Historical Climate Reconstruction for Drought Risk Modeling in NYC's Water Supply

CATSKILL ENVIRONMENTAL RESEARCH & MONITORING CONFERENCE
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The Institute for Sustainable Cities at Hunter College
CERM 2025
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Outline

- Background : Drought & NYC Water Supply
- Methodology : Data sources, models and framework
- Results & Discussion
- Summary

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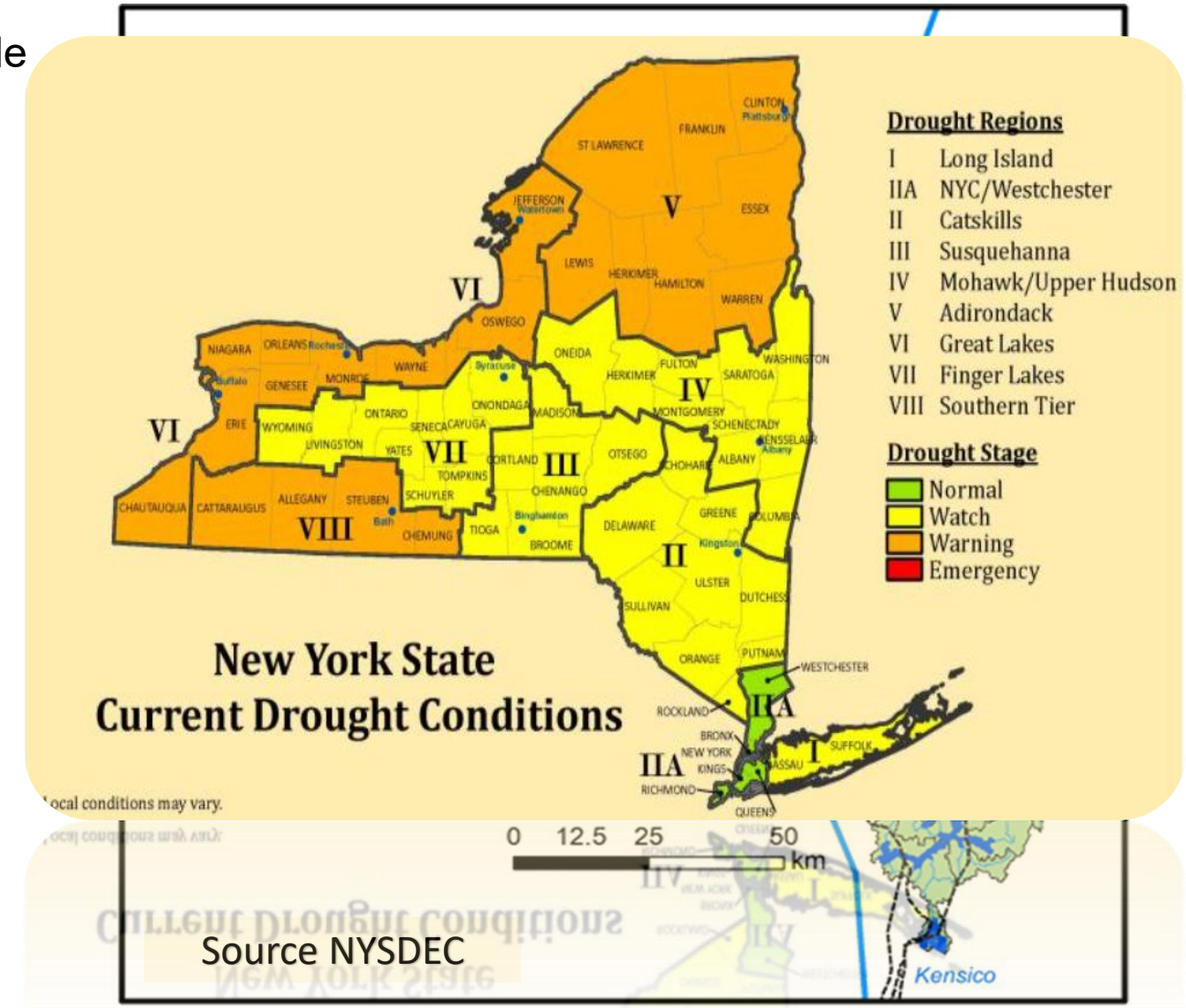
Importance of Drought Assessment for NYC Water Supply

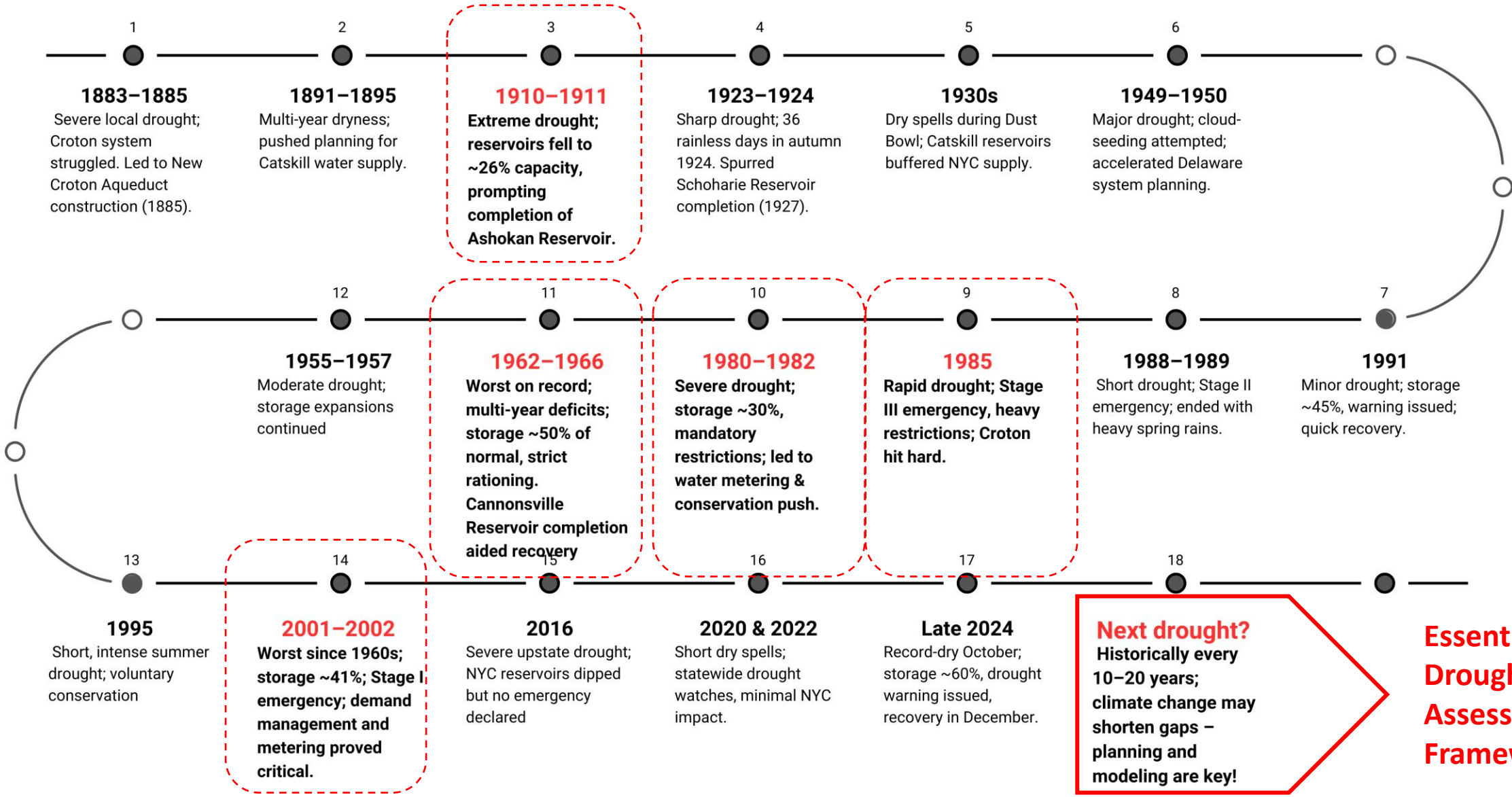
NYC Water Supply System: **Serves ~**9 Million People

- **Drought vulnerability:** Despite ~30% demand reduction since the 1900s, the system remains exposed to drought, and climate change may heighten this risk
- **Periodic droughts:** The system faces drought at intervals over the decades, setting up the historical patterns



Source NYSDEC

NYC WATERSHED DROUGHT TIMELINE



Drought Assessment Framework:

- **Core Components of drought assessment:**
  Monitoring, indexing, modeling, prediction, risk evaluation, and impact assessment.
- **Recent studies emphasize that long-term, high-resolution, and complete datasets** are essential for accurate drought assessment and prediction.
- **Incomplete or low-quality historical data** can significantly reduce the reliability of drought indices and forecast models.
- **Gap filling and data reconstruction** are foundational steps before any advanced modeling.

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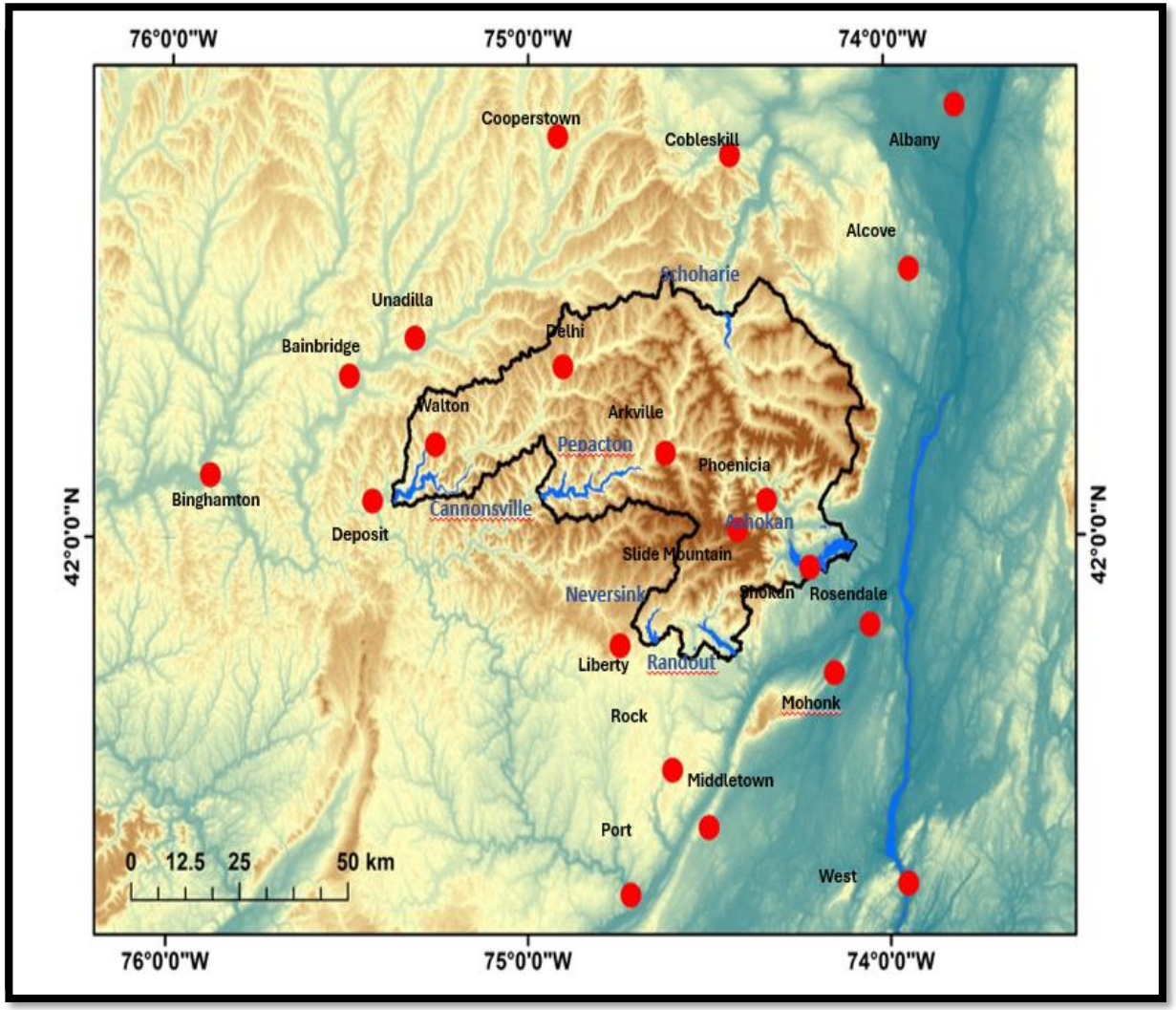
Data Sources

1. PRISM (Parameter-elevation Regressions on Independent Slopes Model) Gridded Product used to estimate basin-scale values back to 1981

- 4 km resolution, daily Tmin, Tmax, PRCP.
- 6 WOH reservoirs Coverage: 1981–2024.
- **Gap free but Limited daily coverage (historical period)**

2. Observational Climate Data from Weather Stations Used to estimate basin-scale values prior to 1981

- NOAA/NCEI Global Historical Climatology Network (GHCN-Daily)
  - 12 temperature and 19 precipitation stations in and around NYC watershed.
  - Records from 1890–2025, with gaps
  - Variables: daily Tmin, Tmax, and PRCP.



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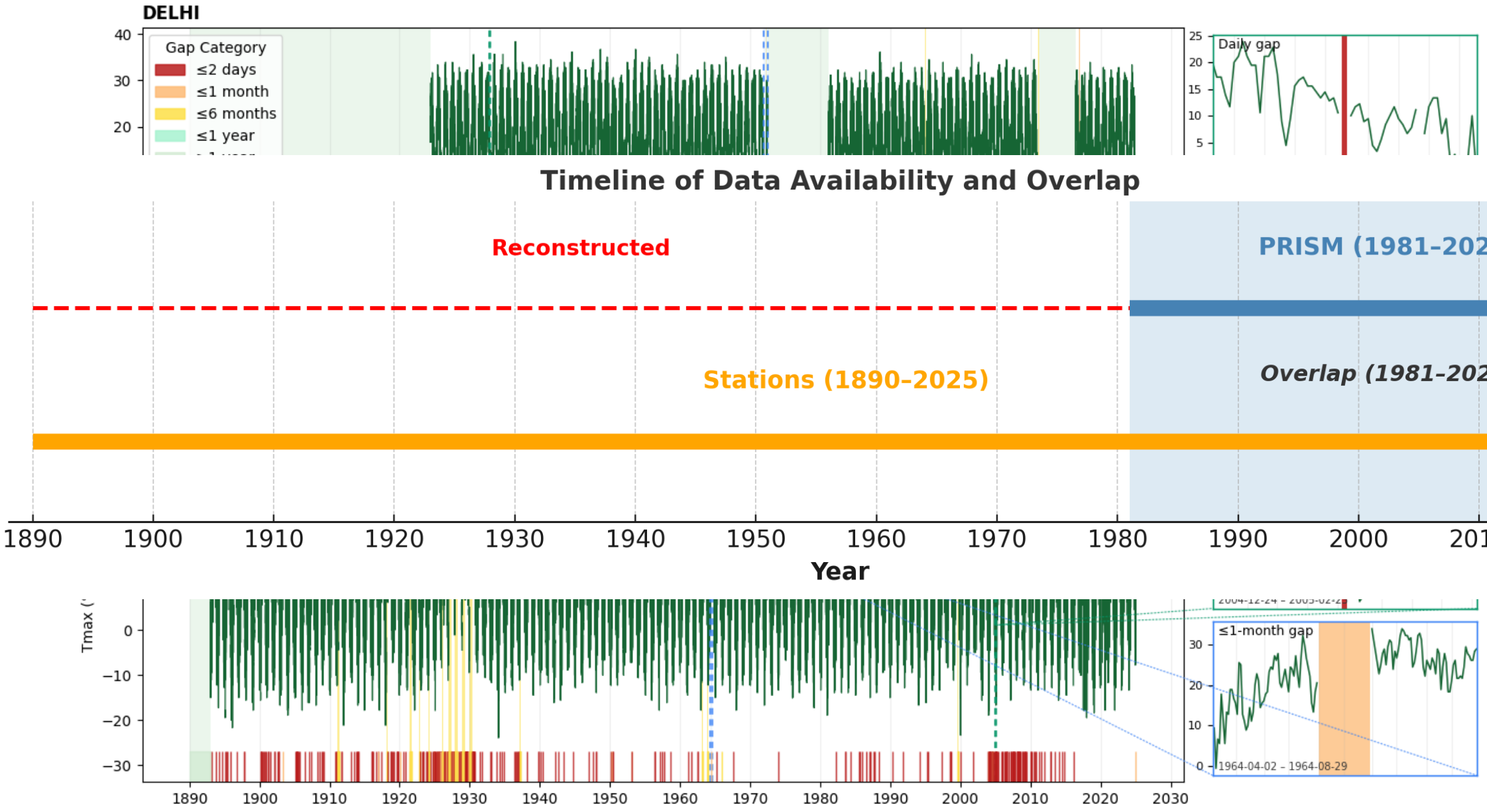
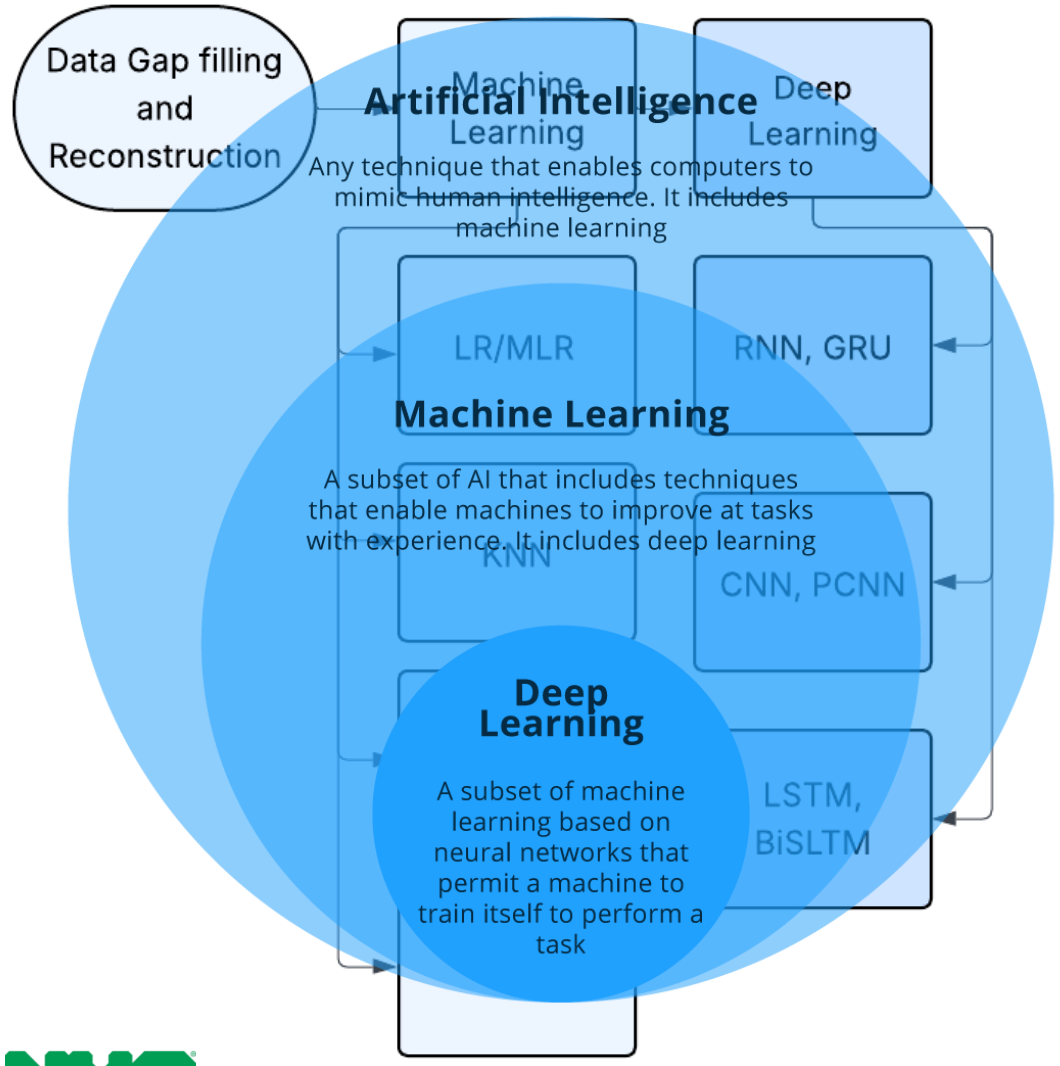


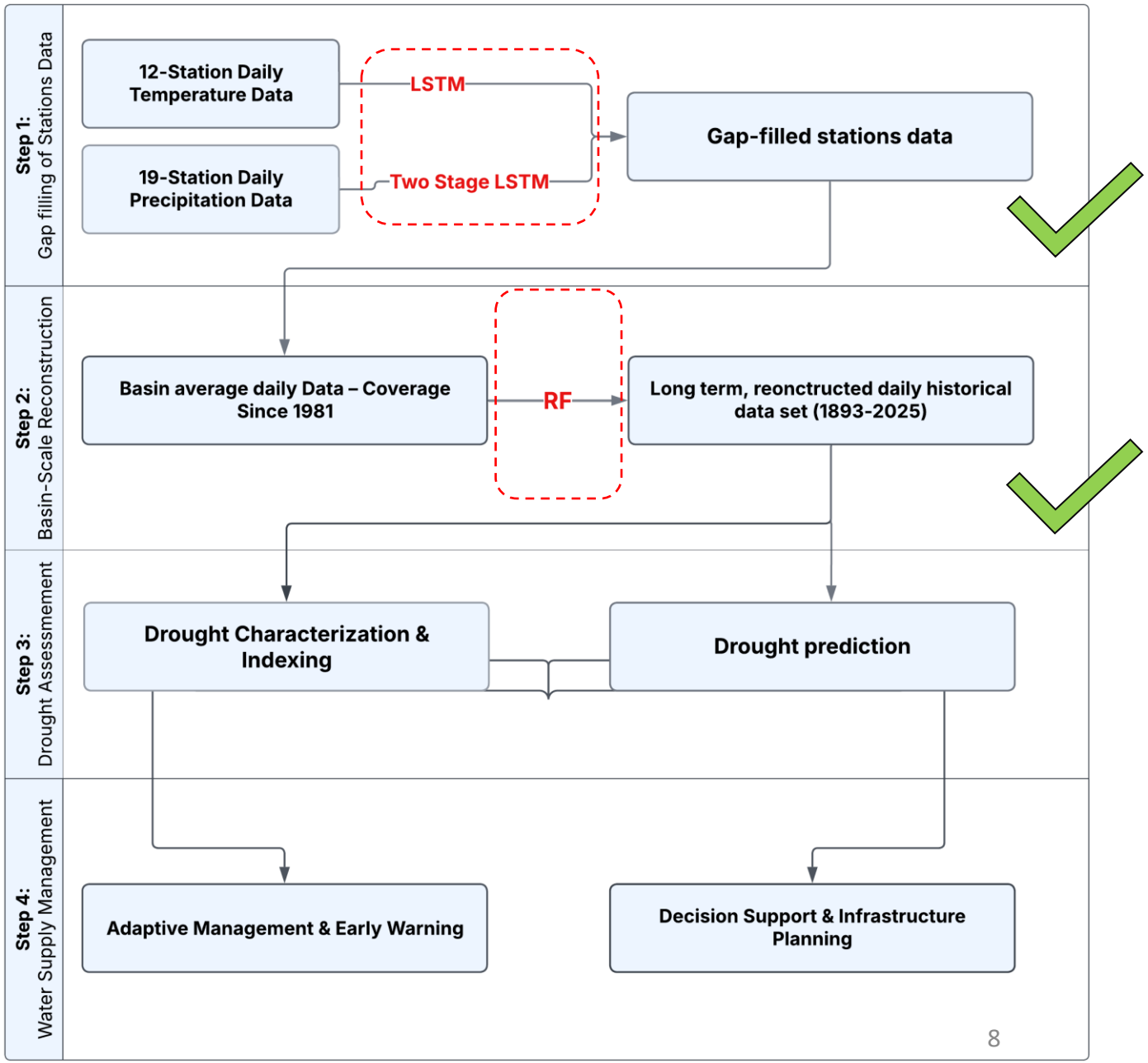
Step 2: Basin-Scale Reconstruction

Recent Methodological Developments in Drought Analysis:

Literature review



Methodological Framework



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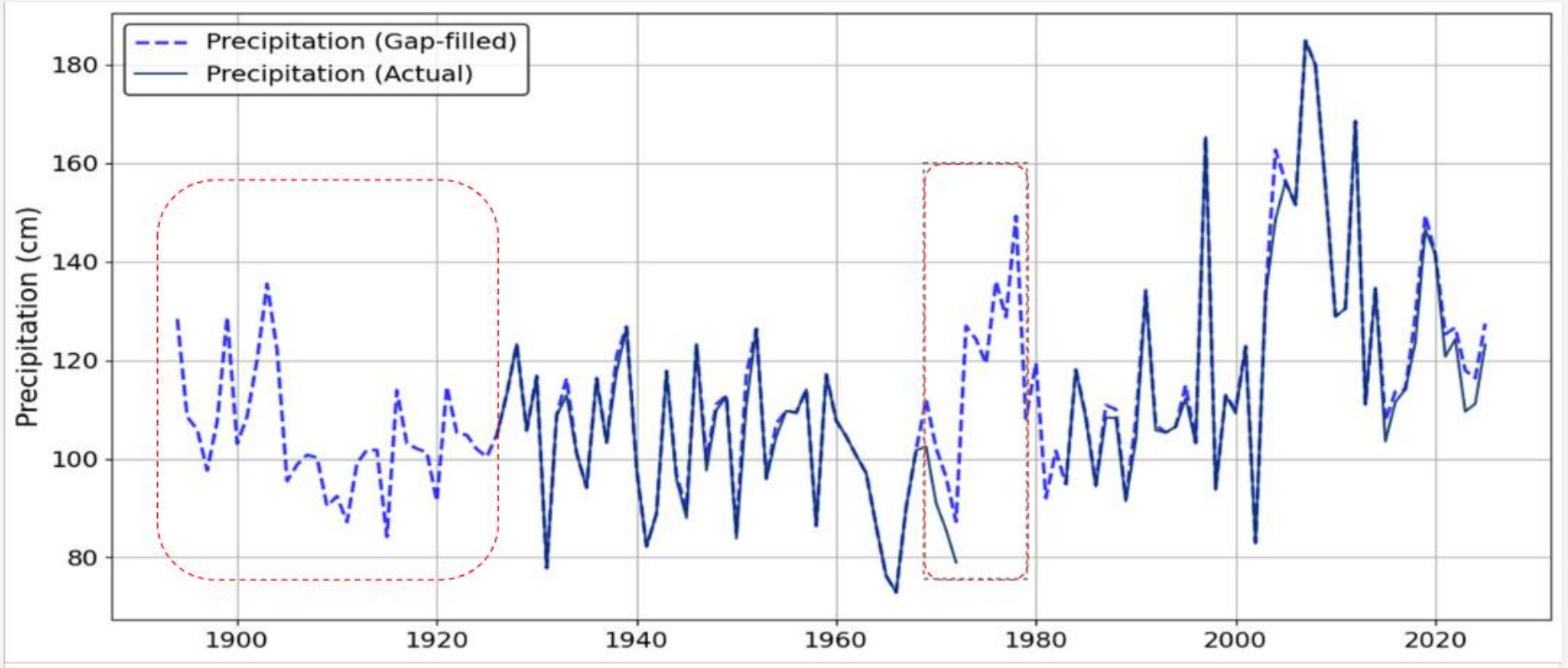
Step 1- Sample Results:

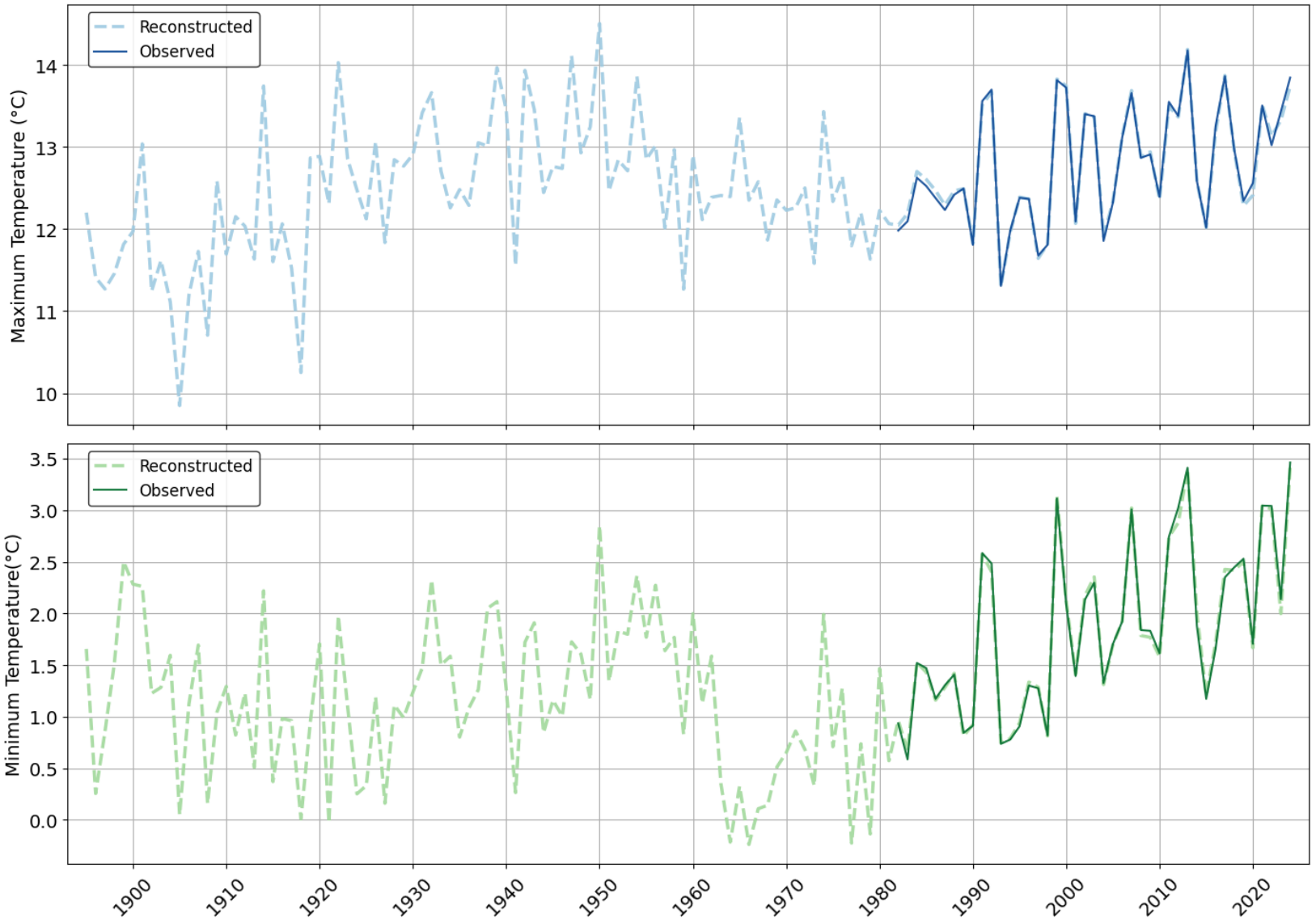
Gap-Filled and Reconstructed time series at DELHI Station



Parameter	Model	MAE	RMSE	R^2
Minimum Temperature	Unified LSTM	0.093°C	0.129°C	0.999
Maximum Temperature	Unified LSTM	0.092°C	0.147°C	0.999
Precipitation	Two-tier LSTM	0.012cm	0.0398cm	0.997

Step 2 - Sample Results:

Reconstructed Time Series of PRISM-based Basin-scale data for Ashokan basin



Parameter	Model	MAE	RMSE	R^2
Precipitation	RF	0.090cm	0.233cm	0.936
Minimum Temperature	RF	0.234 °C	0.331°C	0.999
Maximum Temperature	RF	0.199 °C	0.291°C	0.999

Bias, Uncertainty, and Model validation: How reliable are the results of gap-filling and reconstruction?

Step 1: Early-Period Gap-Filling Reliability:

-Hindcasting

Step 2: PRISM Reconstruction Accuracy:

- Validated against independent NOAA datasets:

- NClimGrid (gridded product: 1951-2024)

Hindcasting and Independent validation confirmed the **accuracy and reliability** of the AI-based framework for historical data gap-filling and reconstruction, supporting its application in drought indexing and forecasting.

Conclusion & Key Takeaways

- **Potential Drought Risk**: Climate change → Drought assessment framework
- **Data Matter:** Long-term, gap free, high-resolution records are essential.
- **AI-based Models:** Frontier in climate data gap-filling and reconstruction.
- **Best Methods:** LSTM for gap-filling; Random Forest for PRISM reconstruction.
- **Validation**: Confirmed through hindcasting & NOAA dataset comparison.
- **Future work:** Advancing drought modeling and water supply management.

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Thank you for your attention!

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Cannonsville reservoir by NYC water

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More information

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- Drought warning issued for 12 Upstate NY counties as dry spell lingers - syracuse.com

Supplementary

Comparison of optimal model's performance for gap filling with other models in the form of RMSE evaluated at Slide-Phoenicia (Training set)

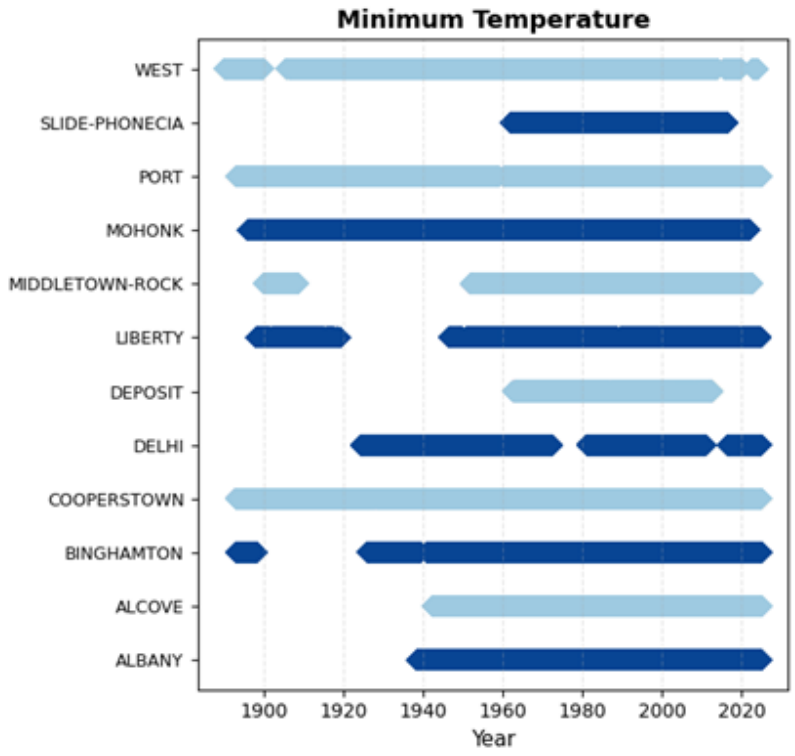
Variable	LSTM	LR	RF	GB
T_{max}	0.089 °C	1.729 °C	0.628 °C	1.677 °C
T_{min}	0.160 °C	2.157 °C	0.761 °C	2.062 °C
Precip_Wet	0.0821 cm	0.899 cm	0.340 cm	0.758 cm
Precip_Dry	0.013 cm	0.196 cm	0.069 cm	0.162 cm

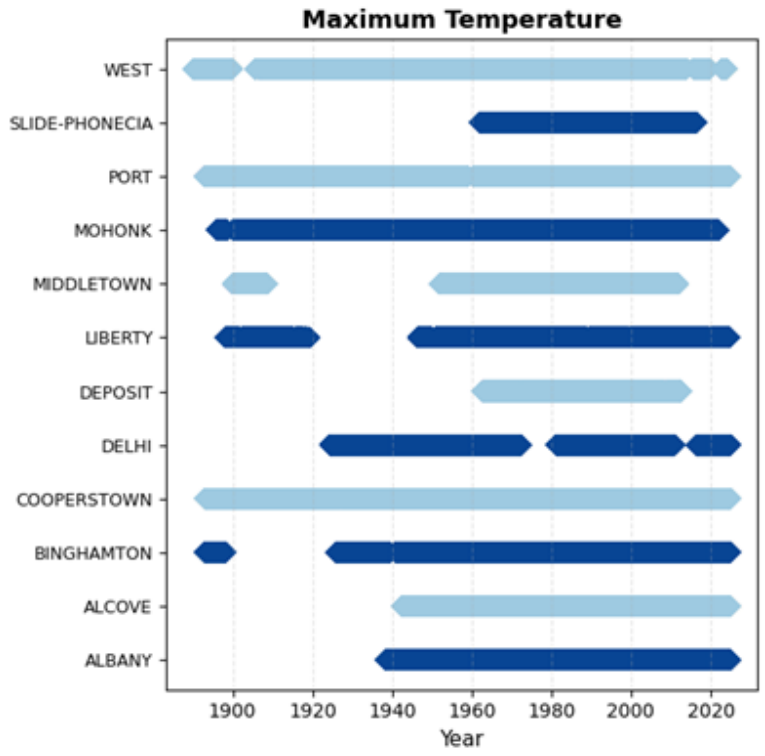
Comparison of optimal model's performance with other models in the form of RMSE evaluated with basin-scale average estimation for Schoharie basin

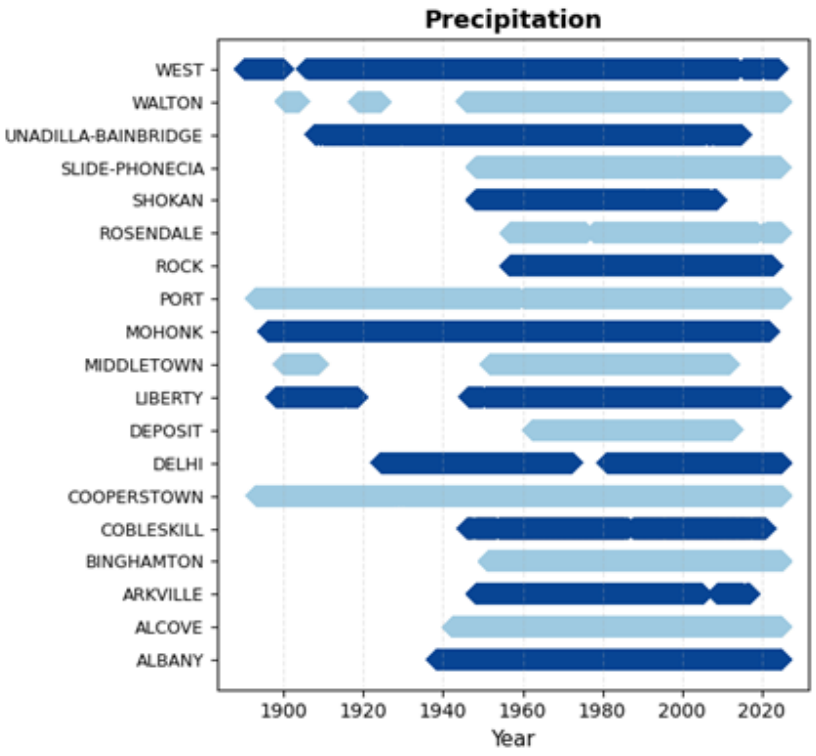
Variable	LSTM	LR	RF	GB
T_{max}	0.846 °C	0.954 °C	0.342 °C	0.967 °C
T_{min}	1.074 °C	1.283 °C	0.441 °C	1.297 °C
Precip_Wet	0.327 cm	0.340 cm	0.134 cm	0.308 cm
Precip_Dry	0.037 cm	0.062 cm	0.019 cm	0.054 cm

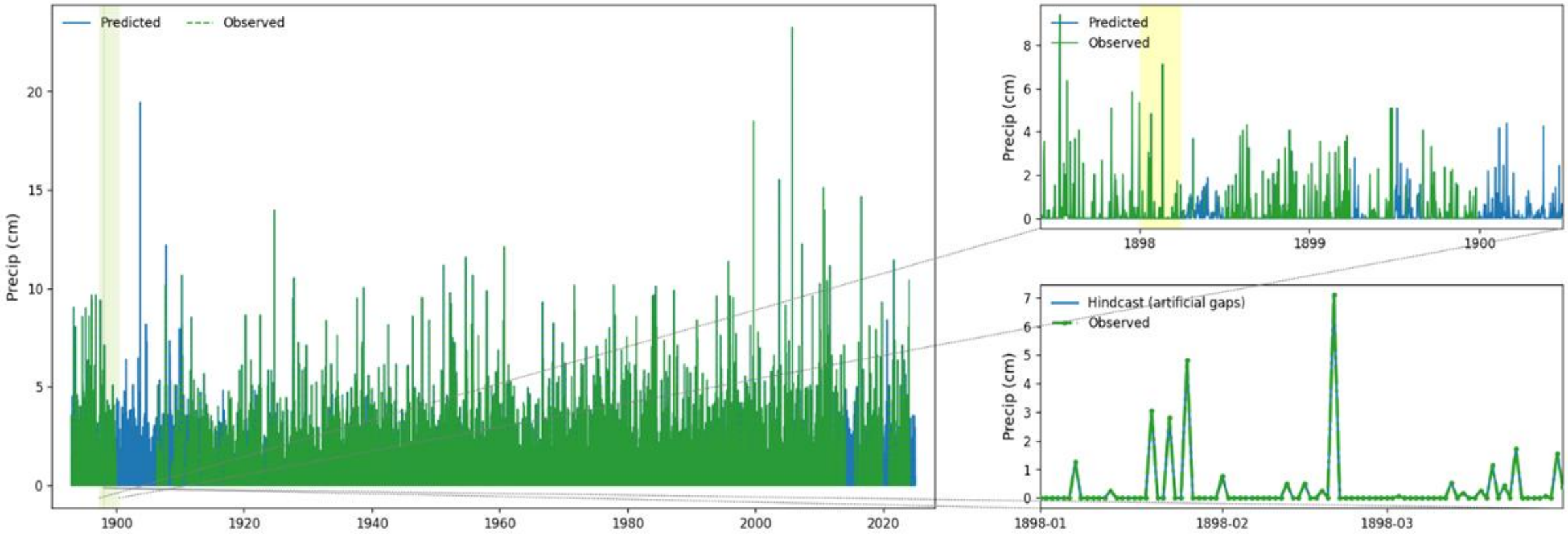
Missing-Value Characterization of Station Observations (Tmin, Tmax, and Precipitation)

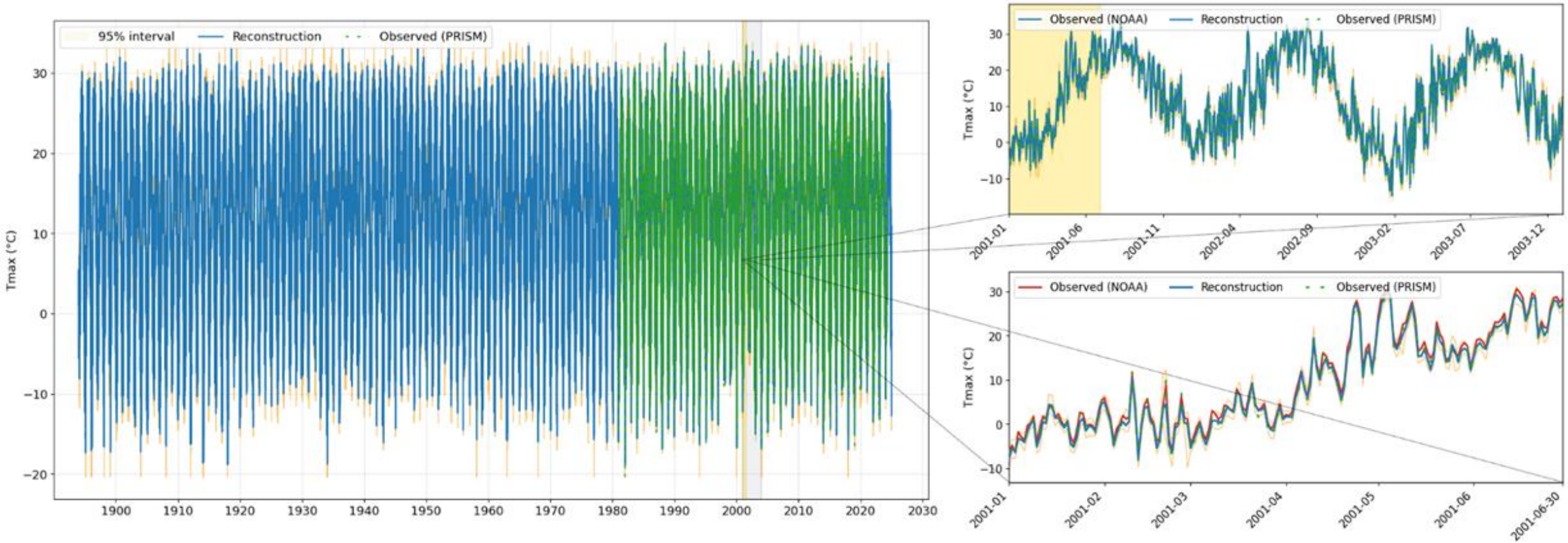
	Coverage period years			Missing pct coverage period (%)			Longest gap coverage (d)		
Stations	T_{max}	T_{min}	Precip	T_{max}	T_{min}	Precip	T_{max}	Tm_{in}	Precip
ALBANY	1938-2025	1938-2025	1938-2025	0.01	0.01	0.01	1	1	1
ALCOVE	1942-2025	1942-2025	1942-2025	6.41	7.76	4.78	153	153	153
ARKVILLE	N/A	N/A	1948-2016	N/A	N/A	7.62	N/A	N/A	1371
BINGHAMTON	1893-2025	1893-2025	1951-2025	22.08	22.1	0.01	10107	10107	2
COBLESKILL	N/A	N/A	1946-2021	N/A	N/A	4.44	N/A	N/A	397
COOPERSTOWN	1893-2025	1893-2025	1893-2025	3.66	3.98	4.71	155	155	152
DELHI	1924-2025	1924-2025	1924-2025	15.32	15.89	9.95	3165	3165	3165
DEPOSIT	1962-2012	1962-2012	1962-2012	4.83	4.42	0.68	31	31	31
LIBERTY	1898-2024	1898-2024	1898-2024	27.65	27.97	28.28	9923	9923	10165
MIDDLETOWN	1900-2011	N/A	1900-2011	41.02	N/A	40.6	15766	N/A	15766
MIDDLETOWN - ROCK	N/A	1900-2022	N/A	N/A	38.3	N/A	N/A	15766	N/A
MOHONK	1896-2021	1896-2021	1896-2021	2.28	1.69	2.86	504	62	123
PORT	1893-2025	1893-2025	1893-2025	2.15	2.15	5.68	451	456	451
ROCK	N/A	N/A	1956-2022	N/A	N/A	2.5	N/A	N/A	136
ROSENDALE	N/A	N/A	1956-2025	N/A	N/A	17.1	N/A	N/A	762
SHOKAN	N/A	N/A	1948-2008	N/A	N/A	3.76	N/A	N/A	242
SLIDE-PHONECIA	1961-2016	1961-2016	1948-2024	2.72	2.21	1.39	127	62	61
UNADILLA-BAINBRIDGE	N/A	N/A	1907-2014	N/A	N/A	4.82	N/A	N/A	242
WALTON	N/A	N/A	1900-2025	N/A	N/A	31.86	N/A	N/A	7823
WEST	1890-2024	1890-2024	1890-2024	11.63	10.62	15.36	2069	2071	2071

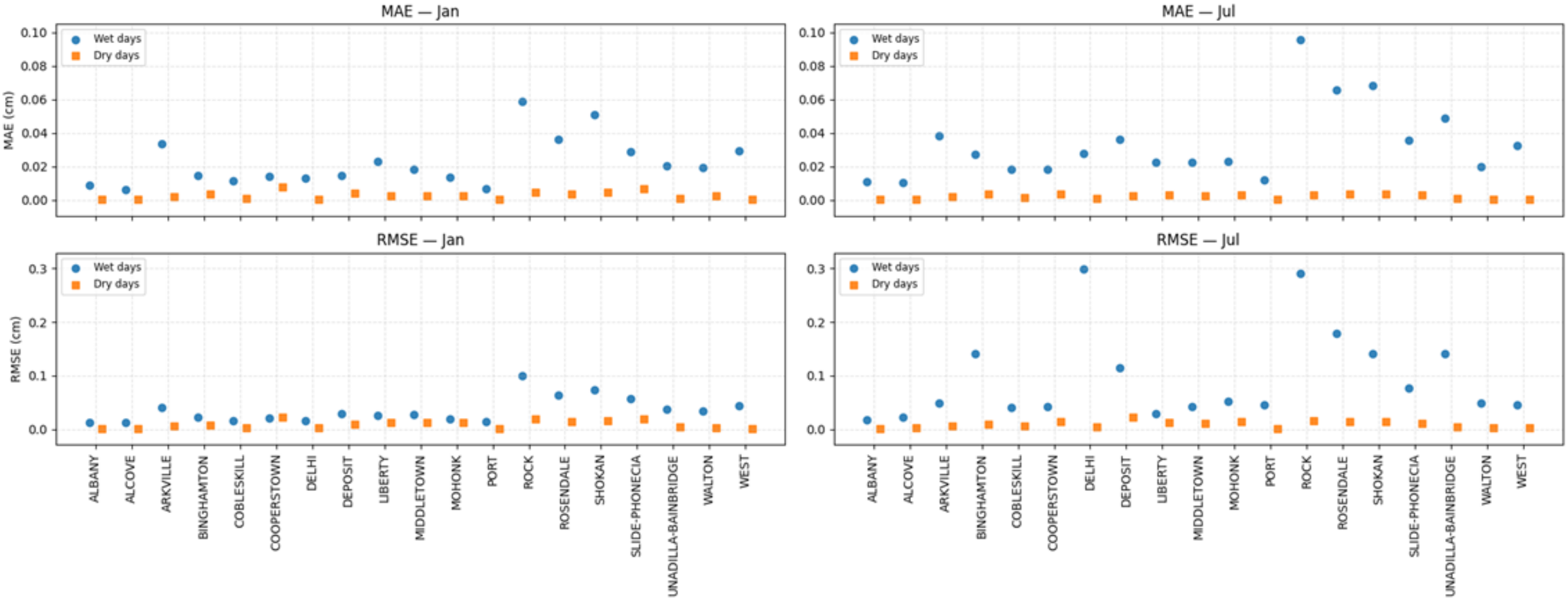

Minimum Temperature
WEST
SLIDE-PHONECIA
PORT
MOHONK
MIDDLETOWN-ROCK
LIBERTY
DEPOSIT
DELHI
COOPERSTOWN
BINGHAMTON
ALCOVE
ALBANY
1900
1920
1940
1960
1980
2000
2020
Year


Maximum Temperature
WEST
SLIDE-PHONECIA
PORT
MOHONK
MIDDLETOWN
LIBERTY
DEPOSIT
DELHI
COOPERSTOWN
BINGHAMTON
ALCOVE
ALBANY
1900
1920
1940
1960
1980
2000
2020
Year

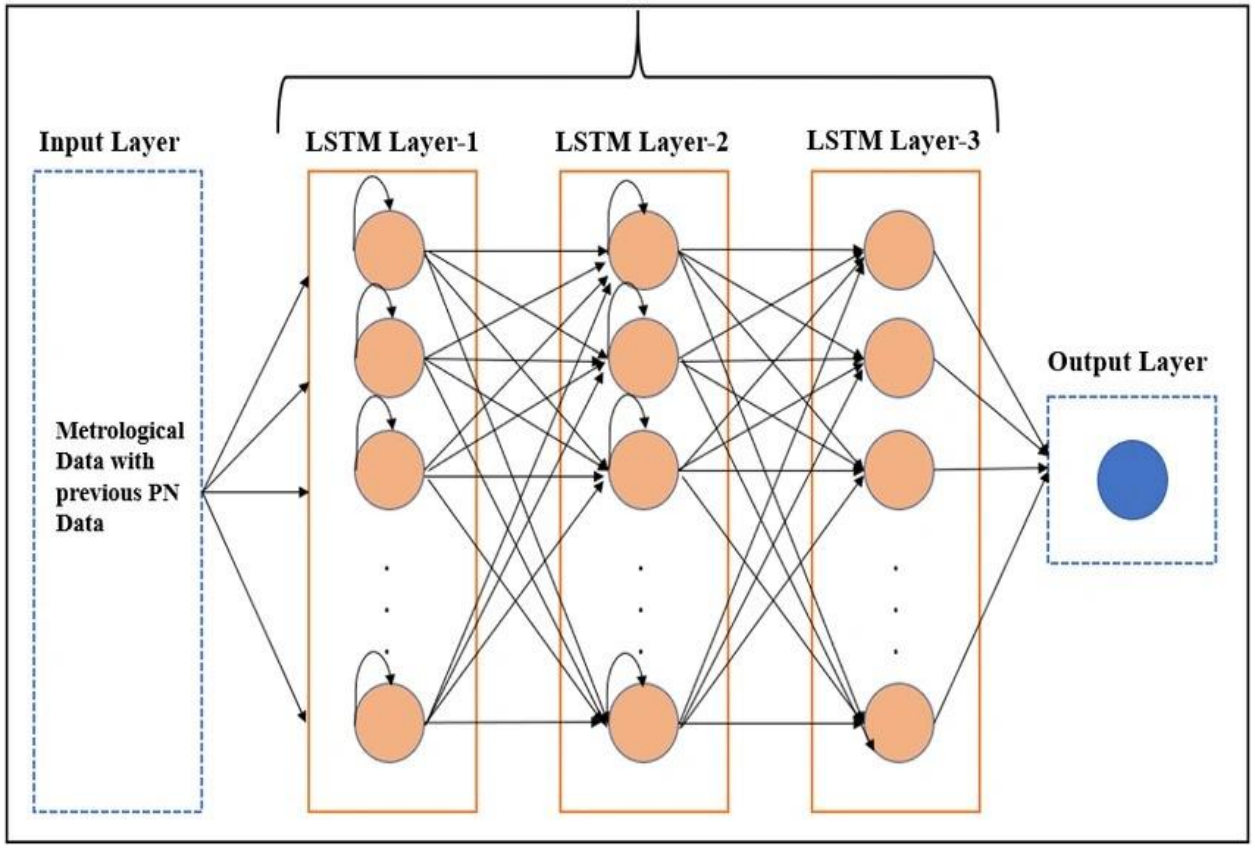

Precipitation
WEST
WALTON
UNADILLA-BAINBRIDGE
SLIDE-PHONECIA
SHOKAN
ROSENDALE
ROCK
PORT
MOHONK
MIDDLETOWN
LIBERTY
DEPOSIT
DELHI
COOPERSTOWN
COBLESKILL
BINGHAMTON
ARKVILLE
ALCOVE
ALBANY
1900
1920
1940
1960
1980
2000
2020
Year


Predicted
Observed
Precip (cm)
0
5
10
15
20
1900
1920
1940
1960
1980
2000
2020
Predicted
Observed
Precip (cm)
0
2
4
6
8
1898
1899
1900
Hindcast (artificial gaps)
Observed
Precip (cm)
0
1
2
3
4
5
6
7
1898-01
1898-02
1898-03


95% interval
Reconstruction
Observed (PRISM)
Tmax (°C)
Observed (NOAA)
Reconstruction
Observed (PRISM)
Tmax (°C)
Observed (NOAA)
Reconstruction
Observed (PRISM)
Tmax (°C)


MAE — Jan
MAE — Jul
RMSE — Jan
RMSE — Jul
Wet days
Dry days
MAE (cm)
RMSE (cm)
0.00
0.02
0.04
0.06
0.08
0.10
0.0
0.1
0.2
0.3
ALBANY
ALCOVE
ARKVILLE
BINGHAMTON
COBLESKILL
COOPERSTOWN
DELHI
DEPOSIT
LIBERTY
MIDDLETOWN
MOHONK
PORT
ROCK
ROSENDALE
SHOKAN
SLIDE-PHONECIA
UNADILLA-BAINBRIDGE
WALTON
WEST

Models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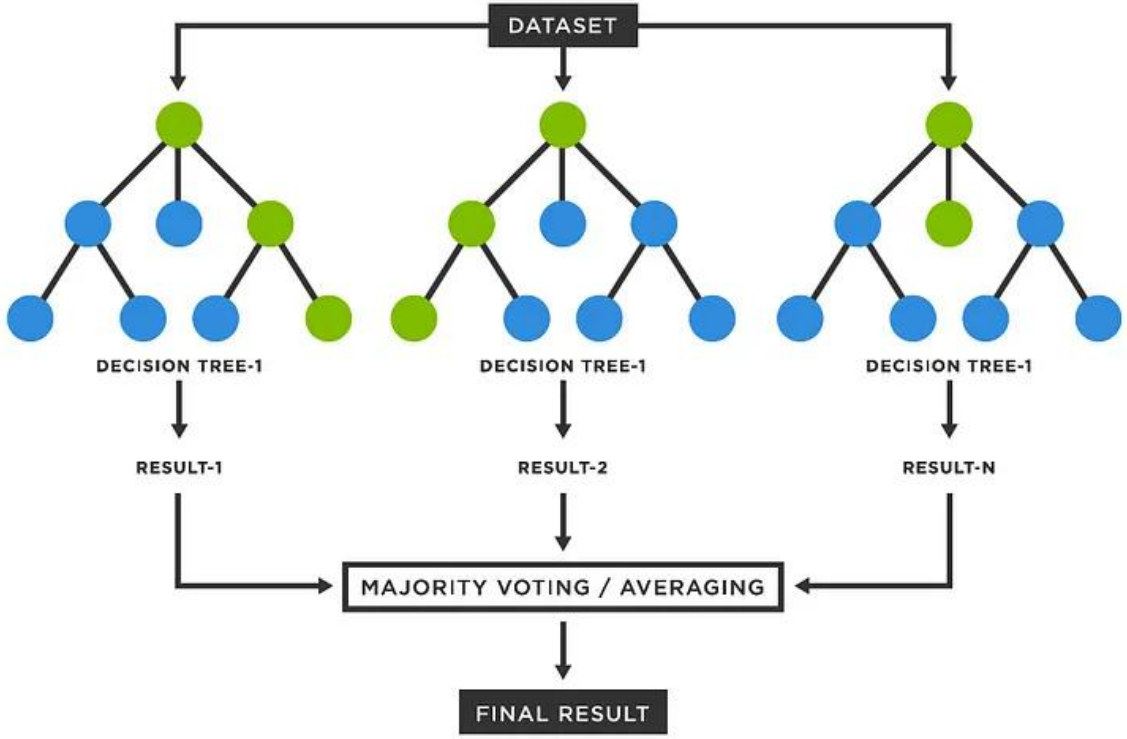
LSTM Layer-2
LSTM Layer-3
Output Layer
Metrological Data with previous PN Data


DATASET
DECISION TREE-1
DECISION TREE-1
DECISION TREE-1
RESULT-1
RESULT-2
RESULT-N
MAJORITY VOTING / AVERAGING
FINAL RESULT