



Volcanic SO₂ plume forecasting : a comparative assessment of satellite data assimilation and source inversion procedures

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Introduction

Motivation: Large quantities of SO₂ and ash are released during eruptions, threatening aviation safety. The aim of VAAC is to forecast the transport of volcanic plumes in near-real time.

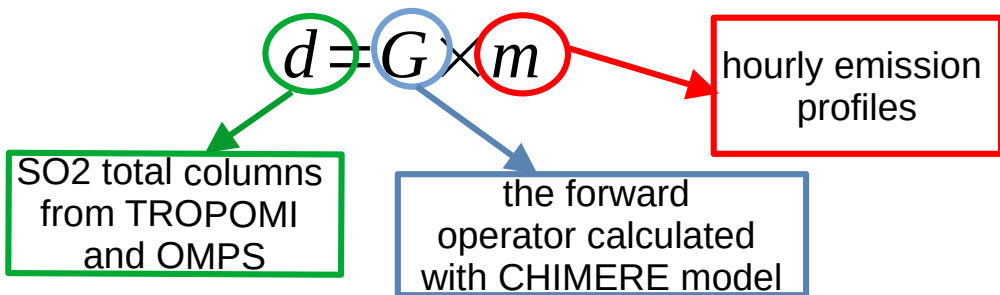
How to simulate volcanic SO₂: Assimilate satellite observations or estimate volcanic emissions by using source inversion method

Goal: Compare the obtained results by these 2 methods and combine them.

Simulations with different scenarii for SO₂ release

Source inversion in CHIMERE CTM

Linear combination between observations and CHIMERE :



- Each element of m must be positive
- Second order Tikhonov side constraint

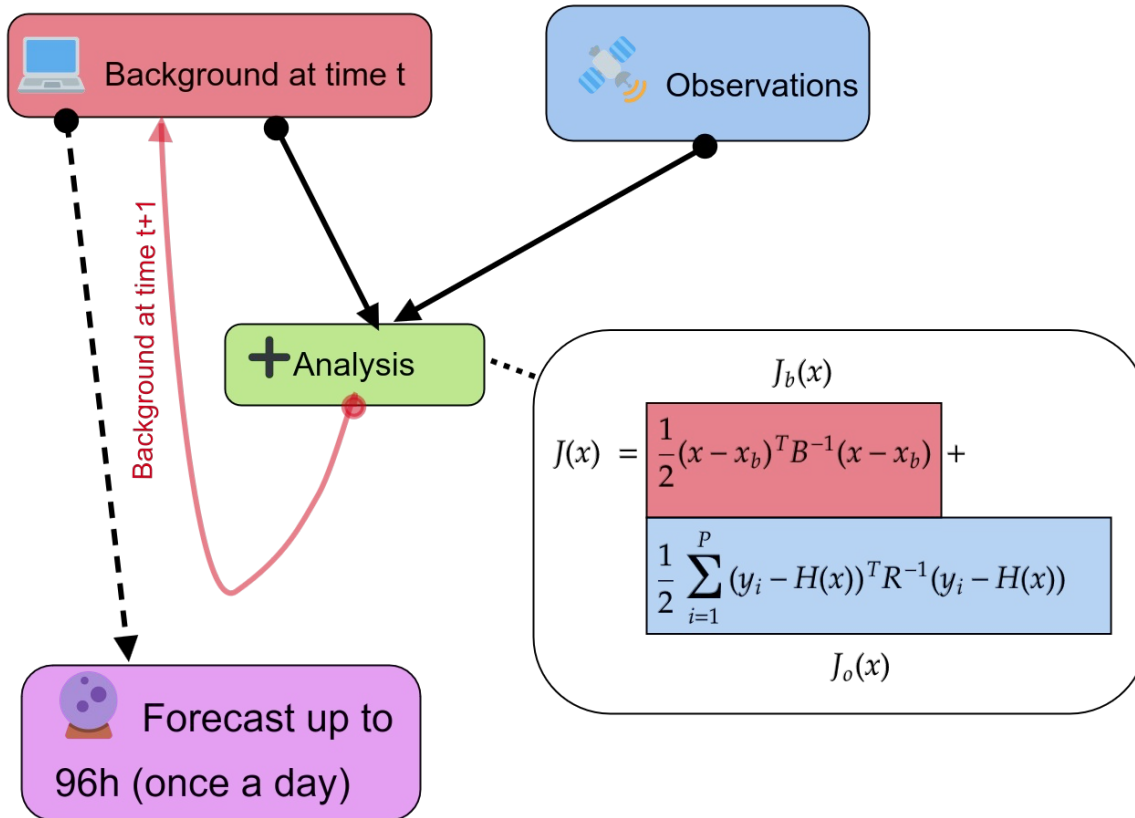
➔ More details in Boichu et al. (2013, 2014, 2015)

Volcanic SO₂ in MOCAGE CTM

- 0.5° global domain
- 60 levels from surface to 0.1 hPa
- Hourly meteorological forcings from ERA5
- Hourly 3D-VAR

SO ₂ emission	Assimilation
Yes	No
No	Yes (TROPOMI)
Yes	Yes (TROPOMI)

The assimilation system in MOCAGE



- H is the observation operator allowing to convert model data into the observations space.

- B and R are the background and the observation error covariance matrices **defined by the users**.

- y is the observations

- x is the model data

- x_b is the background (model data before assimilation)

Definition of the background error covariance matrix B

Assimilation of columns between the ground and 10 hPa. To avoid modifying SO₂ concentration elsewhere than in the plume, we chose to use a background error variance (σ_b^2) depending on longitude, latitude and altitude. These values form the diagonal of the background error covariance matrix B.

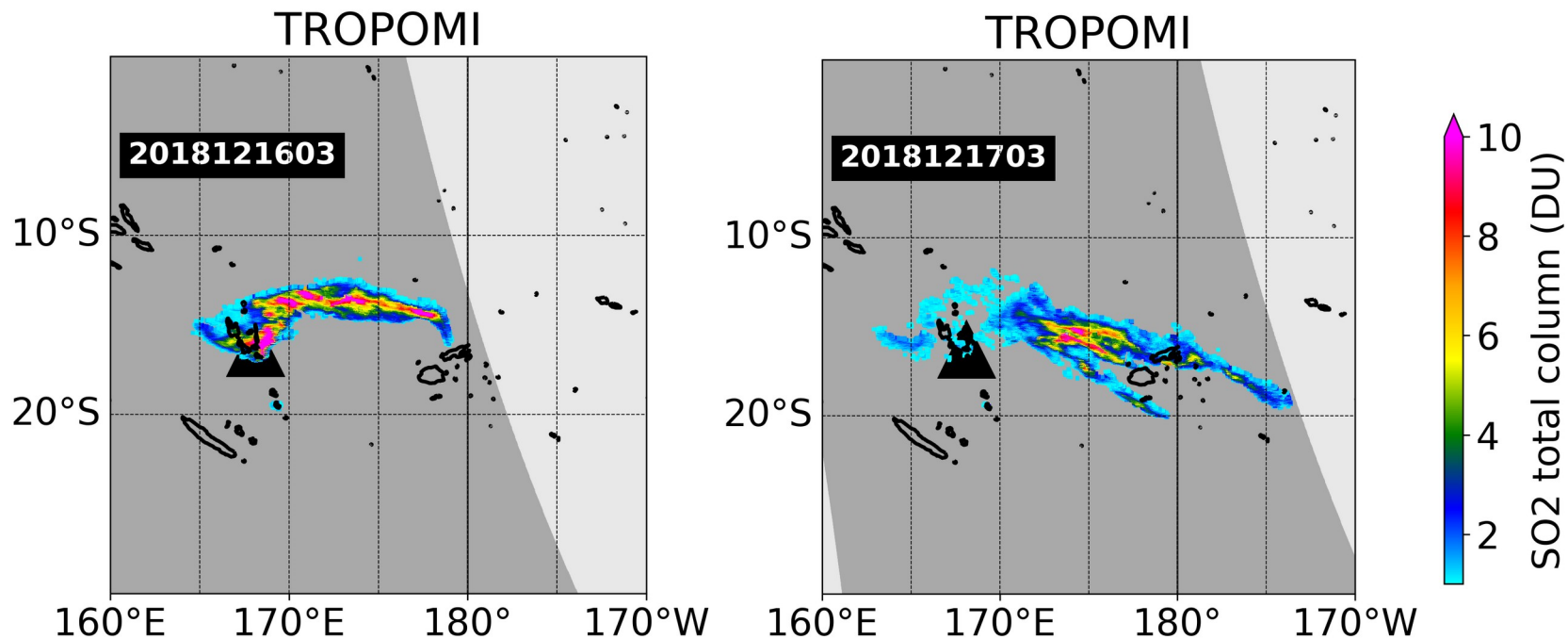
$\sigma_b = 1e-8$ ppv if the concentration at a location and at an altitude above 1000m is above a threshold. Different threshold (given in the table) are used to compute the B matrix. Elsewhere, $\sigma_b = 1e-29$ ppv.

Experiment name	Assimilation	Used threshold	SO2 emission
Emis	No		Yes
Assim_1e-9	Yes	1e-9 ppv	No
Assim_1e-8	Yes	1e-8 ppv	No
Assim_5e-8	Yes	5e-8 ppv	No
Assim_1e-9+Emis	Yes	1e-9 ppv	Yes

Ambrym eruption

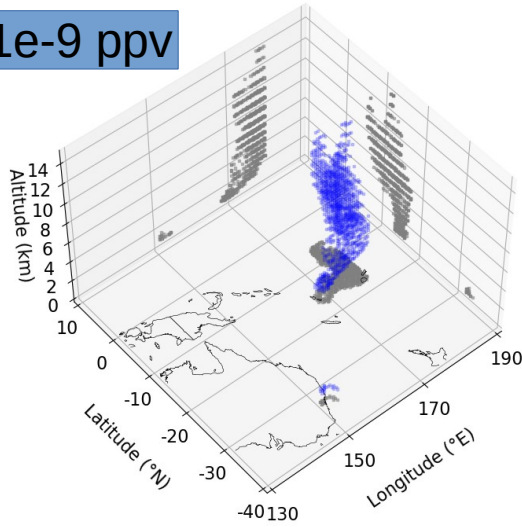
Location 168.1167°E / 16.25°S

Eruption from 14th to 17th December 2018

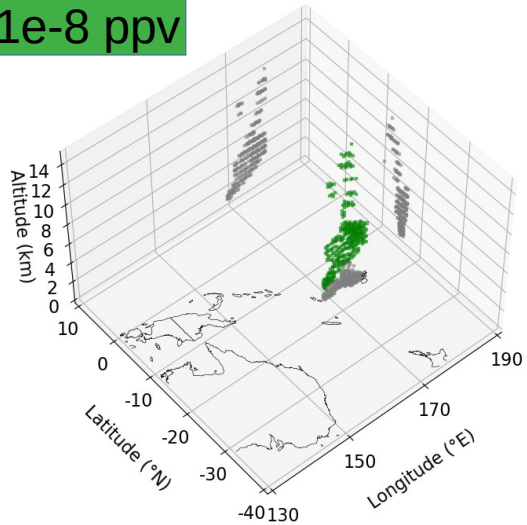


Used background error variance

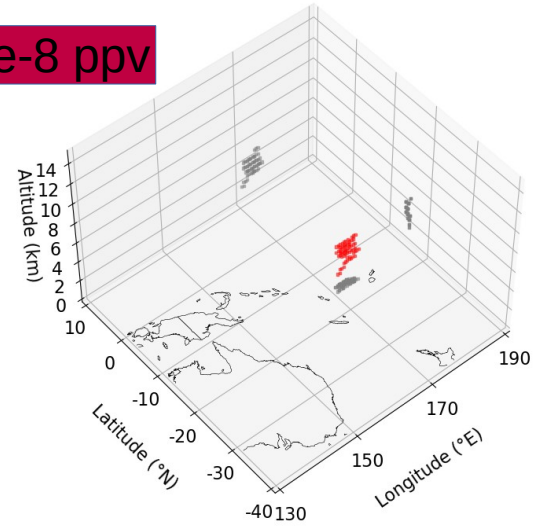
1e-9 ppv



1e-8 ppv

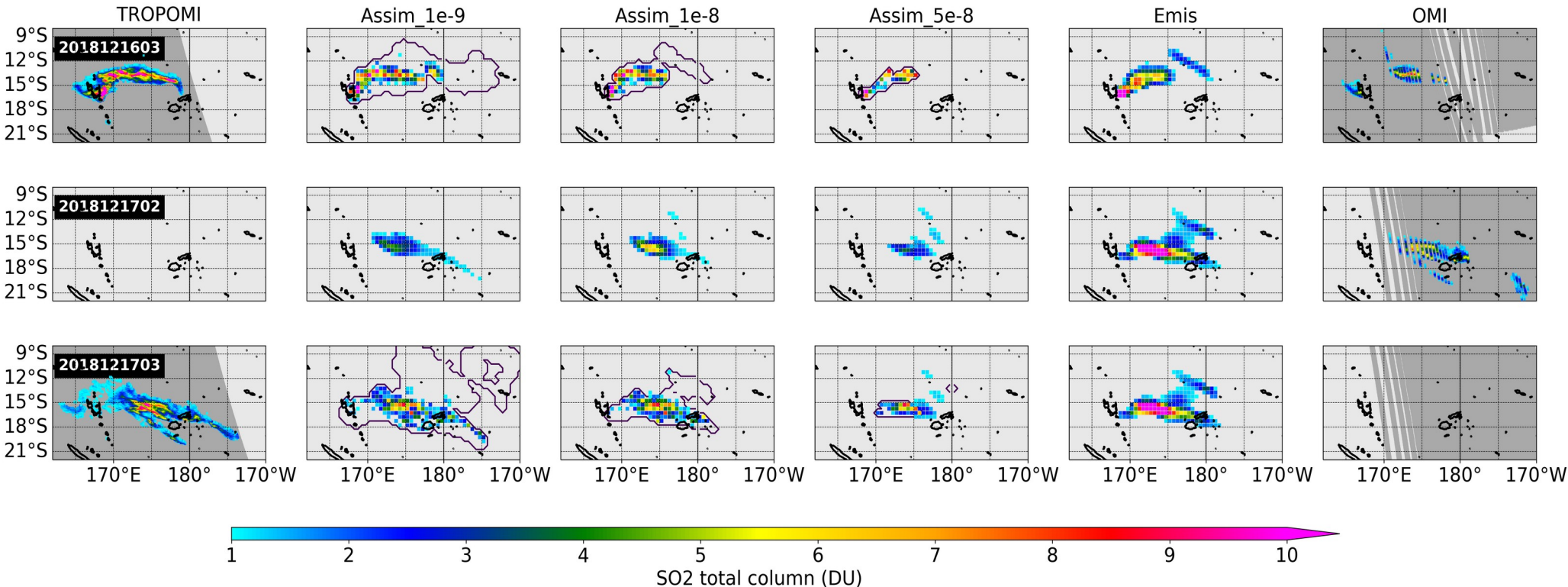


5e-8 ppv



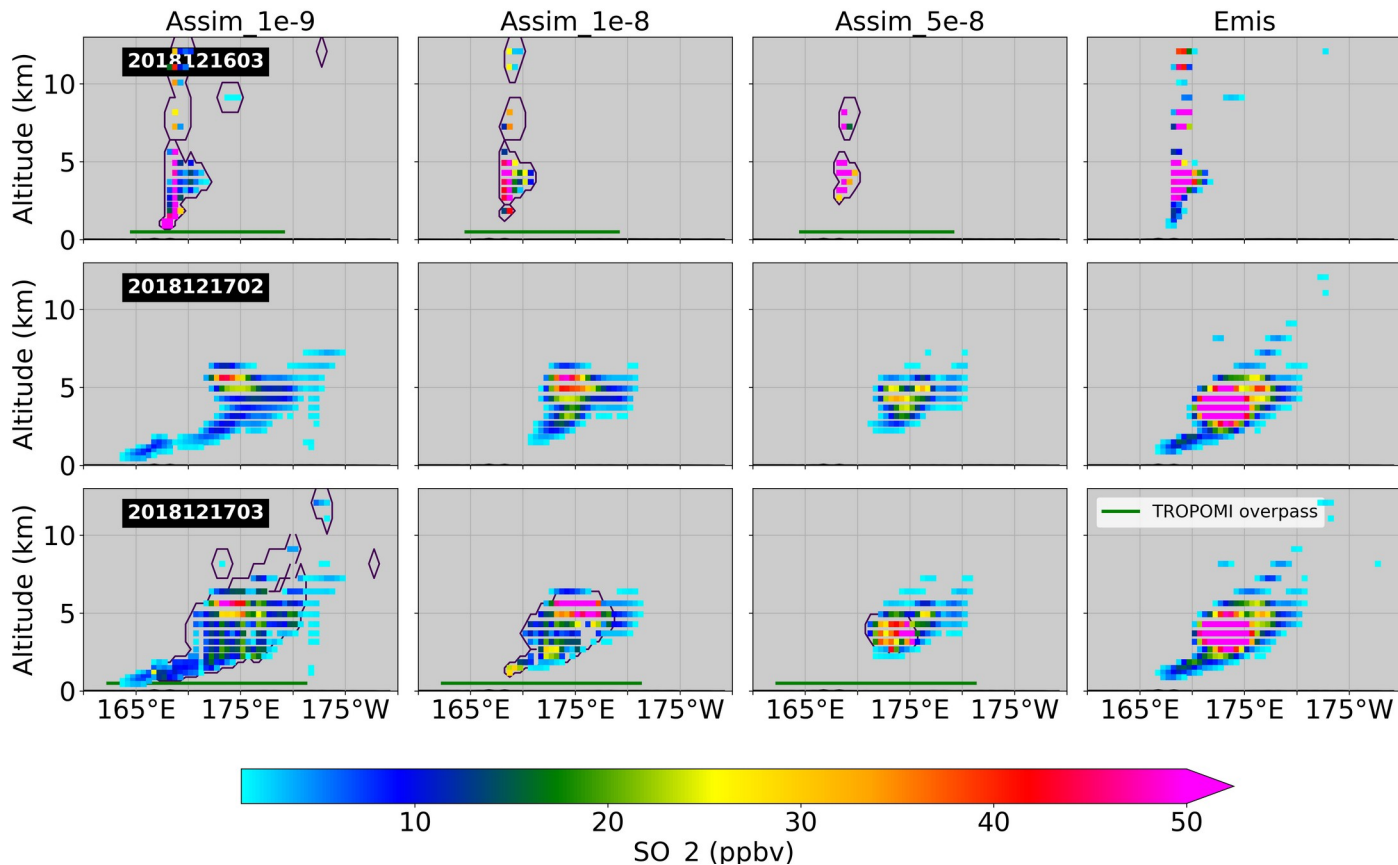
On 17th December 2018 at 3 UTC, $\sigma_b = 1e-8$ ppv where there is a blue, a green or a red point in the scatterplots. Assimilation corrects concentration at these location.

Use of different 3D B matrix for the assimilation



High SO₂ total columns in Emis experiment are not observed by TROPOMI and OMI. Plume is narrower with the decrease of the threshold use to compute σ_b . The shape of the plume is consistent with observations in Assim_1e-9 experiment

Use of different 3D B matrix for the assimilation



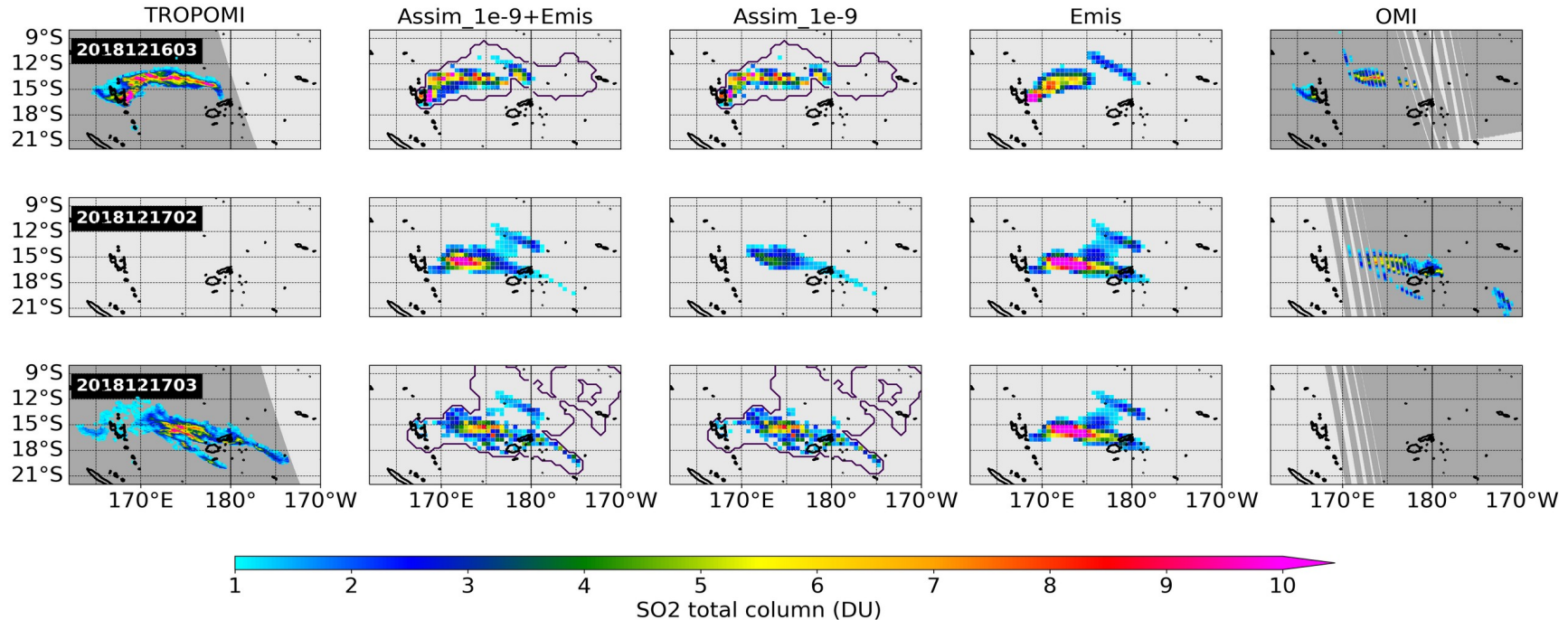
- SO₂ concentration is smaller without the use of the estimated SO₂ emission by inverse modeling.

- The plume is larger in size with the use of smaller threshold to compute B matrix.

- The plume whose shape is close to Emis experiment is obtained by using the 1e-9 ppv threshold to compute B matrix.

Vertical cut at 15.5°S

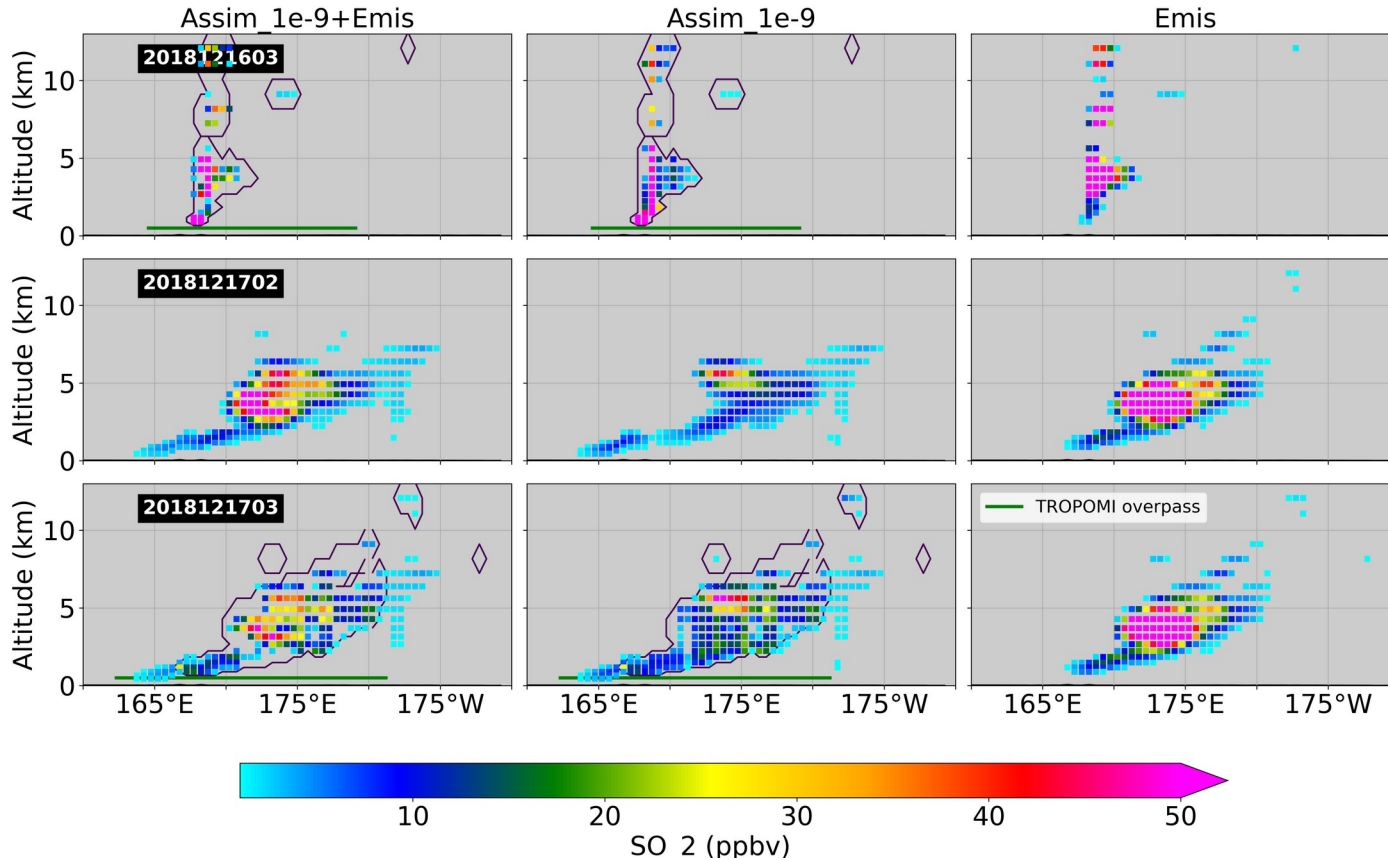
Combination of SO₂ emission and data assimilation



The size of the plume is slightly taller with the use of an estimated emission and with the data assimilation.

When observations are assimilated, SO₂ total columns value are similar between Emis and Assim_1e-9+Emis experiments. Before assimilation, SO₂ total columns are larger in Assim_1e-9+Emis experiment.

Combination of SO₂ emission and data assimilation



The SO₂ concentration decreases in Assim_1e-9+Emis experiment compared to the Emis Experiment.

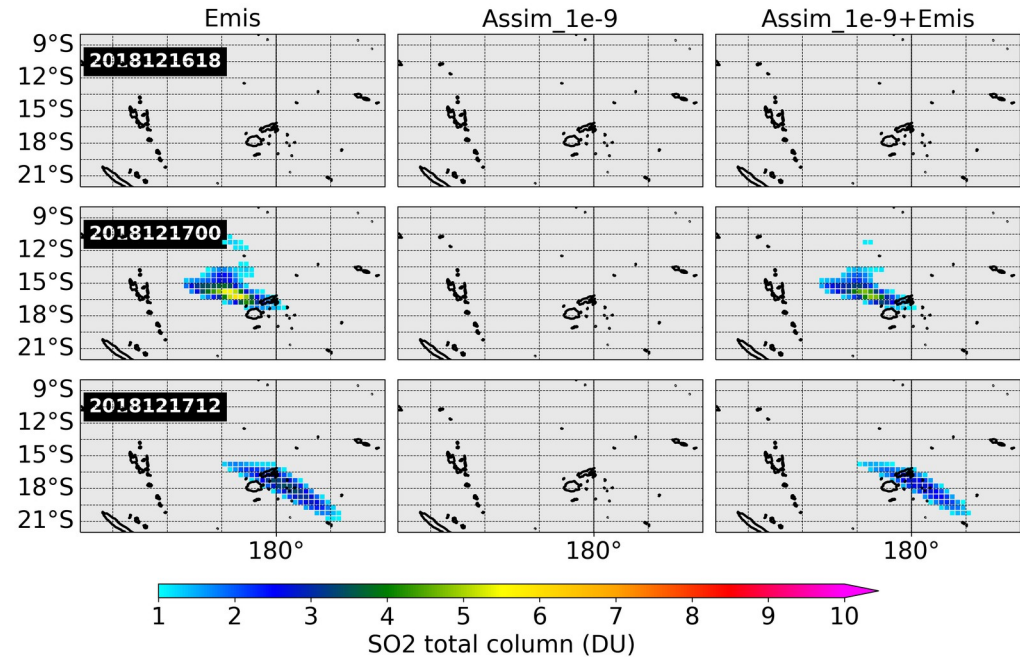
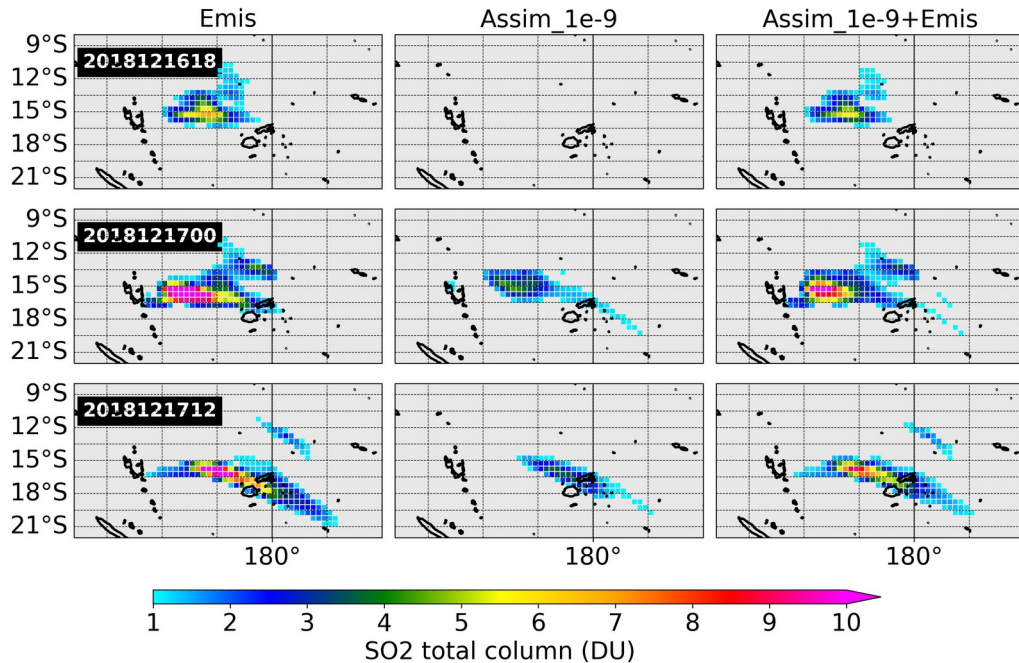
The SO₂ vertical distribution are consistent between experiments.

Vertical cut at 15.5°S

Impact on forecasts

D0 forecast

D1 forecast



- Larger plume and stronger SO₂ total columns are modelled when forecasts are initialized by Emis and Assim_1e-9+Emis analysis.
- For D2 and D3 forecasts, no plume stronger than 1 DU is simulated. For D1 forecast, no plume stronger than 1 DU is modelled in Assim_1e-9 experiment.

Take home messages

- For the Ambrym eruption, we compare the simulation of the volcanic SO₂ using TROPOMI data assimilation and using a SO₂ emissions estimated by inverse modelling. We test different σ_b values for the assimilation. The σ_b are 1e-8 ppv where the simulation with the estimated SO₂ emissions reach 1e-9, 1e-8 or 5e-8 ppv.
 - More this threshold is high, more the plume is small in size. The use of 1e-9 ppv threshold allows to simulate a plume which the shape is closer to the observations. Without data assimilation, SO₂ total columns are too large compared to the observations
 - Combine inversion source and data assimilation leads to a weaker and a narrower plume compared to the simulation with the use of SO₂ emission.
 - Plume is larger both in size and in values when forecasts are initialized by a simulation using source emission or both source emission and data assimilation.
- Work on R and B matrices and on the correlations
 - Validation of our experiments with others observations
 - Assimilation of other instruments



Thank you for your listening

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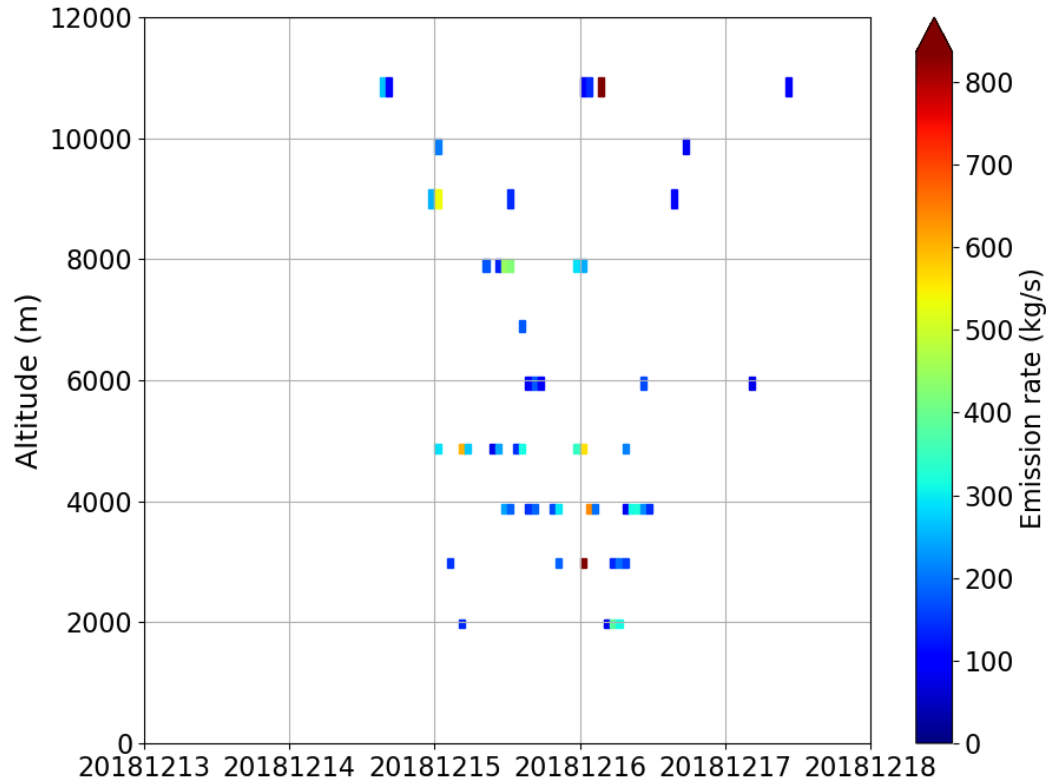
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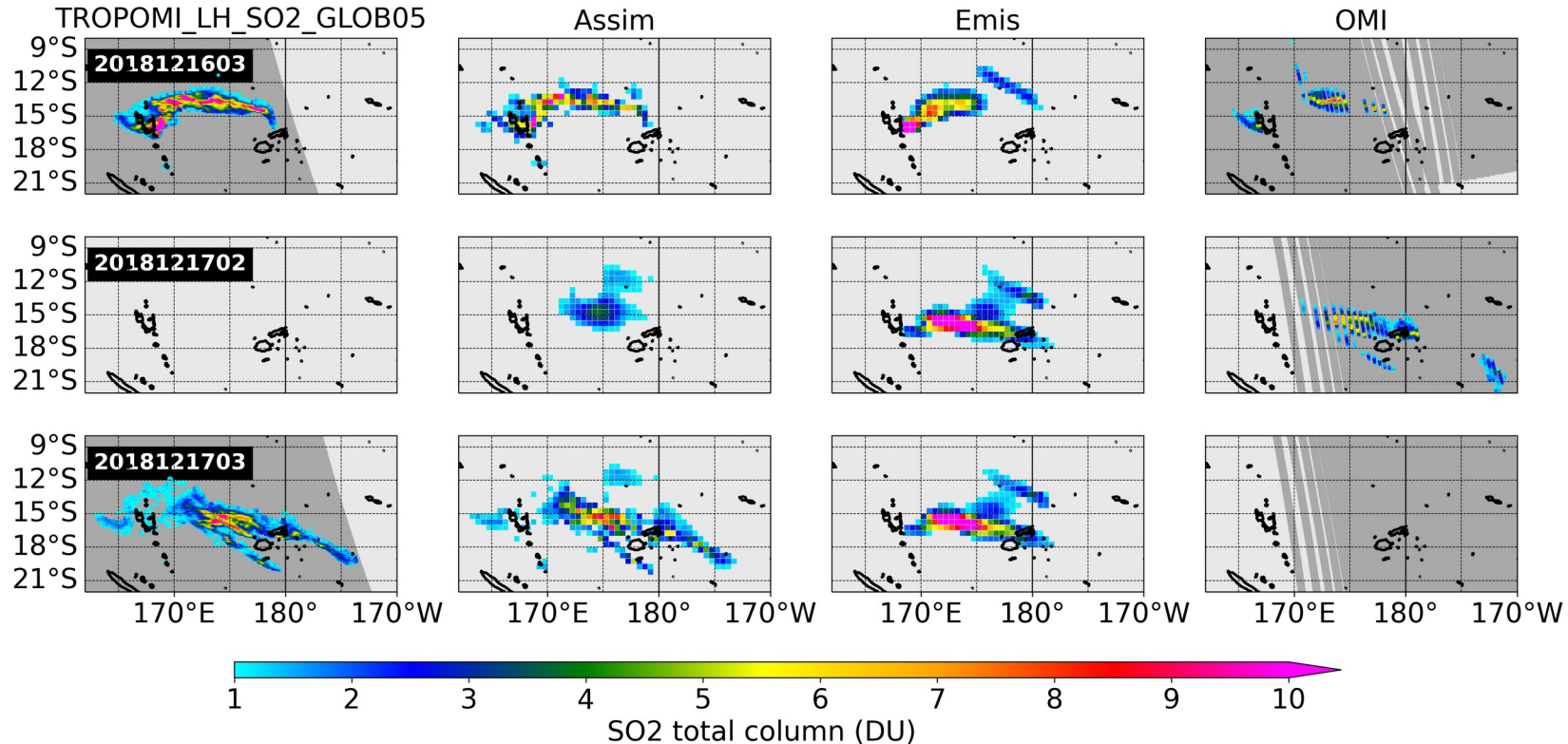
Emission estimated by CHIMERE source inversion procedures



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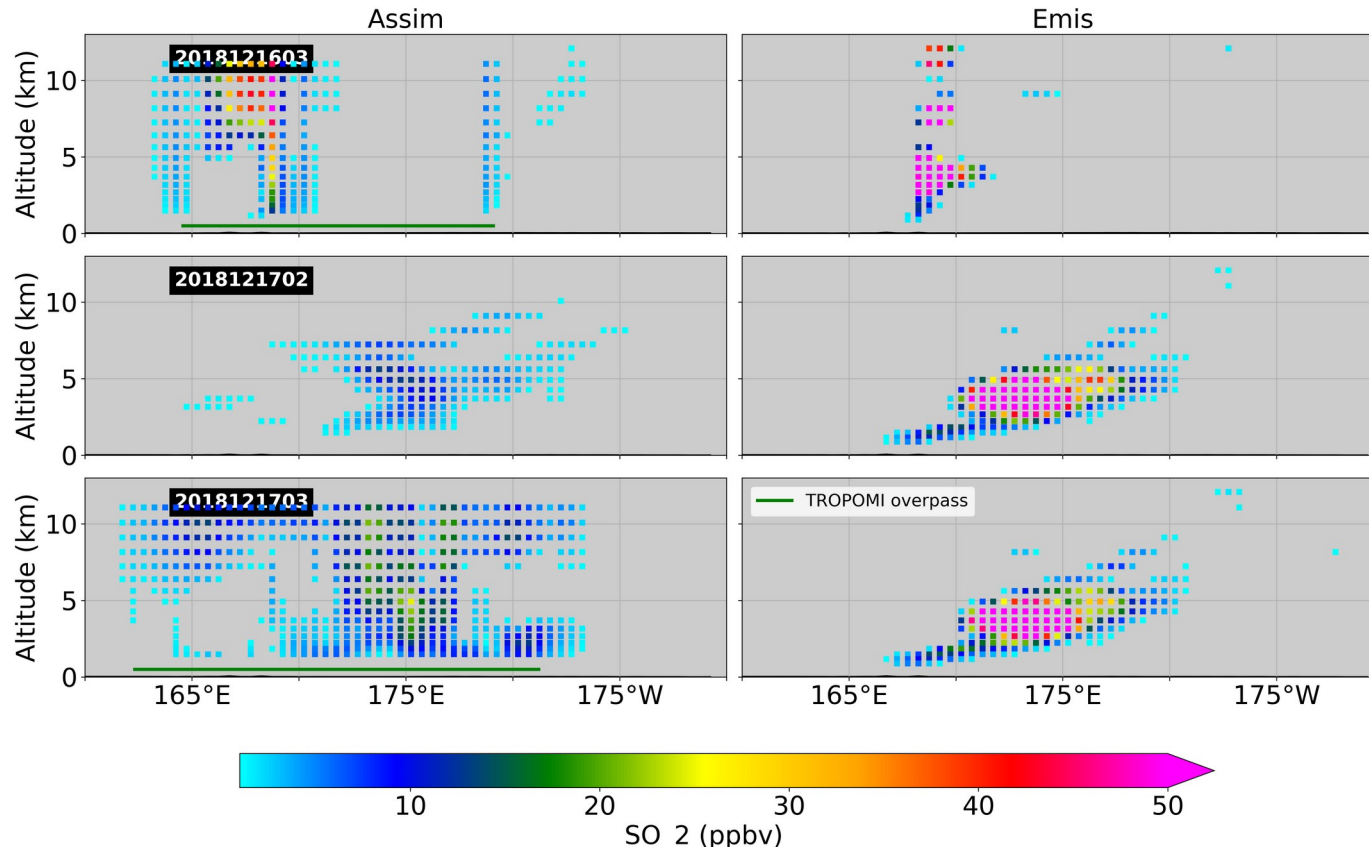


Assimilation of TROPOMI with averaging kernels



In Assim experiment, $\sigma_b = 1e-8$ ppv between 1.6 and 11.5 km of height

Assimilation of TROPOMI with averaging kernels



Vertical cut at 15.5°S

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