Model validation and data insertion with FALL3D-8.0: exploiting geostationary satellite retrievals of volcanic ash and SO_2

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I. EXTENDED ABSTRACT

The new version of FALL3D has recently been released with several new features and improvements in model physics, solving algorithms, code accuracy and performance [1]. Among the new features are a data insertion scheme and the ability to simulate volcanic SO_2 clouds. The data insertion scheme enables users to initialise model runs from satellite retrievals. This modelling approach is useful for removing uncertainties associated with source term parameters such as the mass flow rate, plume height, source duration and start time. Here we demonstrate and validate the new data insertion scheme in *FALL3D-8.0* using geostationary satellite retrievals of volcanic ash and SO_2.

A. Satellite retrievals

1) Volcanic ash: The ash detection scheme presented here exploits the reverse absoprtion signature between 11 and 12 μm and is based on applying successive masks that flag pixels as 'ash-affected' before attempting a subsequent quantitative ash retrieval. We use the June 2011 eruption of Puyehue-Cordón Caulle (Chile) as a case study and apply the ash retrieval to SEVIRI (Meteosat-9) measurements. Once pixels have been identified as being 'ash-affected' we apply a Look-up Table (LuT) approach [2] to retrieve volcanic ash optical depth (τ), effective radius (r_e; in μm), and column mass loading (m_l; in g m^{-2}). The temperature difference model employed here is based on the forward model developed by [3] and [4]. Uncertainties using this method are estimated to be up to 50% [4], [5].

TABLE I. SUMMARY OF THE SAL AND FMS VALIDATION SCORES.

Validation metrics	S	A	L	SAL	FMS
2011 Cordón Caulle					
24 h	-1.00	-0.22	0.08	1.30	0.42
48 h	-0.83	0.08	0.32	1.24	0.14
72 h	0.46	0.89	0.36	1.71	0.10
2019 Raikoke					
24 h	-0.79	-0.61	0.05	1.46	0.23
48 h	-0.93	-0.91	0.03	1.87	0.20

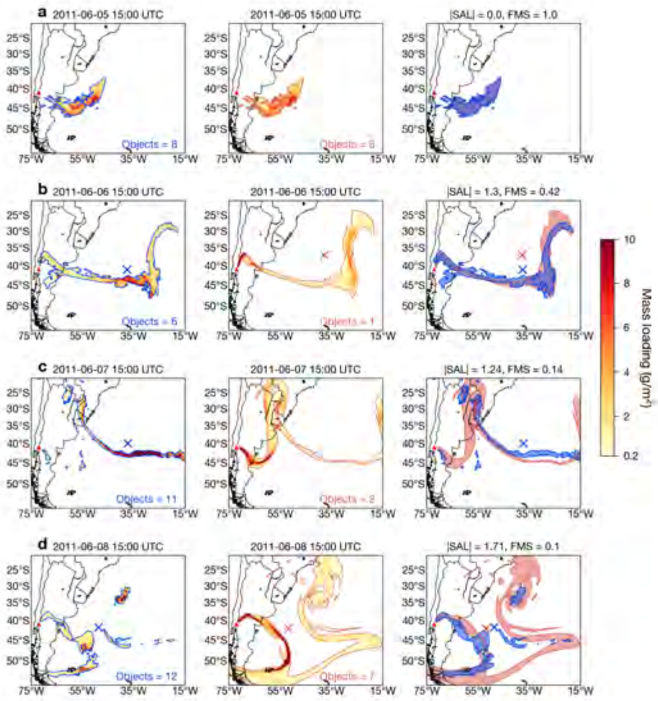

Fig. 1. *FALL3D-8.0* validation of fine ash mass loading using SEVIRI mass loading retrievals. Left panels show satellite retrievals. Middle panels show *FALL3D-8.0* ash simulations. Right panels show spatial overlap of model vs. observed fields.

2) Volcanic SO_2: We apply a three-channel technique to IR geostationary satellite measurements to retrieve total SO_2 column densities in Dobson Units (DU) [6]. This retrieval exploits the SO_2 absorption feature near 7.3 μm. We use the June 2019 eruption of Raikoke (Russia) as a case study and apply the retrieval to AHI (Himawari-8) measurements. To determine whether there is an SO_2 signal in the data, we first construct a synthetic 7.3 μm brightness temperature by interpolating from 6.9 to 11.2 μm in the radiance space and then converting to brightness temperature via the Planck function [6]. One can identify SO_2 clouds by taking the difference between these two variables:

$$\Delta T_{SO_2} = T^{7.3}_{BC} - T^{7.3}_{B} \tag{1}$$

The ΔT_{SO_2} calculated via Eq. (1) is a function of the total column density of SO_2.

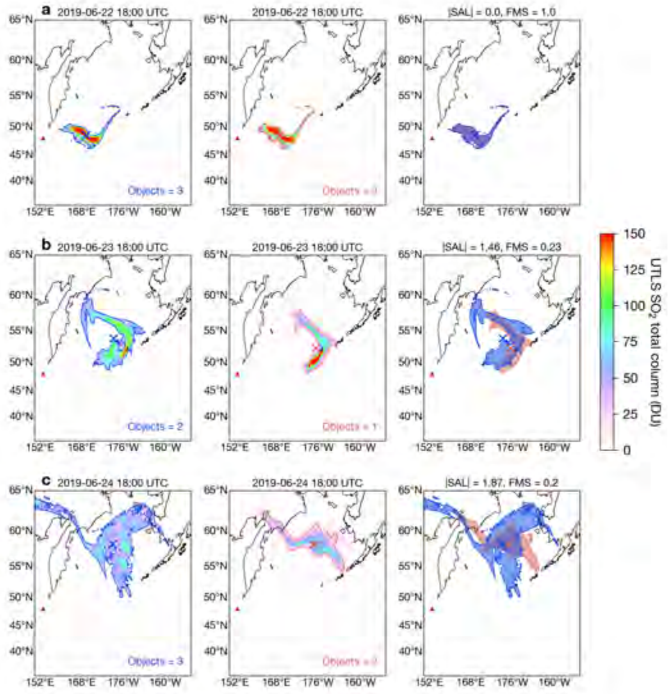

Fig. 2. Same as Fig. 1 but for the Raikoke case study and AHI upper-troposphere lower-stratosphere (UTLS) total column burdens retrievals (DU).

The SO_2 retrieval is based on constructing this function from offline radiative transfer calculations.

B. Validation Metrics

We use the Structure, Amplitude and Location (SAL) metric [7] to quantitatively compare satellite retrievals of volcanic ash and SO_2 to corresponding FALL3D simulations. As in [8] and [9], we also use the Figure of Merit in Space (FMS) score as a complement to SAL for comparing the spatial coverage of observed vs. modelled fields. A detailed mathematical description of the SAL metrics is presented in [7]. SAL varies from 0 (best agreement) to 6 (worst agreement).

C. Results

1) 2011 Cordón Caulle: Figure 1 shows how the satellite retrievals and the model simulations compare using data insertion. FALL3D accurately represents the spatial structure of the satellite retrievals with a SAL score of 1.3 and FMS of 0.42 (Fig. 1b) after 24 hours. After 48 hours, the SAL score is 0.77 and FMS is 0.14 (Fig. 1c; Table I). The main difference between the model and observations at this time is in the centres of mass (L = 0.32). This is due to a second input of mass used in the Cordón Caulle simulations in addition to the large masses retrieved from the satellite near the centre of the domain (near 43°S, 35°W). The satellite is likely overestimating mass in this part of the ash cloud because of the underlying meteorological cloud layer that has not been accounted for in the radiative transfer modelling.

2) 2019 Raikoke: Figure 2 shows the satellite retrievals and model simulations for the Raikoke case study. Over the first 24 hours the SAL score increases from 0 to 1.46 while the FMS decreases from 1 to 0.23 (Fig. 2b). The SAL score is mainly affected by the S and A scores whereas the L score is low (0.05) indicating the FALL3D is able to track the centre of mass of SO_2 very well when initialised with satellite retrievals.

D. Conclusions

In general *FALL3D-8.0* is able to reproduce observations with a high degree of accuracy when initialised using the new data insertion scheme. Both simulations for SO_2 and ash maintained SAL scores below 2 out to 48 hours after data insertion.

II. ACKNOWLEDGMENT

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Dr Andrew Prata received his PhD in Atmospheric Physics at Monash University (Australia) in 2017 after completing an Honours Degree at Monash in 2012 and a BSc in Atmosphere and Ocean Science at the University of Melbourne and the University of California Los Angeles (UCLA) in 2010. Prior to completing his PhD, he completed an internship at NASA JPL (USA) and worked as a Research Assistant at the Australian Bureau of Meteorology. In 2018, he completed a postdoc in the Meteorology Department at the University of Reading (UK). He is currently appointed as a Postdoctoral Research Fellow within the Computer Applications in Science and Engineering (CASE) group at the Barcelona Supercomputing Center, Spain.