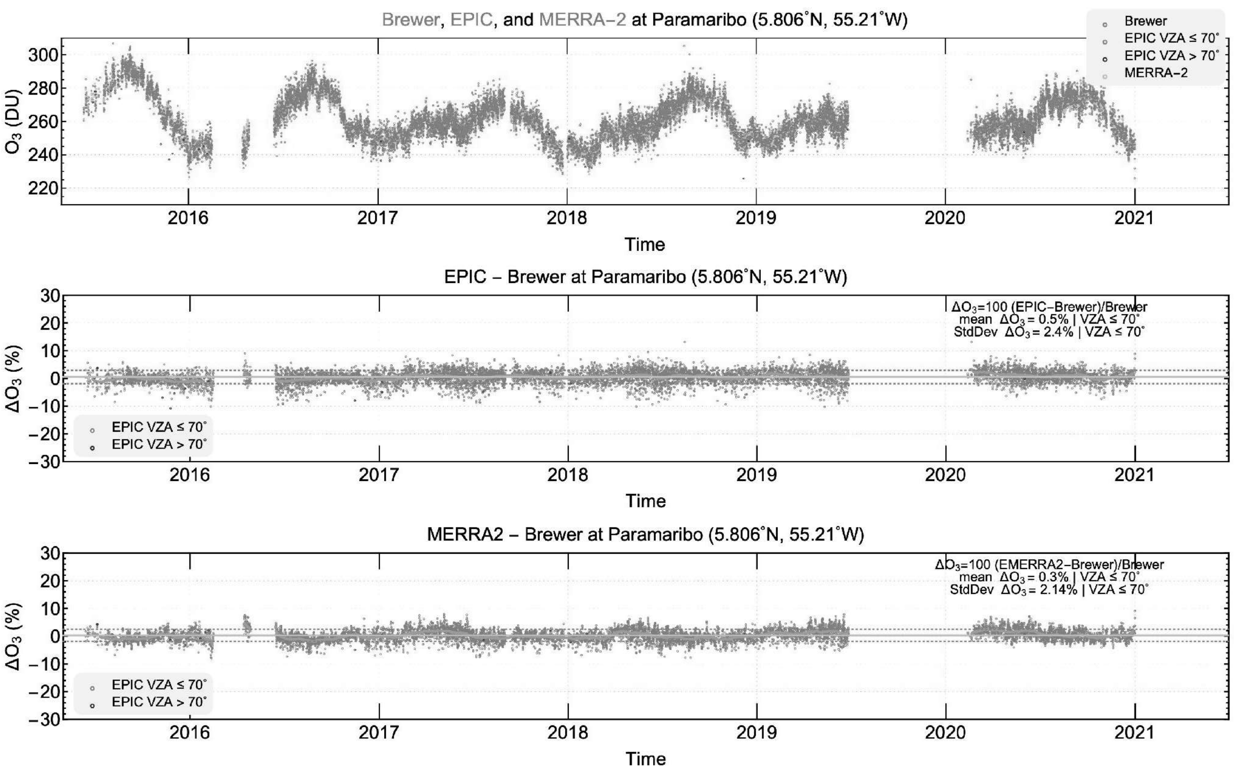


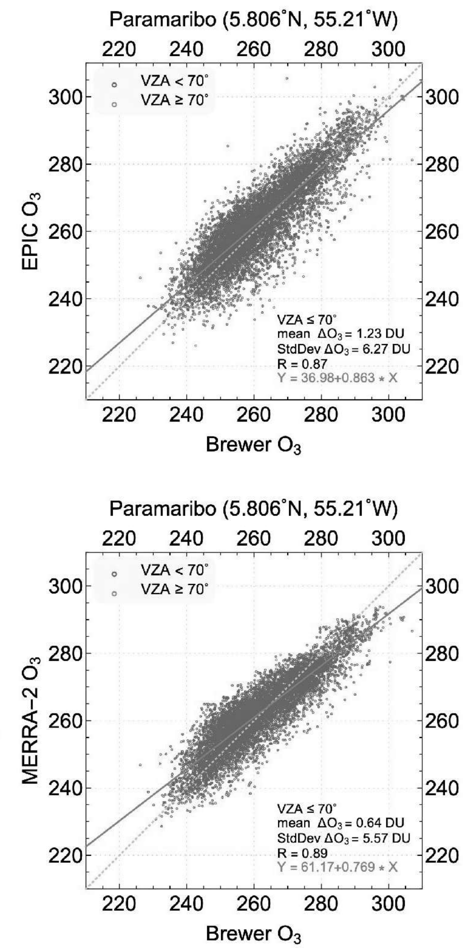
Mid Northern Latitude



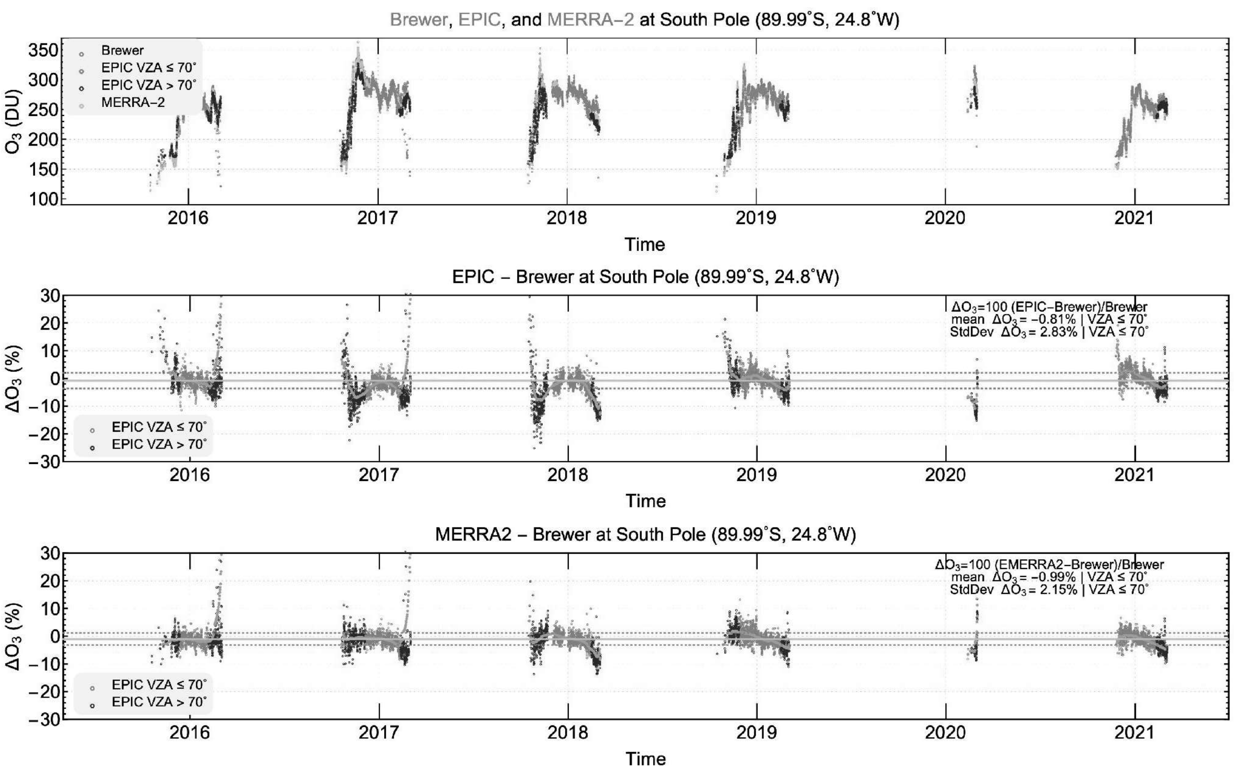


Low Northern Latitude

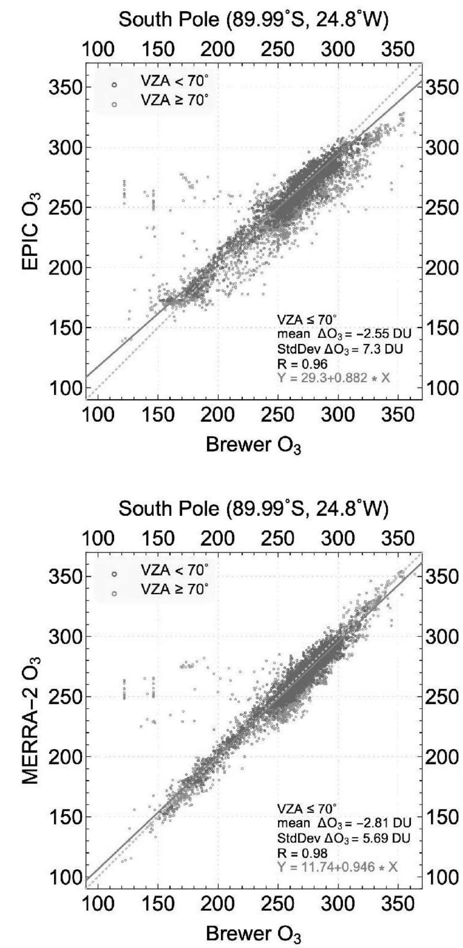




South Pole



Brewer, EPIC, and MERRA−2 at South Pole (89.99˚S, 24.8˚W)
Brewer
EPIC VZA ≤ 70˚
EPIC VZA > 70˚
MERRA−2
O3 (DU)
Time
EPIC − Brewer at South Pole (89.99˚S, 24.8˚W)
ΔO3=100 (EPIC−Brewer)/Brewer
mean ΔO3 = −0.81% | VZA ≤ 70˚
StdDev ΔO3 = 2.83% | VZA ≤ 70˚
EPIC VZA ≤ 70˚
EPIC VZA > 70˚
ΔO3 (%)
Time
MERRA2 − Brewer at South Pole (89.99˚S, 24.8˚W)
ΔO3=100 (EMERRA2−Brewer)/Brewer
mean ΔO3 = −0.99% | VZA ≤ 70˚
StdDev ΔO3 = 2.15% | VZA ≤ 70˚
EPIC VZA ≤ 70˚
EPIC VZA > 70˚
ΔO3 (%)
Time



South Pole (89.99˚S, 24.8˚W)
VZA < 70˚
VZA ≥ 70˚
VZA ≤ 70˚
mean ΔO3 = −2.55 DU
StdDev ΔO3 = 7.3 DU
R = 0.96
Y = 29.3+0.882 * X
EPIC O3
Brewer O3
South Pole (89.99˚S, 24.8˚W)
VZA < 70˚
VZA ≥ 70˚
VZA ≤ 70˚
mean ΔO3 = −2.81 DU
StdDev ΔO3 = 5.69 DU
R = 0.98
Y = 11.74+0.946 * X
MERRA−2 O3
Brewer O3

EPIC Total O_3 Validation Summary

- Time series of O_3 difference between coincident EPIC and Brewer and EPIC and MERRA-2 are stable with similar moving average and standard deviation, showing EPIC O_3 are consistent over time, without noticeable drift.
- The correlations between EPIC and Brewer ($R \geq 0.87$ in tropics and $R \geq 0.96$ outside tropics) are high, demonstrating that EPIC captures the dynamical variability accurately.
- Against Brewer stations, EPIC O_3 has small latitude-dependent biases, which are within $\pm 1\%$ with spreads mostly less than 3%. EPIC O_3 agrees with the Brewer measurements to better than 1% with standard deviations of differences less than 3.5% for all the ground stations.
- The accuracy of the total O_3 retrieval from DSCOVR EPIC is higher than or as good as those from satellite instruments with superior spectral coverage and higher signal-to-noise ratios.

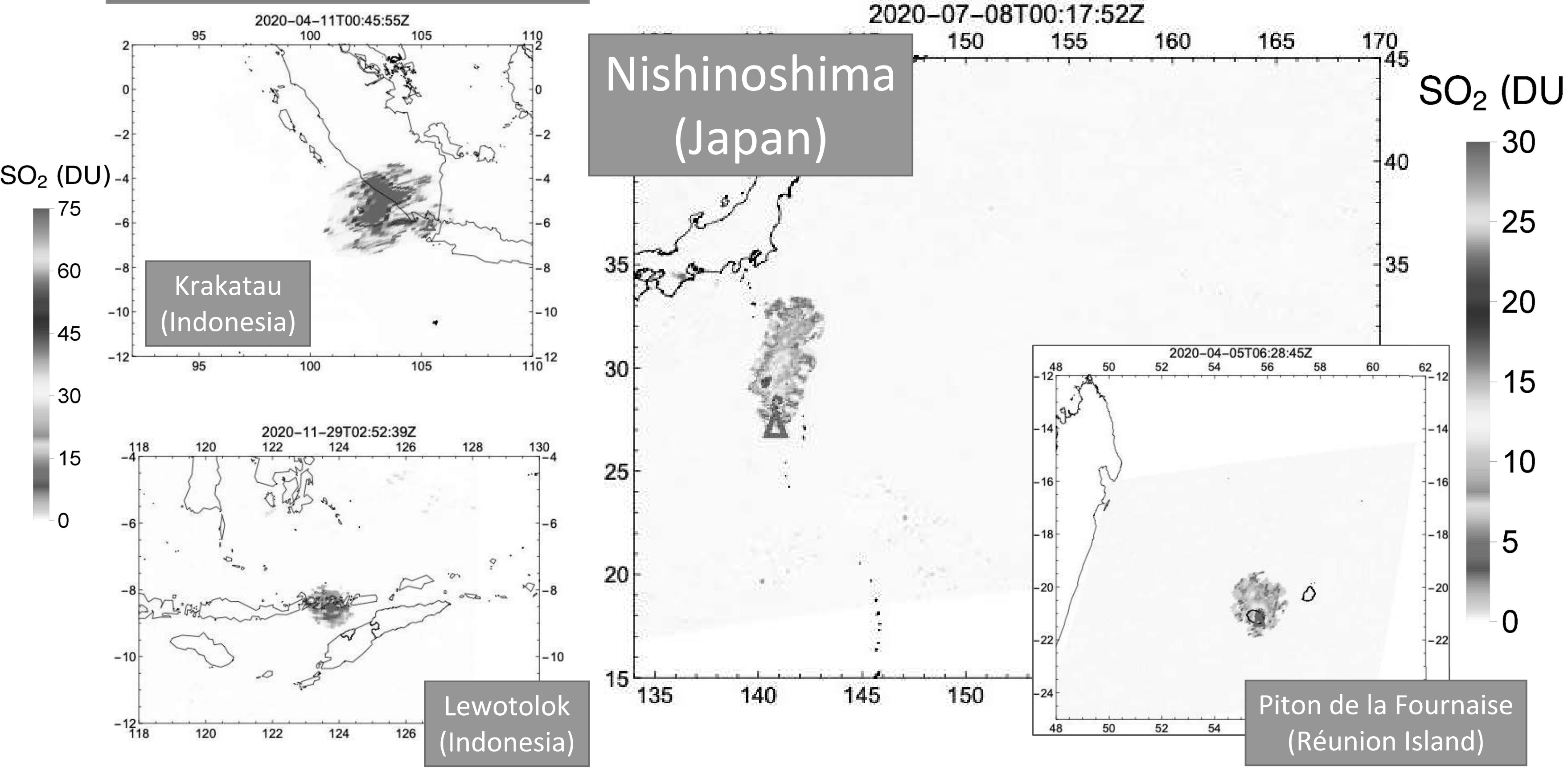
Quantification of Volcanic SO_2 Emissions

- Explicit ash treatment to improve the accuracy of SO_2 retrieval, especially for fresh volcanic clouds.
- Sufficient sensitivity to detect and quantify small eruptions with emissions > ~5 kt

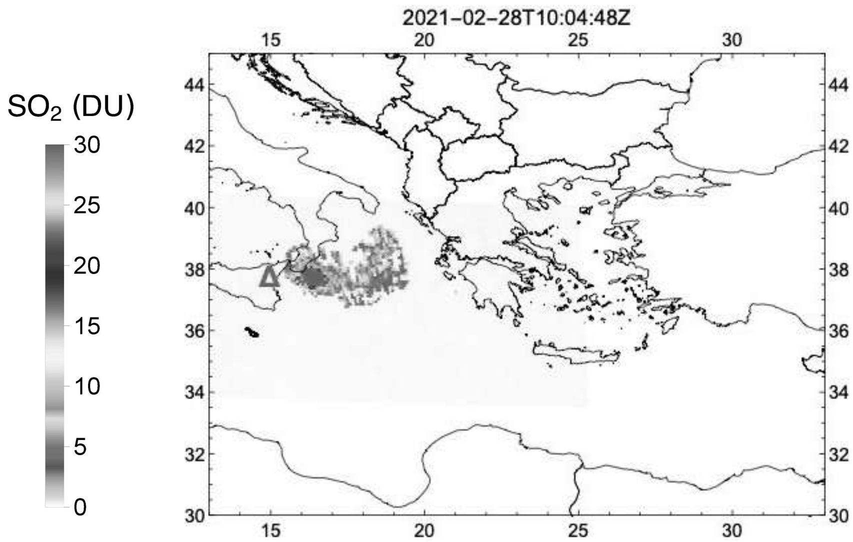
Recent Eruptions

- 2020: Piton de la Fournaise (Réunion Island), Nishinoshima (Japan), Krakatau (Indonesia), Lewotolok (Indonesia)
- 2021: Etna (Italy), Sangay (Ecuador), La Soufrière (Caribbean Island of Saint Vincent)

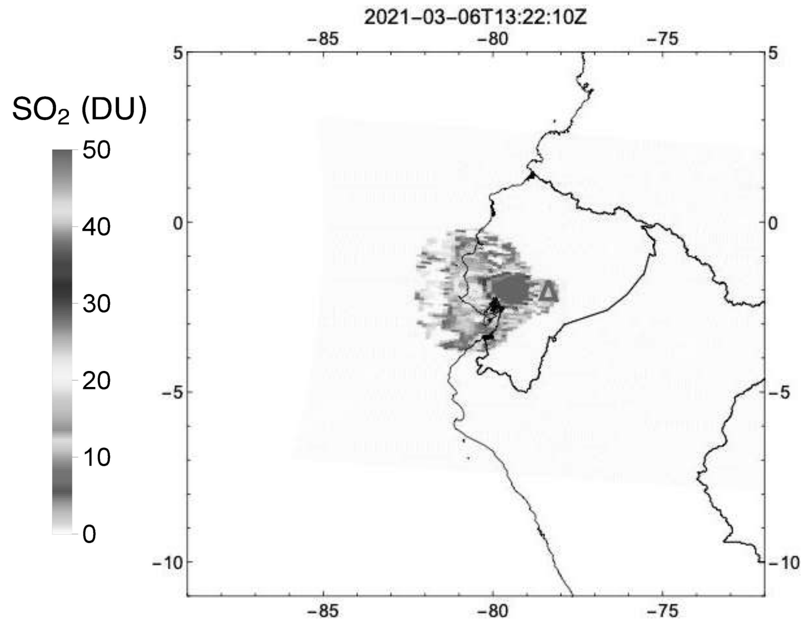
2020 Eruptions



2021 Eruptions

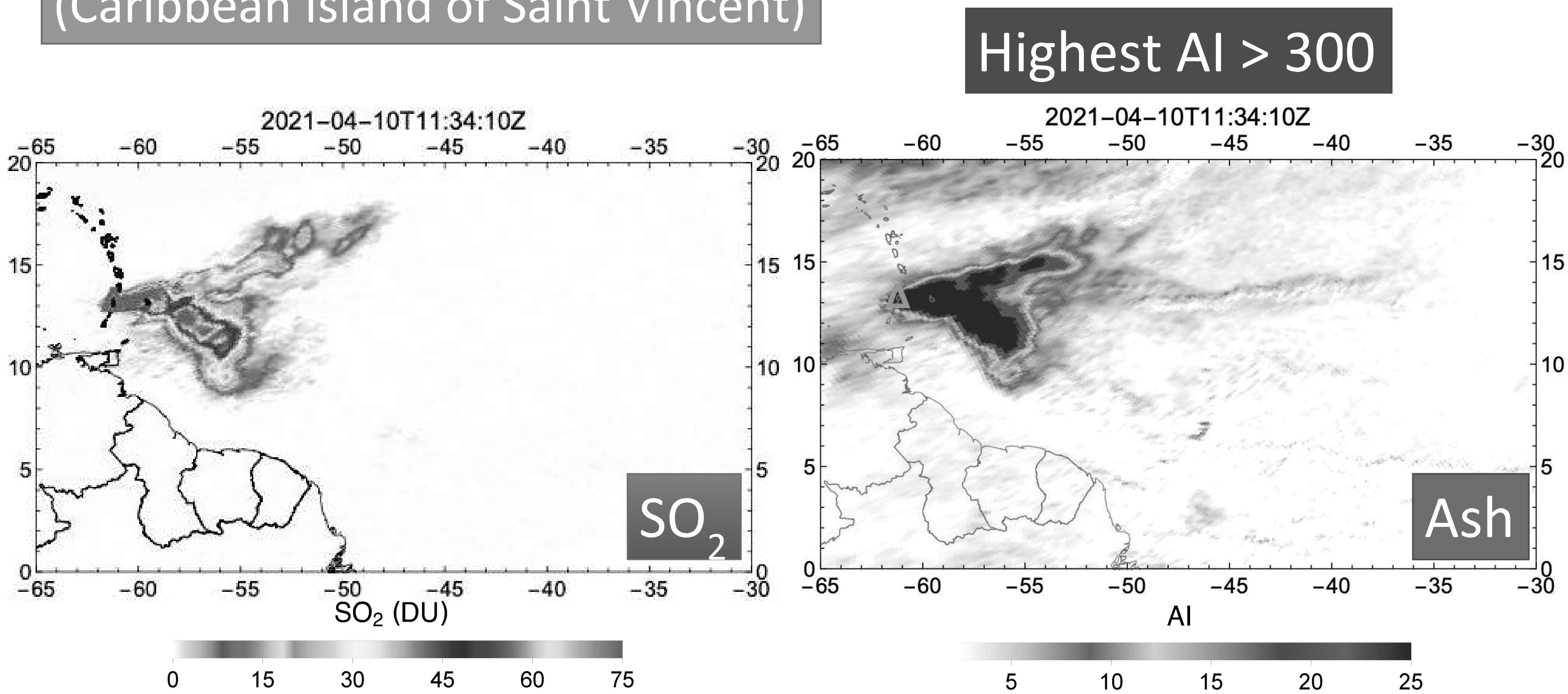


Etna (Italy)



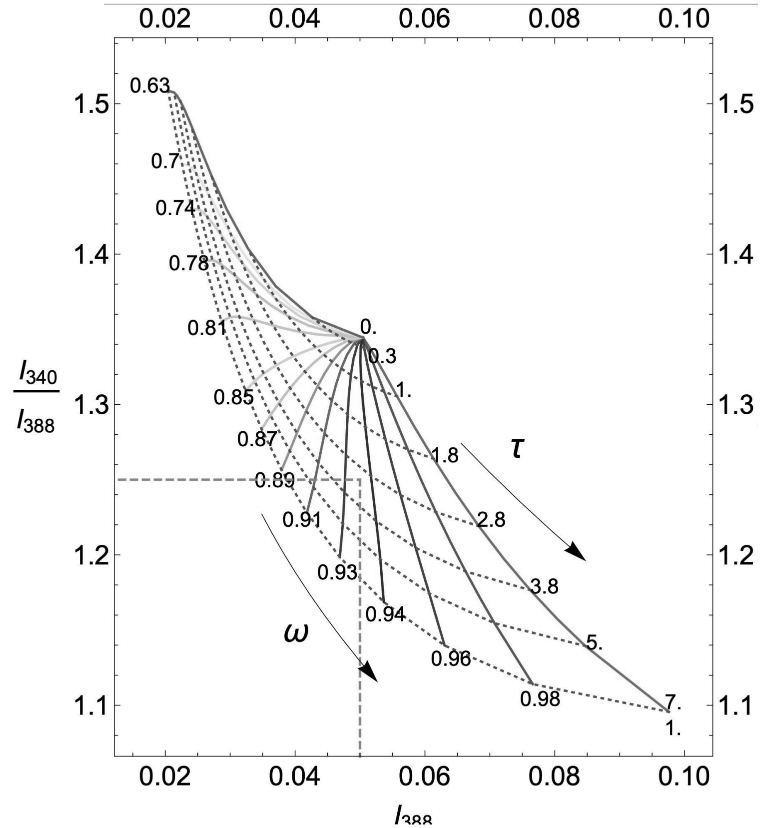
Sangay (Ecuador)

La Soufrière
(Caribbean Island of Saint Vincent)



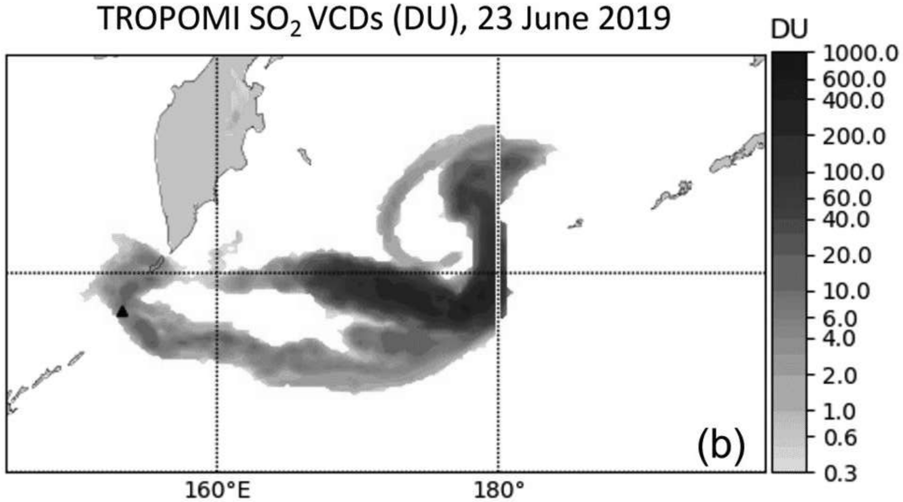
Simultaneous Quantification of Volcanic Ash and SO_2

- Ash cloud model: mixture of ash particles and water/ice clouds, replacing the MLER treatment of elevated particles
- Estimation of ash single scattering albedo and optical depth from long wavelength UV bands.
- Extending the single scattering albedo and optical depth to short UV bands based on the ash cloud model.
- Retrieval of O_3 and SO_2 amounts, with online radiative transfer modeling of particle laden atmosphere to match radiance measurements from short UV bands.

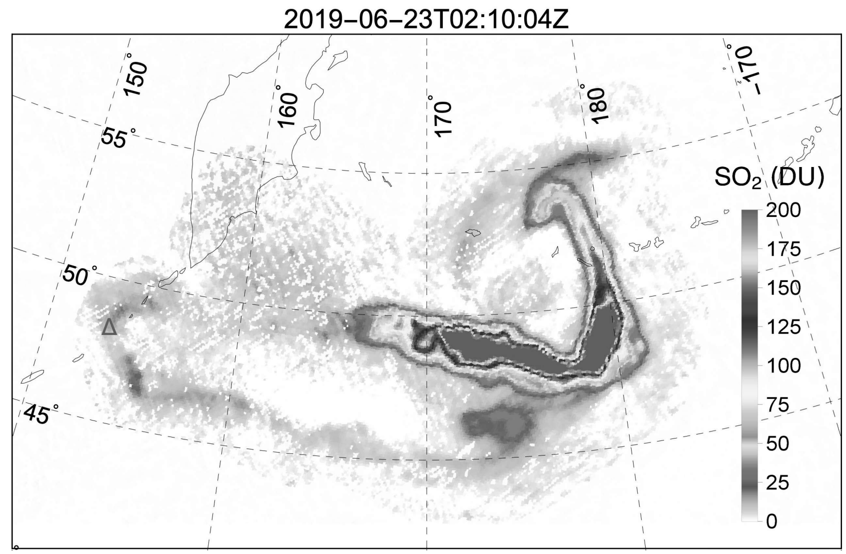


In this case, simultaneous retrieval provides huge accuracy improvement, reducing SO_2 loadings to half or even one-third of the estimates from the MLER treatment.

SO_2 Comparison:



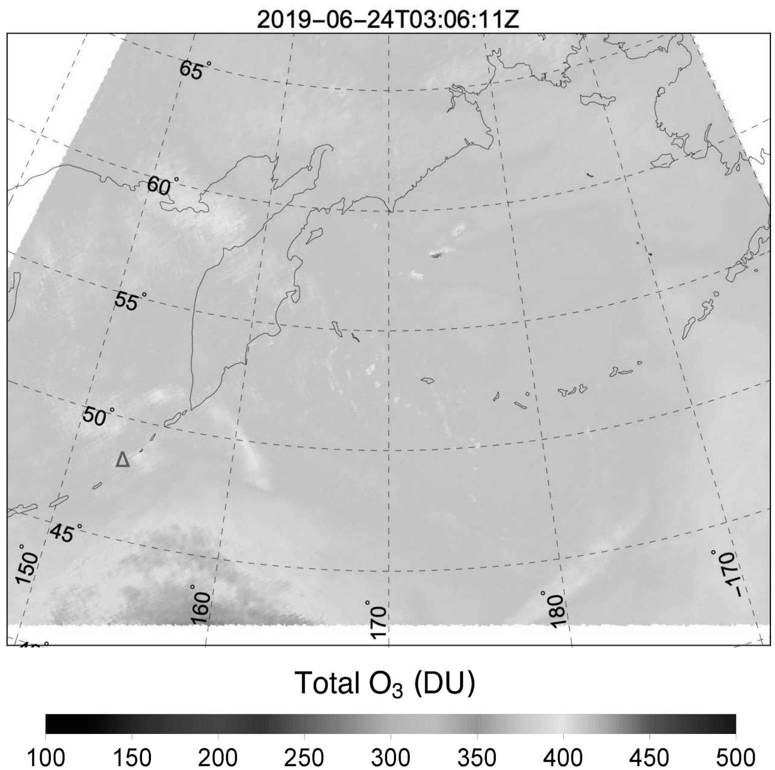
DSCOVR EPIC

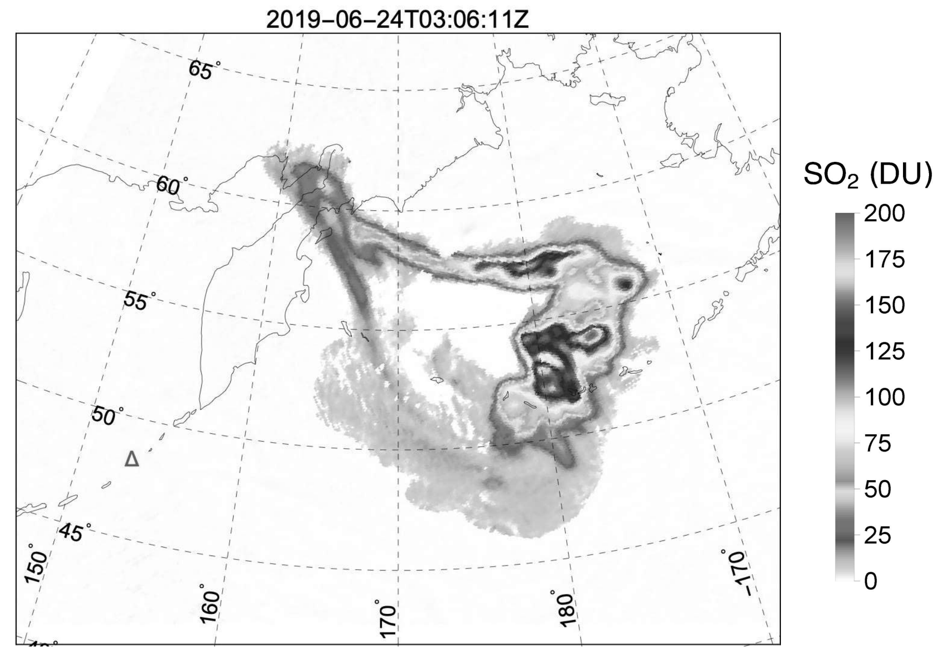


06/23/2019. 00:22:02 UT
SO_2 mass = 1350 kt, area = 2.9x10^6 km^2.
SO_2 max = 667.49 DU @ lon = 179.01°E, lat = 49.11 $^\circ$N
This figure is taken from de Leeuw et al., https://doi.org/10.5194/acp-21-10851-2021

06/23/2019. 02:10:04 UT
SO_2 mass = 1792 kt, area = 2.5x10^6 km^2.
SO_2 max = 356 DU @ lon = 175.62°E, lat = 48.48 $^\circ$N

Raikoke SO_2 Emission > 1.94 Teragram





SO_2 max = 200.55 (DU) @ lon = 176.164°W, lat = 53.977°N
SO_2 mass = 1941.3 kt, area = 2.01×10^6 (km^2)

Raikoke SO_2 Emission

- TROPOMI : 1.5±0.2 Tg

  Ref: de Leeuw et al., 2021, doi: 10.5194/acp-21-10851-2021

- DSCOVR EPIC: > 1.94 Tg
- Best estimate : 2.1±0.2 Tg

  Ref: Cai et al., 2021, doi: 10.5194/egusphere-egu21-9111

Summary

- EPIC O3SO2AI provides more accurate SO_2 quantifications from large volcanic eruptions than most other satellite retrievals, owing to the high SO_2 accuracy achieved with the DVCF algorithm and EPIC's high-cadence observations that allow better identification of the peak loading of volcanic SO_2 plume.

ATBD

- ATBD Completed, submission to AMT soon.