Supplementary Document

Table-ST1: Hyper parameters and error statistic of SVR model in MODIS and Ground based observations and in MISR and Ground based observations.

Sensor	ML-function	R^2	R	RMSE	MAE
MODIS	Train	0.48	0.7	0.22	0.15
	Test	0.72	0.85	0.15	0.12
MISR	Train	0.59	0.76	0.20	0.15
	Test	0.60	0.84	0.13	0.12

Table – ST2: The Spatio-temporal sensitivity test statistics regarding the instantaneous satellite overpass in the month of 2021 Nov.

Spatio-temporal domain	**R** Pearson Correlation coefficient	**RMSE**	**MAE**	**N** (Colocation Points)	**ΔRMSE** ($RMSE_{current\ cell} - RMSE_{previous\ cell}$)	**ΔMAE** ($MAE_{current\ cell} - MAE_{previous\ cell}$)	**ΔR** ($R_{current\ cell} - R_{previous\ cell}$)
				MISR			
0.2deg-30min	0.94	0.20	0.12	24			
0.2deg-60min	0.93	0.20	0.12	25	-0.0004	0.0003	-0.0008
0.2deg-120min	0.94	0.19	0.12	26	-0.0035	-0.0026	0.0060
0.5deg-30min	0.93	0.18	0.10	31			
0.5deg-60min	0.92	0.18	0.10	33	-0.0022	-0.0038	-0.0116
0.5deg-120min	0.91	0.17	0.10	36	-0.0034	-0.0008	-0.0052
1deg-30min	0.84	0.22	0.13	38			
1deg-60min	0.82	0.22	0.13	41	0.0032	0.001	-0.0232
1deg-120min	0.83	0.21	0.13	46	-0.0158	-0.0053	0.0159
2 deg-30min	0.83	0.24	0.15	48			
2 deg-60min	0.82	0.24	0.15	52	-0.0005	0.0025	-0.0164
2 deg-120min	0.79	0.22	0.14	59	-0.0150	-0.0070	-0.0244
				MODIS			
0.2deg-30min	0.93	0.14	0.10	110			
0.2deg-60min	0.93	0.14	0.10	114	-0.0003	0.000931	-0.0004
0.2deg-120min	0.93	0.14	0.10	118	-0.0023	0.001017	0.0020
0.5deg-30min	0.93	0.13	0.10	148			
0.5deg-60min	0.93	0.13	0.10	157	-0.0028	0.000615	0.0003
0.5deg-120min	0.93	0.13	0.09	165	-0.0045	-0.00233	0.0035
1deg-30min	0.93	0.16	0.10	175			
1deg-60min	0.93	0.16	0.10	189	-0.0059	-0.00222	0.0010
1deg-120min	0.93	0.16	0.10	202	-0.0033	-0.00158	0.0002
2 deg-30min	0.89	0.20	0.12	187			
2 deg-60min	0.89	0.19	0.12	204	-0.0105	-0.00415	0.0026
2 deg-120min	0.90	0.19	0.11	219	-0.0084	-0.00565	0.0033

Table – ST3: Variogram used in sensitivity of Fig. S15 analysis

MODIS			
Model	**Nugget**	**sill**	**Range(in km)**
Matheron	0	0.030028	548.35
MISR			
Exponential	0.000022	0.014509	638.76

Table - ST4: Winter (January) AOD from different sensors and fused AOD at different regions of India.

	MODIS	**MISR**	**FUSED**	**MODIS**	**MISR**	**FUSED**	**MODIS**	**MISR**	**FUSED**
	2012			**2016**			**2021**		
NE	0.38±0.21	0.25±0.15	0.42±0.19	0.35±0.21	0.25±0.16	0.27±0.19	0.29±0.18	0.18±0.09	0.28±0.19
IGP	0.70±0.18	0.48 ±0.12	0.53±0.13	0.99±0.31	0.60±0.14	0.87±0.16	0.83±0.24	0.49±0.12	0.74±0.23
Peninsular	0.27±0.1	0.26 ±0.05	0.32±0.05	0.38±0.10	0.35±0.08	0.52±0.13	0.50±0.21	0.46±0.16	0.74±0.19
Central	0.41 ±0.08	0.31 ±0.06	0.39 ± 0.07	0.40±0.12	0.31±0.12	0.52±0.11	0.57±0.14	0.38±0.16	0.59±0.14
NW	0.29±0.11	0.29 ±0.07	0.38±0.07	0.32±0.10	0.29±0.07	0.48±0.08	0.35±0.11	0.30±0.10	0.40±0.10

Table - ST5: Pre-monsoon (May) AOD from different sensors and fused AOD at different regions of India.

	MODIS	**MISR**	**FUSED**	**MODIS**	**MISR**	**FUSED**	**MODIS**	**MISR**	**FUSED**
	2012			**2016**			**2021**		
NE	0.41±0.16	0.31±0.13	0.32±0.13	0.44±0.19	0.30±0.12	0.27±0.11	0.51±0.20	0.36±0.13	0.46±0.22
IGP	0.65±0.15	0.53±0.09	0.58±0.14	0.80±0.19	0.61±0.13	0.59±0.15	0.72±0.18	0.53±0.10	0.74±0.22
Peninsular	0.40±0.10	0.42 ±0.09	0.43±0.12	0.30 ±0.07	0.35±0.06	0.46±0.07	0.42±0.16	0.39±0.14	0.51±0.22
Central	0.36 ±0.09	0.44 ±0.06	0.39±0.08	0.35±0.11	0.47±0.06	0.57±0.07	0.38±0.09	0.40±0.07	0.49±0.13
NW	0.34 ±0.08	0.44 ±0.06	0.45±0.08	0.33 ±0.14	0.44 ±0.06	0.52±0.05	0.29±0.16	0.49±0.11	0.54±0.15

Table - ST6: Post-monsoon (November) AOD from different sensors and fused AOD at different regions of India.

	MODIS	**MISR**	**FUSED**	**MODIS**	**MISR**	**FUSED**	**MODIS**	**MISR**	**FUSED**
	2012			**2016**			**2021**		
NE	0.15±0.11	0.12±0.09	0.22±0.11	0.09±0.05	0.09±0.07	0.11±0.04	0.15±0.09	0.13±0.07	0.08±0.06
IGP	0.72±0.18	0.47±0.08	0.61±0.20	0.69±0.19	0.45±0.11	0.60±0.23	0.74±0.18	0.51±0.10	0.80±0.25
Peninsular	0.41±0.11	0.36±0.08	0.45±0.17	0.41±0.10	0.34±0.09	0.47±0.14	0.43±0.14	0.36±0.13	0.50±0.22
Central	0.44±0.09	0.37±0.07	0.40±0.09	0.42±0.11	0.34±0.08	0.36±0.09	0.55±0.09	0.42±0.08	0.59±0.16
NW	0.35±0.11	0.33±0.09	0.31±0.10	0.32±0.09	0.29±0.05	0.43±0.10	0.41±0.10	0.34±0.07	0.40±0.12

Table - ST7: ARFINET stations

Station Name	STN	longitude	latitude
Agartala	AGT	91.2	23.5
Agra	AGR	78.0	27.1
Anantapur	ATP	77.6	14.4
Bangalore	BLR	77.5	12.9
Bhubaneswar	BBR	85.8	20.2
Challekere	CHK	76.6	14.3
Chennai	CHN	79.9	12.7
Dehradun	DDN	78.0	30.3
Delhi	DEL	77.2	28.6
Dibrugarh	DBR	94.6	27.3
Goa	GOA	73.8	15.4
Gorakhpur	GKP	83.3	26.7
Hanle	HNL	78.9	32.7
Hyderabad	HDT	78.5	17.4
Jaisalmer	JSL	70.9	26.9
Kadappa	KDP	78.8	14.4
Kolkata	KKT	88.3	22.5
Kullu	KLU	77.1	31.9
Nainital	NTL	79.4	29.3
Ooty	OTY	76.7	11.4
Patiala	PTL	76.4	30.3
Port-Blair	PBR	92.7	11.6
Pune	PUN	73.8	18.5
Rajkot	RJK	70.7	22.3
Shillong	SHN	91.9	25.6
Trivandrum	TVM	77.0	08.5
Udaipur	UDP	73.9	24.6
Varanasi	VNS	82.9	25.3

Table - ST8: AERONET stations

Station Name	STN	longitude	latitude
Bhola (Bangladesh)	BHL	90.7	22.2
Dhaka university	DHK	90.3	23.7
Doi_Ang_Khang (Thailand)	DOK	99.0	19.9
Dushanbe	DSB	68.8	38.5
Gandhi college (West UP)	WUP	84.1	25.8
Kanpur	KNP	80.2	26.5
Karachi(Pakistan)	KRC	67.1	24.9
NAM_CO (Tibet)	NMC	90.9	30.7
Pokhara (Nepal)	PKH	83.9	28.1
QOMS-CAS (China)	CAS	86.9	28.3
Doi_Inthanon (Thailand)	DIT	98.4	18.5
Karunya university (Coimbatore)	CMB	76.7	10.9
MCO_Hanimaadho (Maldives)	MAL	73.1	6.7
Omkai(Thailand)	OMK	98.4	17.7
Silpakorn university (Thailand)	SLK	100.0	13.8
Chiang_Mai_Met_Sta (Thailand)	CMM	98.9	18.7
Jomsom	JMS	83.7	28.7
Lahore (Pakistan)	LHR	74.2	31.4
EVK2-CNR	EVT	86.8	27.9
Myanmar	MYN	96.1	16.8
Dibrugad (Aeronet)	DBU	94.8	27.4

Table - ST9: Modified AOD value for sensitive analysis between UK and RK ML method.

Station	long	latitude	AOD (observed)	AOD (modified for sensitivity analysis)
DDN	78.04	30.34	0.50	0.70
JSL	70.95	26.92	0.36	0.10
KLU	77.10	31.90	0.38	0.20
PBR	92.71	11.64	0.22	0.90
JMS	83.71	28.77	0.04	1.00
LHR	74.26	31.47	0.77	1.30

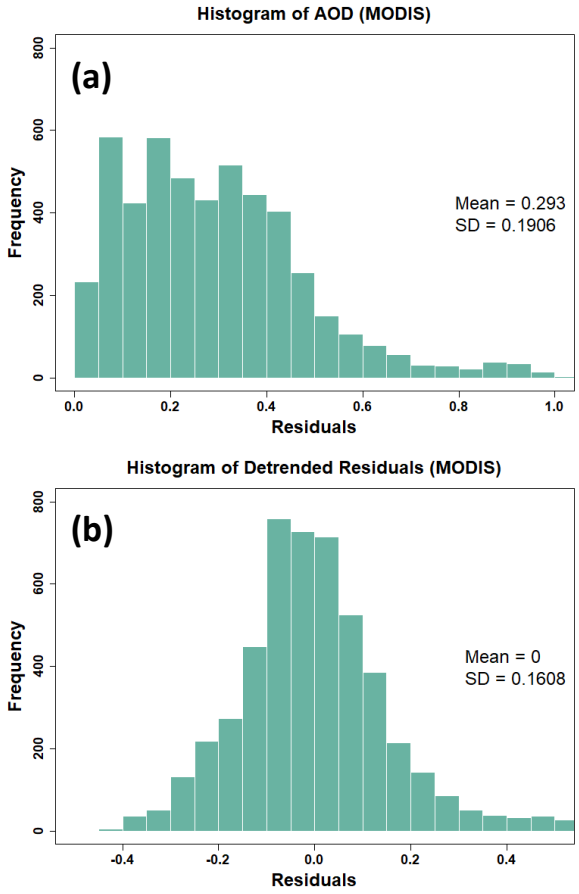


Figure - S1. Histogram of (a) MODIS AOD and (b) Detrended residuals from MODIS AOD with respect to latitude, longitude, elevations.

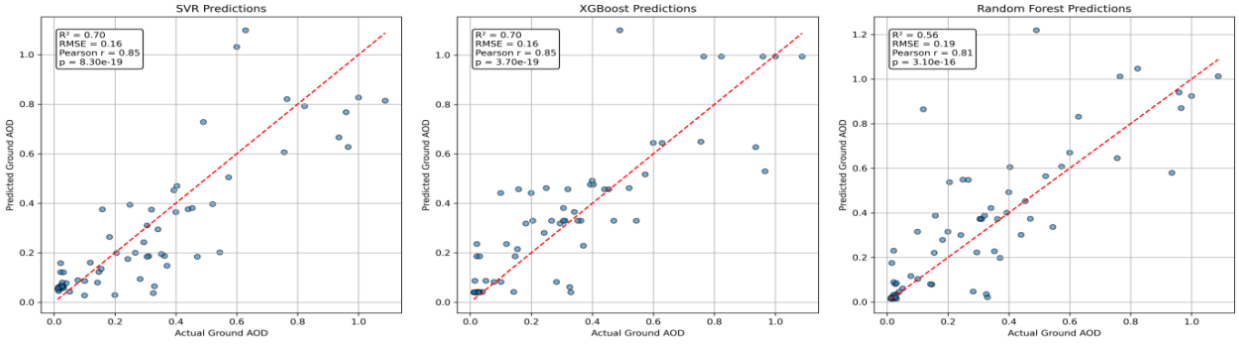


Figure – S2. Comparison plot of SVR, XGBoost, Random Forest performance on 20% test data (MODIS).

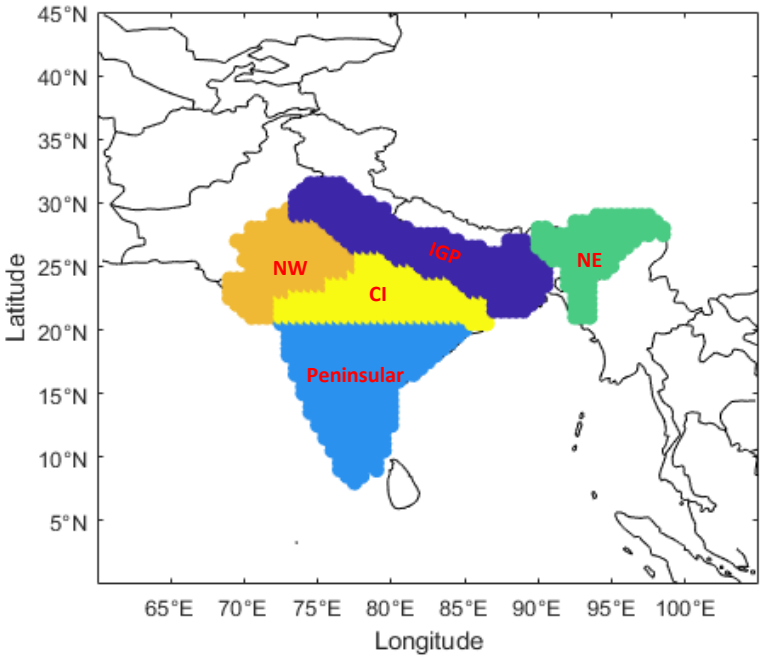


Figure - S3: Classification of different regions of India and their boundaries used in this study.

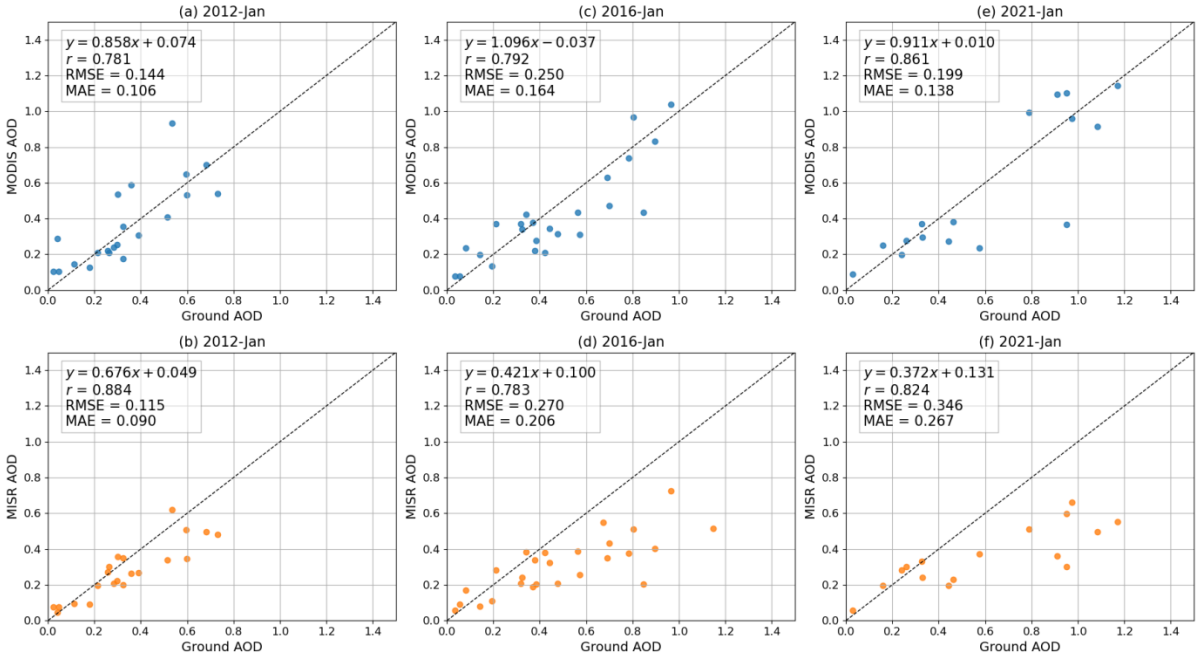


Figure – S4. Comparison between MODIS (top) and MISR (bottom) versus ground AOD for the month of January 2012 (N=21), 2016 (N=26), and 2021(N=16), respectively.

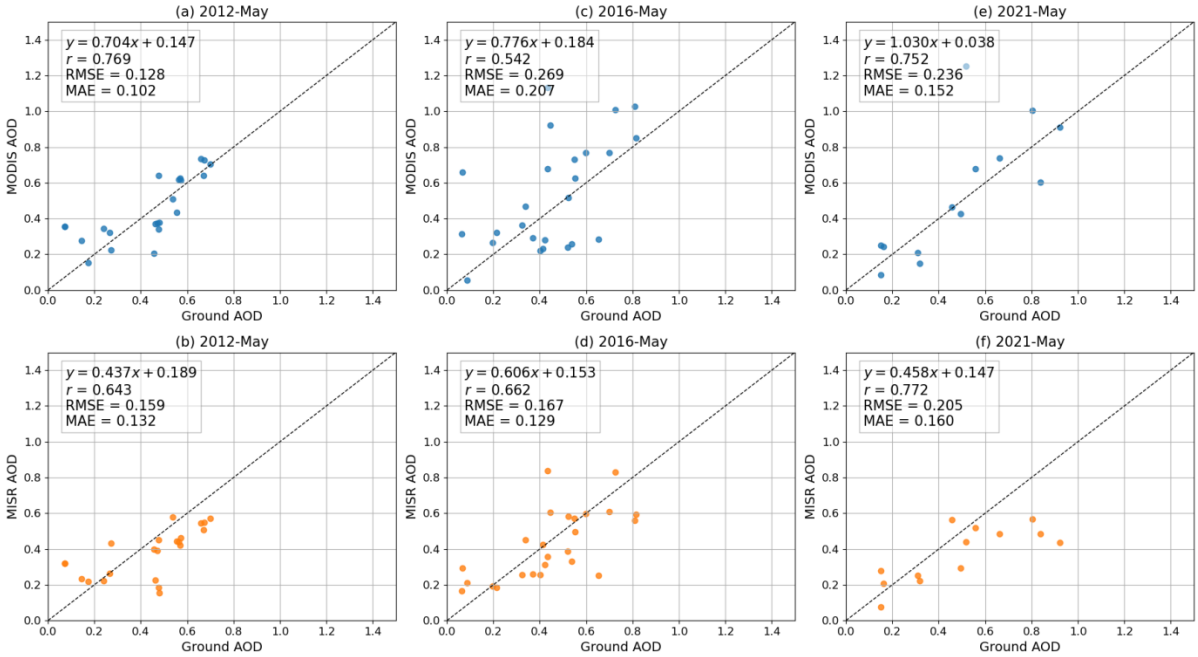


Figure S5. Comparison between MODIS (top) and MISR (bottom) versus ground AOD for the month of May 2012 (N=22), 2016 (N=25), and 2021(N=13), respectively.

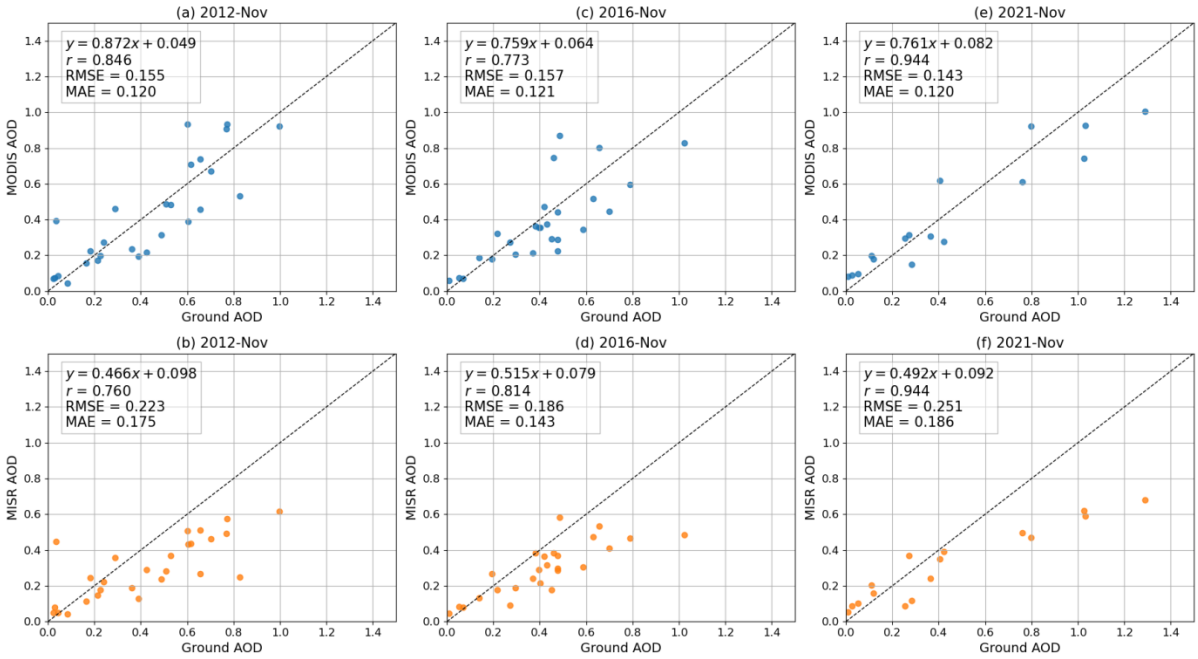


Figure – S6. Comparison between MODIS (top) and MISR (bottom) versus ground AOD for the month of November 2012 (N=27), 2016 (N=26), and 2021 (N=16), respectively.

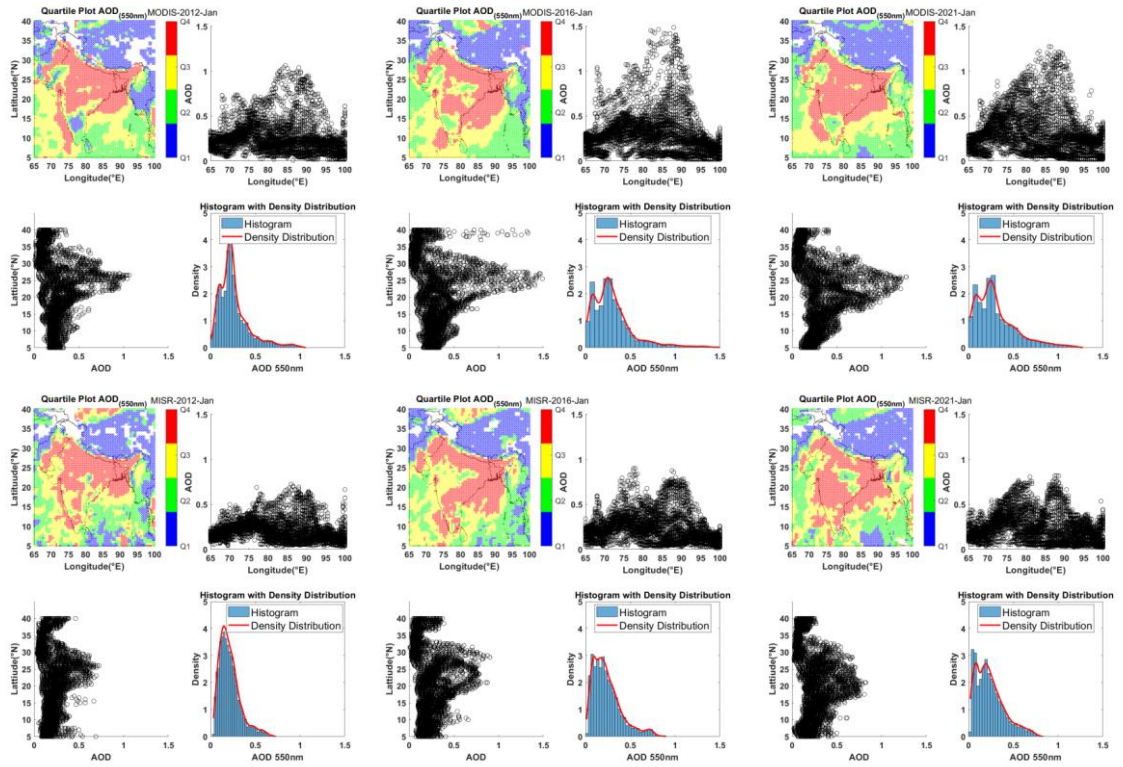


Figure – S7. Quartile plots of MODIS and MISR AOD at 0.55 μm for January 2012, 2016, and 2021 over India followed by AOD distribution over longitude and latitude and its histogram showing density distribution.

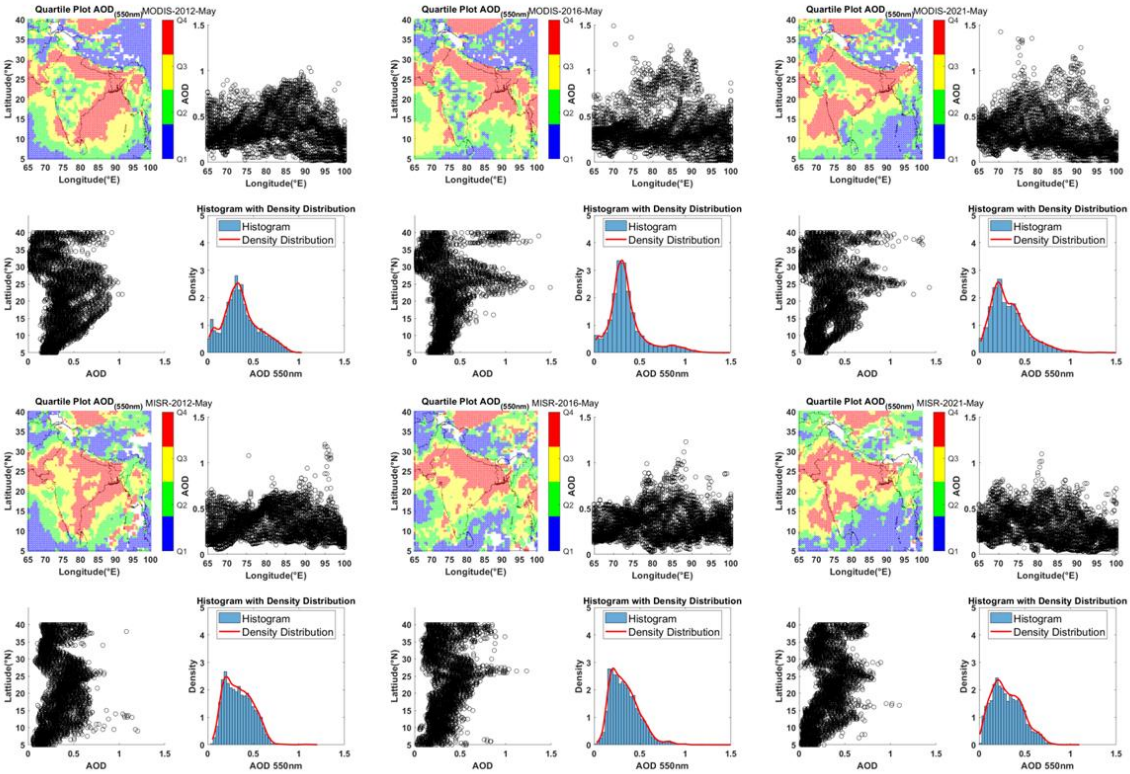


Figure – S8. Quartile plots of MODIS and MISR AOD at 0.55 μm for May 2012, 2016, and 2021 over India followed by AOD distribution over longitude and latitude and its histogram showing density distribution.

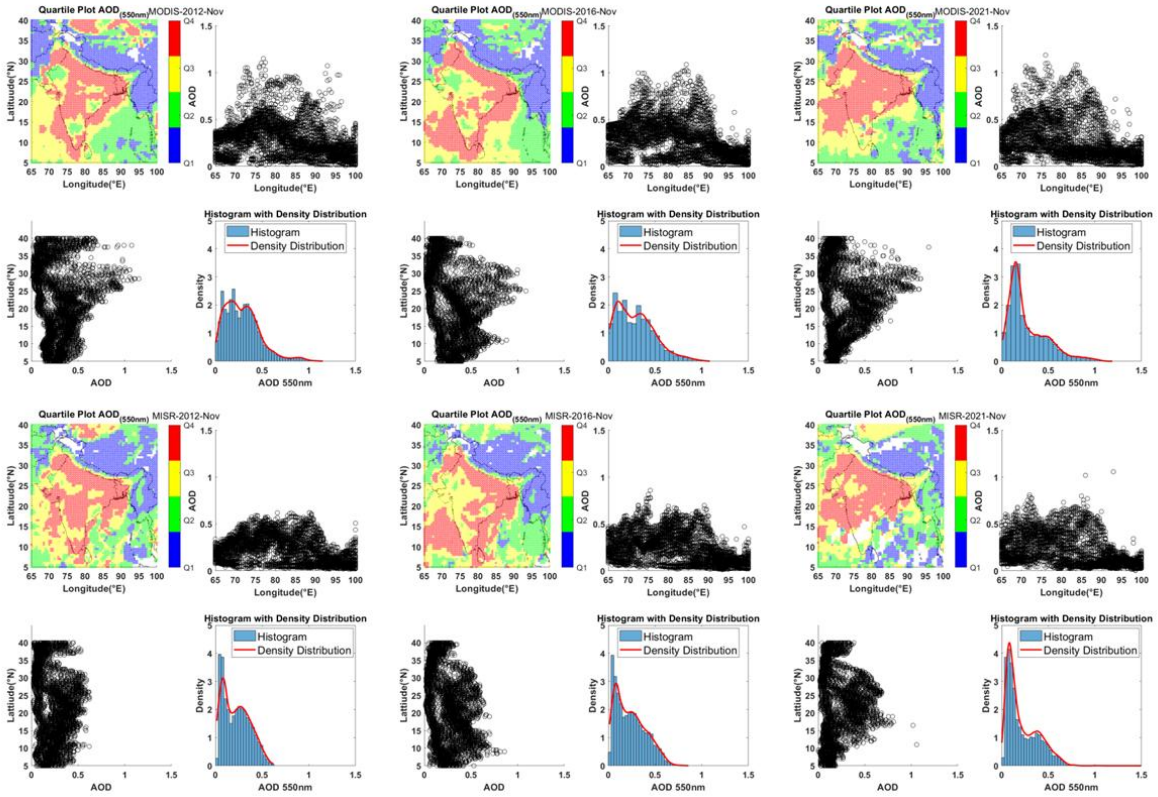


Figure – S9. Quartile plots of MODIS and MISR AOD at 0.55 μm for November 2012, 2016, and 2021 over India followed by AOD distribution over longitude and latitude and its histogram showing density distribution.

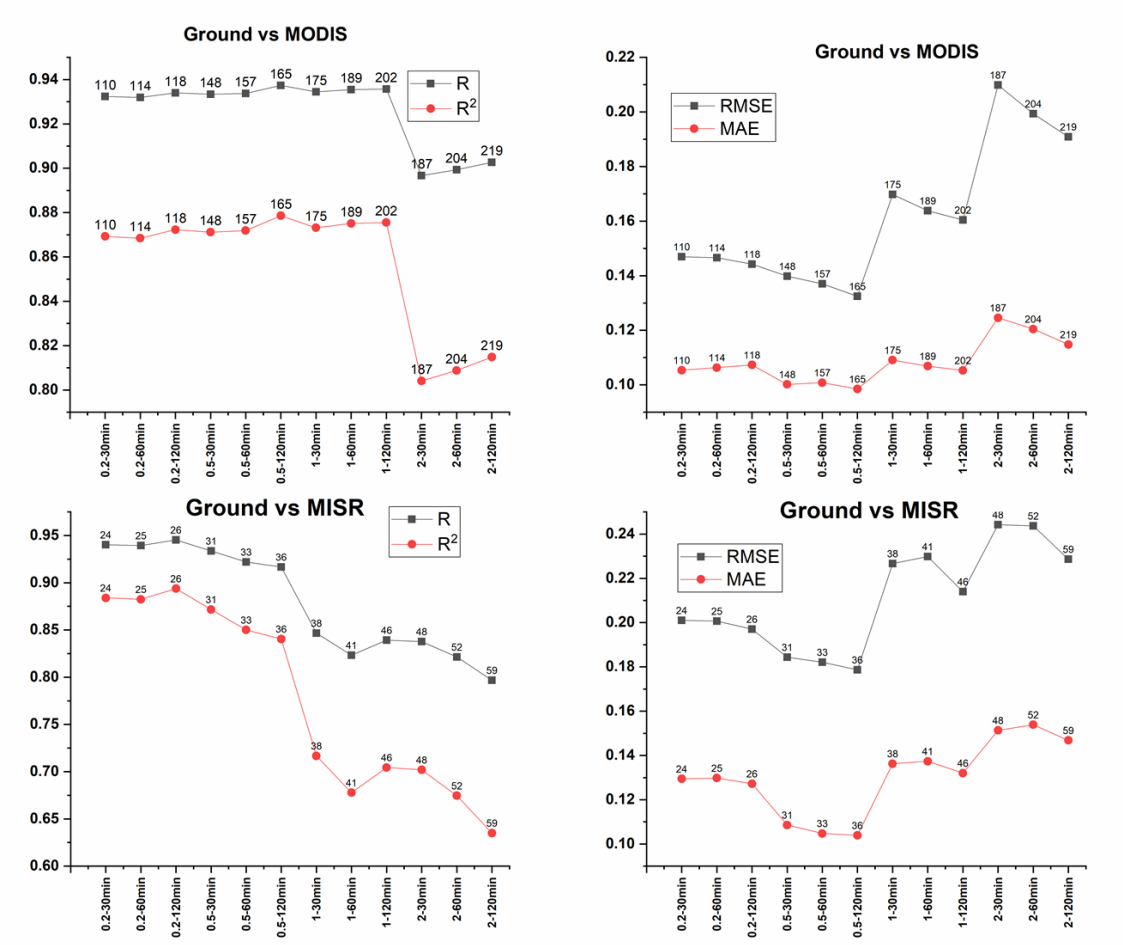


Figure. S10: Spatio-temporal association between collocated ground and satellite AOD for 2021 Nov. (a) R and R^2 and (b) RMSE and MAE for ground vs. MODIS; (c) R and R^2 and (d) RMSE and MAE for ground vs. MISR. The numerical values above the lines represent the number of collocated points for different spatio-temporal windows.

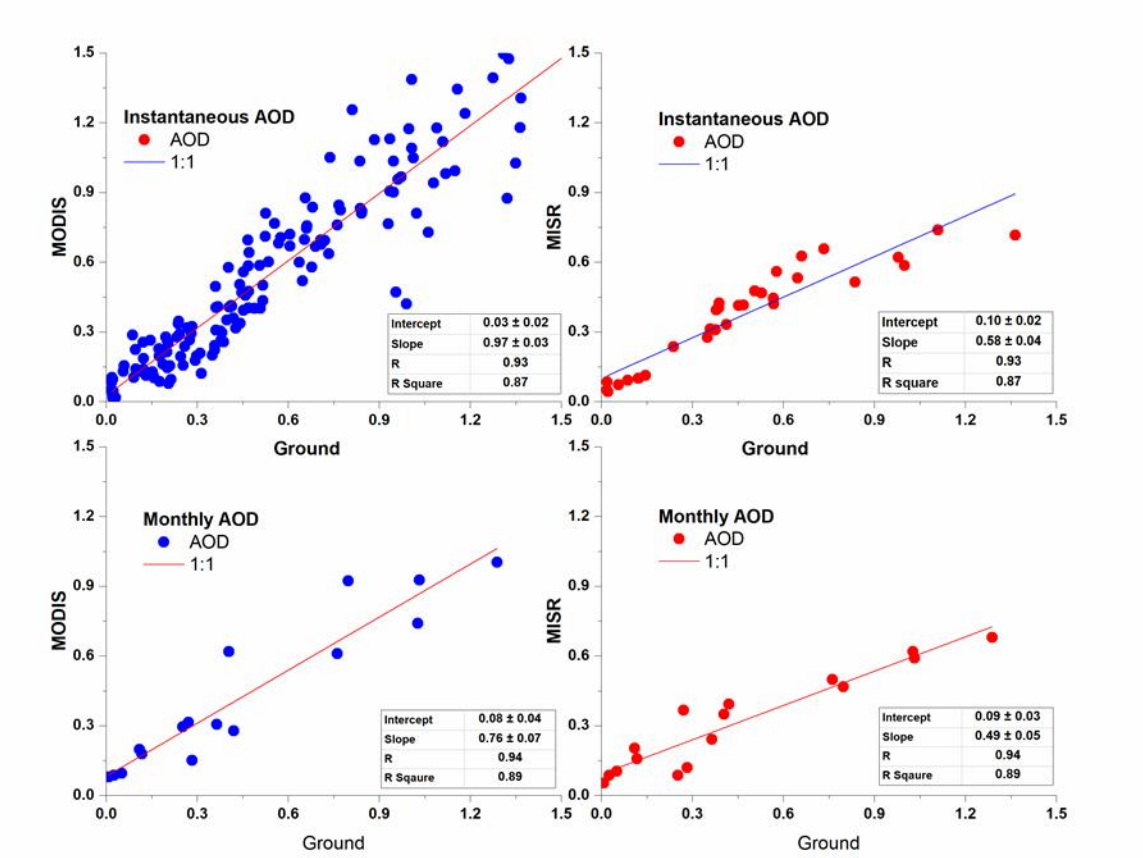


Figure – S11. Scatter plot between collocated points between Ground and MODIS (Top left: Overpass Instantaneous AOD, Bottom left: Monthly mean) and Ground and MISR (Top right: Overpass Instantaneous AOD, Bottom right: Monthly mean)

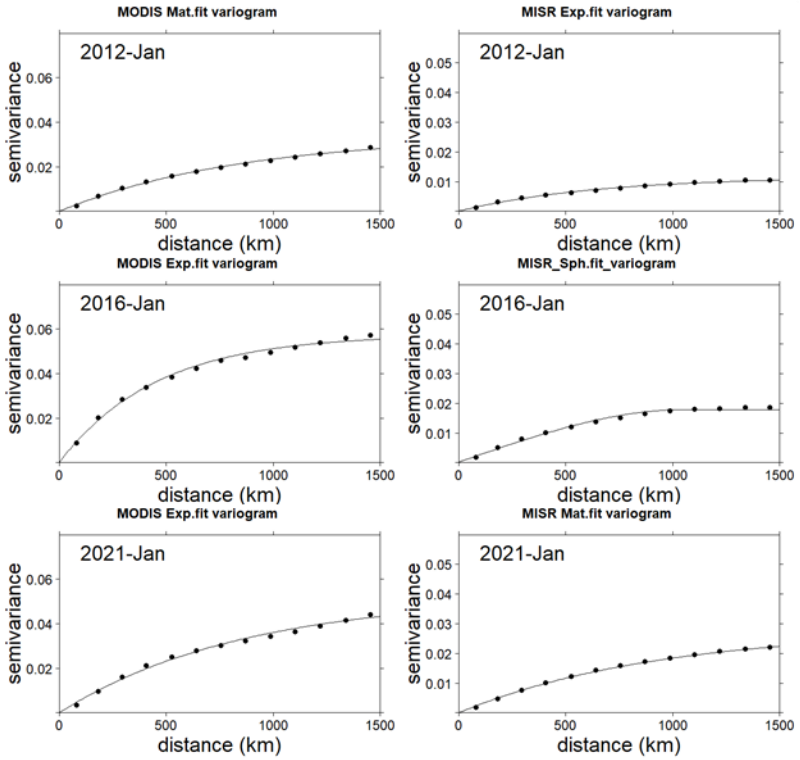


Figure - S12: Experimental variogram of MODIS (left) and MISR (right) for the month of January 2012, 2016, and 2021.

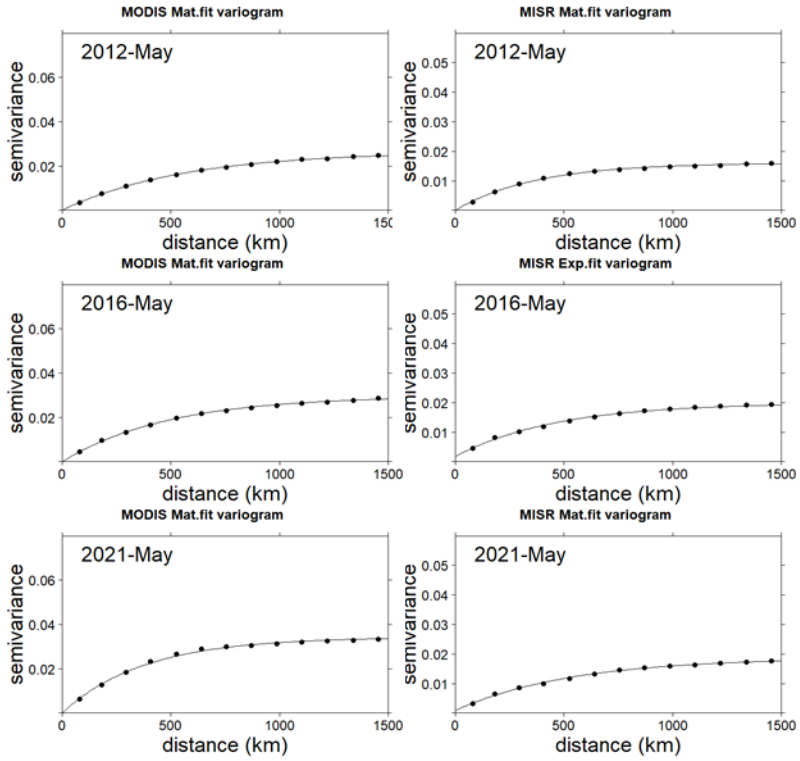


Figure - S13. Experimental variogram of MODIS (left) and MISR (right) for the month of May 2012, 2016, and 2021.

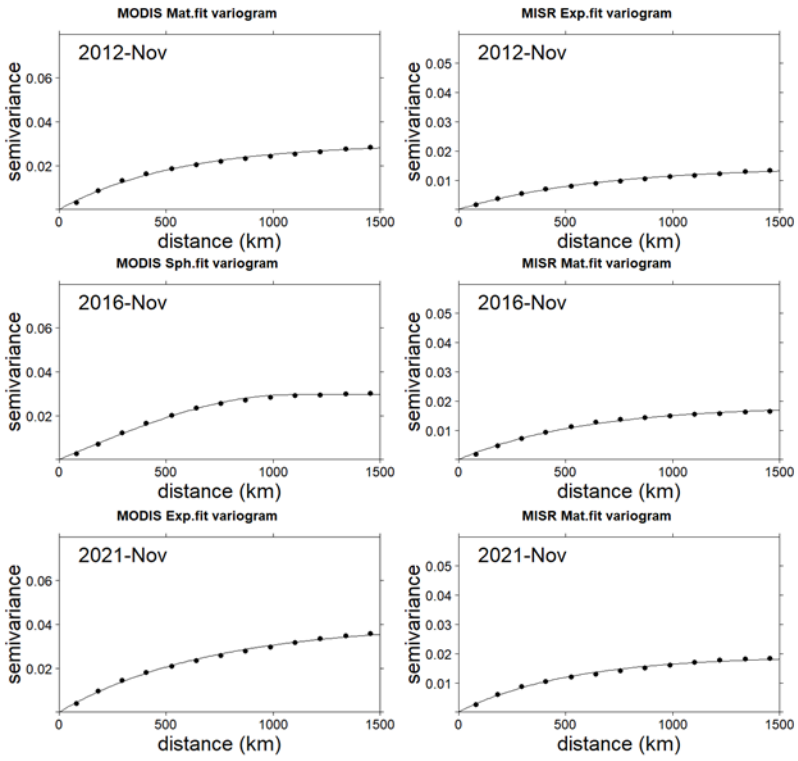


Figure - S14. Experimental variogram of MODIS (left) and MISR (right) for the month of November 2012, 2016, and 2021.

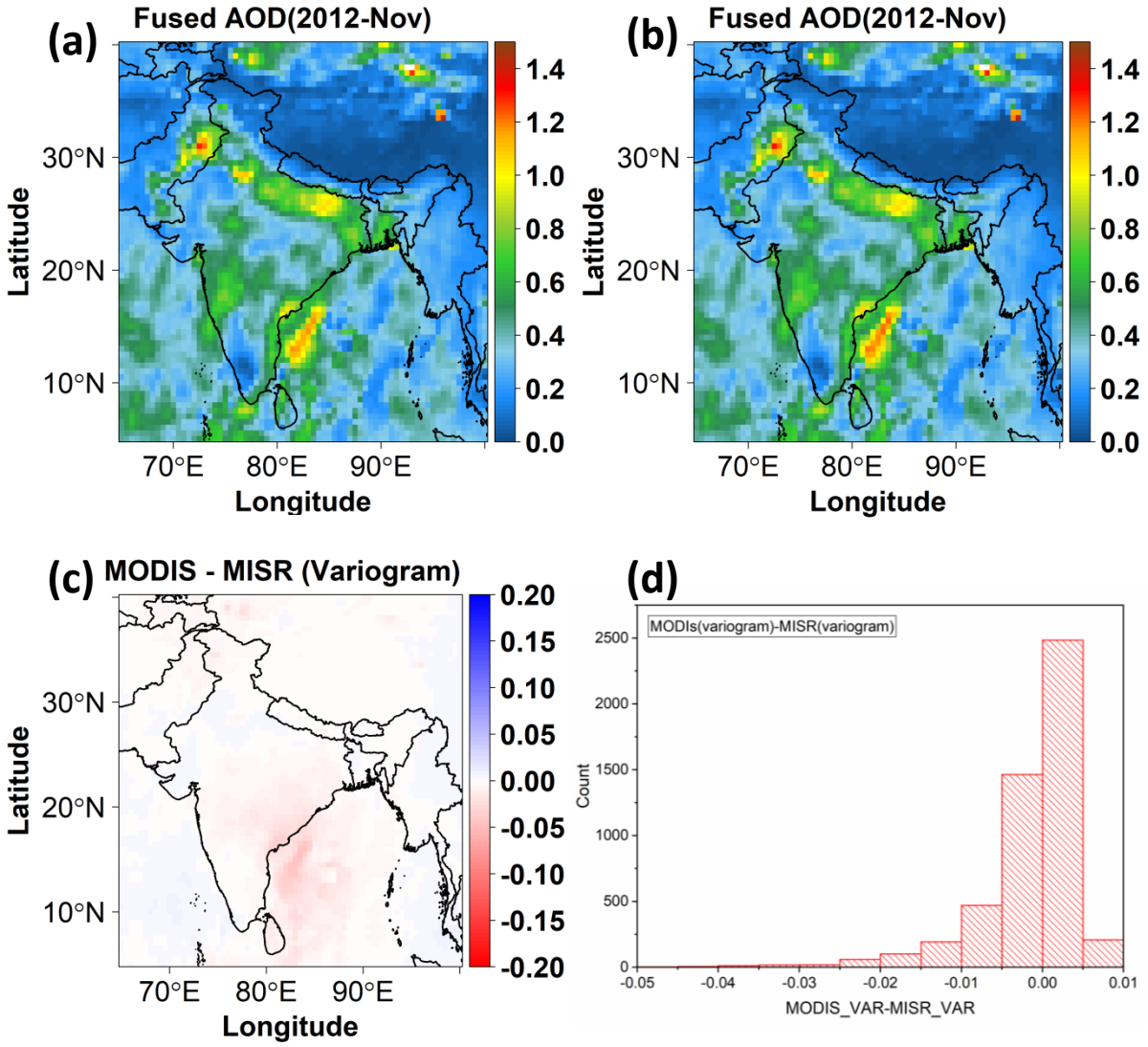


Figure – S15. Fused AOD generated from (a) MODIS variogram and (b) MISR variogram (c) spatial map of difference MODIS-MISR (variogram), (d) Histogram of differences (MODIS-MISR (variogram)). Details are in (Table-ST3). The difference values are ~ -0.01 to 0.01 while over mainland it is close to ~0 than oceanic regions.

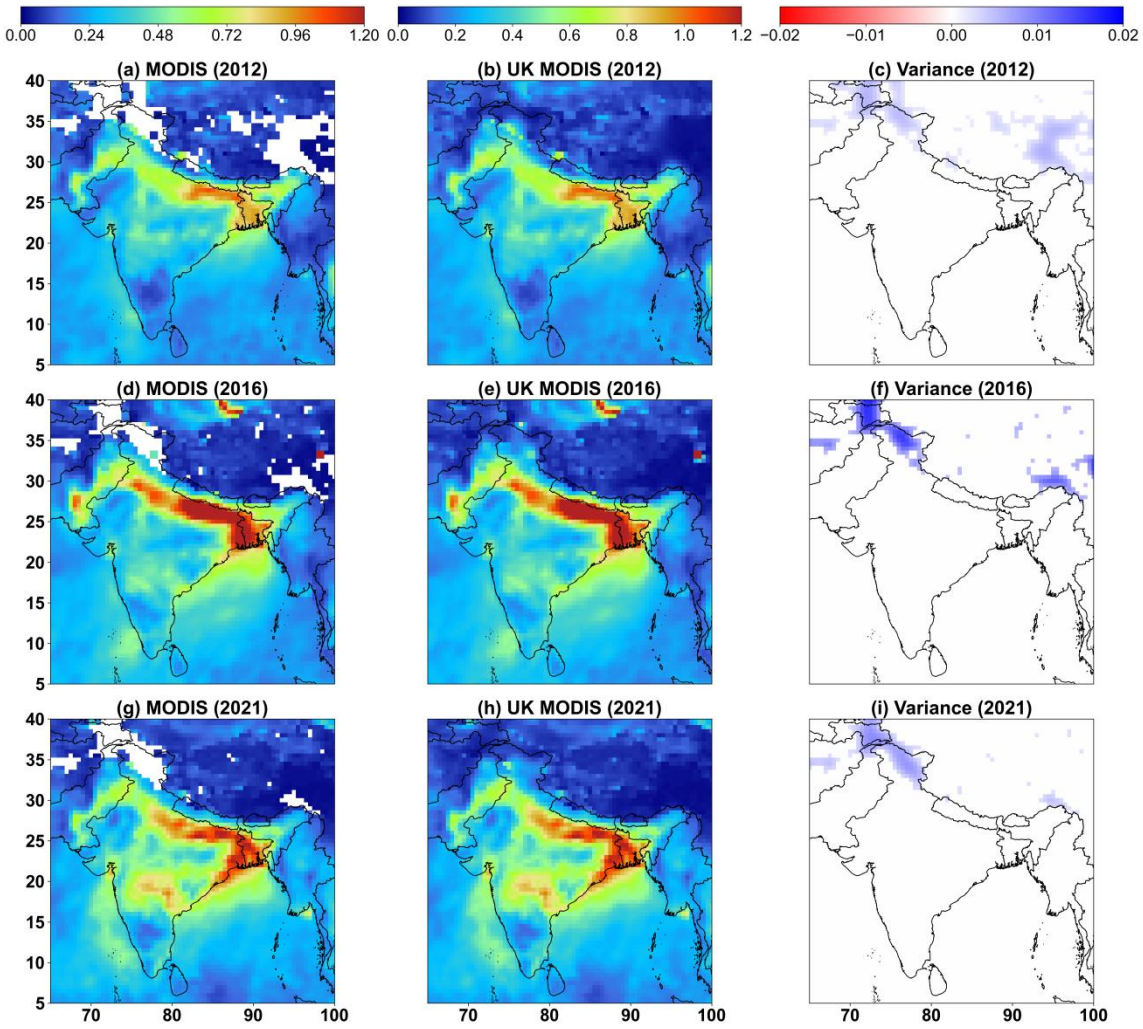


Figure - S16. Monthly mean $0.5° \times 0.5°$ gridded MODIS AOD for January 2012, 2016, and 2021; MODIS AOD [(a), (d), (g)], spatial prediction using UK [(b), (e), (h)], and variance of predictions [(c), (f), (i)].

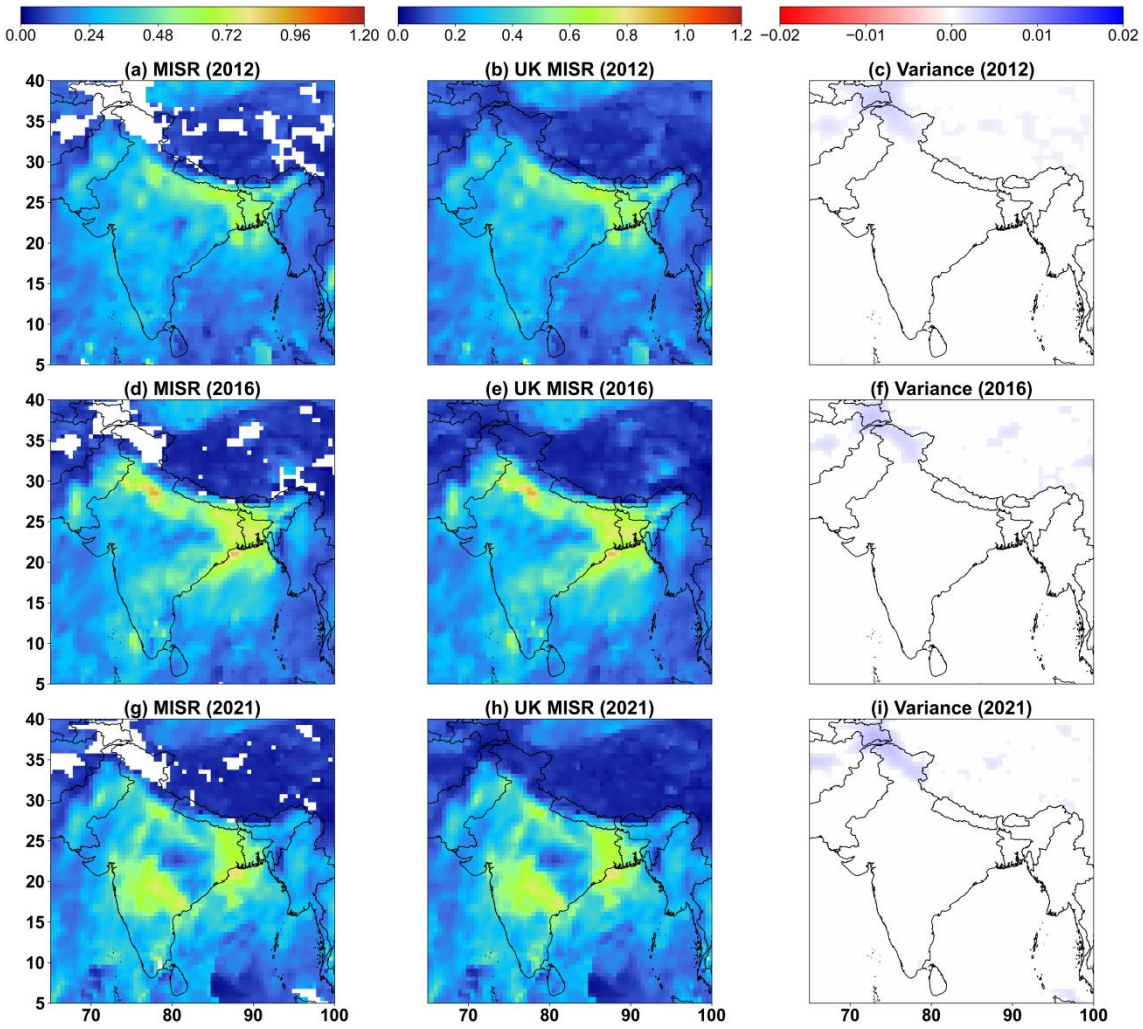


Figure - S17. Monthly mean $0.5° \times 0.5°$ gridded MISR AOD for January 2012, 2016, and 2021; MISR AOD [(a), (d), (g)], spatial prediction using UK [(b), (e), (h)], and variance of predictions [(c), (f), (i)].

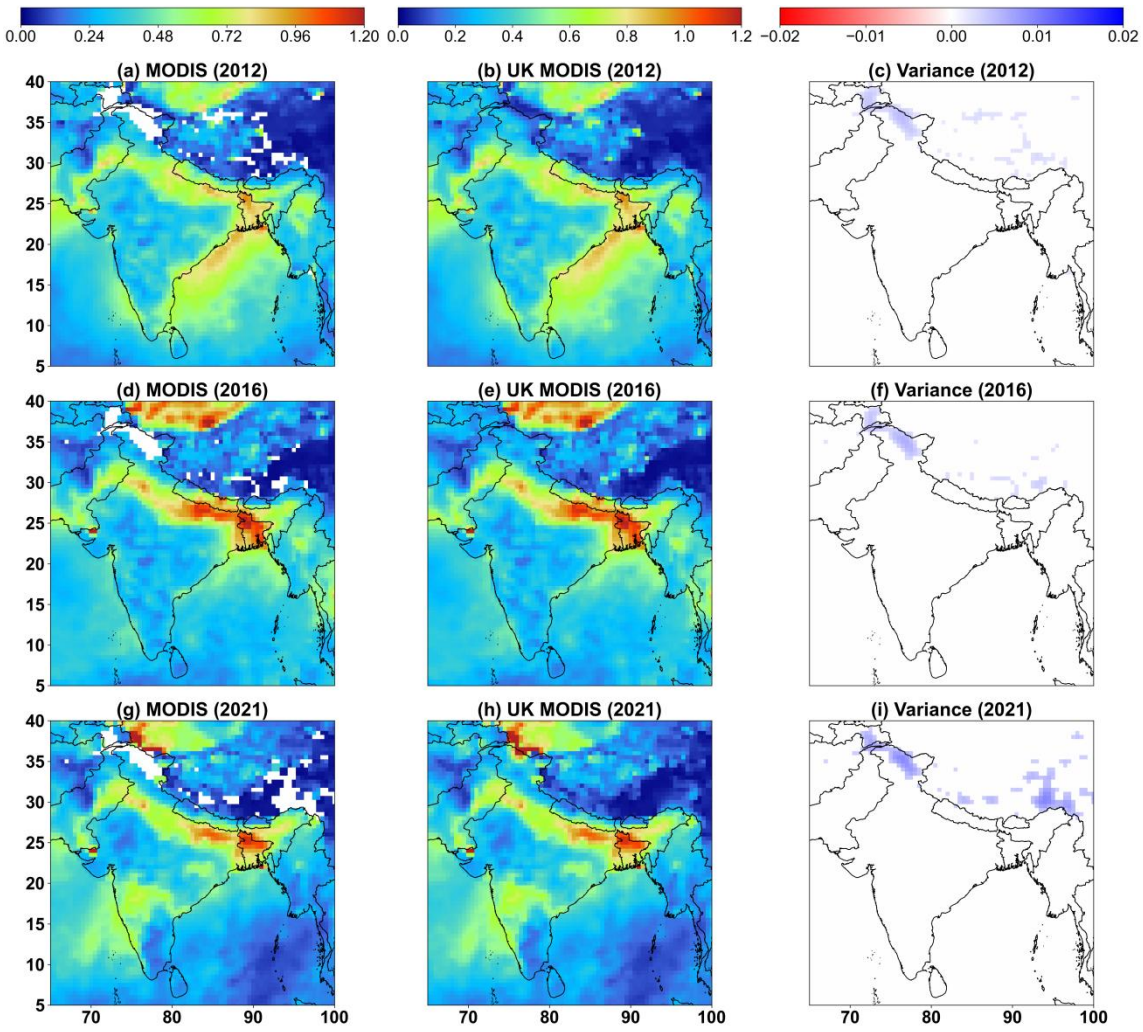


Figure - S18. Monthly mean 0.5°×0.5° gridded MODIS AOD for **May** 2012, 2016, and 2021; MODIS AOD [(a), (d), (g)], spatial prediction using UK [(b), (e), (h)], variance of predictions [(c), (f), (i)].

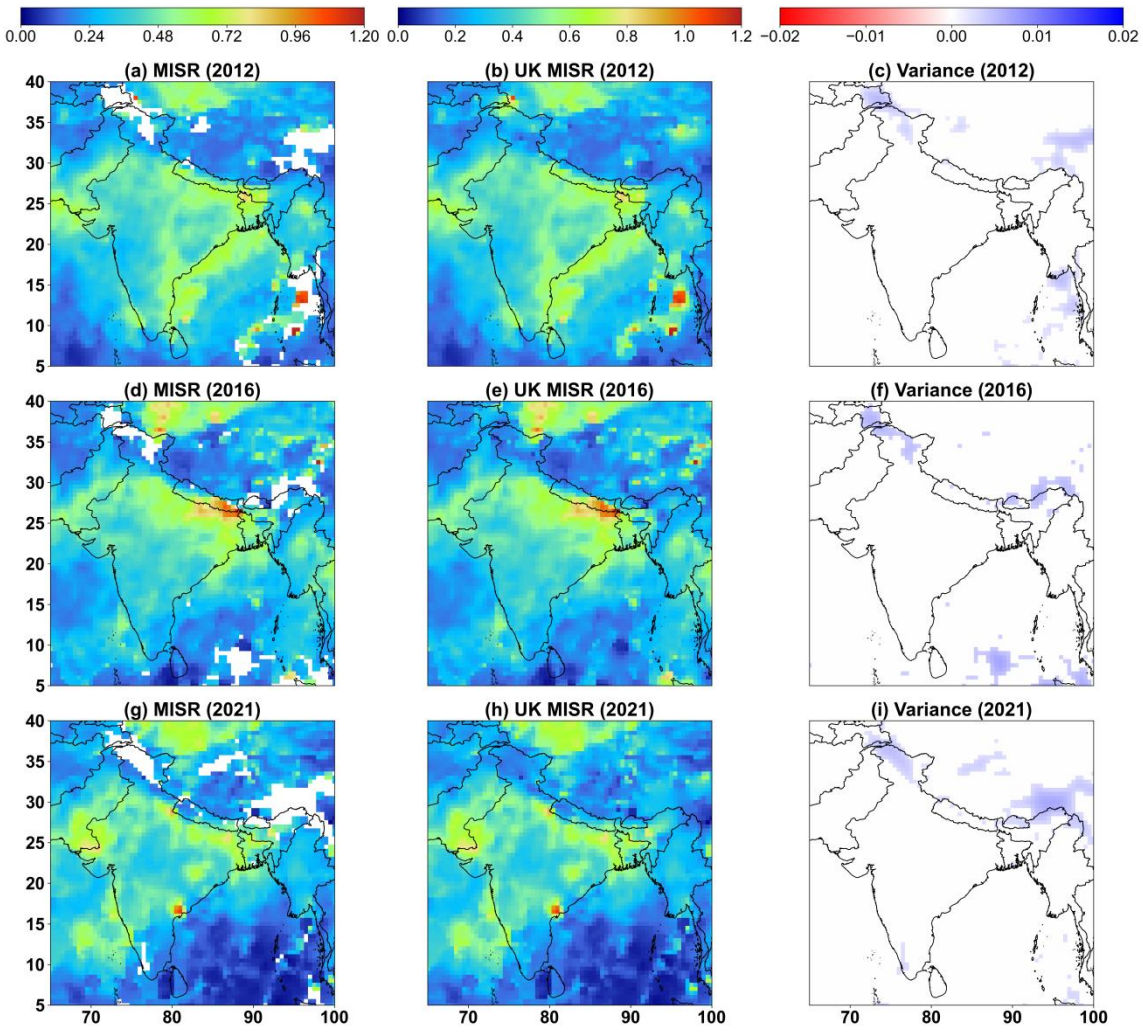


Figure - S19. Monthly mean 0.5°×0.5° gridded MISR AOD for May 2012, 2016, and 2021; MISR AOD [(a), (d), (g)], spatial prediction using UK [(b), (e), (h)], variance of predictions [(c), (f), (i)].

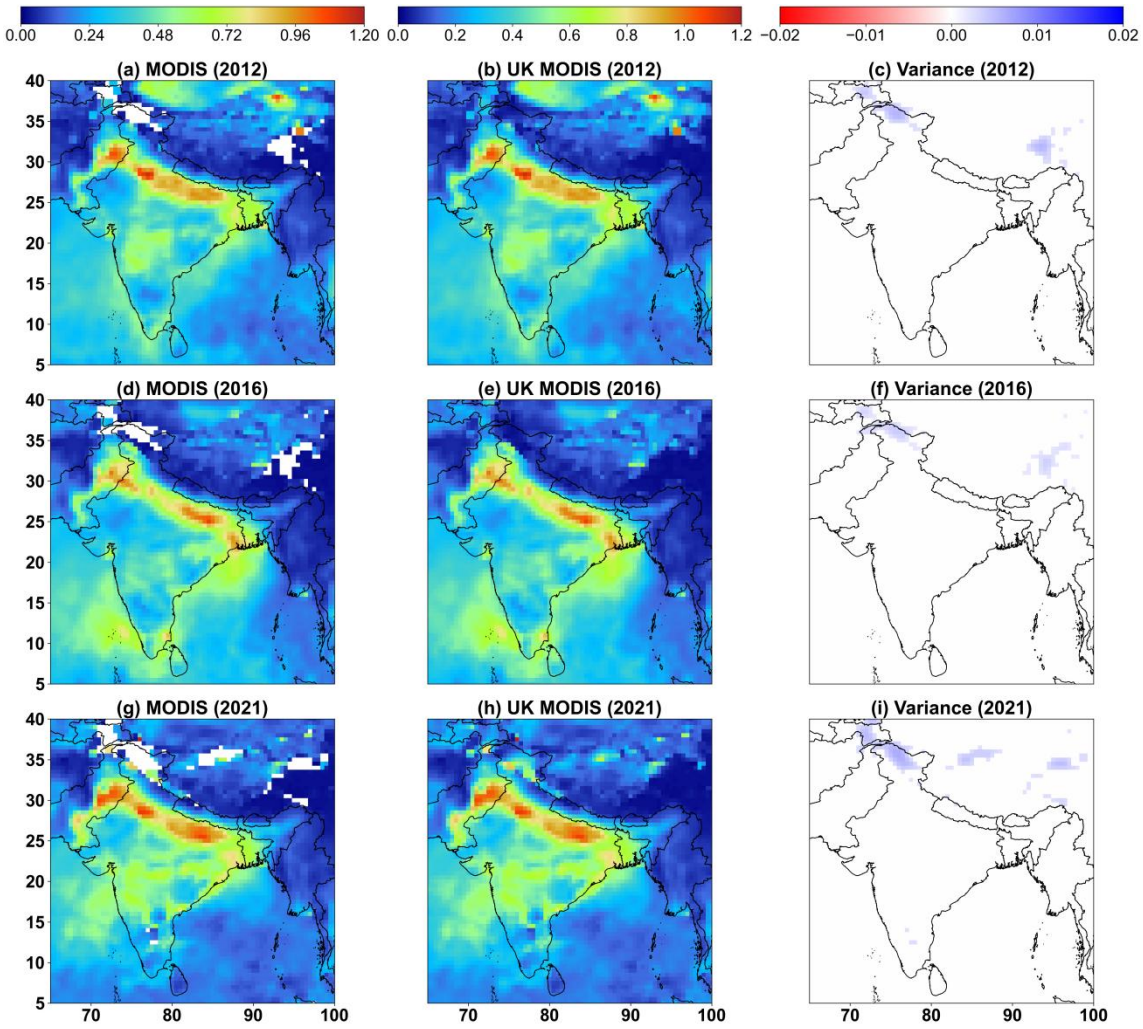


Figure - S20. Monthly mean 0.5°×0.5° gridded MODIS AOD for Nov 2012, 2016, and 2021; MODIS AOD [(a), (d), (g)], spatial prediction using UK [(b), (e), (h)], variance of predictions [(c), (f), (i)].

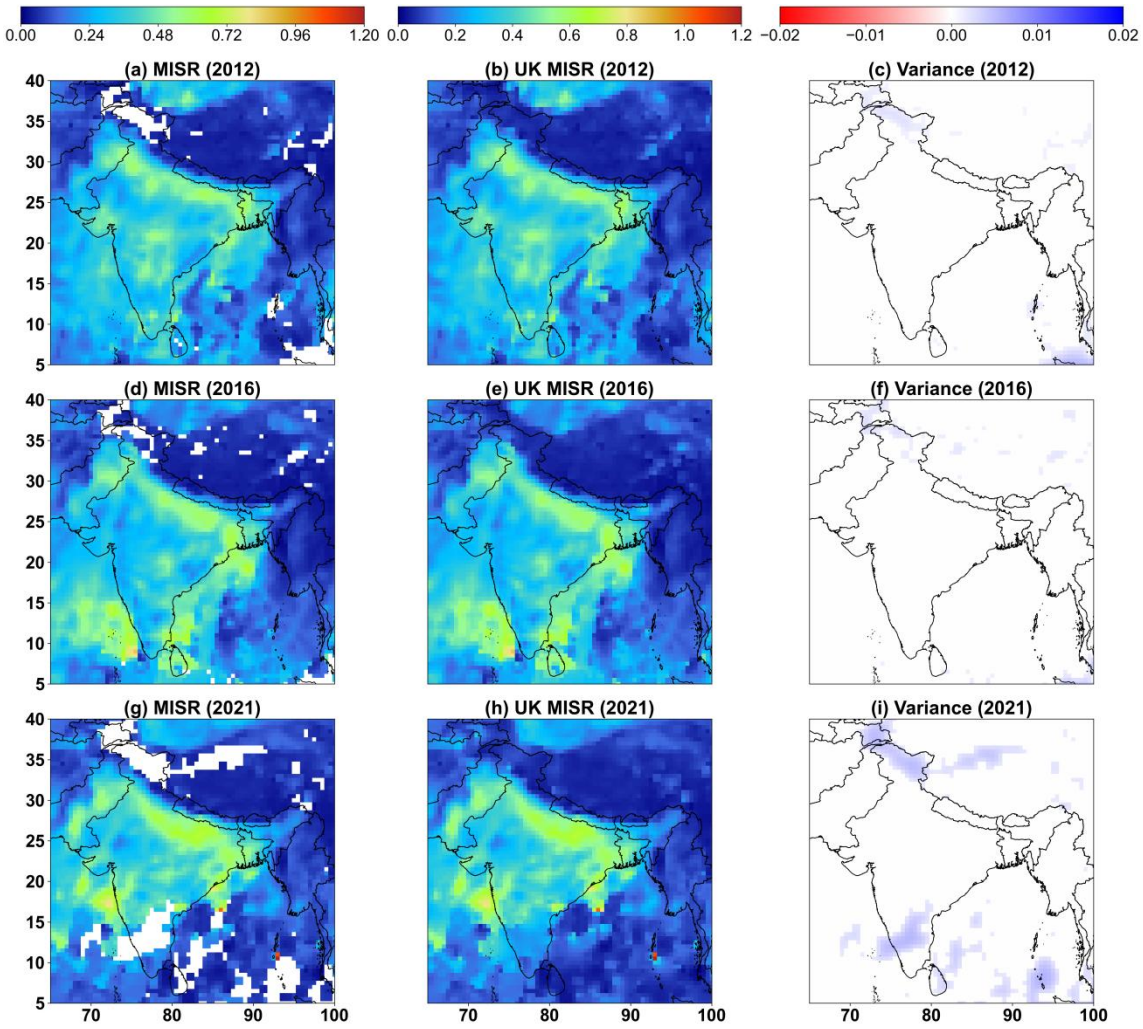


Figure - S21. Monthly mean 0.5°×0.5° gridded MISR AOD for Nov 2012, 2016, and 2021, MISR AOD [(a), (d), (g)], spatial prediction using UK [(b), (e), (h)], variance of predictions [(c), (f), (i)].

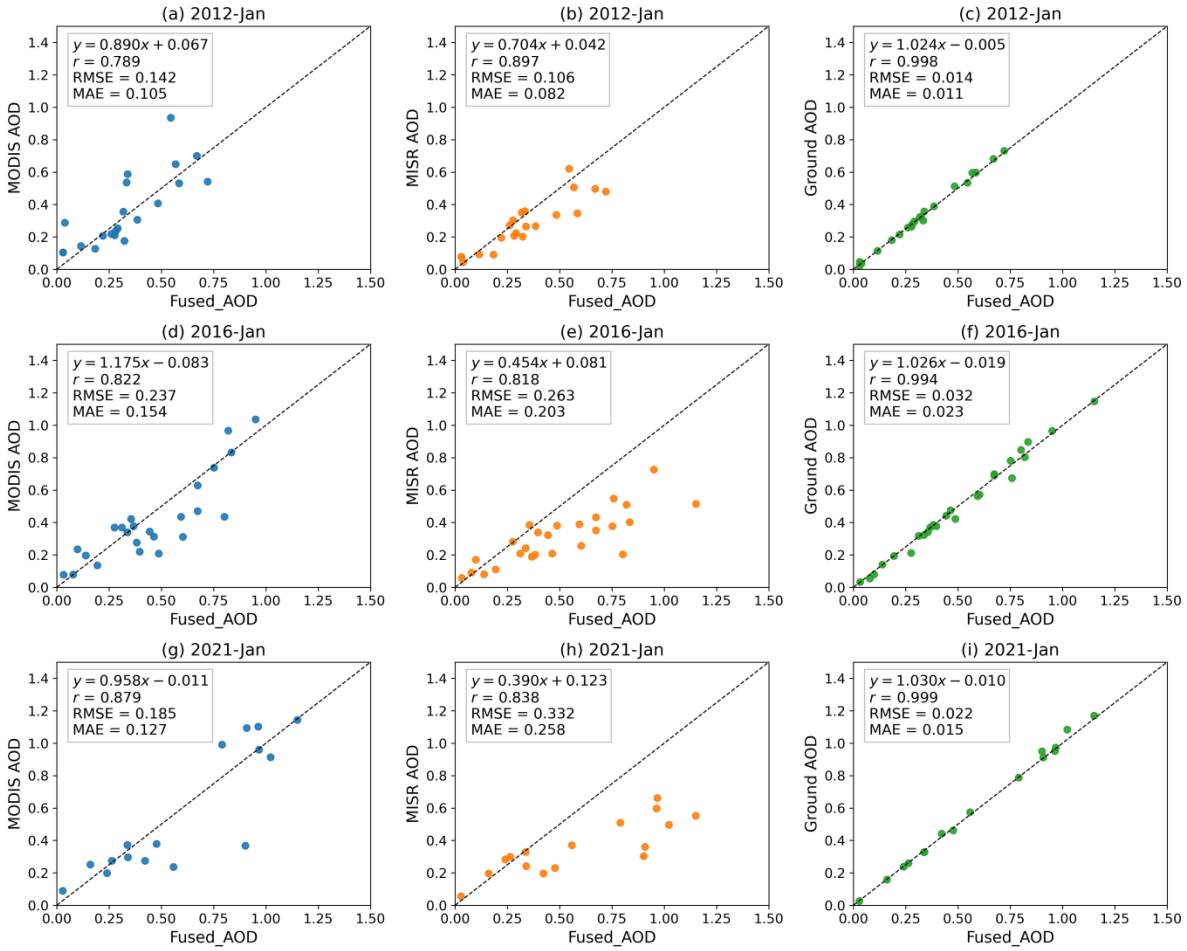


Figure - S22. Comparison of fused AOD with MODIS [(a), (d), (g)], MISR [(b), (e), (h)], and ground observation [(c), (f), (i)] for the month of January 2012, 2016, and 2021.

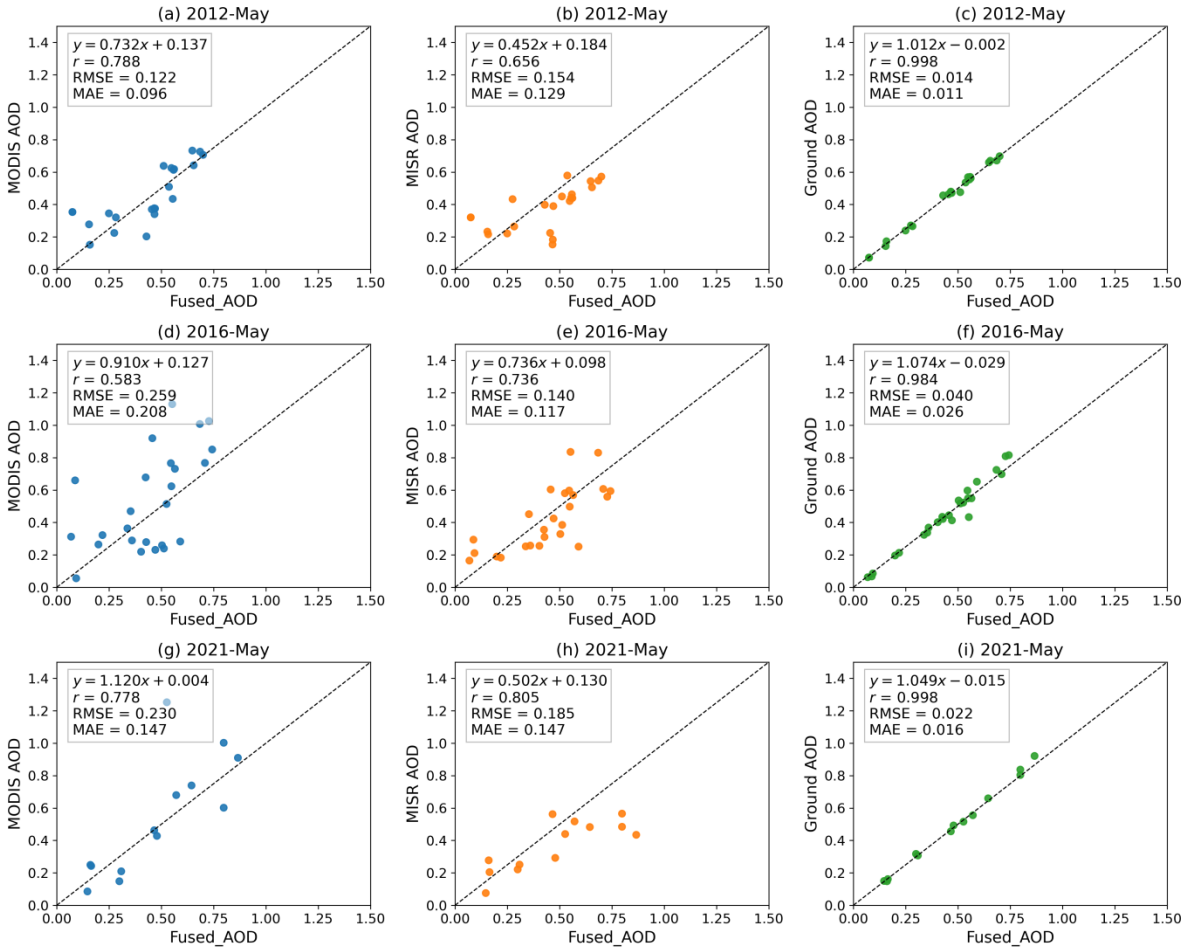


Figure - S23. Comparison of fused AOD with MODIS [(a), (d), (g)], MISR [(b), (e), (h)], and ground observation [(c), (f), (i)] for the month of May 2012, 2016, and 2021.

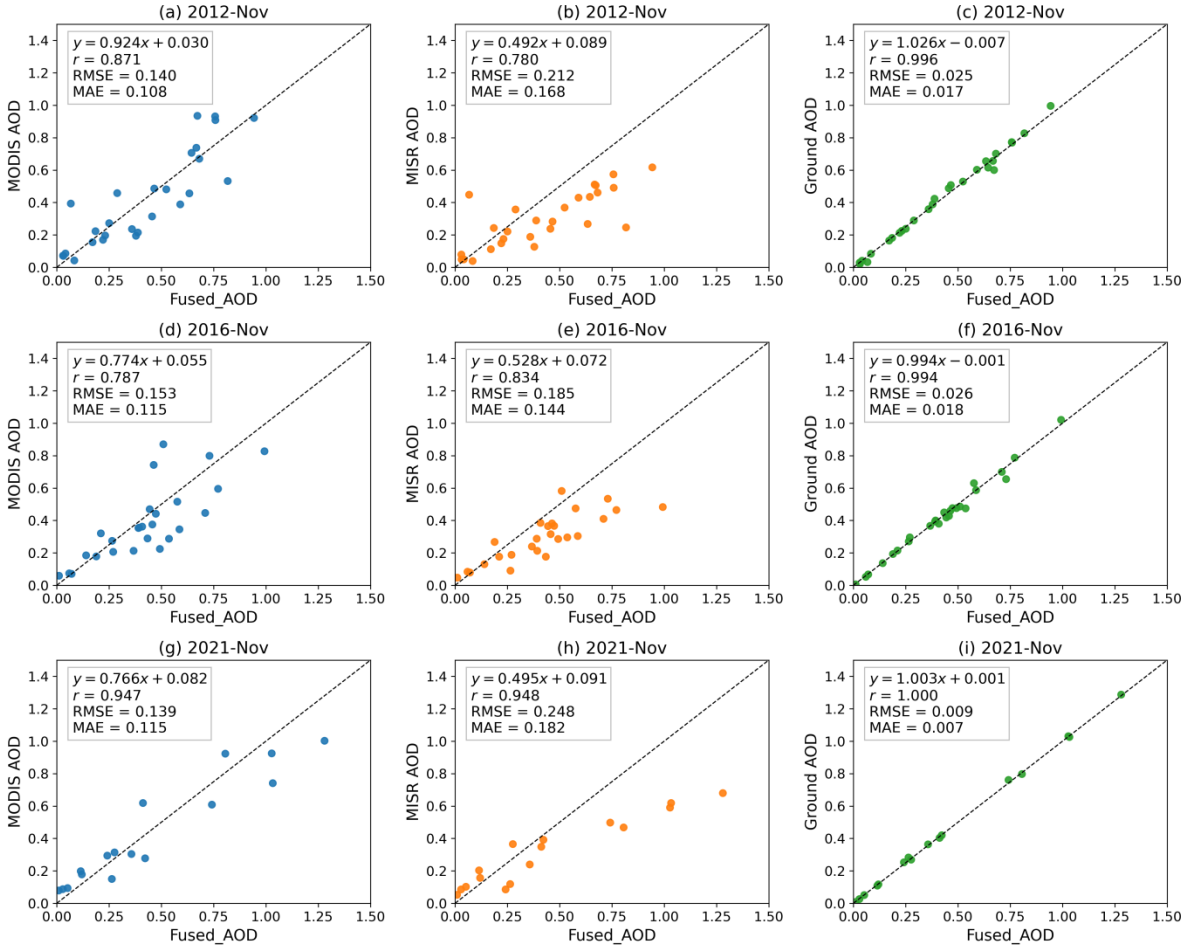


Figure - S24. Comparison of fused AOD with MODIS [(a), (d), (g)], MISR [(b), (e), (h)], and ground observation [(c), (f), (i)] for the month of November 2012, 2016, and 2021.

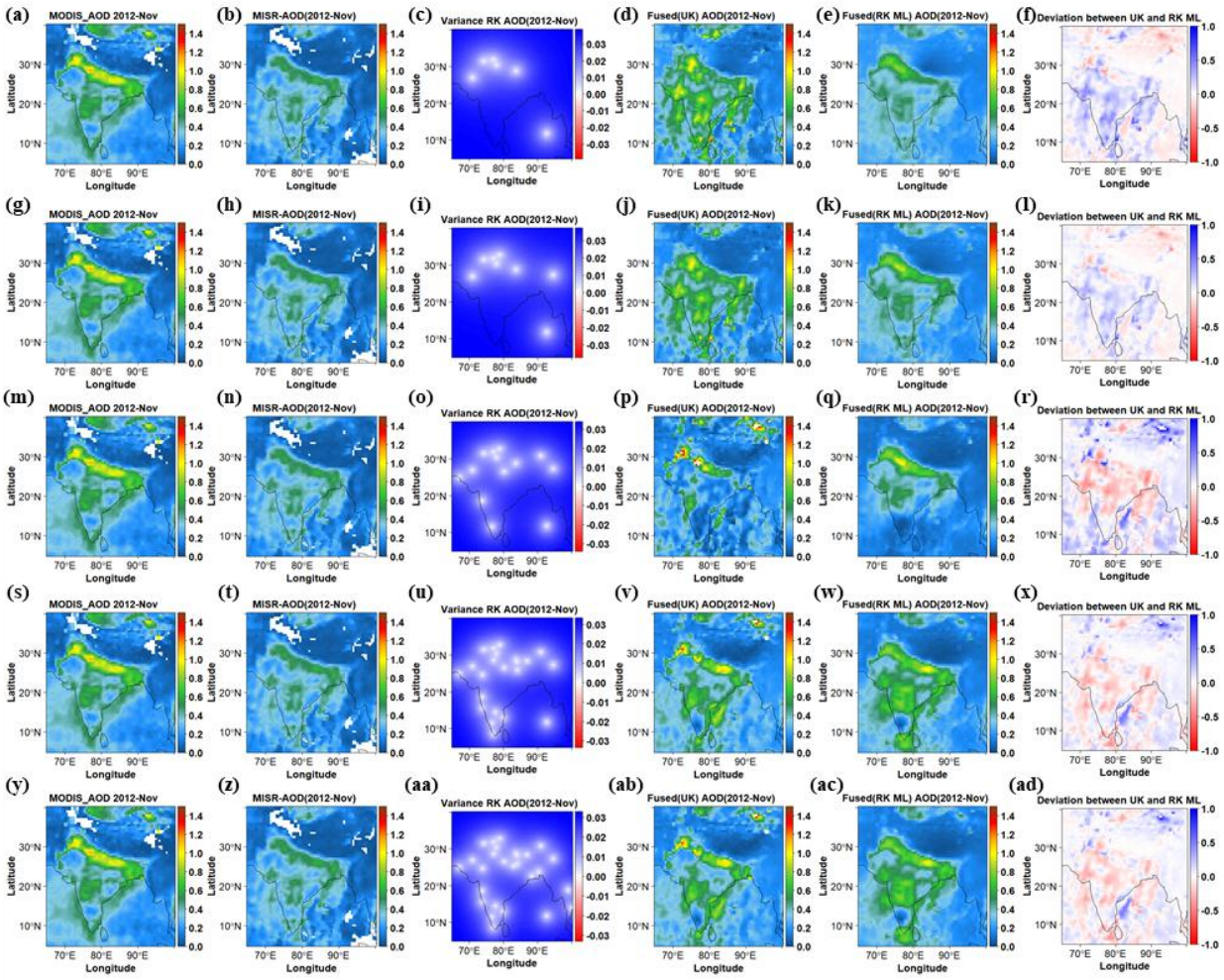
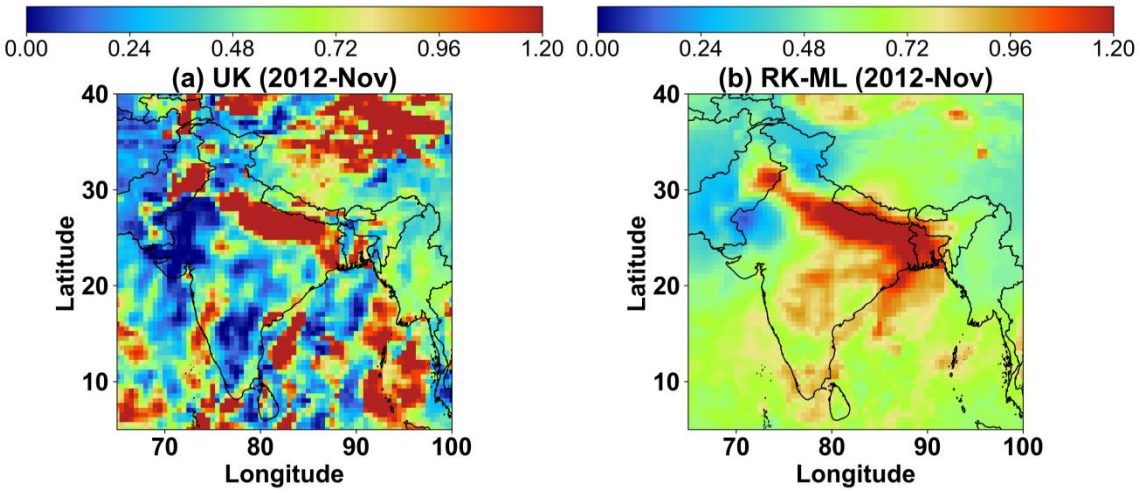


Figure - S25. Sensitivity study of AOD from two methods (UK and RK ML) in Nov 2012. The ground points are taken as 6 [(a)-(f)], 8 [(g)-(l)], 13[(m)-(r)], 22[(s)-(x)], 27[(y)-(ad)] respectively. The impact of using less number of ground data points are observed to change the spatial signature from respective satellite sensors in the UK method, while RK ML is robust to such changes.



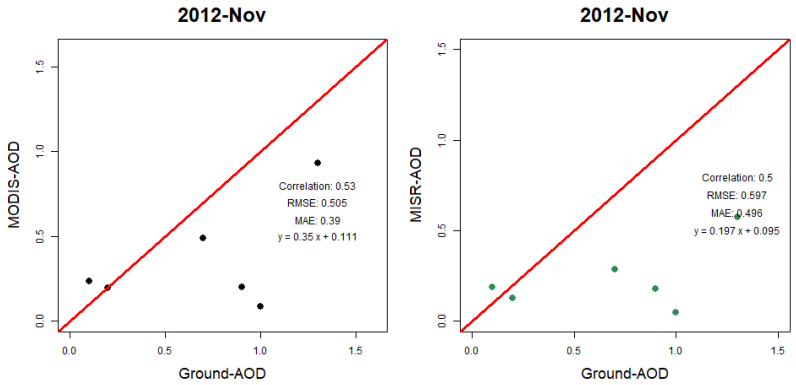


Figure - S26. Sensitivity study of modified AOD from two methods (UK and RK ML) in Nov 2012. The impact of using less number of ground data (Table-ST9) are seen when erroneous points present.

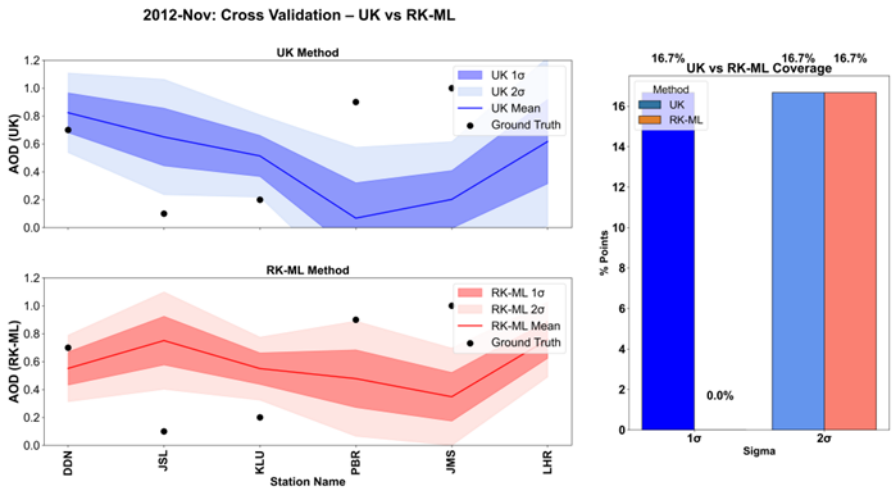


Figure - S27. LOOCV comparison between two methods (UK and RK ML) for Nov 2012 for modified AOD. Both scores are very low and hence, LOOCV scores (right panel) can be treated as threshold to accept the fused estimates using both the methods.