



JULES Annual Science Meeting, 2026

Improvement of Soil Moisture Forecasts using Indian Soil Moisture Network Observations

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Agenda

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- Need for Quality Control
- Common Soil Moisture Errors

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- AGRO-AWS Stations
- AGRO-AWS data before QC
- Soil Moisture QC checks
- QC Flow Chart
- AGRO-AWS data after QC
- Quality Control Soil Moisture/Temperature Observations Stations
- Qualitative Comparison with Mithuna-GLB Soil Moisture/Temperature Forecast
- Methodology: Bias Correction of Model Forecast Soil Moisture

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Soil Moisture Data Plots

- Soil Moisture Layer #1, #2, #3, #4
- Soil Moisture Forecast 12, 24, 48, 72 Hour Leadtimes.
- Feature importance

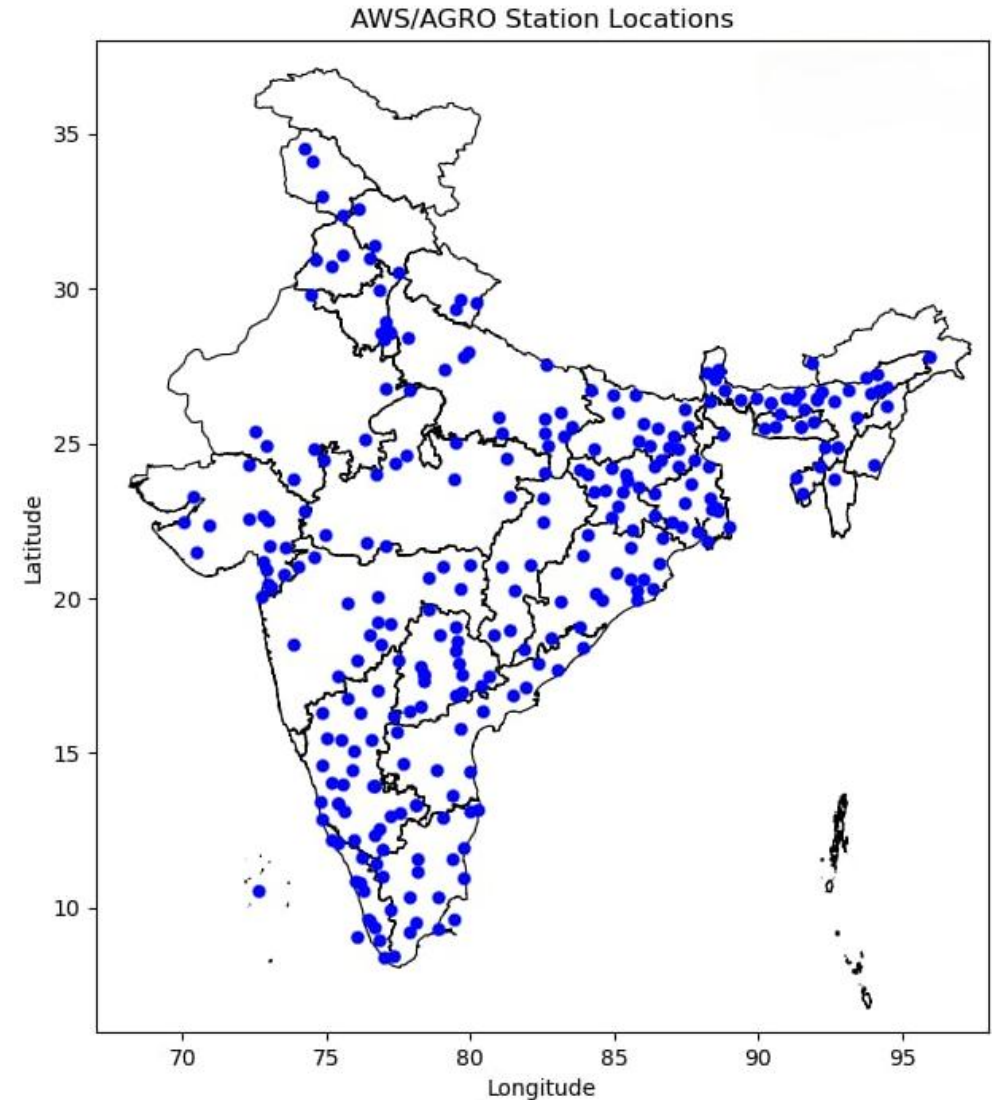
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Conclusion and summary

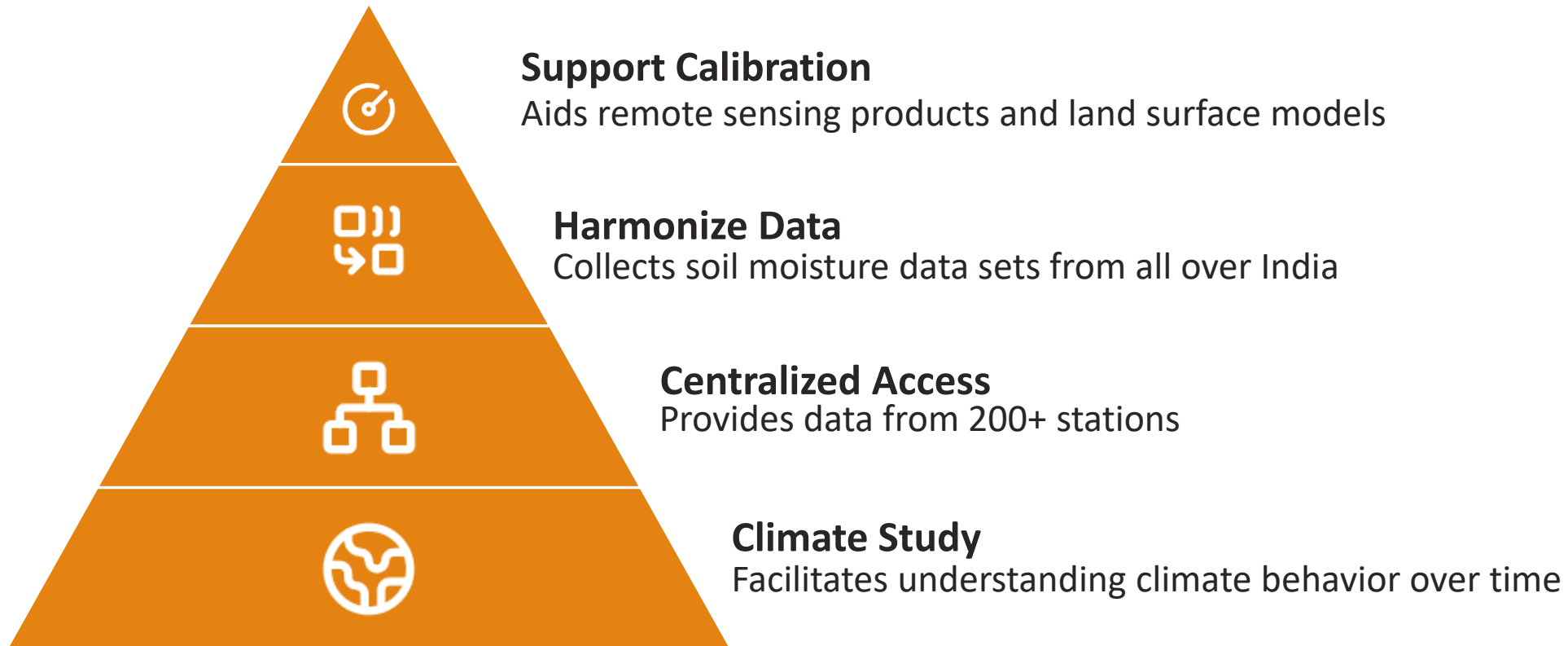
AGRO-AWS Stations

The Indian Meteorological Department has installed around ~200 AGRO-AWS stations for soil moisture and soil temperature measurements over the Indian region.

These stations are giving the measurements up to 4 soil layers (10, 30, 70, 100 cm) at every ~15 minutes temporal resolution



The Soil Moisture Network



Common Soil Moisture Errors

Constant Values

Invariable readings, sensor drop-outs, saturation

Spikes

Sudden, unpredictable rises or drops, often sensor failure

Breaks

Abrupt, enduring increases or decreases, creating offsets

Other Errors

Preferential flow, biases, lack of representativeness, drift



Need for Quality Control



- **Missing and Redundant Observations**
- Incomplete temporal records and potential sensor errors



- **Lack of Standardization**
- Maintenance practices and environmental exposure affect data consistency



- **Manual QC Infeasible**
- Not practical for large, near real-time networks



- **Automated Methods Essential**
- Needed for accurate quality characterization and data use

AGRO-AWS data before QC

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hashmi@ncmr-login00 2026-06-02]$
```

Data is collected in CSV format

Multiple parameters are available in the collected data

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```

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Top

Soil Moisture Quality Control checks



Dynamic Range Check

Flags values exceeding physical plausibility limits (0.0 – 0.6 m³/m³)



Missing/NaN Values

Flag missing observation station



Using Precipitation

Flag an observation as questionable if there is a rise in soil moisture but no significant rainfall amount in the preceding 24 h. $x_t - x_{t-24} > 2\sigma_{x[t-24,t]}$



Spike Detection

The Soil moisture derivatives (First & second) have been computed based on Savitzky-Golay filter. Increase/decrease >15% from the previous value. Check the ratio of second derivatives between t-1 and t+1 & check the ratio of variance and average over an interval of 24h

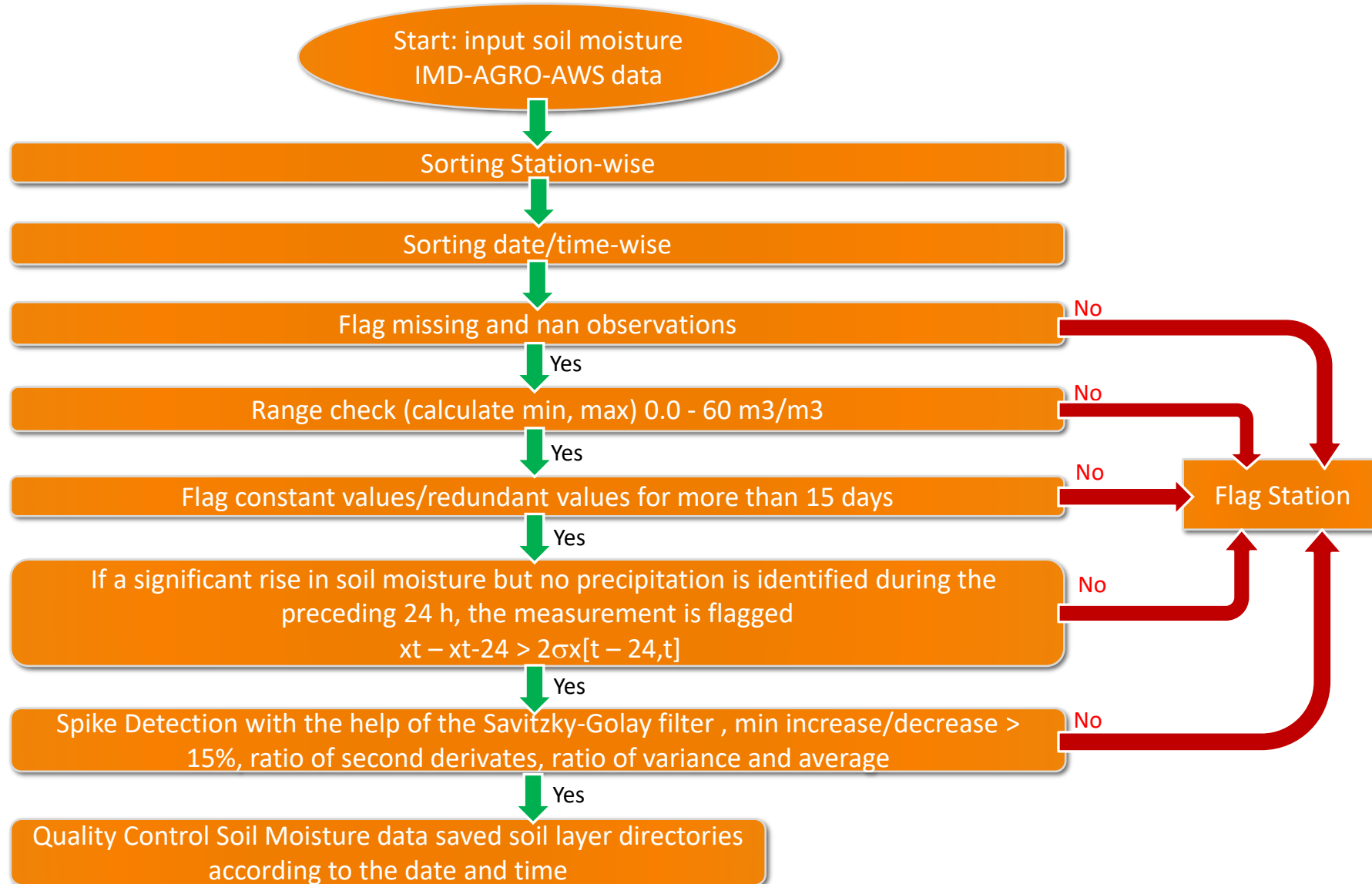


Constant Values or flatline check

Detects prolonged invariant high or low readings for more than 15 days.

Sources: Dorigo et al. 2013, 2018; Xia et al. 2015; Fatima et al. 2025

Quality Control Flowchart



AGRO-AWS Data after QC

The QC data has been kept in soil layer-wise directories (SM1, SM2, SM3, SM4)

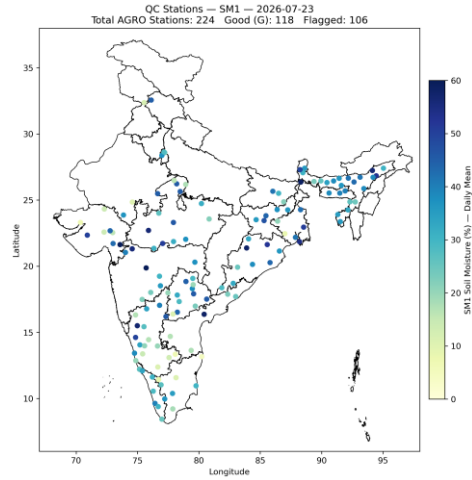
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[hashmi@ncmr-login00 2026-06-02]$ cd SM1
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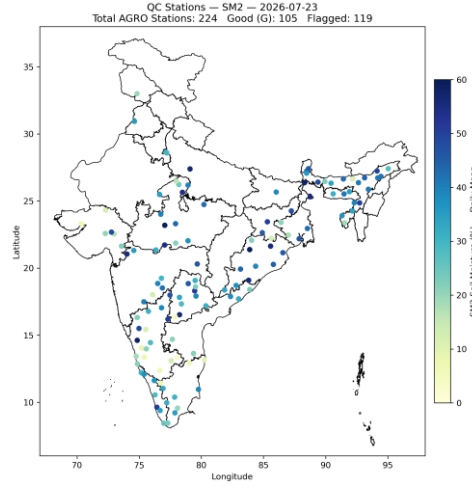
Observed Quality Control Data

Quality Control Soil Moisture Observations Stations

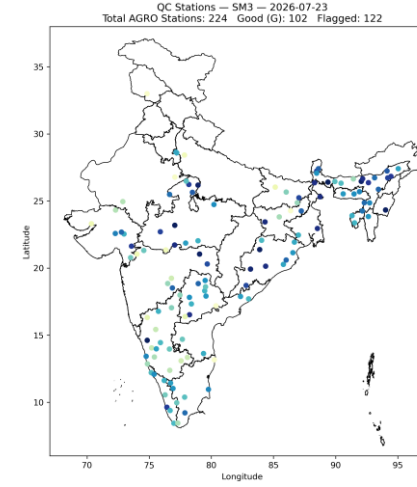
Layer 1: 10 cm



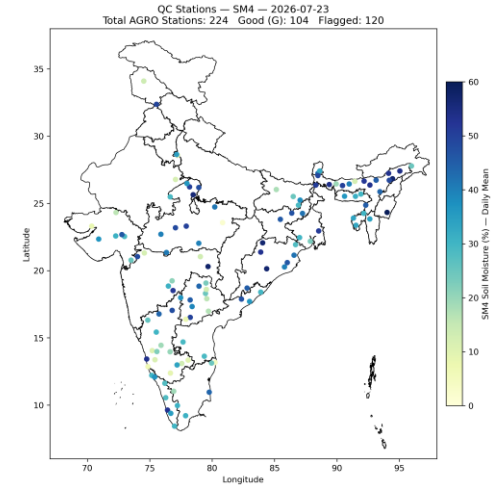
Layer 2: 30 cm



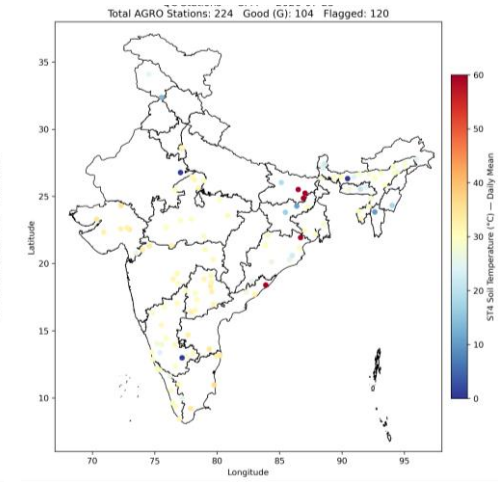
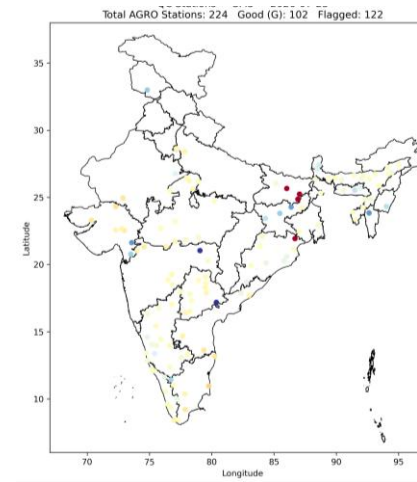
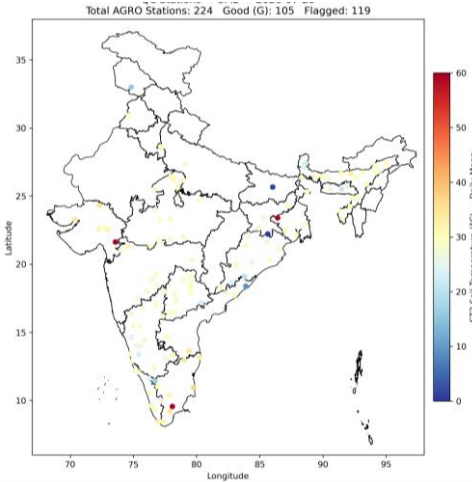
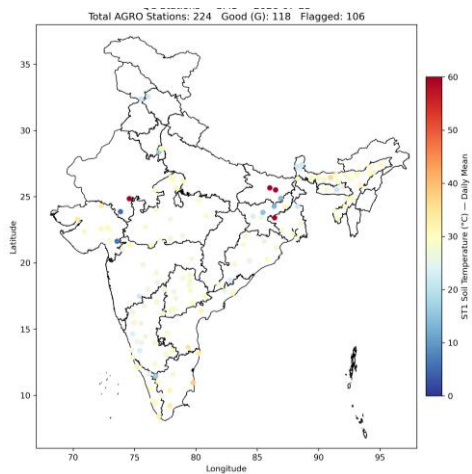
Layer 3: 70 cm



Layer 4: 100 cm

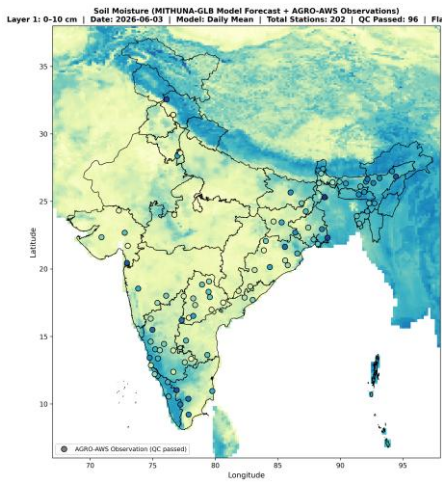


Quality Control Soil Temperature Observations Stations

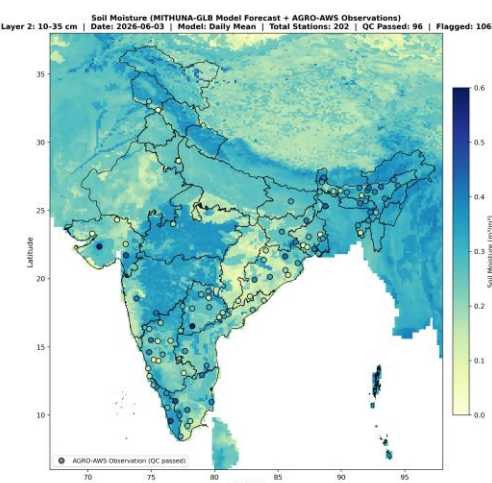


Qualitative Comparison with Mithuna-GLB Soil Moisture/Temperature Forecast

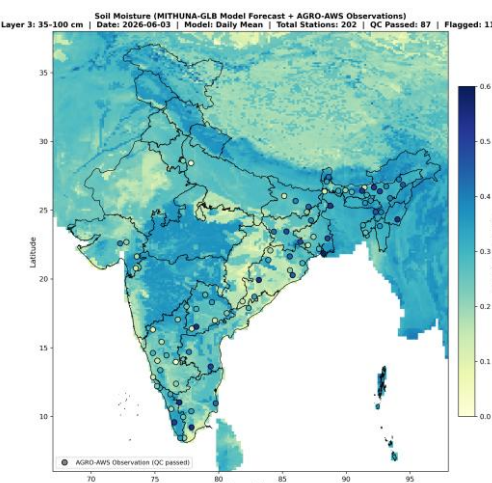
Layer 1: 10 cm



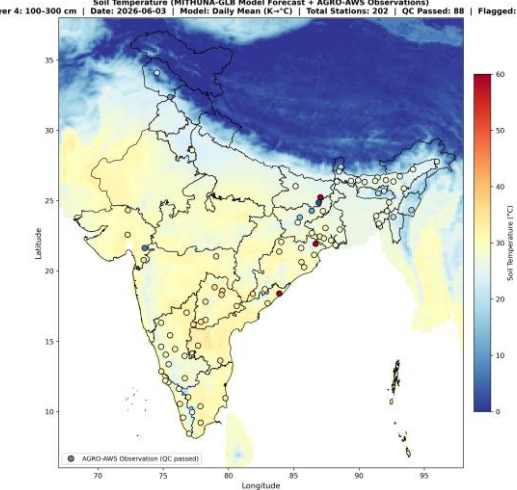
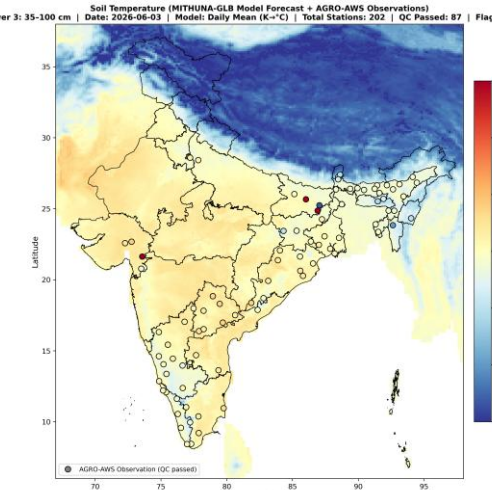
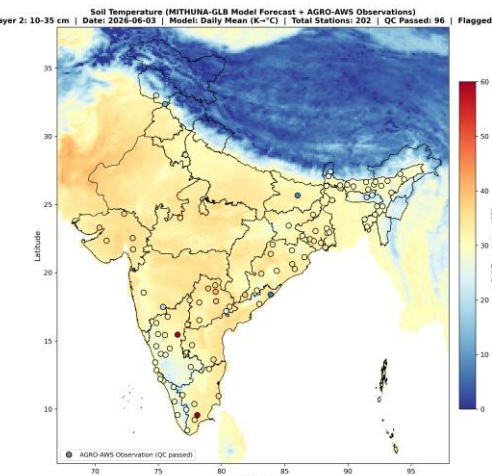
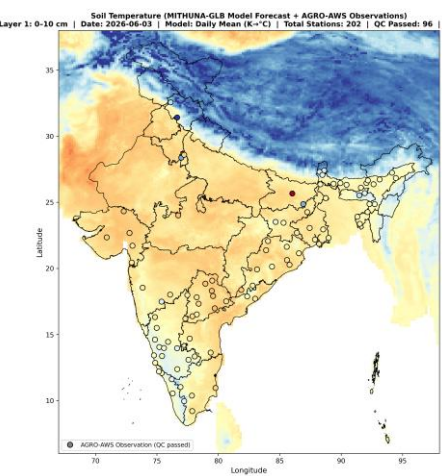
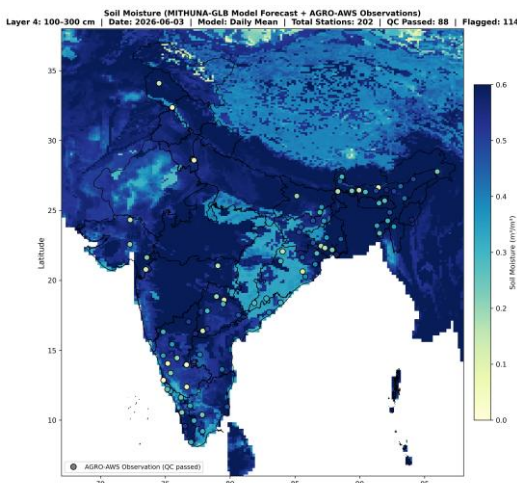
Layer 2: 30 cm



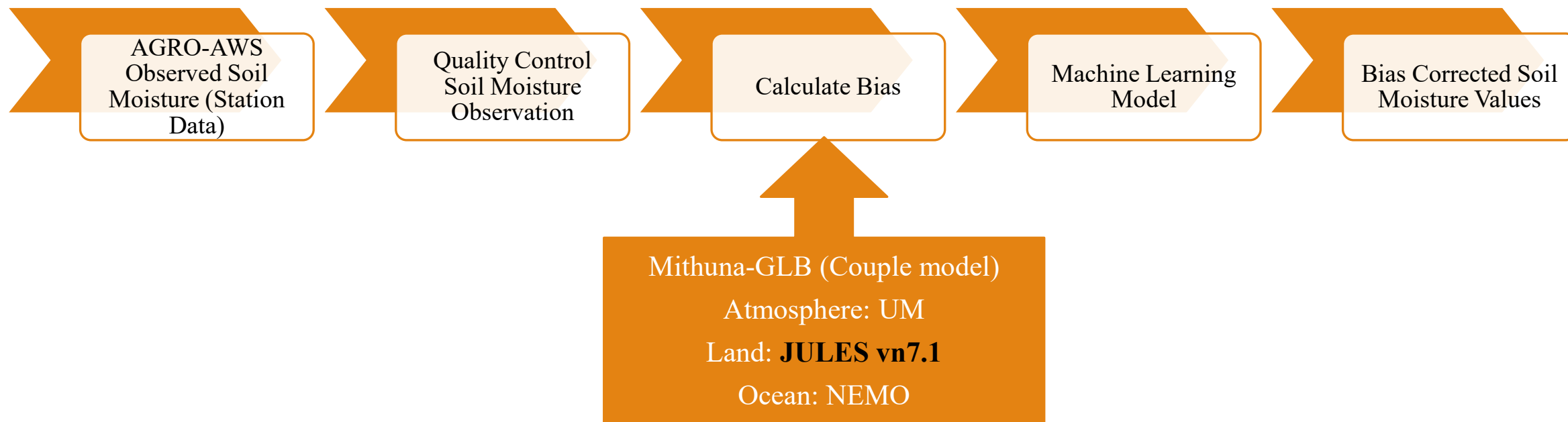
Layer 3: 70 cm



Layer 4: 100 cm

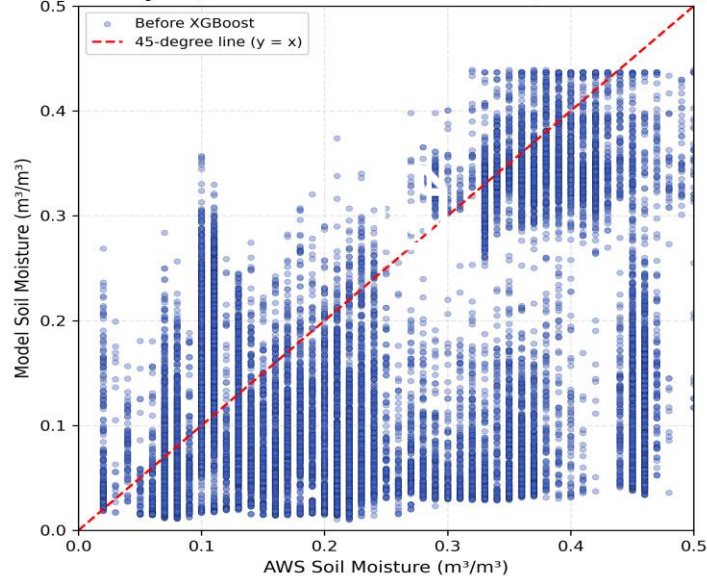


Methodology: Bias Correction of Model Forecast Soil Moisture

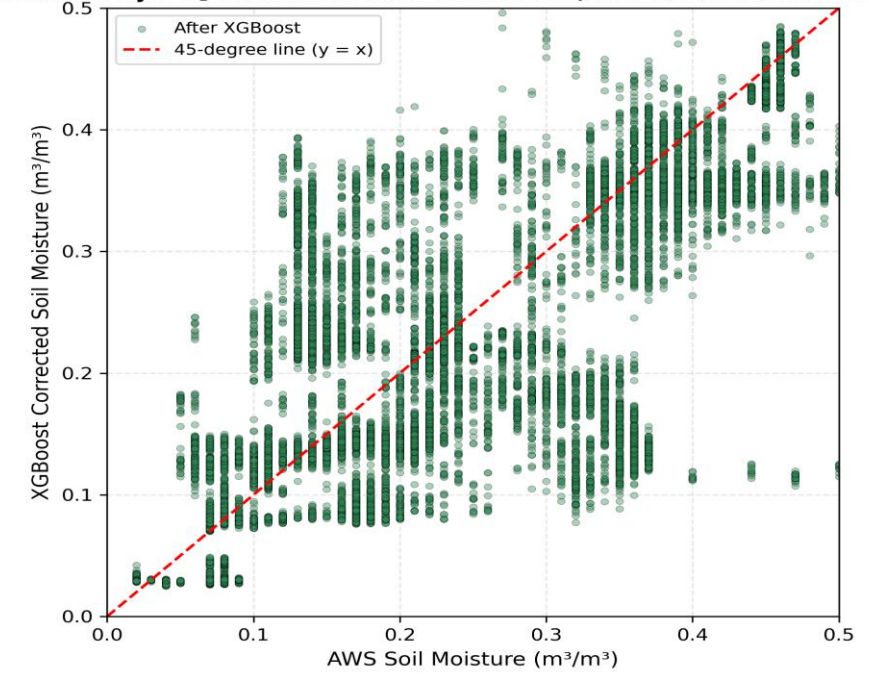


Soil Moisture Layer 1

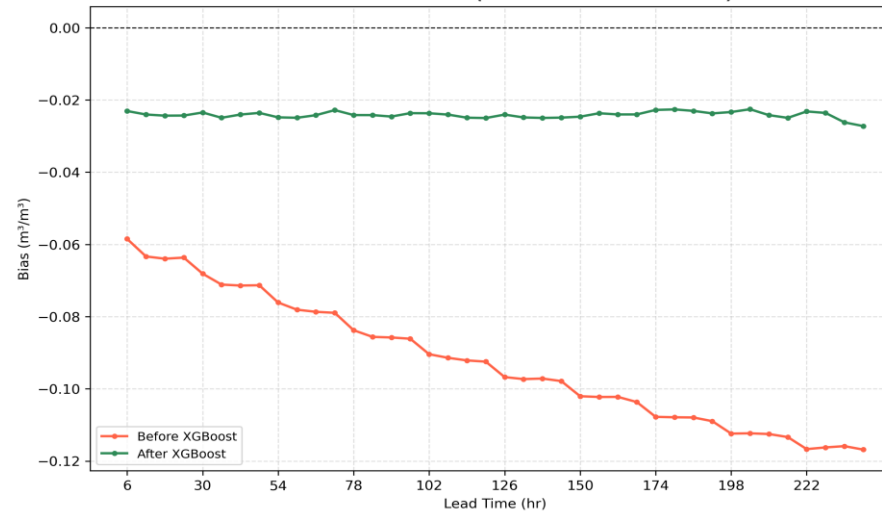
[Soil Moisture Layer 1] Correlation Before Correction (AWS vs MODEL) = 0.4428



[Soil Moisture Layer 1] Correlation After Correction (AWS vs XGB CORRECTED) = 0.8081

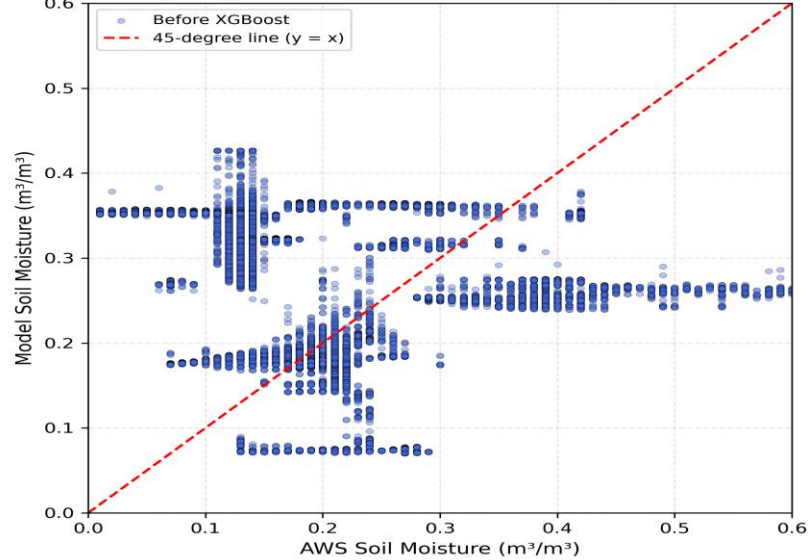


Mean Bias vs Lead Time — SM1: 0-10 cm
Before vs After XGBoost (MITHUNA-GLB – AGRO-AWS)

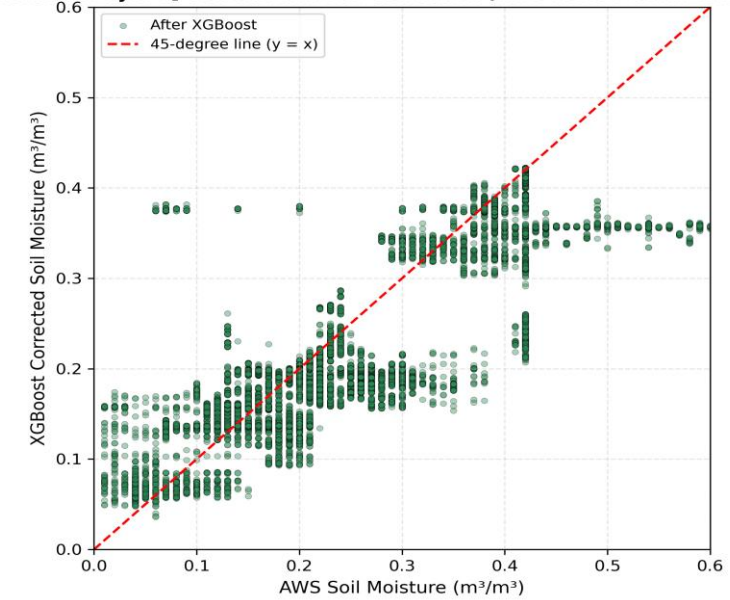


Soil Moisture Layer 2

[Soil Moisture Layer 2] Correlation Before Correction (AWS vs MODEL) = 0.1305

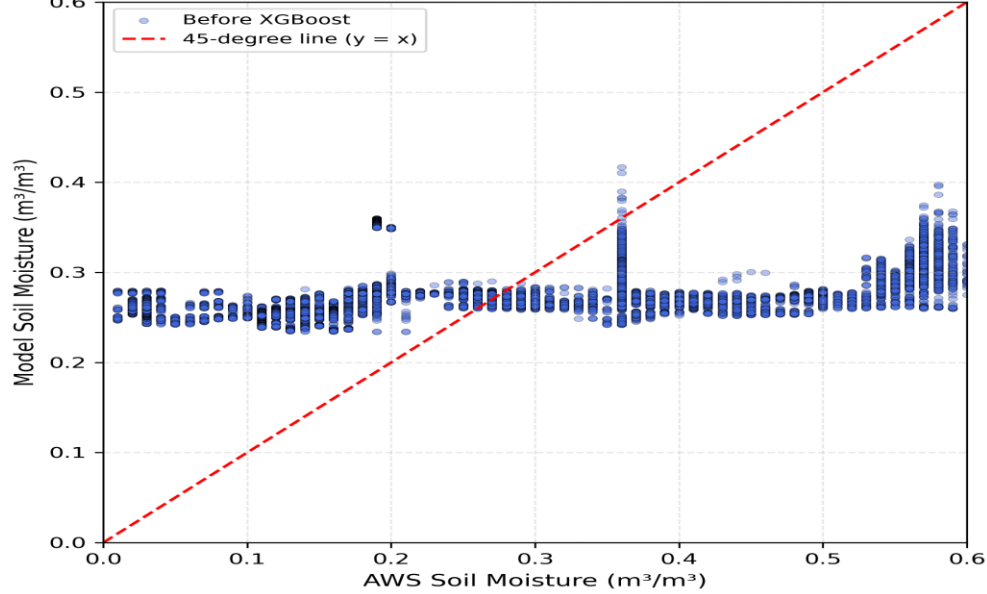


[Soil Moisture Layer 2] Correlation After Correction (AWS vs XGB CORRECTED) = 0.8570

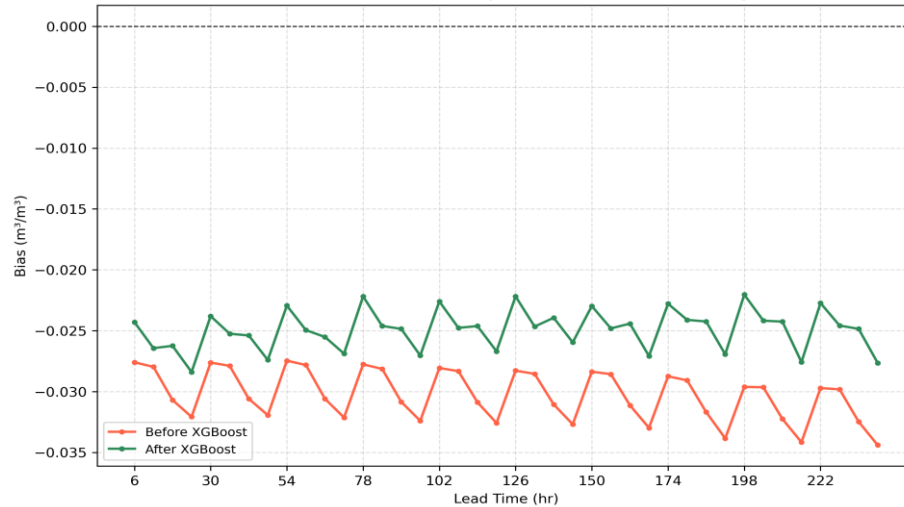


Soil Moisture Layer 3

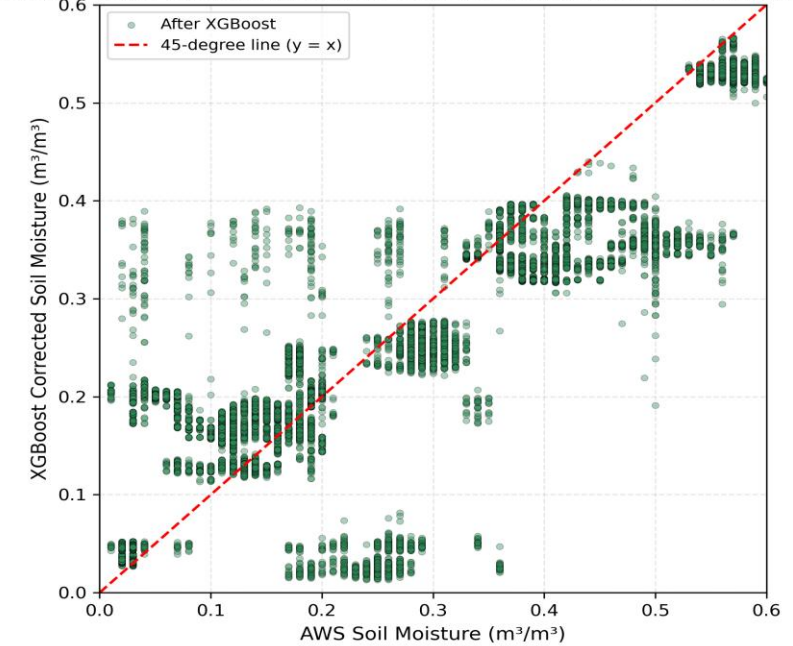
[Soil Moisture Layer 3] Correlation Before Correction (AWS vs MODEL) = 0.4119



Mean Bias vs Lead Time — SM3: 35-100 cm
Before vs After XGBoost (MITHUNA-GLB — AGRO-AWS)

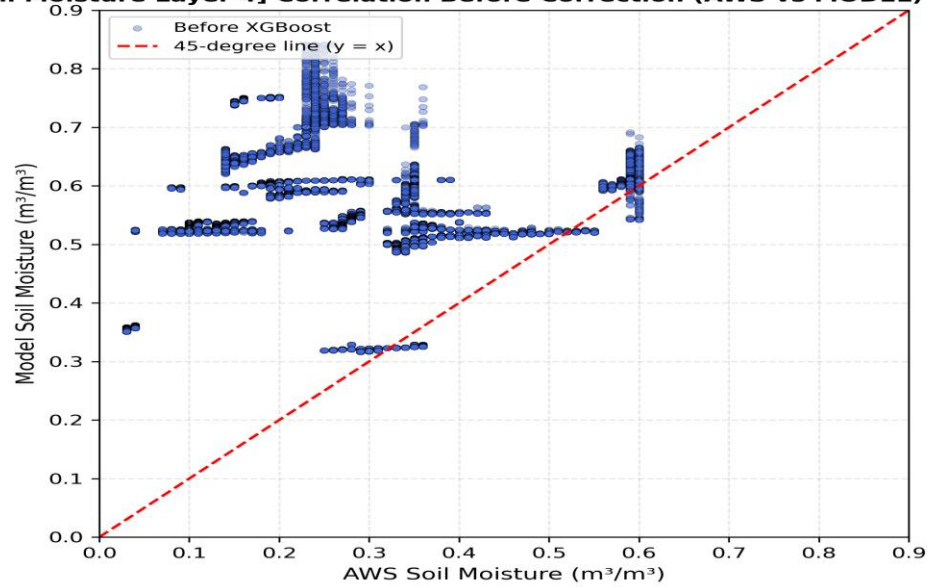


[Soil Moisture Layer 3] Correlation After Correction (AWS vs XGB CORRECTED) = 0.9081

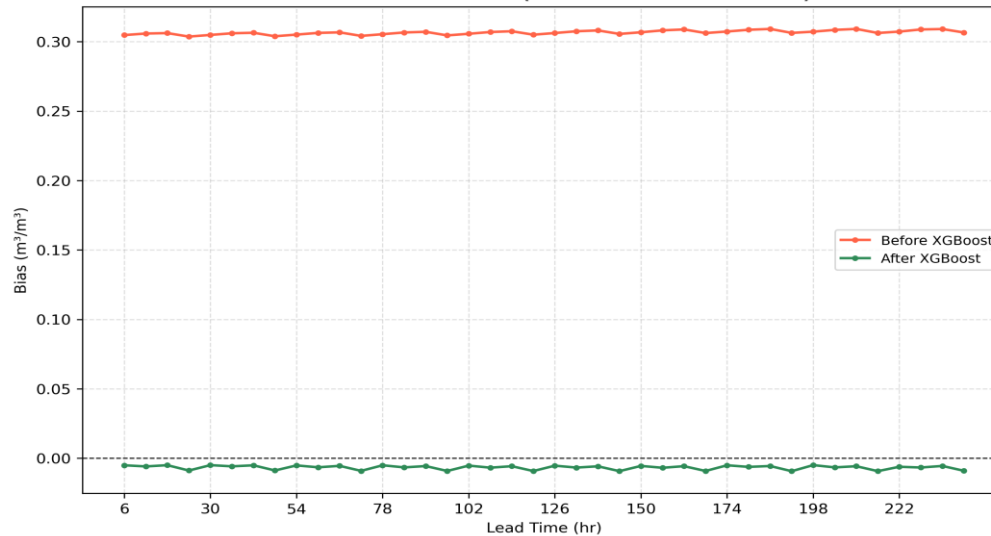


Soil Moisture Layer 4

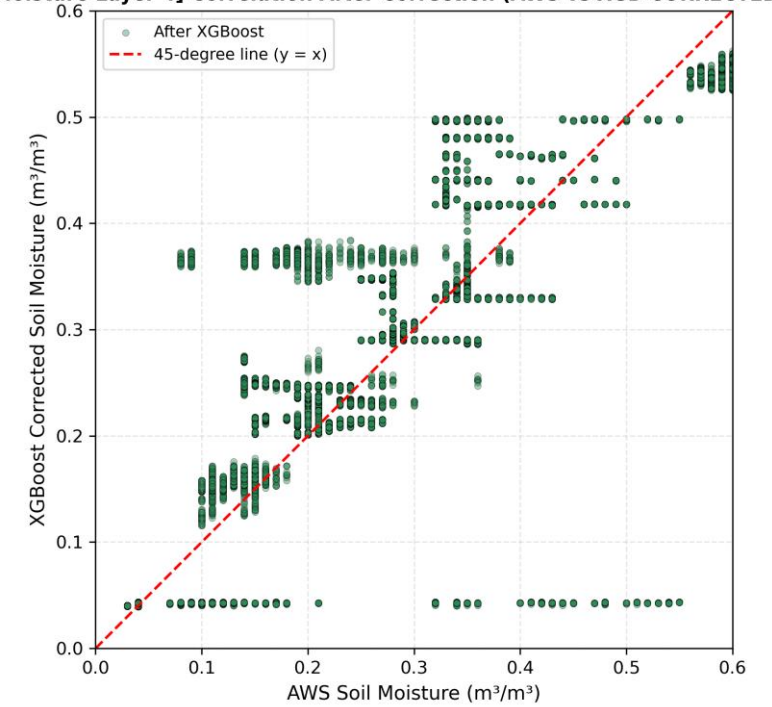
[Soil Moisture Layer 4] Correlation Before Correction (AWS vs MODEL) = 0.0799



Mean Bias vs Lead Time — SM4: 100-300 cm
Before vs After XGBoost (MITHUNA-GLB – AGRO-AWS)

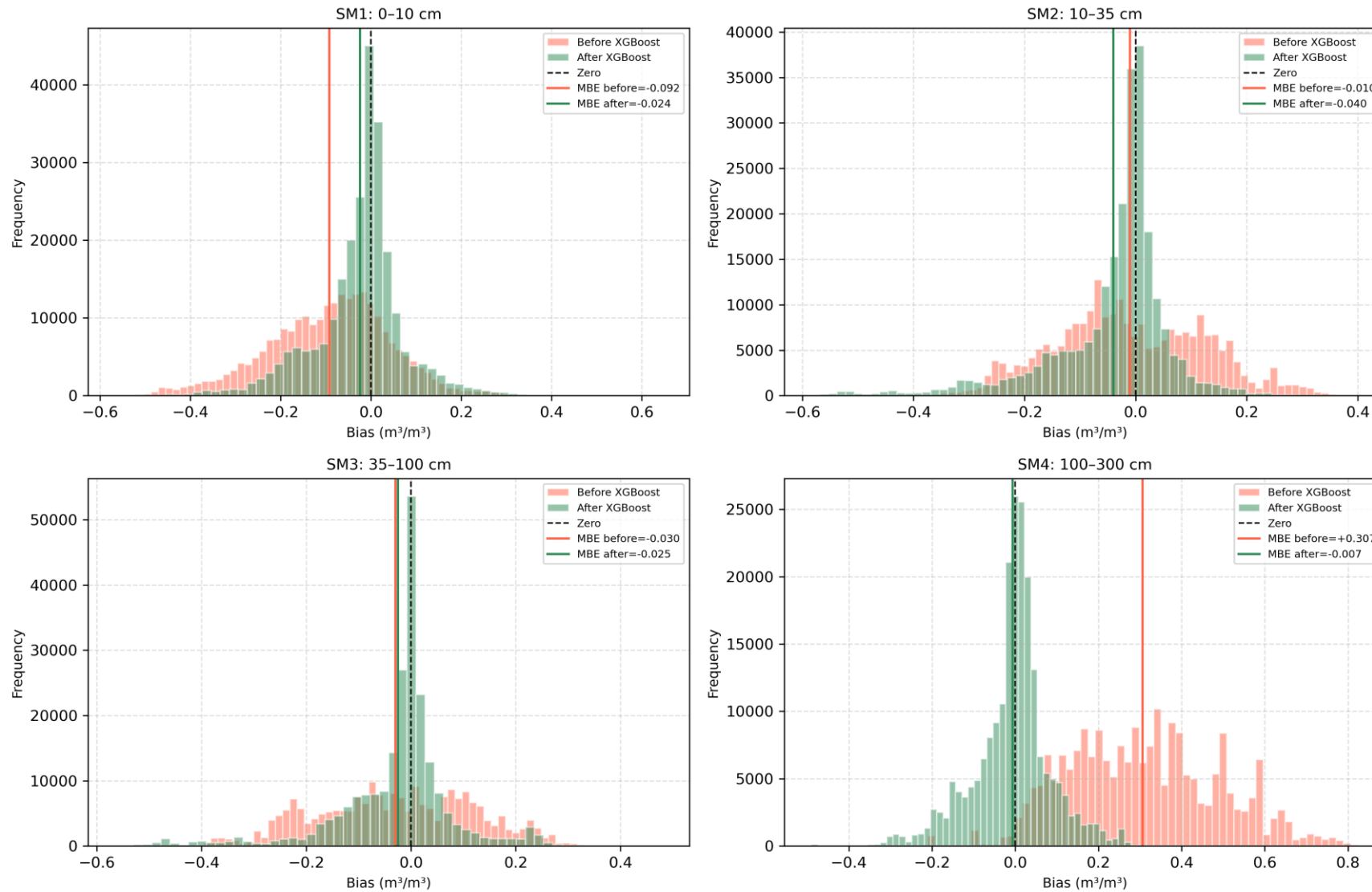


[Soil Moisture Layer 4] Correlation After Correction (AWS vs XGB CORRECTED) = 0.8312



Bias Distribution per Layer

**Bias Distribution per Layer — Before vs After XGBoost
(MITHUNA-GLB — AGRO-AWS)**



Soil Moisture Forecast : 12 Hour Leadtime

Layer	Period	MBE	RMSE	MAE	ubRMSE	R2	Correlation
							Coefficient
Layer 1	Before BC	-0.049377	0.120543	0.086726	0.109967	0.154493	0.568463
	After BC	-0.014141	0.076736	0.050582	0.075422	0.657365	0.830542
Layer 2	Before BC	0.034425	0.136151	0.111244	0.131727	-0.480514	0.120964
	After BC	-0.011393	0.061907	0.040956	0.060849	0.693912	0.840231
Layer 3	Before BC	0.05935	0.174778	0.154286	0.164392	-0.010319	0.398664
	After BC	0.012741	0.086728	0.055228	0.085787	0.751224	0.873823
Layer 4	Before BC	0.338094	0.380636	0.339514	0.17486	-6.569567	0.062157
	After BC	0.021202	0.07538	0.051219	0.072337	0.70313	0.856861

Soil Moisture Forecast : 24 Hour Leadtime

Layer	Period	MBE	RMSE	MAE	ubRMSE	R2	Correlation
							Coefficient
Layer 1	Before BC	-0.0243	0.100473	0.069903	0.09749	0.396353	0.666848
	After BC	-0.03726	0.077447	0.054112	0.067893	0.641333	0.851216
Layer 2	Before BC	0.038883	0.110933	0.089176	0.103895	-0.56828	0.299054
	After BC	-0.01556	0.043064	0.029742	0.040155	0.763659	0.891833
Layer 3	Before BC	0.054771	0.18675	0.169279	0.178537	0.147772	0.873127
	After BC	0.007193	0.049197	0.02994	0.048668	0.940856	0.973773
Layer 4	Before BC	0.316592	0.365827	0.318015	0.1833	-6.40839	-0.23052
	After BC	0.017514	0.047973	0.038513	0.044662	0.872601	0.957853

Soil Moisture Forecast : 48 Hour Leadtime

Layer	Period	MBE	RMSE	MAE	ubRMSE	R2	Correlation
							Coefficient
Layer 1	Before BC	-0.04671	0.110695	0.080743	0.100359	0.084524	0.571888
	After BC	-0.01371	0.085551	0.05941	0.084447	0.453174	0.712129
Layer 2	Before BC	0.038932	0.112636	0.090438	0.105693	-0.61679	0.286093
	After BC	-0.01551	0.042337	0.029208	0.039393	0.771581	0.895767
Layer 3	Before BC	0.054206	0.186952	0.169702	0.178921	0.145929	0.848004
	After BC	0.007665	0.051273	0.031871	0.050696	0.93576	0.971063
Layer 4	Before BC	0.31648	0.365795	0.317958	0.18343	-6.40709	-0.23246
	After BC	0.018532	0.048704	0.038511	0.04504	0.86869	0.956039

Soil Moisture Forecast : 72 Hour Leadtime

Layer	Period	MBE	RMSE	MAE	ubRMSE	R2	Correlation Coefficient
Layer 1	Before BC	-0.05844	0.12036	0.089549	0.105221	-0.08234	0.542258
	After BC	-0.01385	0.08392	0.059485	0.082769	0.473834	0.719312
Layer 2	Before BC	0.03846	0.113411	0.090975	0.10669	-0.63912	0.279529
	After BC	-0.01804	0.044726	0.031546	0.040928	0.74507	0.886976
Layer 3	Before BC	0.053057	0.187079	0.170065	0.179397	0.144767	0.86659
	After BC	0.004854	0.04976	0.03267	0.049523	0.939493	0.973227
Layer 4	Before BC	0.31631	0.365741	0.317755	0.183613	-6.40489	-0.23499
	After BC	0.020384	0.047921	0.038842	0.04337	0.872875	0.960724

Conclusion and summary

- Systematic biases vary by depth and forecast lead time: model generally underestimating surface soil moisture and overestimating deep layer soil moisture.
- There is significant improvement in MAE, MBE, RMSE and correlation coefficient.
- Feature importance analysis shows that station latitude and longitude dominate the correction, indicating the model primarily learns a spatially varying climatological adjustment
- An ablation experiment confirms that dynamic predictors (model soil moisture, lead time, month, rainfall, and soil temperature) nonetheless carry a genuine standalone bias-correction signal.
- These findings show that machine learning effectively corrects point-scale soil moisture bias but has limitations in ungauged areas, highlighting the need for gridded bias correction across the model domain.

Thank You