

Supplementary Material for the paper:  
Ensemble-Based Data Assimilation of volcanic  
ash clouds from satellite observations: application  
to the 24 December 2018 Mt.Etna explosive  
eruption

April 7, 2020

## 1 Introduction

Here we collect the supplementary figures for EXP2, EXP3, EXP4, EXP5 and EXP6. Mean values and standard deviations are presented as done in the main text, as well as the True Positive, False Positive and False Negative pixels from which evaluation metrics  $R_j$ ,  $R_{mp}$  and  $R_{ms}$  were computed. The main features of each experiment are briefly recapitulated at the beginning of each section, while the complete set of input parameters can be found in Tables 1 and 2 of the main text. Figures S1 - S5: results of EXP2, Figures S6 - S10 results of EXP3, S11 - S17 results of EXP4, S18 - S20 results of EXP5, S21 - S25 results of EXP6.

## 2 Results of EXP2

EXP2 differs from EXP1 for the standard deviation used to perturb the reference wind-field (i.e.  $10^\circ$  instead of  $15^\circ$  as for EXP1).

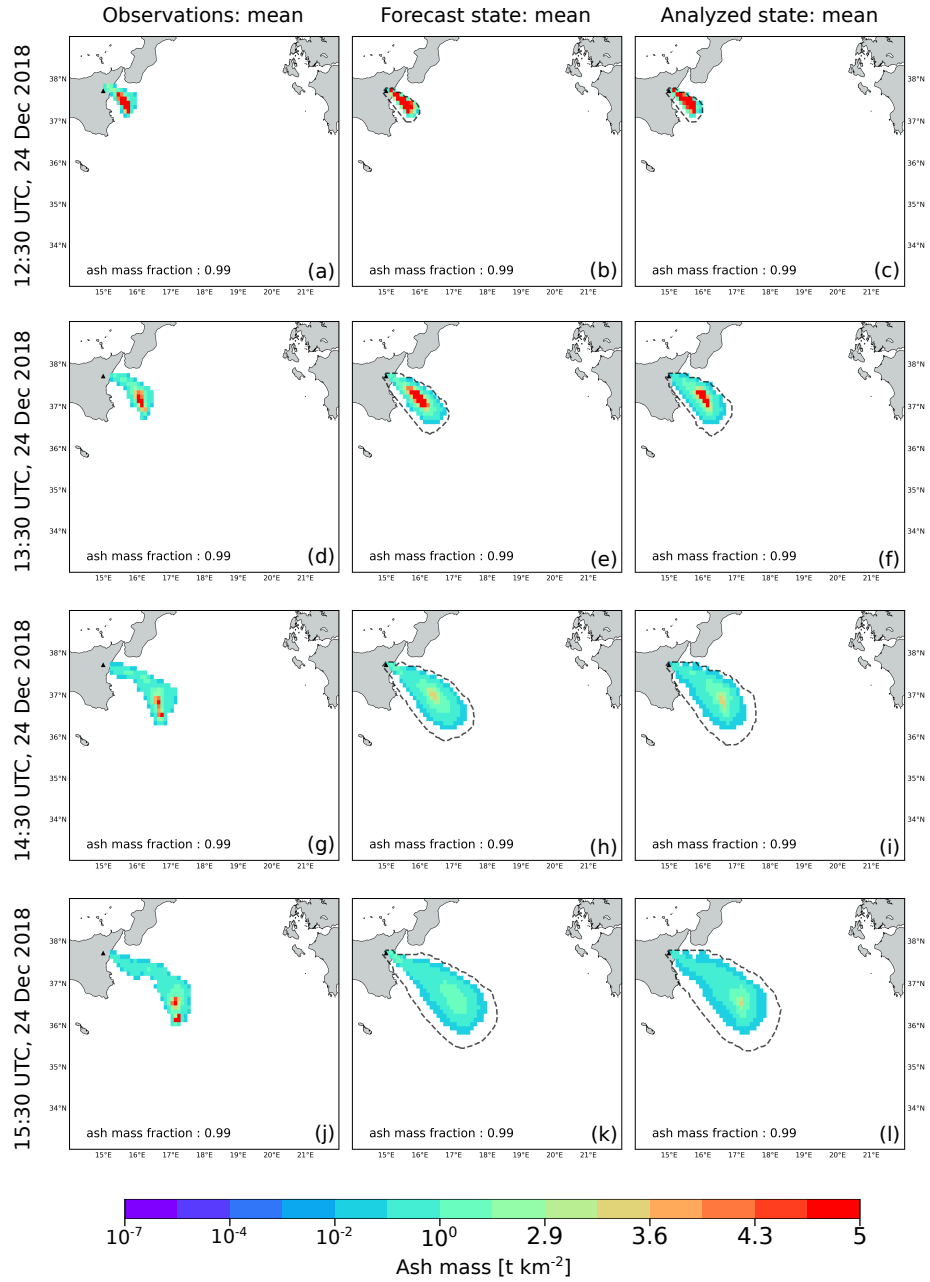


Figure S1: Mean states resulting from EXP2. Panels (a),(d),(g) and (j) show the ash cloud as detected from space (Observations). Panels (b),(e),(h) and (k) illustrate the ash cloud as predicted by the numerical model PLUME-MoM&HYSPLIT (Forecast state), while Panels (c),(f),(i) and (l) present the results of the assimilation cycles (Analyzed state). A cut-off of  $0.01 \text{ t km}^{-2}$  was applied to original ash column density. The edges of the original ash cloud (both forecast and analyzed) are indicated by the black dotted lines. In this figure are displayed the assimilation cycles performed at 12:30, 13:30, 14:30 and 15:30.



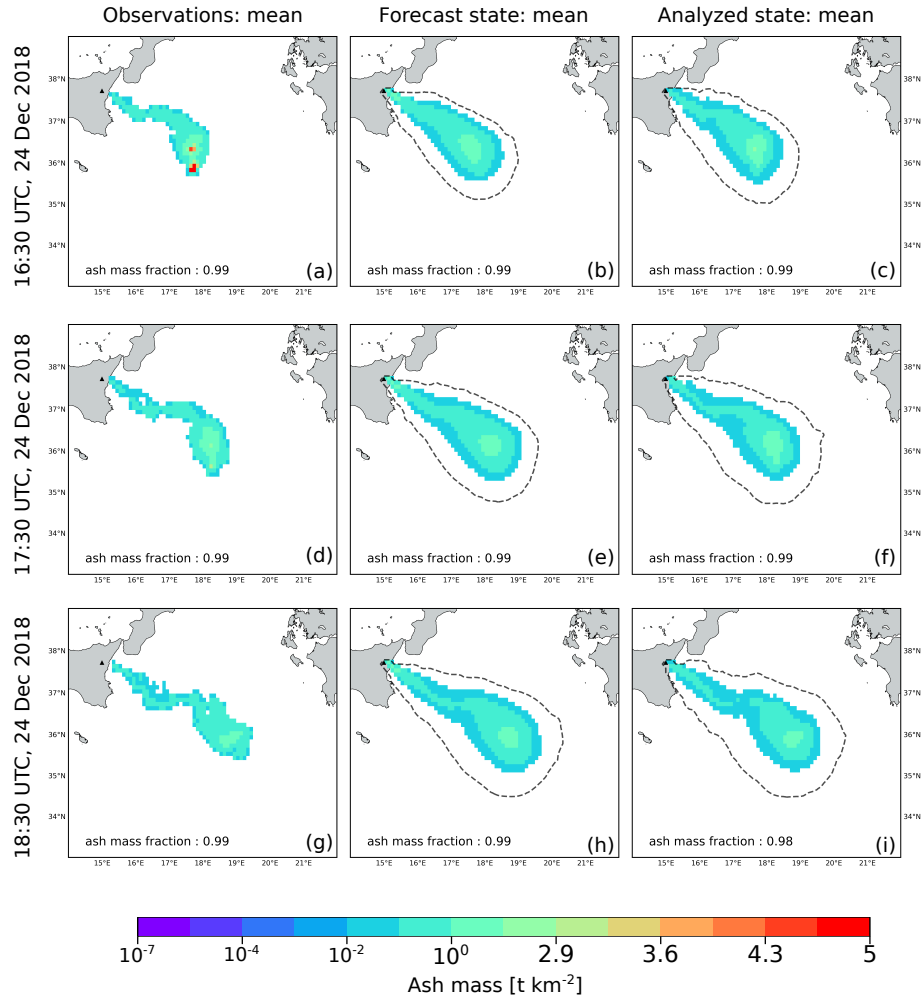


Figure S2: Same as Figure S1 but for the assimilation cycles performed at 16:30, 17:30 and 18:30.

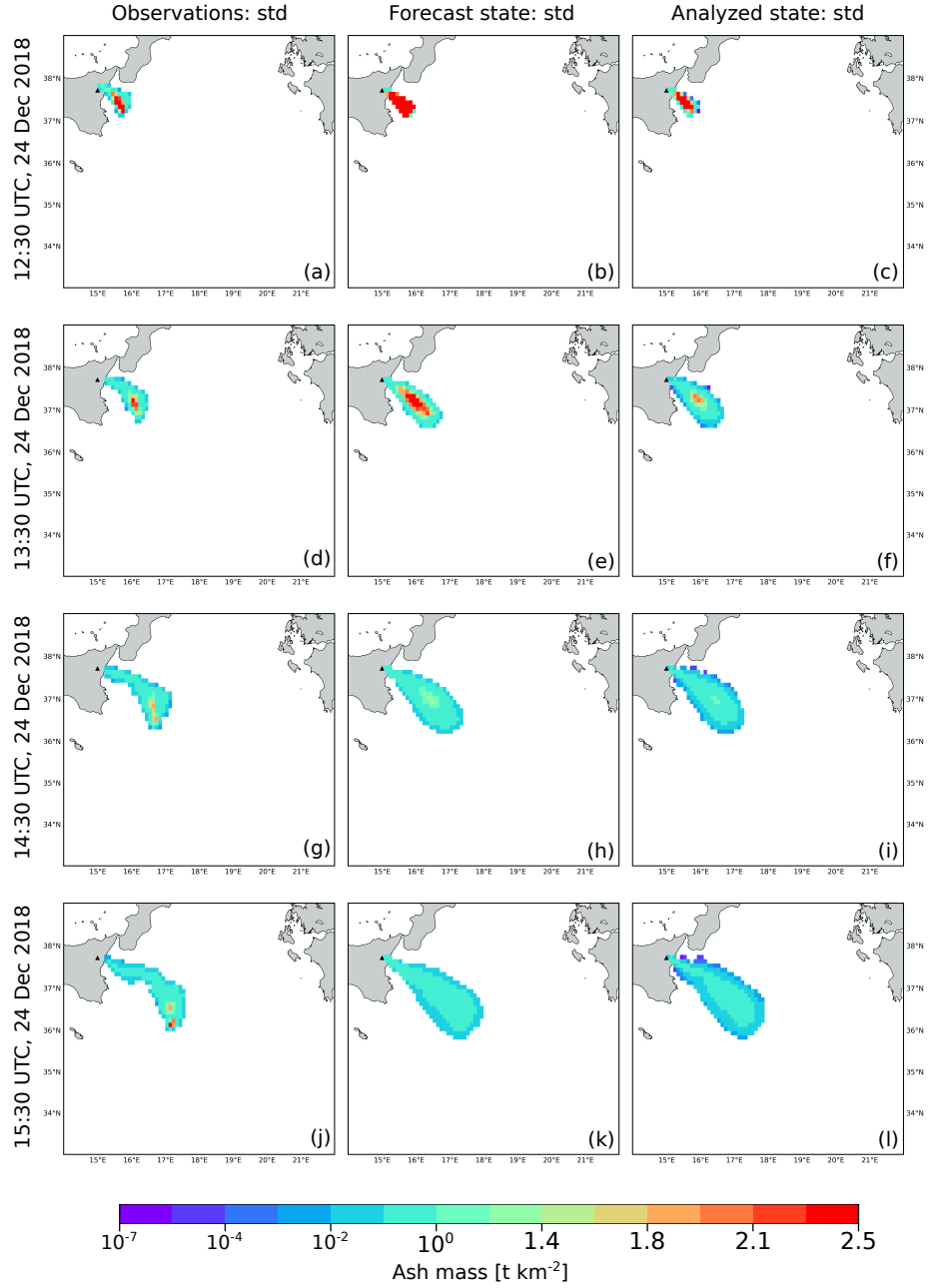


Figure S3: Standard deviations of ash columnar content computed for EXP2. Observations (panels (a), (d), (g) and (j)), Forecast state (panels (b), (e), (h) and (k)) and Analyzed state (panels (c), (f), (i) and (l)) are shown for assimilation cycles performed at 12:30, 13:30, 14:30 and 15:30.

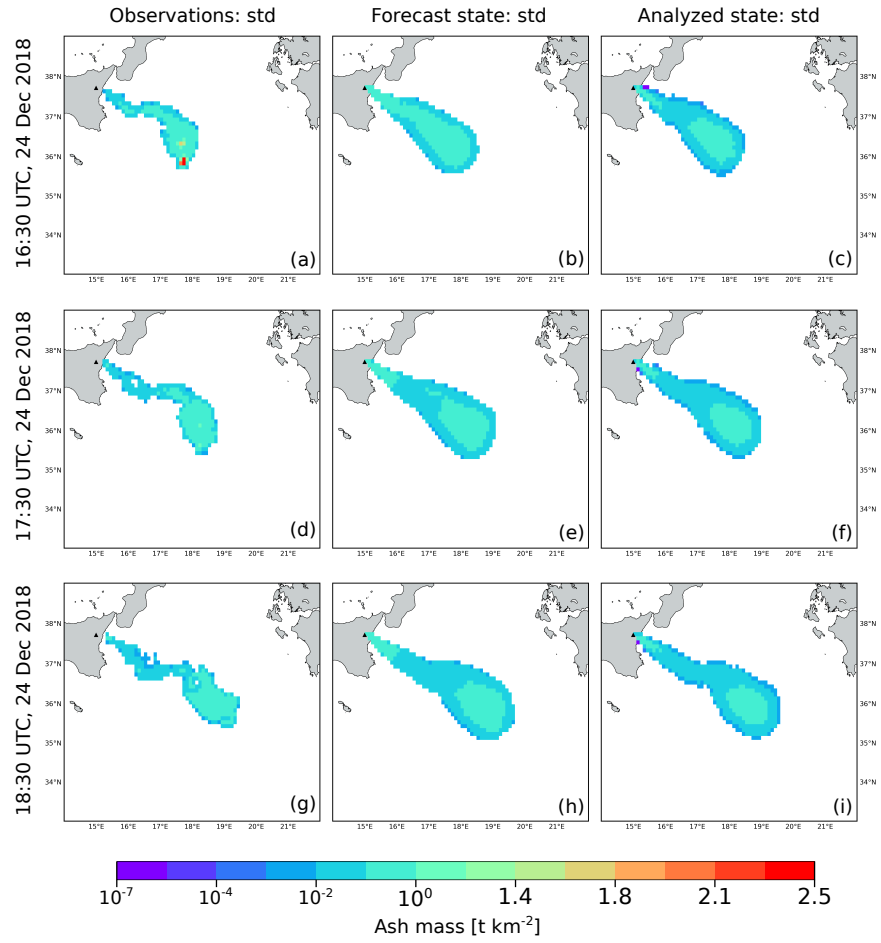


Figure S4: Same as Figure S3, but for assimilation cycles performed at 16:30, 17:30 and 18:30.

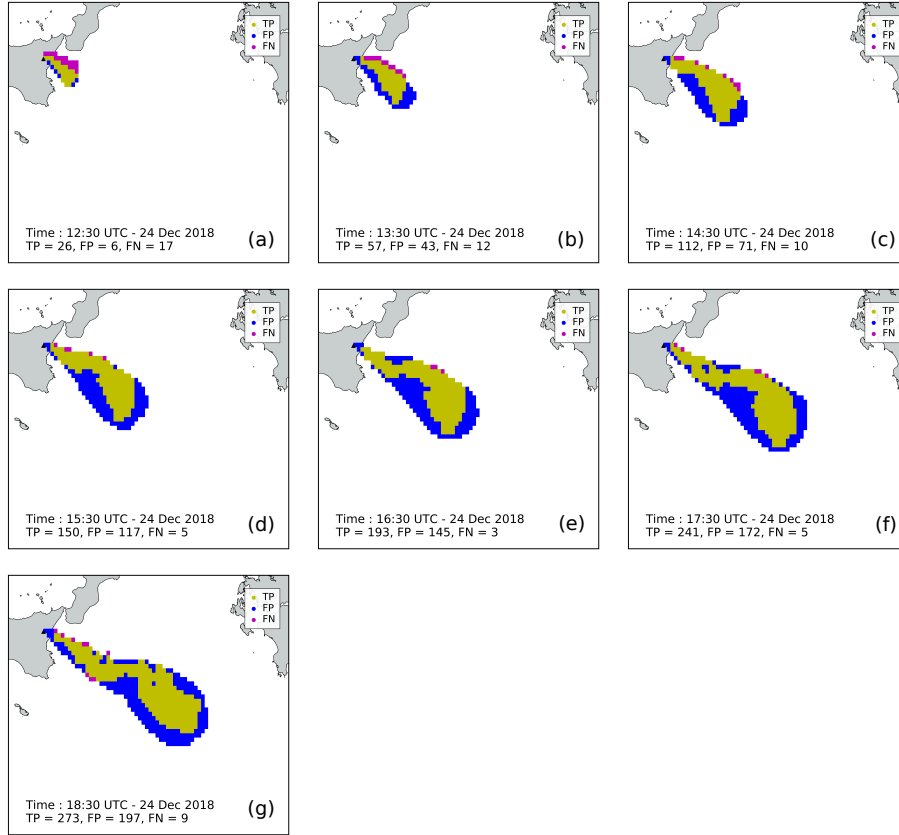


Figure S5: True Positive, False Positive and False Negative pixels computed for EXP2.

### 3 Results of EXP3

As for EXP2, also EXP3 differs from EXP1 for the standard deviation used to perturb the reference wind-field. In this case we considered  $20^\circ$  instead of  $15^\circ$  as for EXP1.

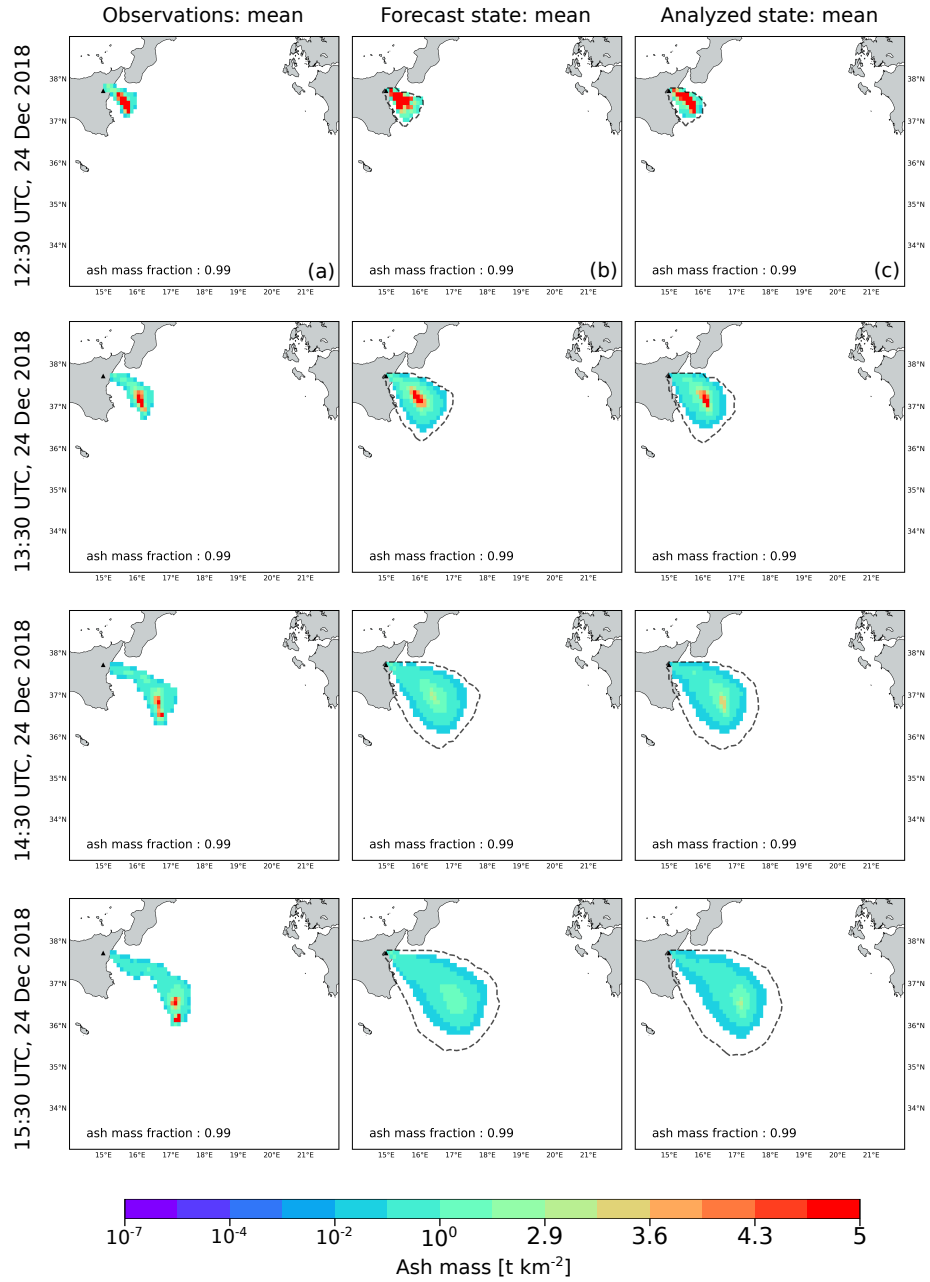


Figure S6: Mean states resulting from EXP3. Panels (a),(d),(g) and (j) show the ash cloud as detected from space (Observations). Panels (b),(e),(h) and (k) illustrate the ash cloud as predicted by the numerical model PLUME-MoM&HYSPLIT (Forecast state), while Panels (c),(f),(i) and (l) present the results of the assimilation cycles (Analyzed state). A cut-off of  $0.01 \text{ t km}^{-2}$  was applied to original ash column density. The edges of the original ash cloud (both forecast and analyzed) are indicated by the black dotted lines. In this figure are displayed the assimilation cycles performed at 12:30, 13:30, 14:30 and 15:30.

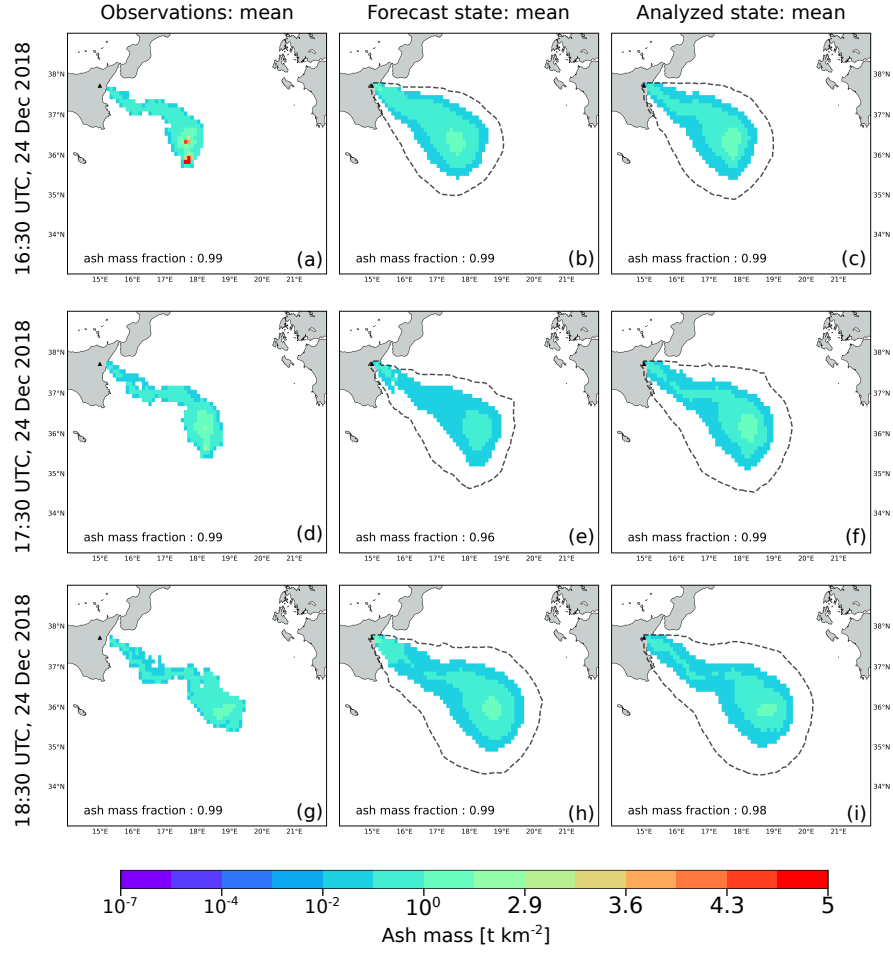


Figure S7: Same as Figure S6, but for the assimilation cycles performed at 16:30, 17:30 and 18:30.

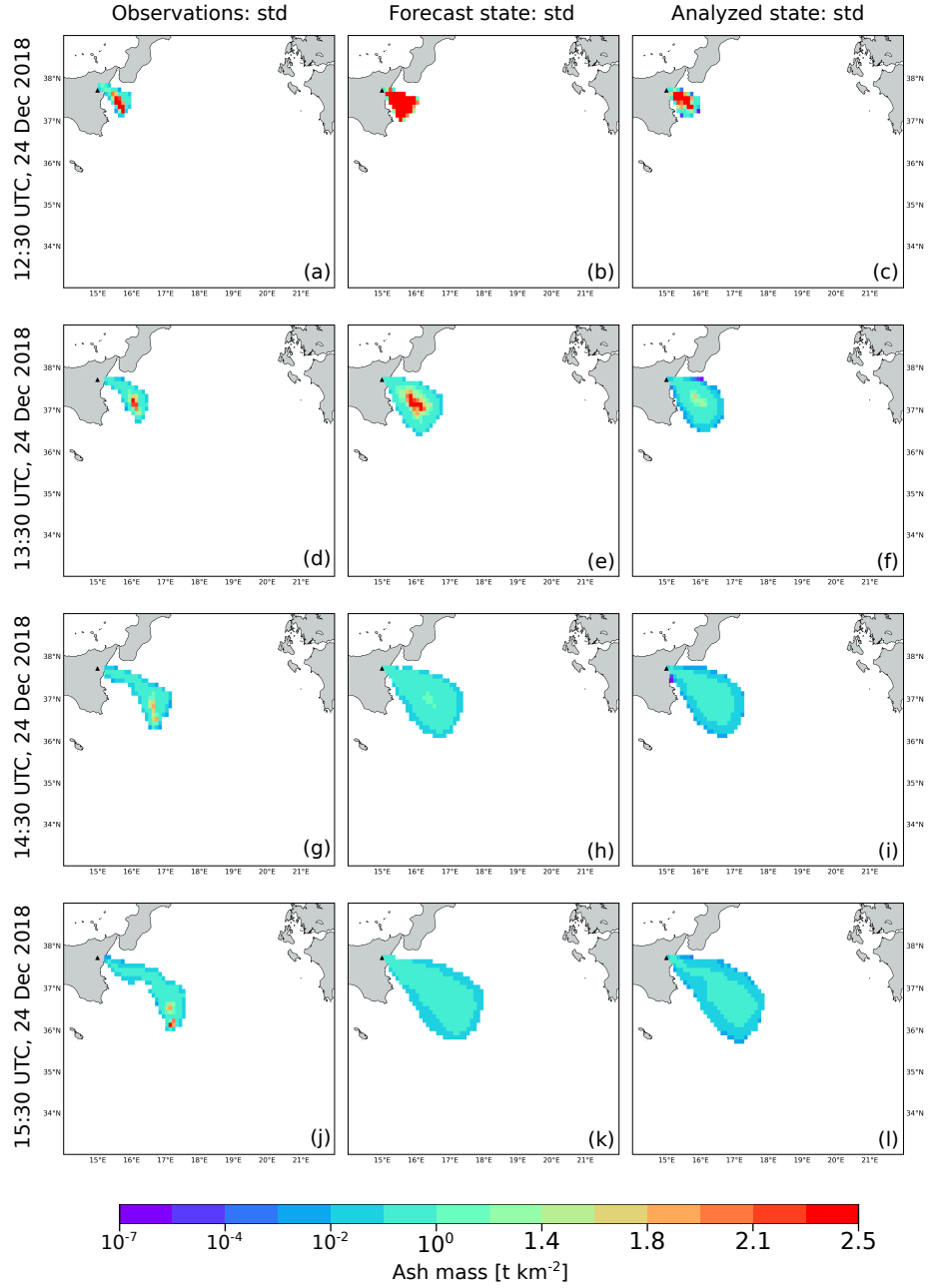


Figure S8: Standard deviations of ash columnar content computed for EXP3. Observations (panels (a), (d), (g) and (j)), Forecast state (panels (b), (e), (h) and (k)) and Analyzed state (panels (c), (f), (i) and (l)) are shown for assimilation cycles performed at 12:30, 13:30, 14:30 and 15:30.

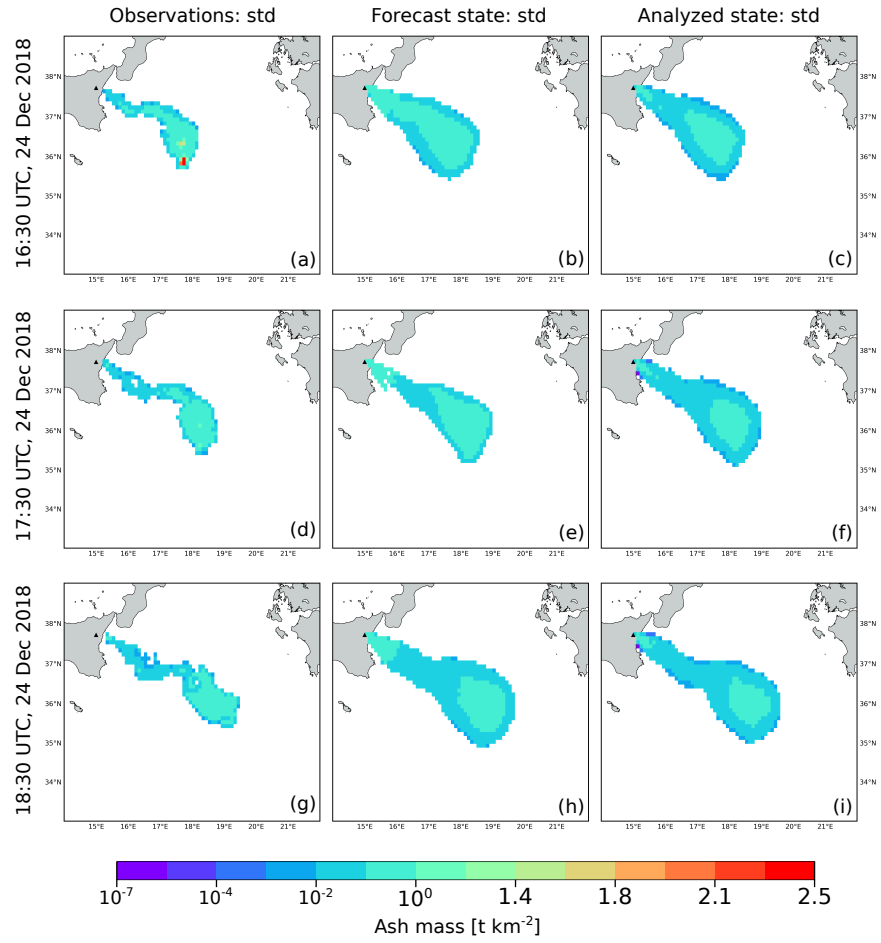


Figure S9: Same as Figure S8, but for assimilation cycles performed at 16:30, 17:30 and 18:30.



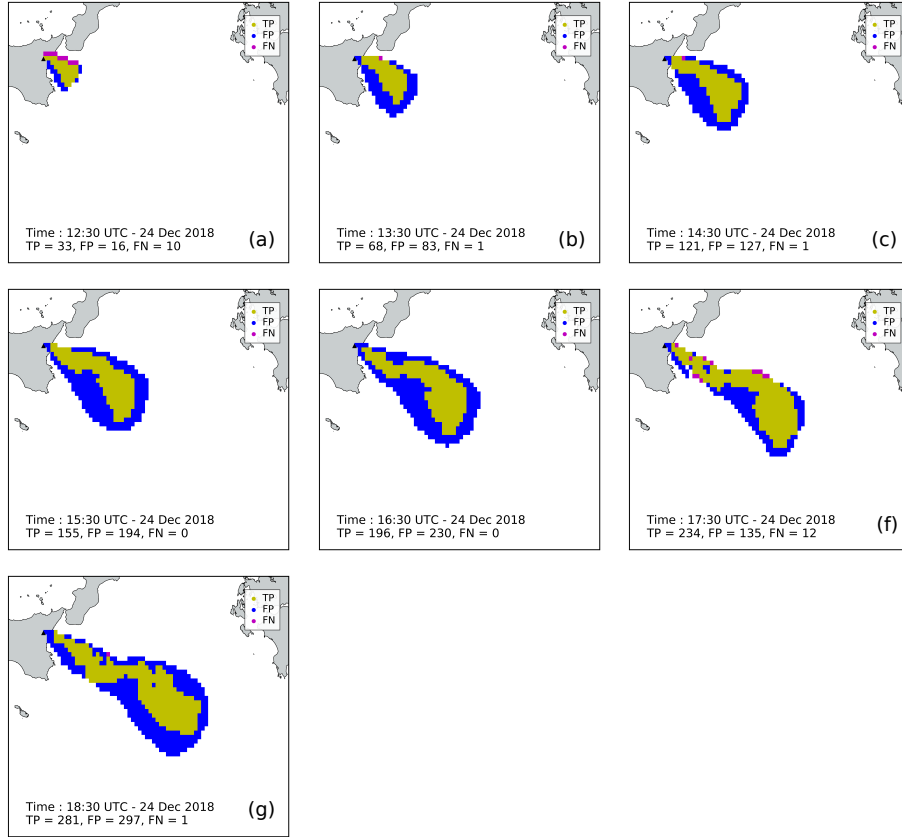


Figure S10: True Positive, False Positive and False Negative pixels computed for EXP3.

## 4 Results of EXP4

EXP4 was performed with an observation sampling time interval of 30 min instead of 1 h as done in EXP1.

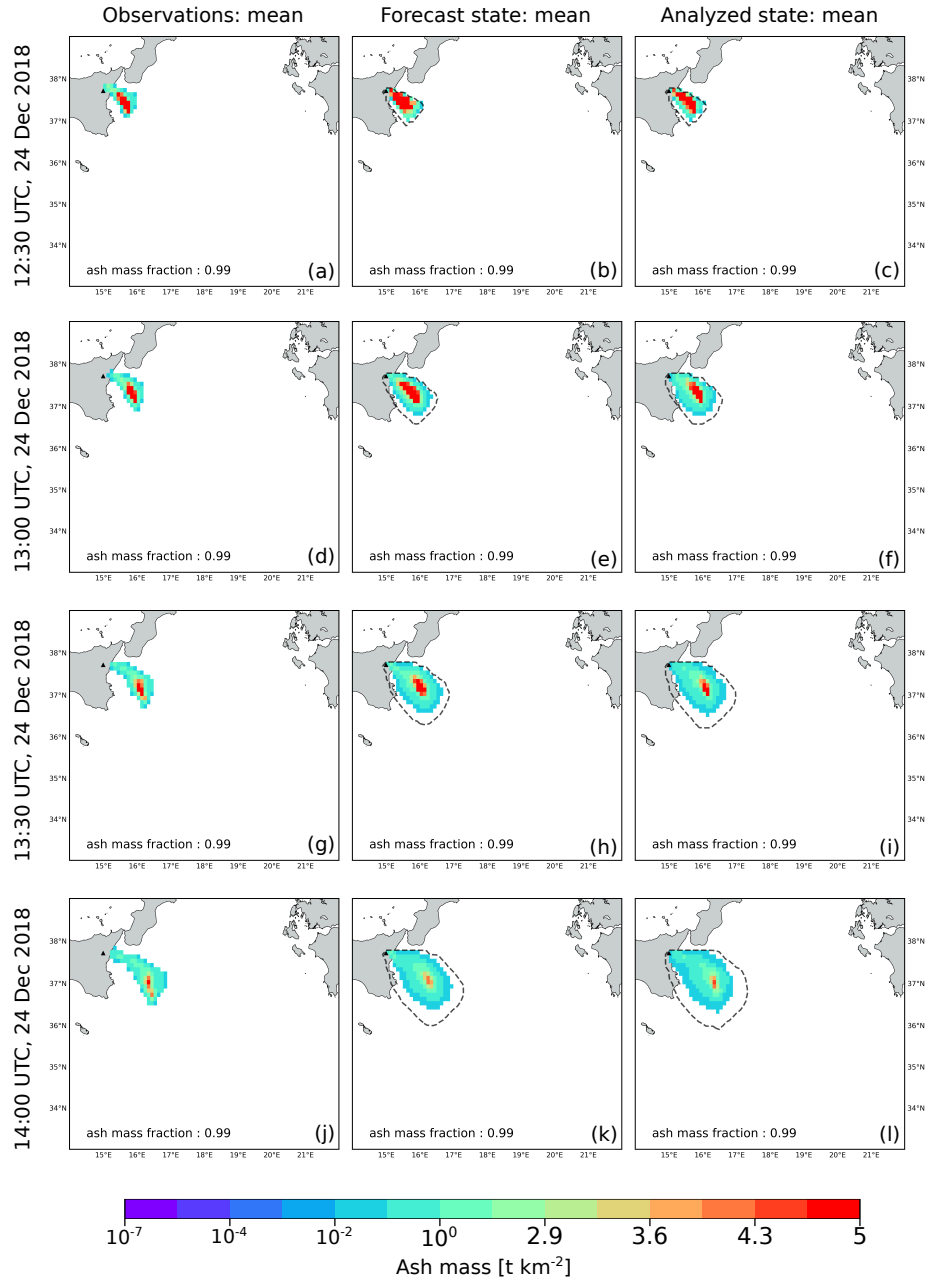


Figure S11: Mean states resulting from EXP4. Panels (a),(d),(g) and (j) show the ash cloud as detected from space (Observations). Panels (b),(e),(h) and (k) illustrate the ash cloud as predicted by the numerical model PLUME-MoM&HYSPLIT (Forecast state), while Panels (c),(f),(i) and (l) present the results of the assimilation cycles (Analyzed state). A cut-off of  $0.01 \text{ t km}^{-2}$  was applied to original ash column density. The edges of the original ash cloud (both forecast and analyzed) are indicated by the black dotted lines. In this figure are displayed the assimilation cycles performed at 12:30, 13:00, 13:30 and 14:00.

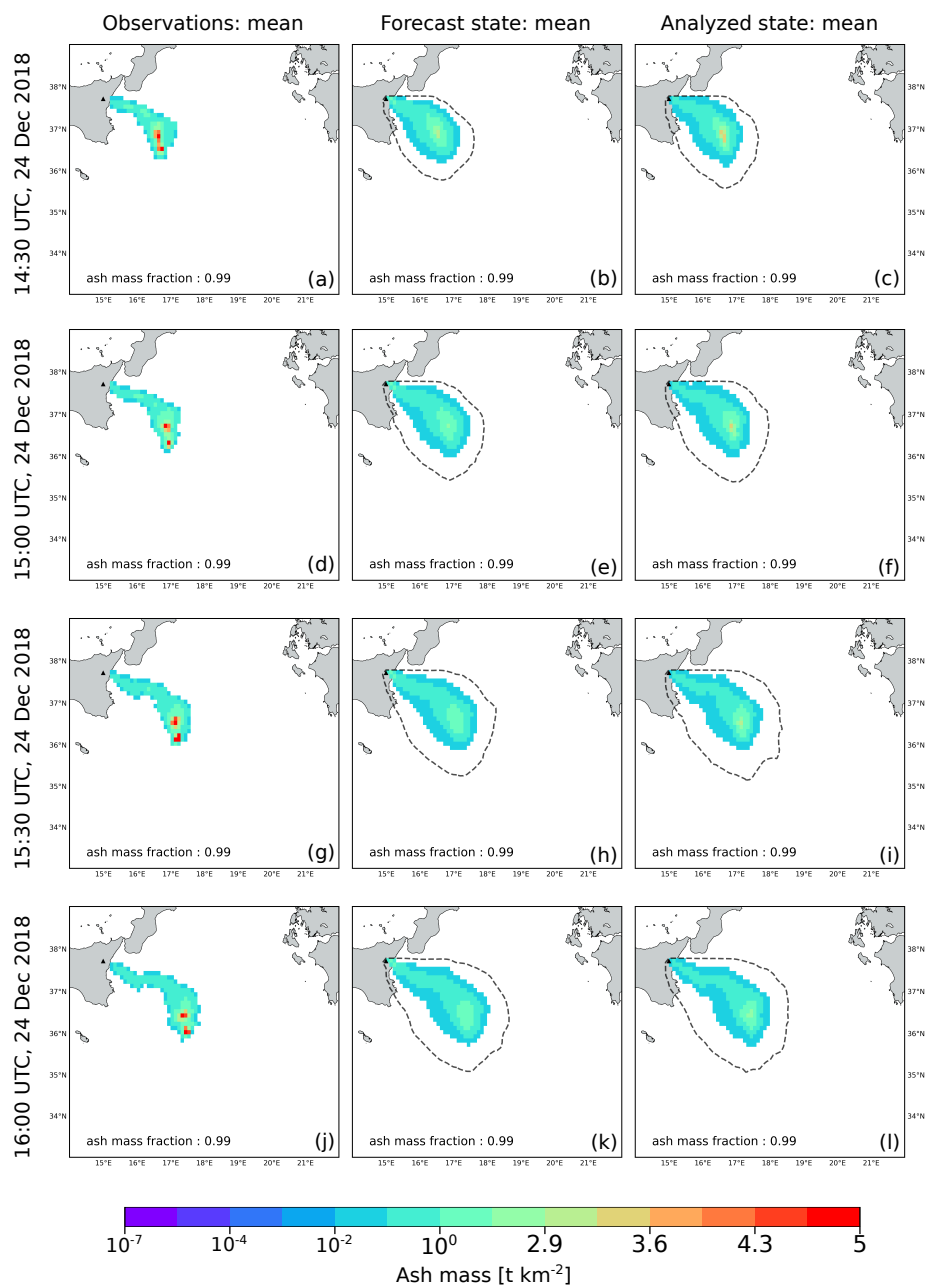


Figure S12: Same as Figure S11 but for the assimilation cycles performed at 14:30, 15:00, 15:30 and 16:00.

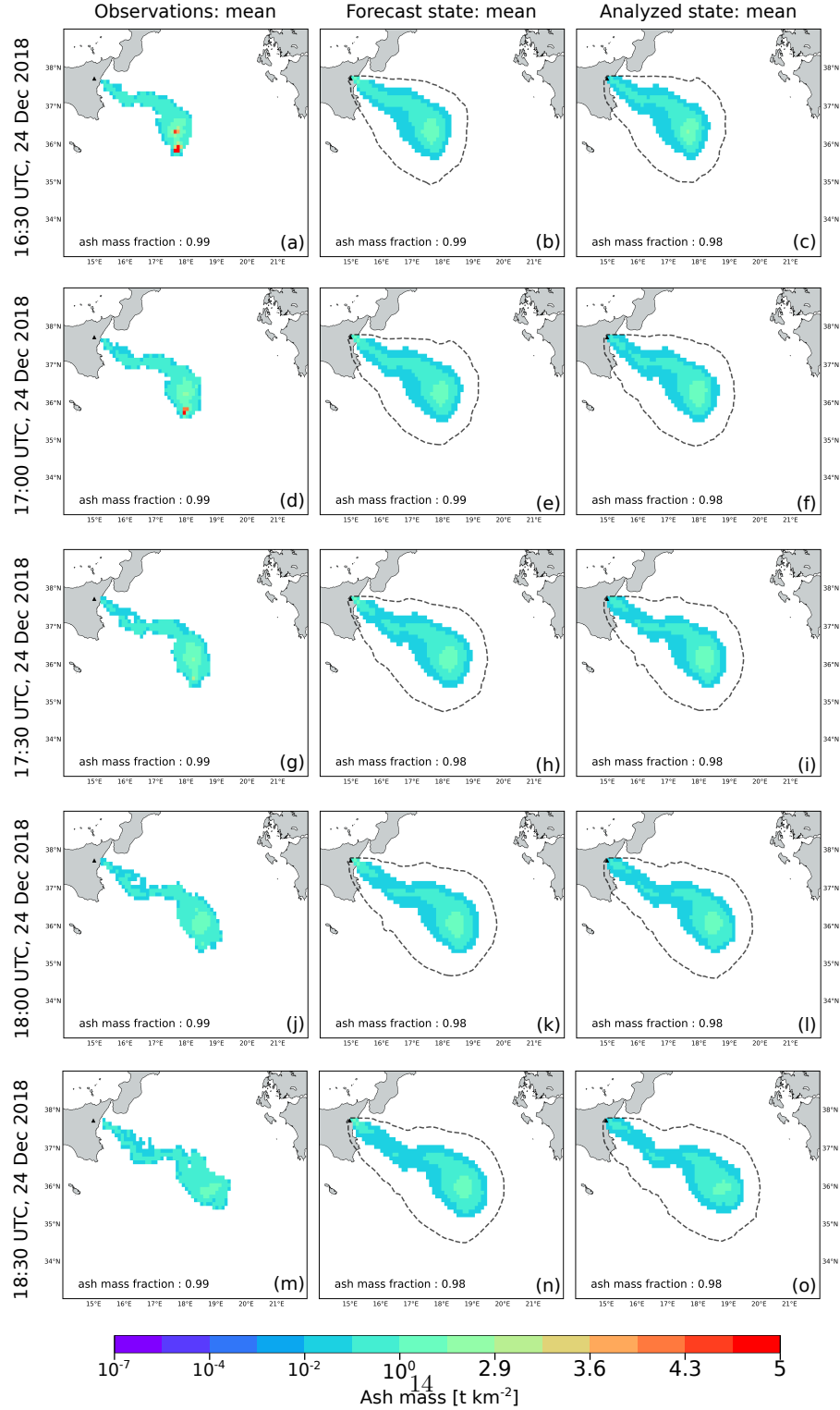


Figure S13: Same as Figure S11 but for the assimilation cycles performed at 16:30, 17:00, 17:30, 18:00 and 18:30.

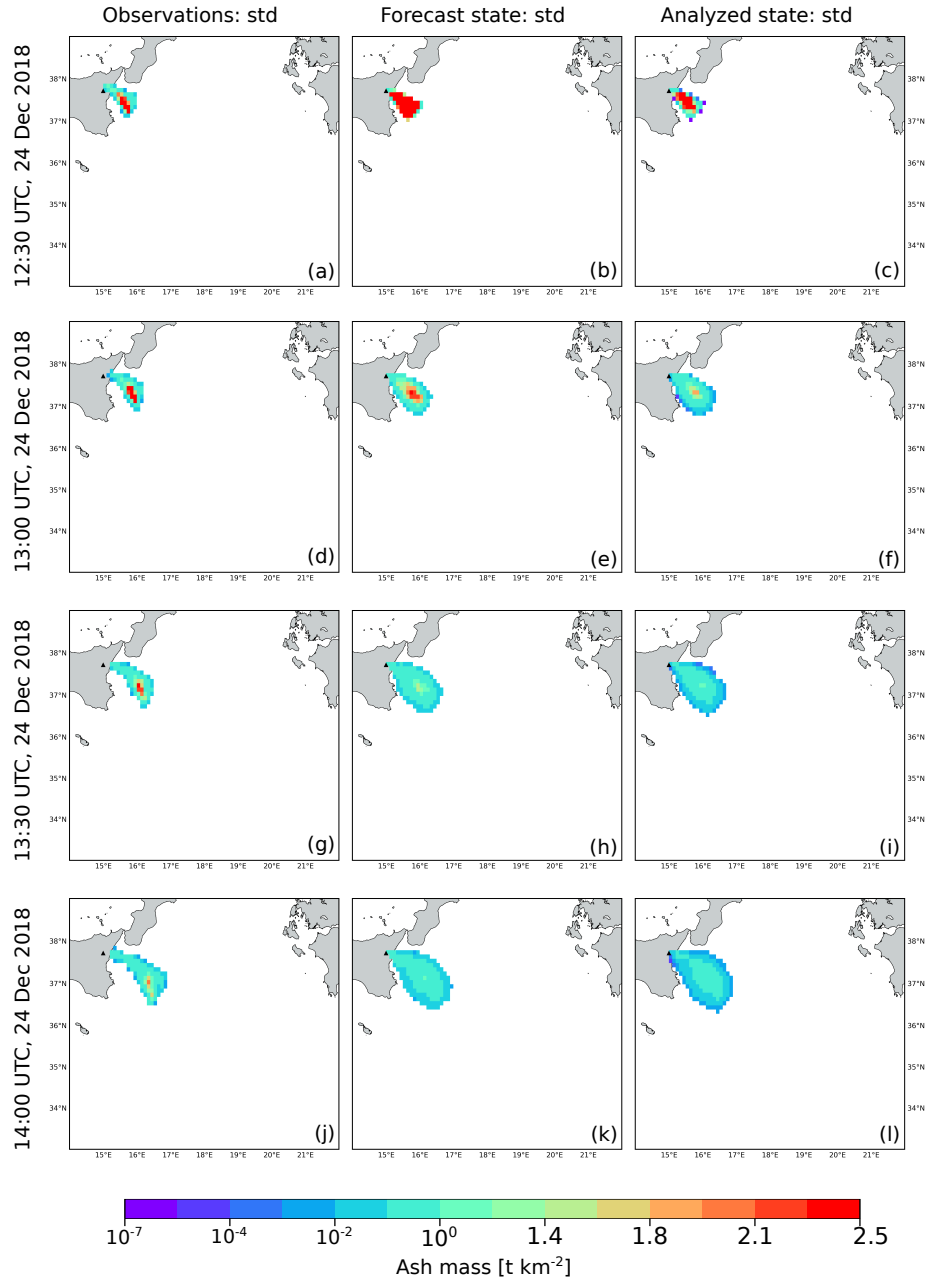


Figure S14: Standard deviations of ash columnar content computed for EXP4. Observations (panels (a), (d), (g) and (j)), Forecast state (panels (b), (e), (h) and (k)) and Analyzed state (panels (c), (f), (i) and (l)) are displayed for assimilation cycles performed at 12:30, 13:00, 13:30 and 14:00 are displayed.

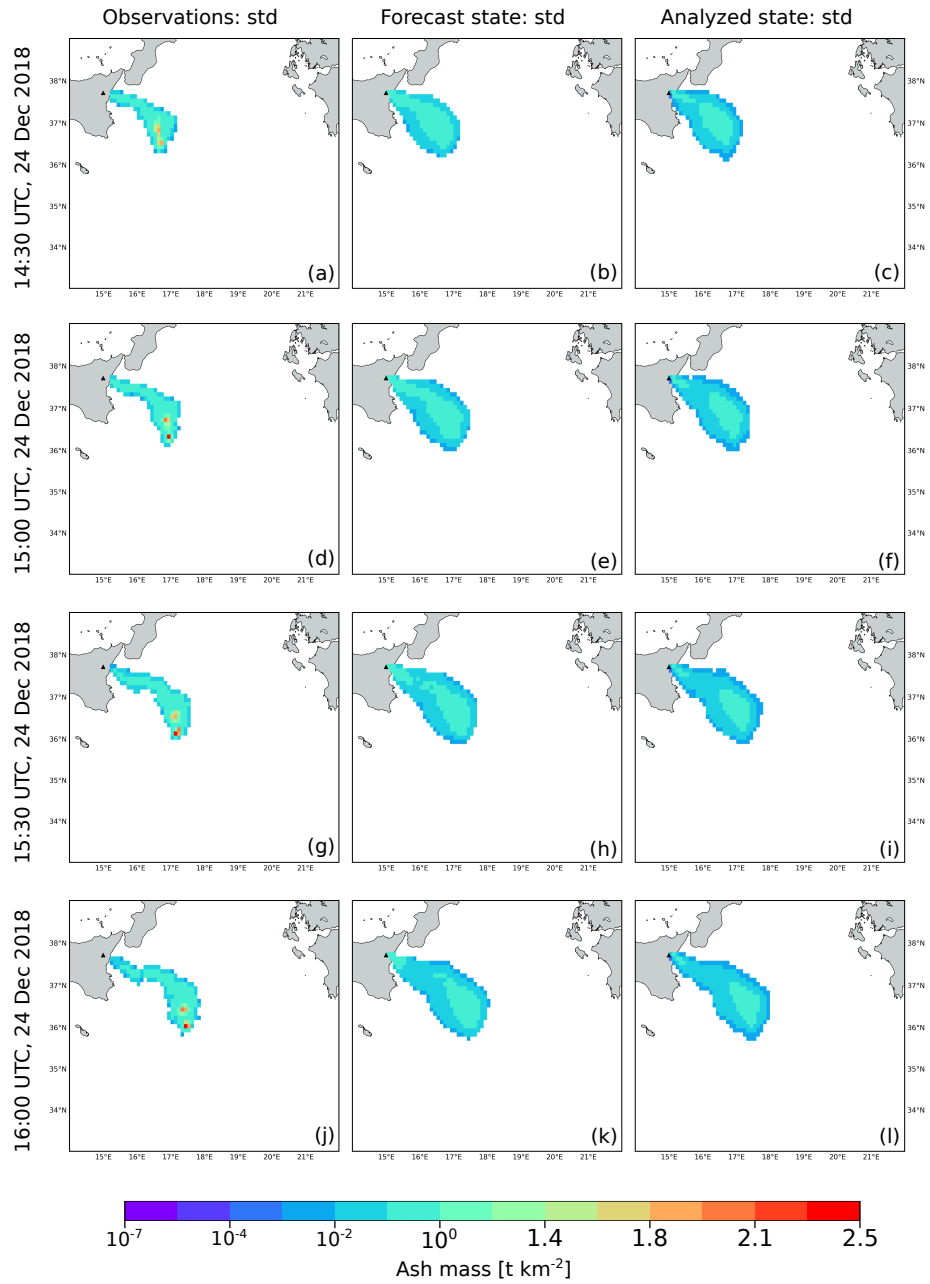


Figure S15: Same as Figure S14, but for time instants 14:30, 15:00, 15:30 and 16:00.

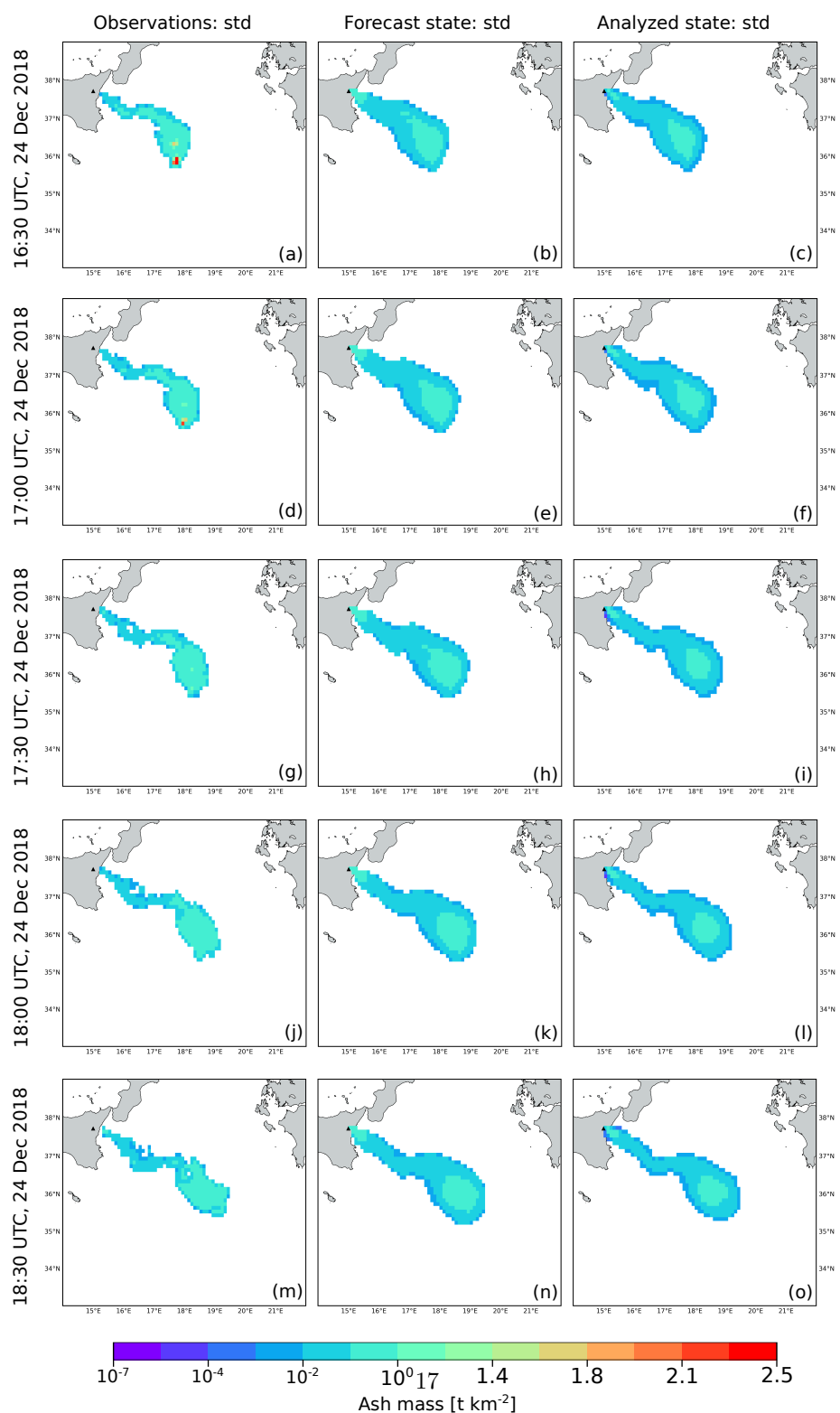


Figure S16: Same as Figure S14, but for time instants 16:30, 17:00, 17:30, 18:00 and 18:30.

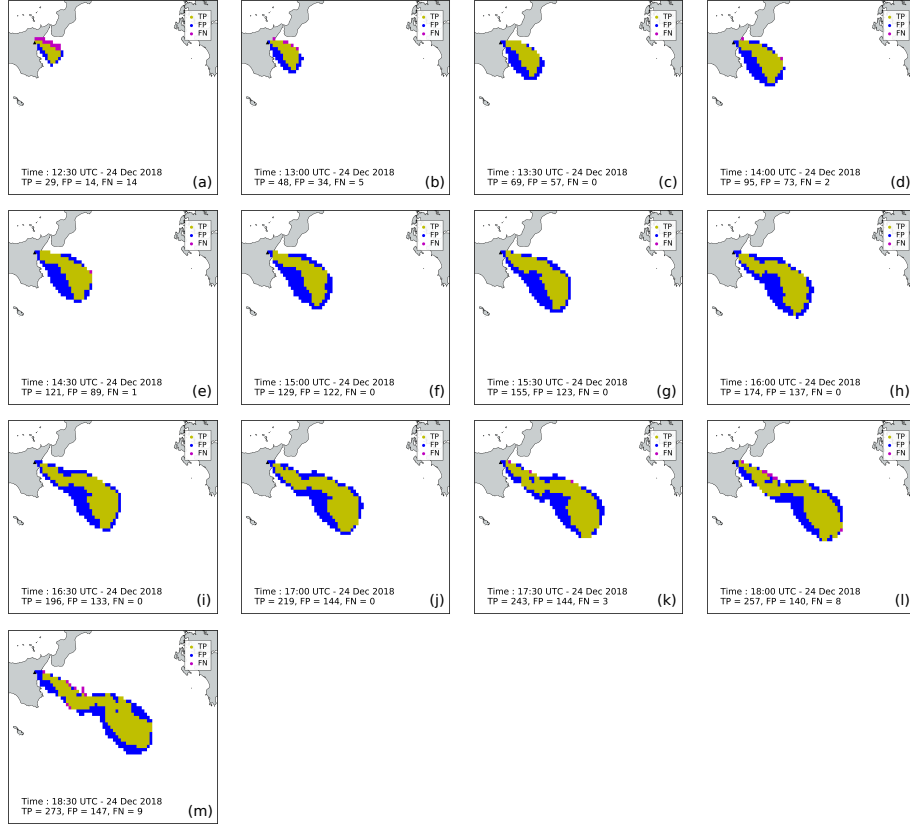


Figure S17: True Positive, False Positive and False Negative pixels computed for EXP4.

## 5 Results of EXP5

EXP5 was performed with an observation sampling time interval of 2 h instead of 1 h as done in EXP1. Setting parameters can be found in Tables 1 and 2 of the main text.



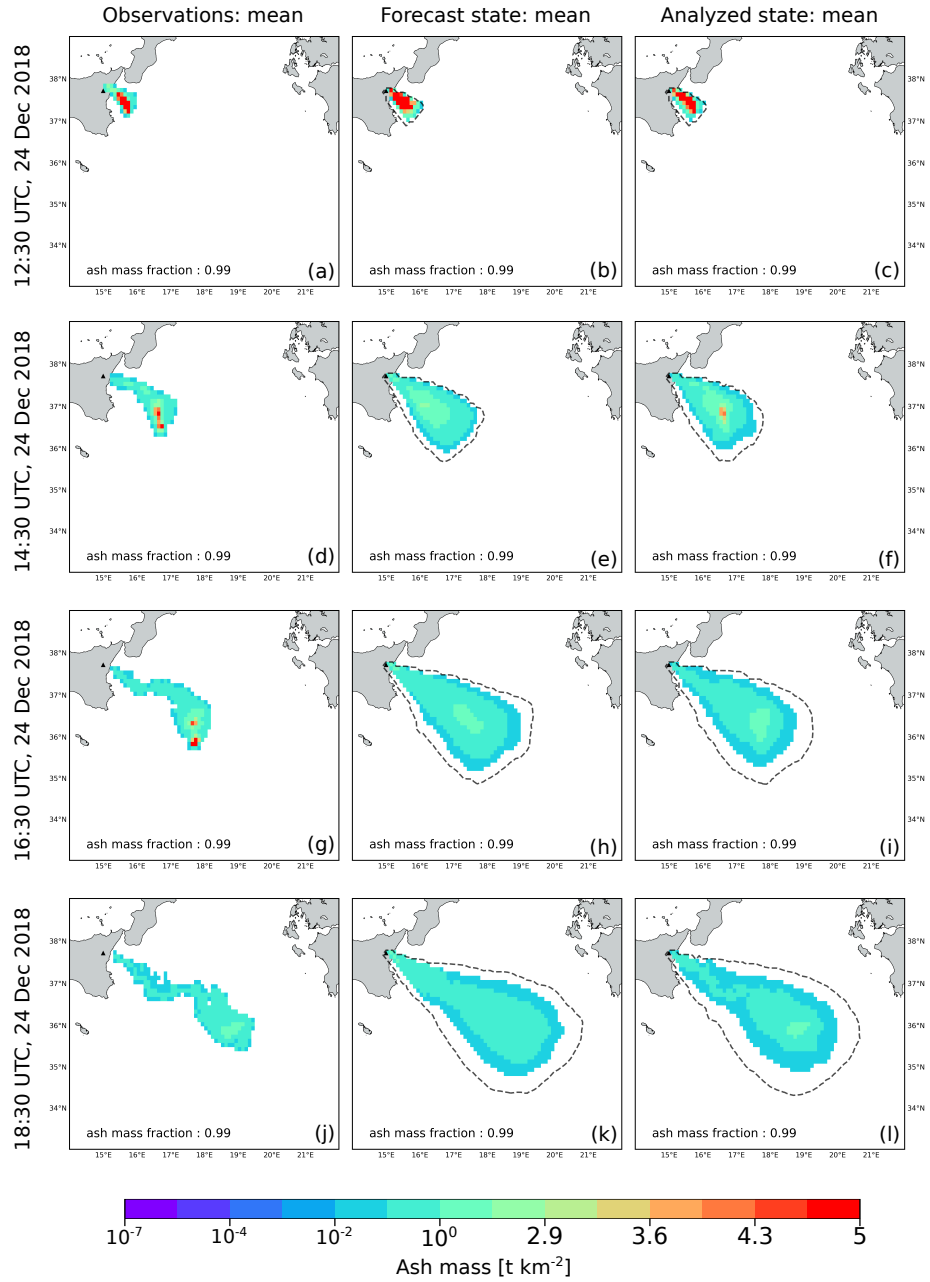


Figure S18: Mean states resulting from EXP5. Panels (a),(d),(g) and (j) show the ash cloud as detected from space (Observations). Panels (b),(e),(h) and (k) illustrate the ash cloud as predicted by the numerical model PLUME-MoM&HYSPLIT (Forecast state), while Panels (c),(f),(i) and (l) present the results of the assimilation cycles (Analyzed state). A cut-off of  $0.01 \text{ t km}^{-2}$  was applied to original ash column density. The edges of the original ash cloud (both forecast and analyzed) are indicated by the black dotted lines. In this figure are displayed the assimilation cycles performed at 12:30, 14:30, 16:30 and 18:30.

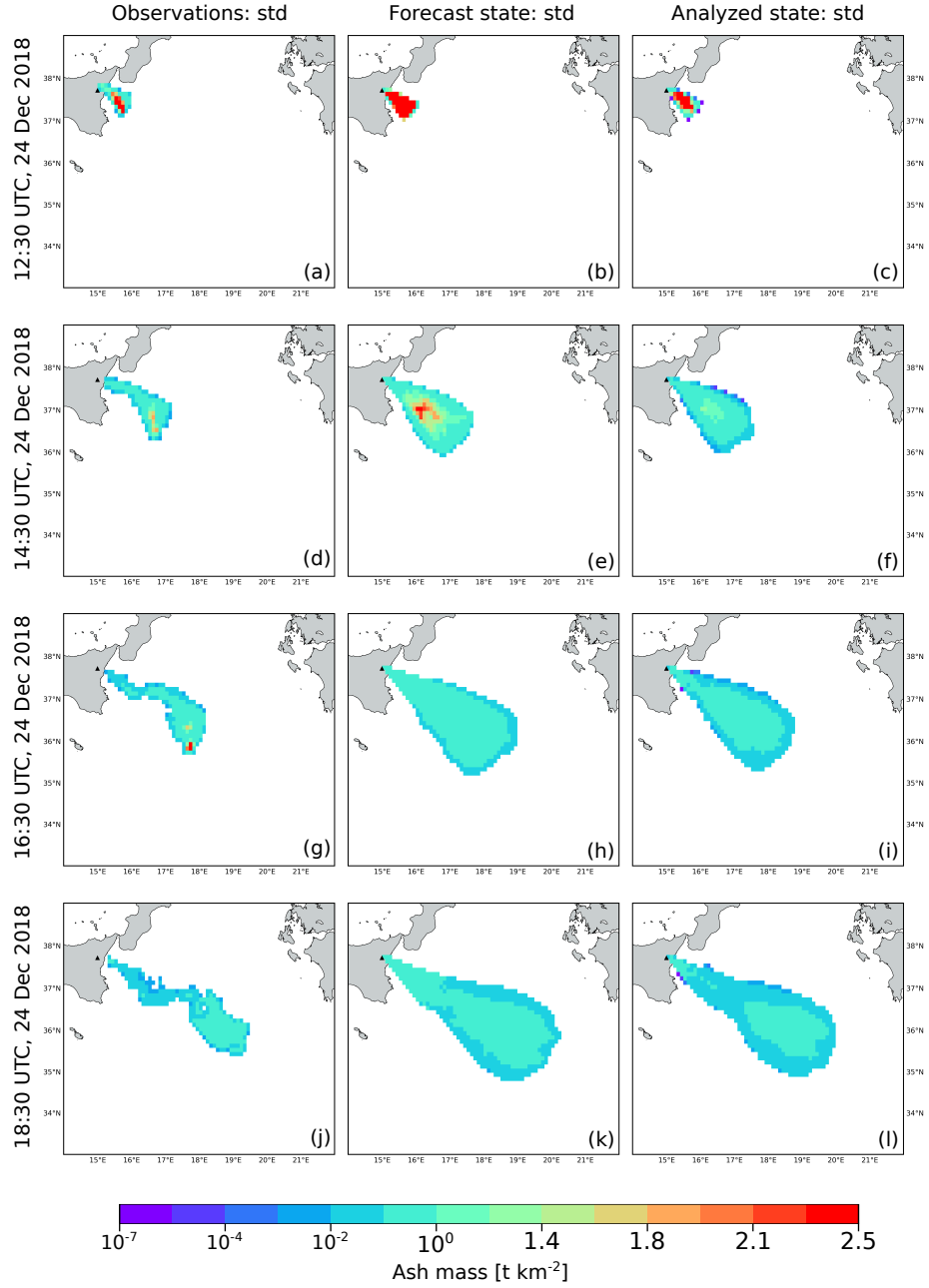


Figure S19: Standard deviations of ash columnar content computed for EXP5. Observations (panels (a), (d), (g) and (j)), Forecast state (panels (b), (e), (h) and (k)) and Analyzed state (panels (c), (f), (i) and (l)) are shown for assimilation cycles performed at 12:30, 14:30, 16:30 and 18:30.

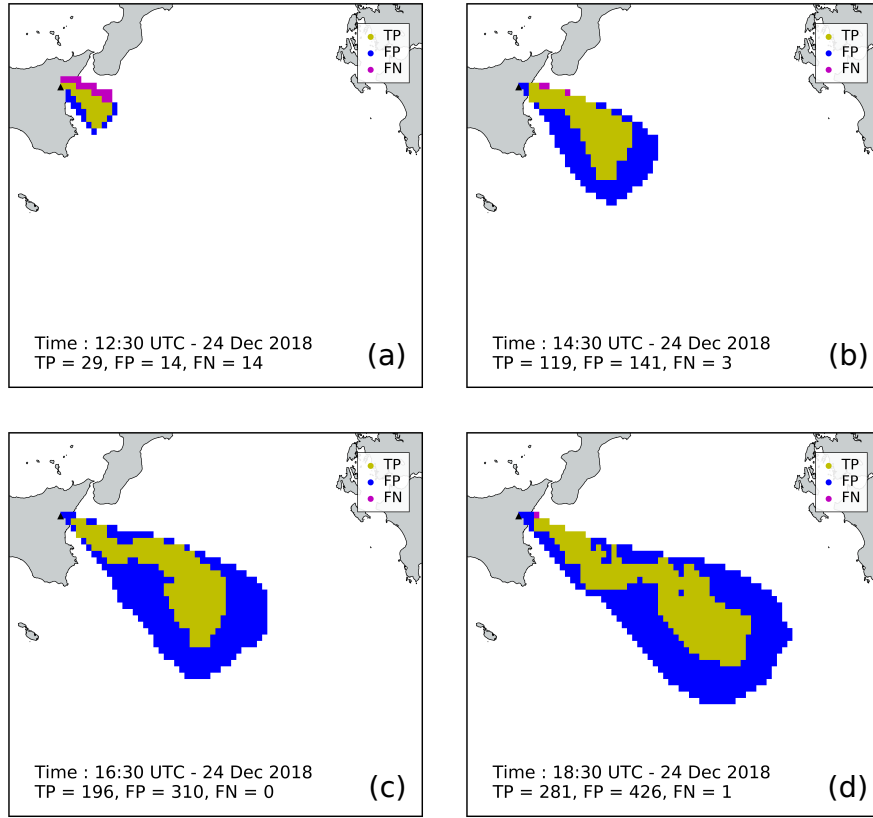


Figure S20: True Positive, False Positive and False Negative pixels computed for EXP5.

## 6 Results of EXP6

EXP6 was performed to investigate the effects of highly uncertain Eruptive Source Parameters on assimilation results. Differently from previous experiments, ensemble members were created from 5 possible column heights reflecting different eruptive scenarios. The values that we chose are 1000, 4000, 8000, 12000, 15000 m above the vent.

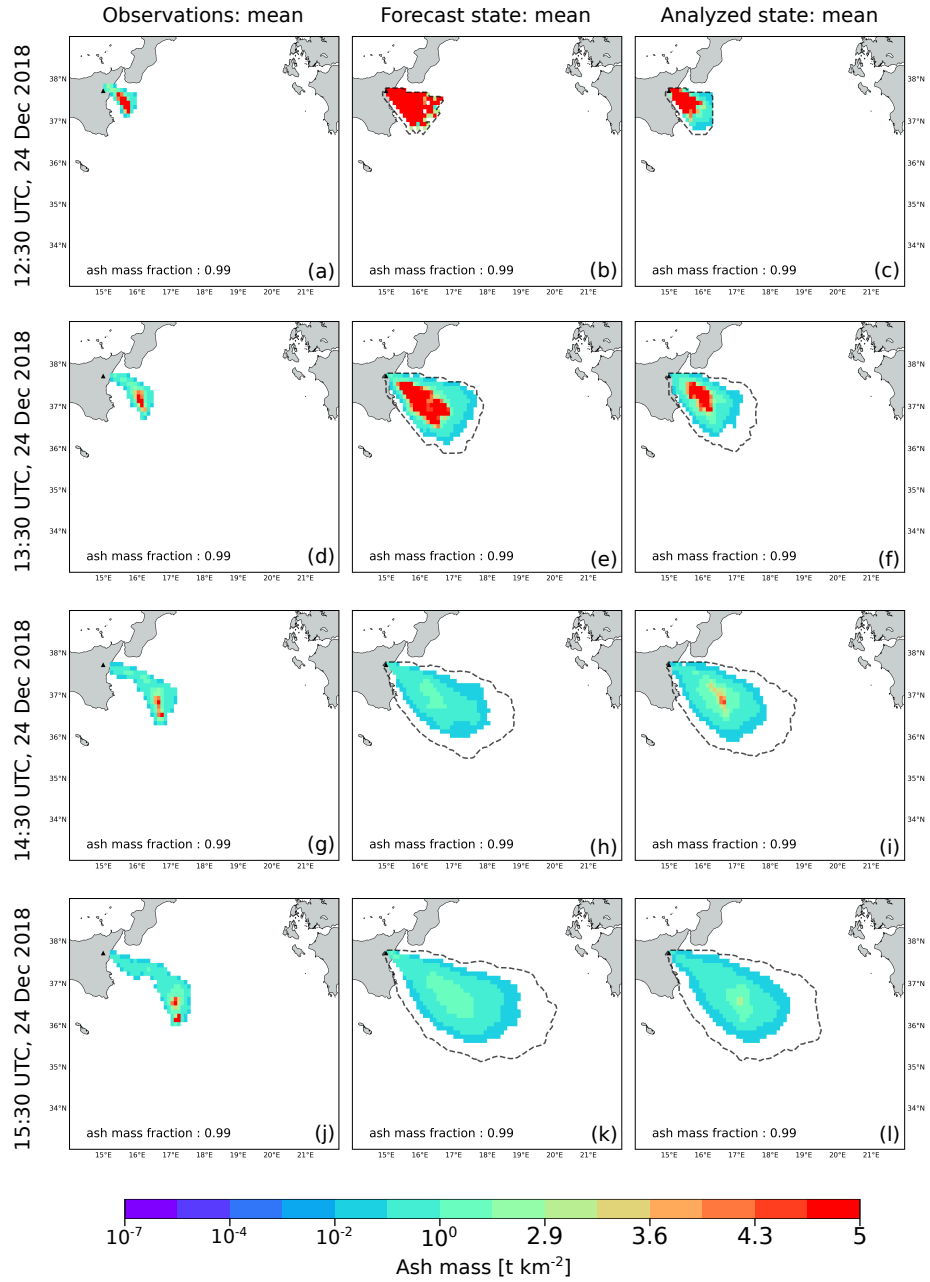


Figure S21: Mean states resulting from EXP6. Panels (a),(d),(g) and (j) show the ash cloud as detected from space (Observations). Panels (b),(e),(h) and (k) illustrate the ash cloud as predicted by the numerical model PLUME-MoM&HYSPLIT (Forecast state), while Panels (c),(f),(i) and (l) present the results of the assimilation cycles (Analyzed state). A cut-off of 0.01 t km<sup>-2</sup> was applied to original ash column density. The edges of the original ash cloud (both forecast and analyzed) are indicated by the black dotted lines. In this figure are displayed the assimilation cycles performed at 12:30, 13:30, 14:30 and 15:30.

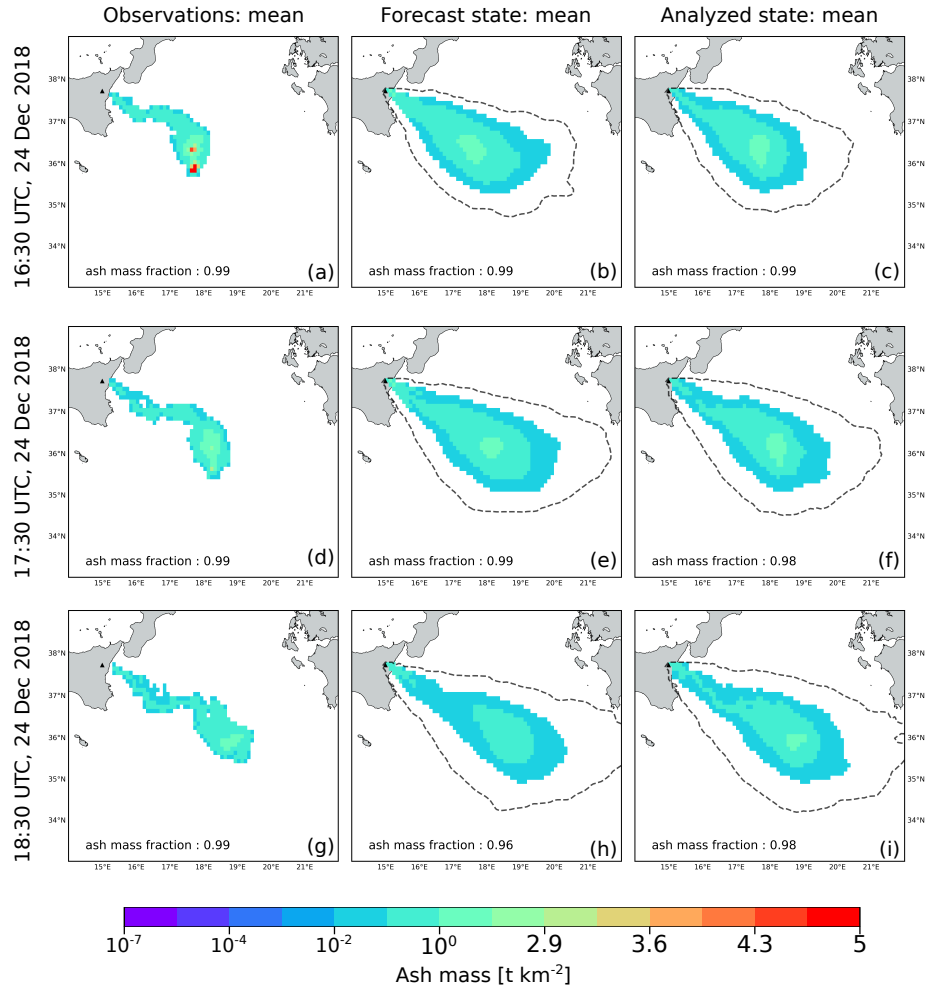


Figure S22: Same as Figure S21 but for the assimilation cycles performed at 16:30, 17:30 and 18:30.

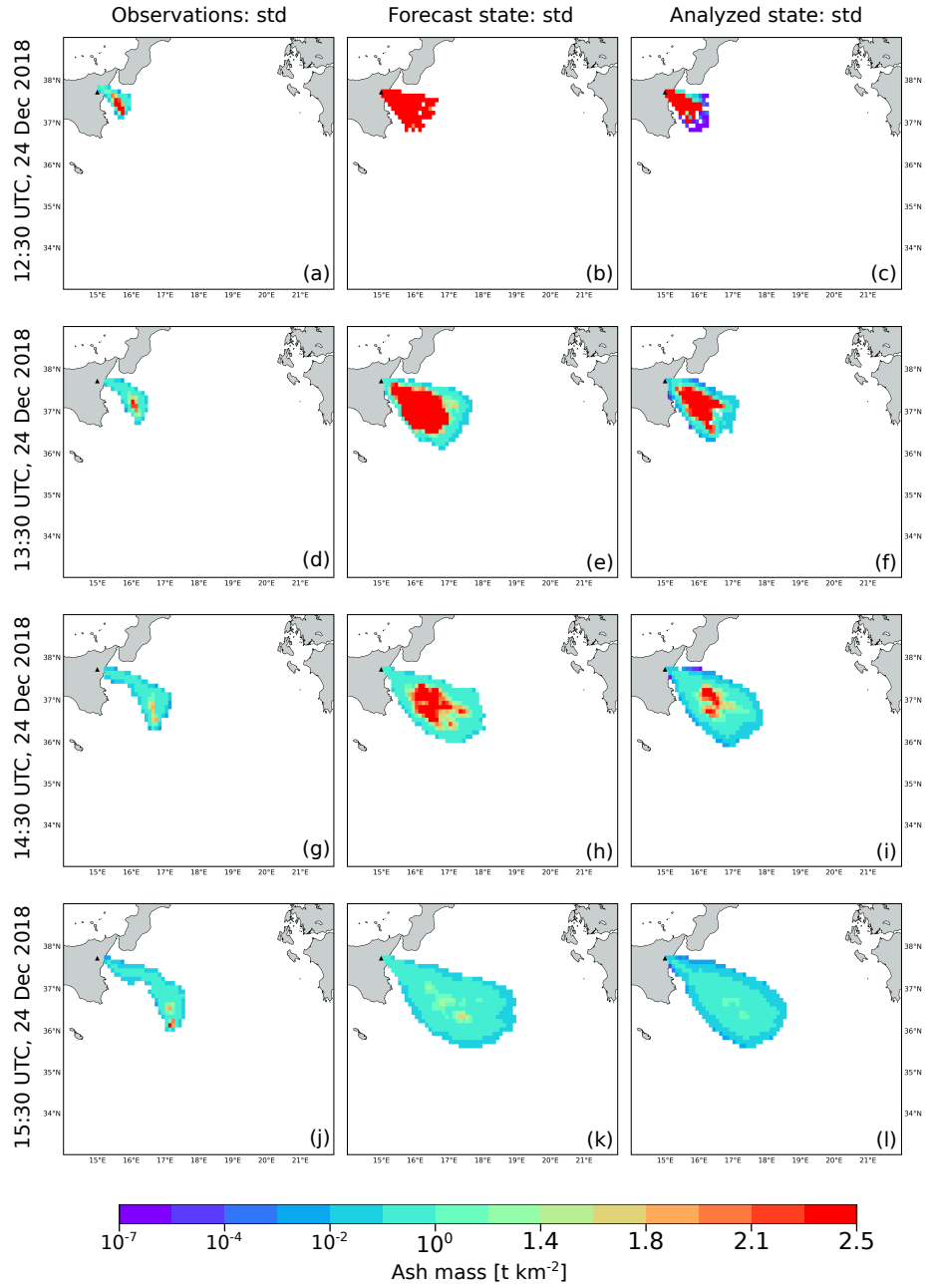


Figure S23: Standard deviations of ash columnar content computed for EXP6. Observations (panels (a), (d), (g) and (j)), Forecast state (panels (b), (e), (h) and (k)) and Analyzed state (panels (c), (f), (i) and (l)) are shown for assimilation cycles performed at 12:30, 13:30, 14:30 and 15:30.

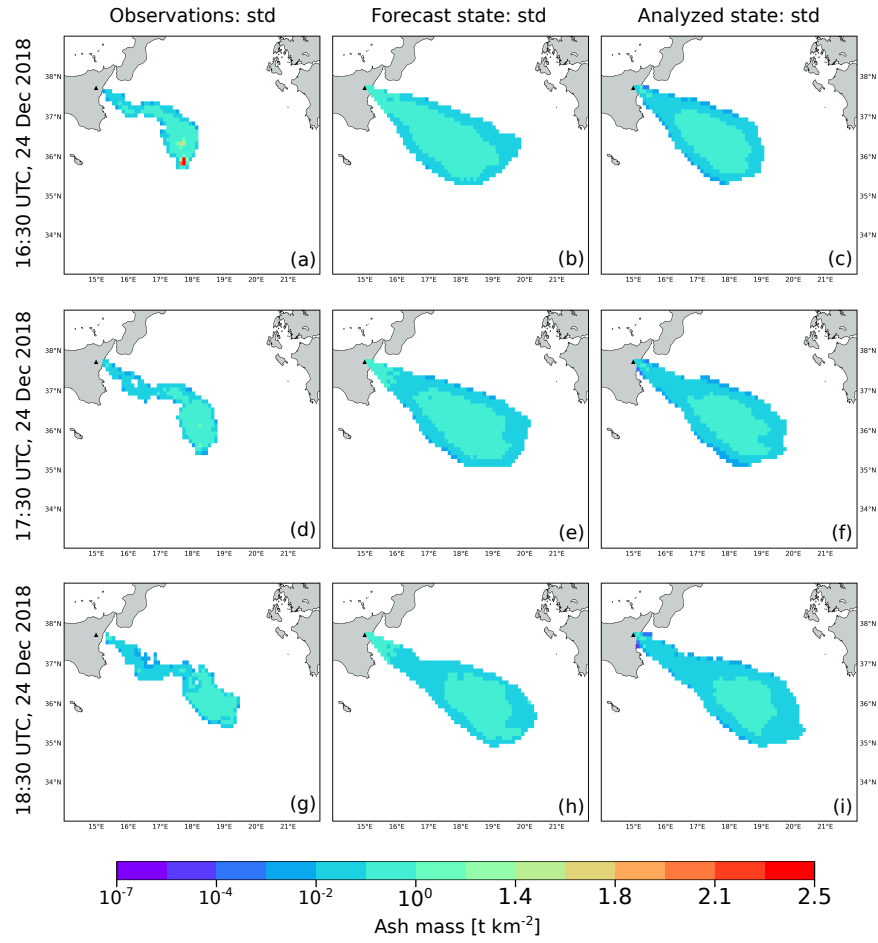


Figure S24: Standard deviations of ash columnar content computed for EXP6. Assimilation cycles performed at 16:30, 17:30 and 18:30 are shown.

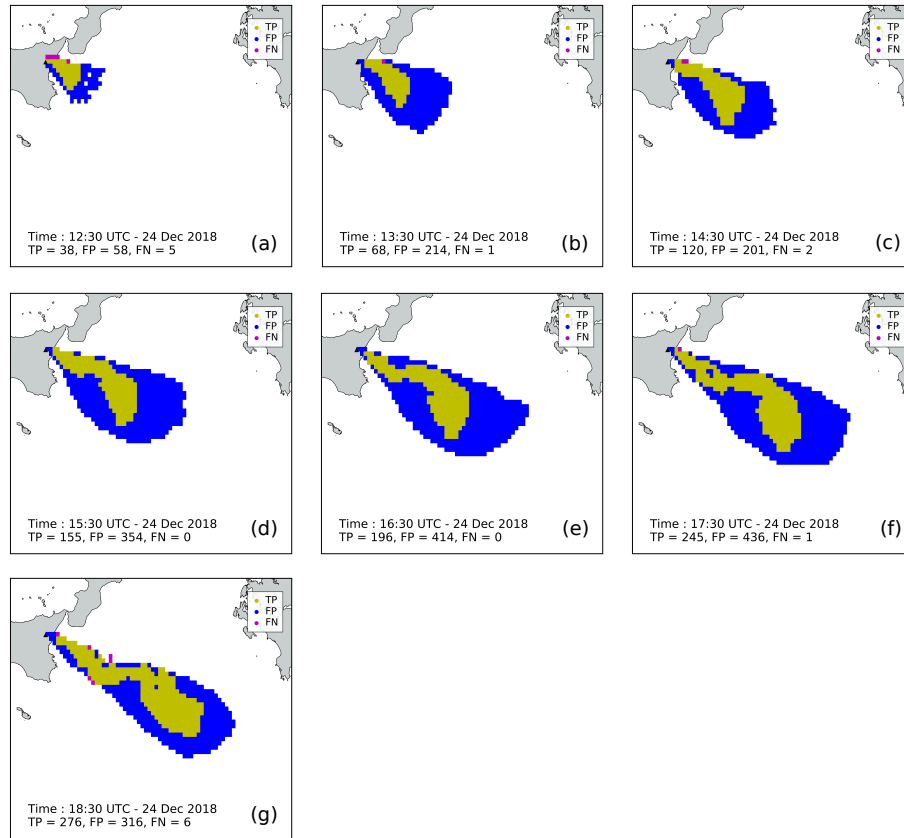


Figure S25: True Positive, False Positive and False Negative pixels computed for EXP6.