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Inverse modeling of fire emissions constrained by smoke plume transport using HYSPLIT dispersion model and geostationary satellite observations

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Abstract. We provide supplementary information and descriptions of twin experiments.

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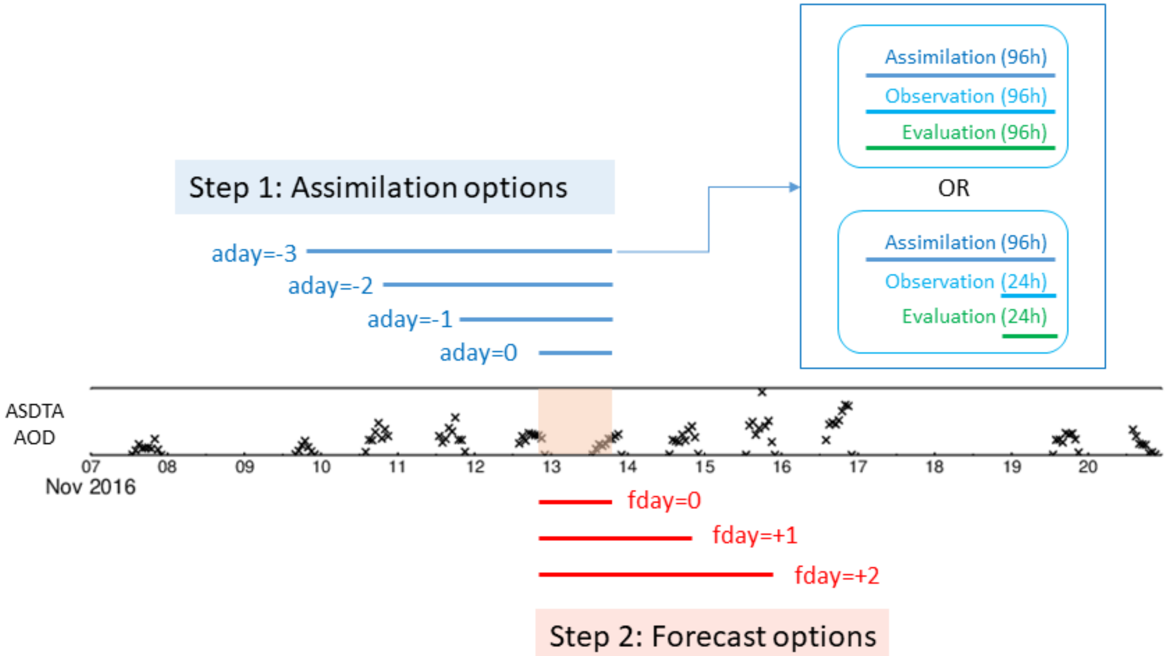

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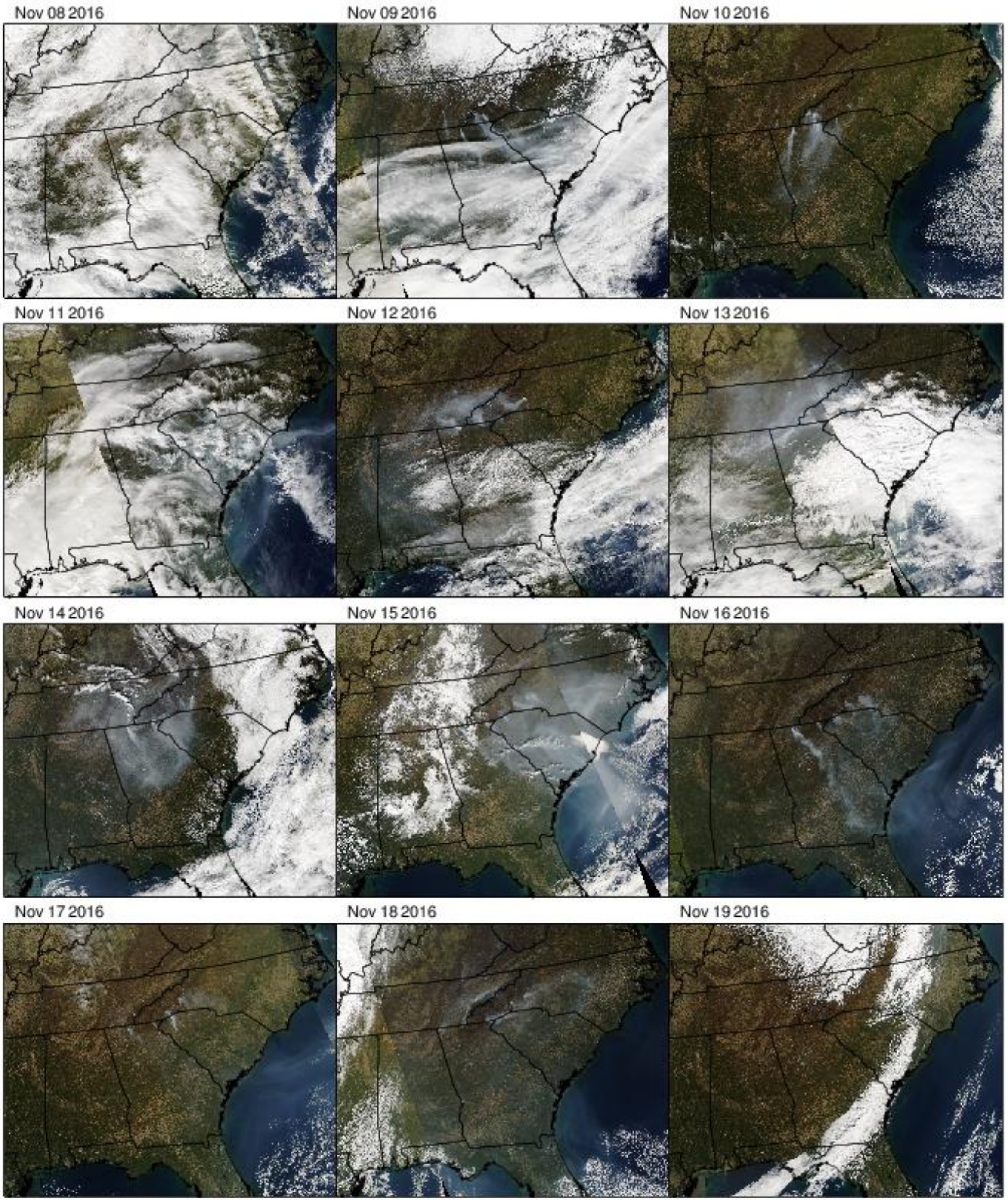

Figure S2 Daily evolution of wildfire events observed from MODIS truecolor images over southeastern US during November 8-19, 2016.

Twin experiments

A series of twin experiments have been conducted to test the range of uncertainties that come from the design of fire emission inverse modeling system. A twin experiment denotes an idealized modeling test in which we assume a modeled world mimics well the real world. In the twin experiment, we have true solution for the situation, so we can test the system's capability to reproduce the true answer.

Figure S3 demonstrates the domain coverage of the twin experiments. In these experiments, hourly pseudo-observations are generated using known sources from given fire locations. In this test, we have constant smoke releases at noe fire location for two days from 6Z on August 2017. Hourly pseudo-observations of satellite mass loadings are assumed based on the HYSPLIT results. All 48 hourly non-zero mass loadings are assumed retrieved accurately.

We have assigned a fixed fire emissions, 10^5kg/hr, for first guess input for nine locations at five altitudes. Figure S4 shows the results of Case 1. X-axis denote the indices of nine fire locations, and y-axis denote five altitudes at which fire emissions are assigned and dispersion models are conducted. In most of cases, the system was able to reproduce the location and height of fire emission when compared with the "true" fire emission information.

Three types of potential uncertainties (e.g. temporal coverage, spatial coverage and impact of observations errors) are test through ten cases. Table S1 summaries the list of twin experiments configurations.

Temporal coverage. Cases 1-2 were conducted to test the sensitivity from temporal availability of observational data. Case 1 assumes the observations are available for 48 hours while case 2 assumes that the observations are available for the last 24 hours. When 48-hour observational data available, the system could reproduce the day 1 fire emission with very high accuracy (i.e. NMAE=0.77% and NRMSE=1.21%). The performance of the system drops quickly for the day 2 prediction when less observational data (e.g. 24-hour) is available.

Spatial coverage. As clouds may block the views of satellites, the effect of missing observations due to clouds is investigated. With all 48 hourly column observations available, the smoke emissions at all nine locations as a function of day and height are recovered extremely well. Table S2 also show that missing satellite observations in key regions (Region B in Case 4) could dramatically affect the emission estimations.

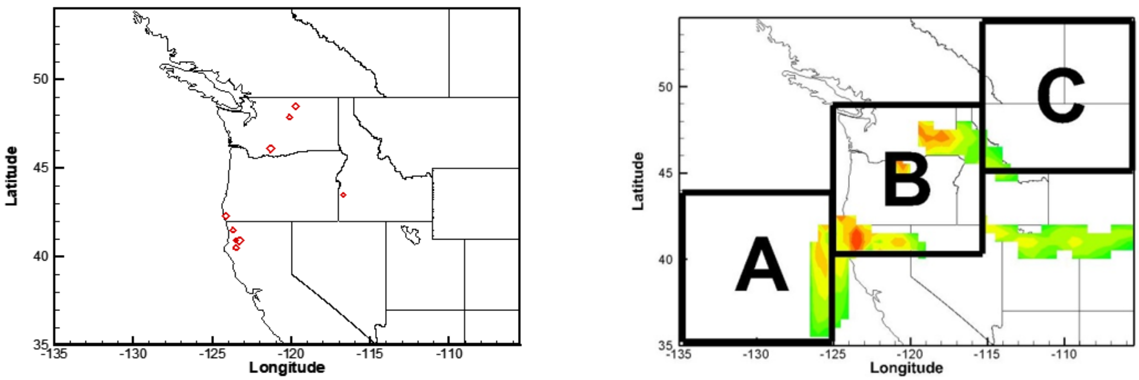

Figure S3 Twin experiments setup. Constant smoke releases at noe fire locations (left) for two days from 6Z on August 17, 2015, at 1500m or 2000m are simulated by HYSPLIT. Hourly pseudo-observations of satellite mass loadings are generated based on the HYSPLIT results (right). Regions A,B,C are used for sensitivity tests with spatial coverage in twin experiments cases 3-5.

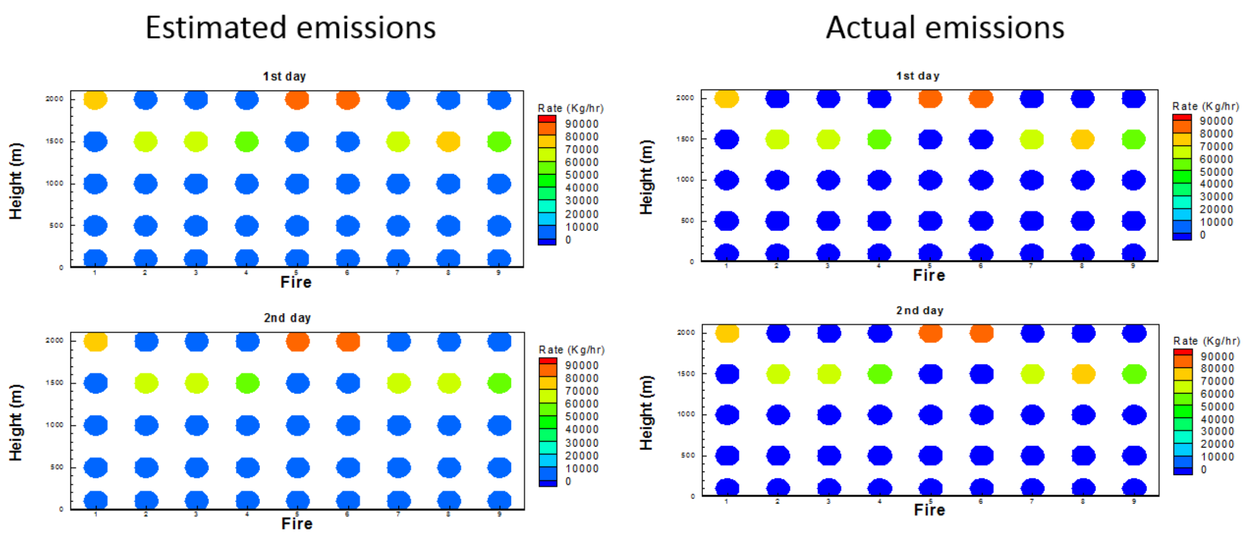

Figure S4 Test of fire emission vertical allocation. Comparison of the estimated smoke emission rates of Case 1 in Table 2 (left) at the nine locations (fire 1-9 as x-axis) for the two days (upper: 1st day; lower: 2nd day) and the "actual" sources (right) used in the twin experiment.

Table S1 List of twin experiments configurations.

Test	Case	Descriptions
Temporal coverage	Case 1	Observations available at all 48 hours
	Case 2	Observations available for last 24 hours
Spatial coverage	Case 3	24-hour observations with region A blocked
	Case 4	24-hour observations with region B blocked
	Case 5	24-hour observations with region C blocked
Observational error	Case 6	10% observational error
	Case 7	20% observational error
	Case 8	50% observational error
	Case 9	100% observational error

Table S2. Smoke source term error statistics of the twin experiments. MAE: mean absolute error; NMAE: normalized MAE; RMSE: root-mean-square error; NRMSE: normalized RMSE.

Cases	Source term	MAE(kg/hr)	NMAE	RMSE(kg/hr)	NRMSE
Case 1 (48-h obs)	Day 1	534.9	0.77%	841.4	1.21%
	Day 2	1760.5	2.53%	3332.5	4.78%
Case 2 (24-h obs)	Day 1	1985.8	2.85%	3310.2	4.75%
	Day 2	1393.0	2.00%	2943.2	4.22%
Case 3 (region A blocked)	Day 1	606.4	0.87%	1156.3	1.66%
	Day 2	301.2	0.43%	573.4	0.82%
Case 4 (region B blocked)	Day 1	23834.6	34.21%	32157.9	46.16%
	Day 2	66177.5	94.99%	78653.3	112.90%
Case 5 (region C blocked)	Day 1	3974.9	5.71%	8803.3	12.64%
	Day 2	3400.6	4.88%	10663.2	15.31%
Case 6 (10% error)	Day 1	1448.6	2.08%	2259.7	3.24%
	Day 2	4418.7	6.34%	11121.8	15.96%
Case 7 (20% error)	Day 1	2105.8	3.02%	3954.7	5.68%
	Day 2	8567.9	12.30%	22884.4	32.84%
Case 8 (50% error)	Day 1	6227.6	8.94%	12047.1	17.29%
	Day 2	22034.5	31.63%	67298.2	96.60%
Case 9 (100% error)	Day 1	10104.2	14.50%	19759.9	28.36%
	Day 2	34560.9	49.61%	131203.9	188.33%

Table S3. Sensitivity tests for vertical layers resolution from two to six layers. The best performance is marked as bold. [NRMSE unit: %]

	Date	2 layers (100, 5000m)	3 layers (100, 2000, 5000m)	4 layers (100, 1000, 2000, 5000m)	5 layers (100, 1000, 1500, 2000, 5000m)	6 layers (100, 500, 1000, 1500, 2000, 5000m)
NRMSE	Nov. 10	72.9	69.2	65.9	63.7	**63.7**
	11	79.0	71.6	68.1	66.4	**65.9**
	12	70.7	67.8	65.5	65.0	**63.5**
	13	68.7	67.6	66.1	65.9	**65.7**
	14	72.9	70.6	67.2	67.0	**66.3**
	15	83.3	77.1	72.0	71.0	**70.9**
	16	78.9	**72.0**	73.2	72.5	72.5
	17	72.2	70.6	70.2	70.0	**69.8**
R	Nov. 10	0.577	0.593	0.630	0.654	**0.654**
	11	0.490	0.558	0.598	0.614	**0.620**
	12	0.292	0.285	0.303	0.303	**0.309**
	13	0.449	0.450	0.468	0.470	**0.476**
	14	0.404	0.419	0.439	0.440	0.444
	15	0.252	0.276	0.338	0.346	**0.348**
	16	0.112	**0.164**	0.144	0.149	0.150
	17	**0.198**	0.139	0.139	0.139	0.146