Impact of the Tomorrow.io Microwave Sounder Constellation on Global Precipitation Retrievals

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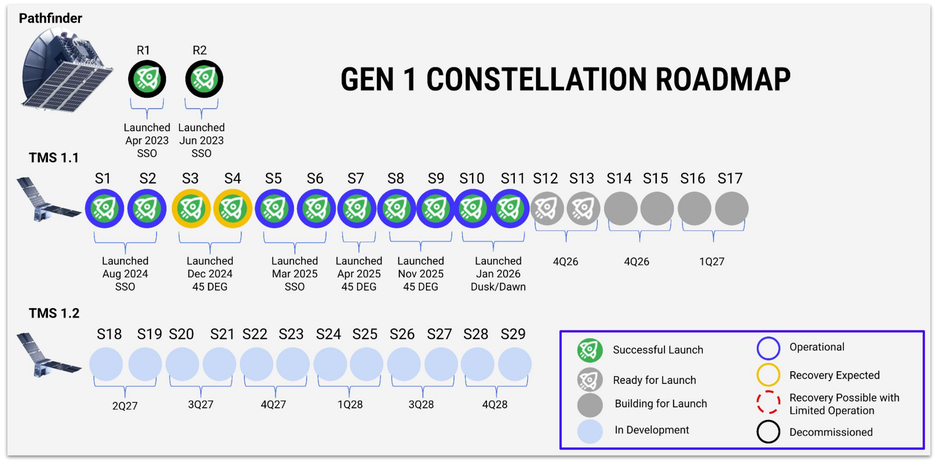
Motivation

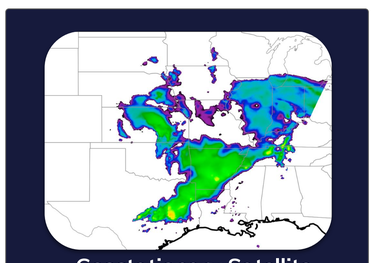
Can a constellation of rapid revisit microwave sounders improve global precipitation estimation and nowcasting?

We are building a constellation of microwave sounders that will enable sub-hourly updates globally. 11 satellites are already on orbit, more planned for the end 2026 and an upgraded version beginning launch in 2027/28. Hourly (or better) revisit is planned through 2030.



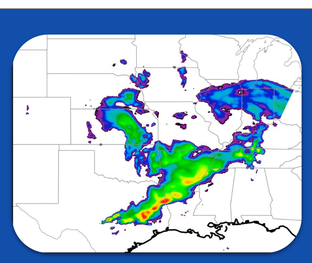
- **TMS Payload:** 12 channels from 91–204 GHz
- Retrieves profiles of temperature and humidity
- Channels sensitive to precipitation as well
- 15–30 km resolution depending on channel

Big picture: Observation Capability



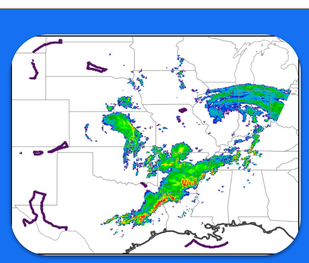
Geostationary Satellite Vis/IR Observations

Broad but Blurred: Geostationary satellite imagery provides continuous monitoring over vast areas. However, it estimates precipitation from cloud-top observations, leading to less precise quantification of surface precipitation, especially in areas with rapid weather changes.



MW Sounder Observations

Depth over Detail: Microwave (MW) sounder data gives us a three-dimensional view of atmospheric moisture and temperature profiles, offering valuable insights into precipitation potential and contributing to improved forecasting accuracy, particularly in the absence of radar data.



Radar Observations

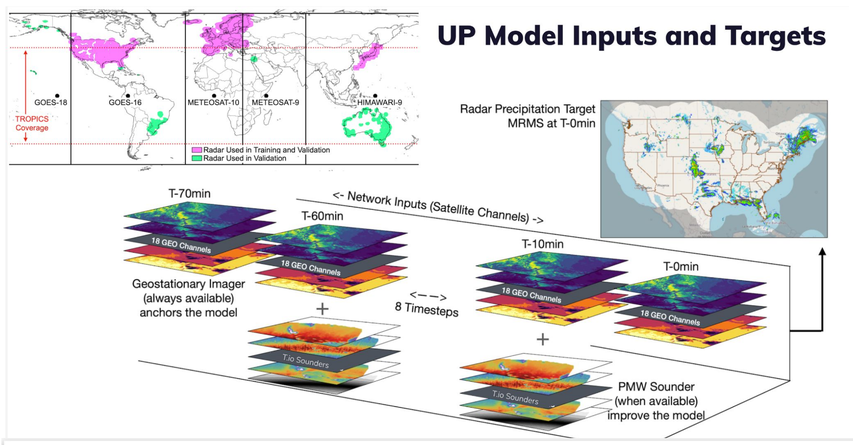
Precision and Clarity: Radar's high-resolution precipitation measurements offer unmatched detail and accuracy. Its ability to discern precipitation intensity and type provides critical data for calibrating and validating quantitative precipitation models, crucial for precise weather predictions.

Indirect Observation → Direct Observation

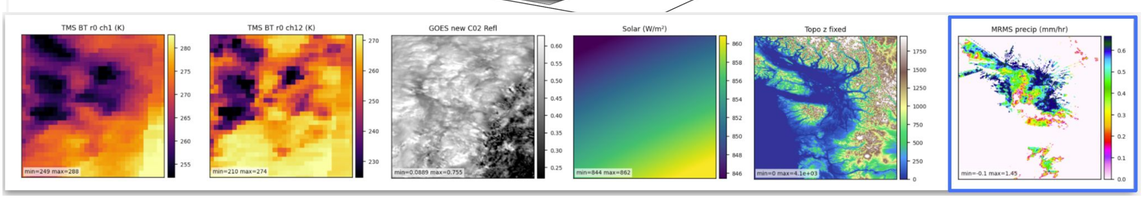
Highest Coverage Today → Lowest Coverage Today

Methods: Training Datasets & Architecture

Training data instrument coverage map and diagram of multi-instrument, multi-channel satellite inputs to convolutional neural network architecture and radar-observed precipitation target.



The precipitation retrieval framework presented here utilizes the EfficientNetV2 architecture for image processing within a sequence-based framework. The CNN employs an encoder-decoder structure incorporating MBConv blocks, with an additional convolution across the time dimension. The model uses a quantile loss function.

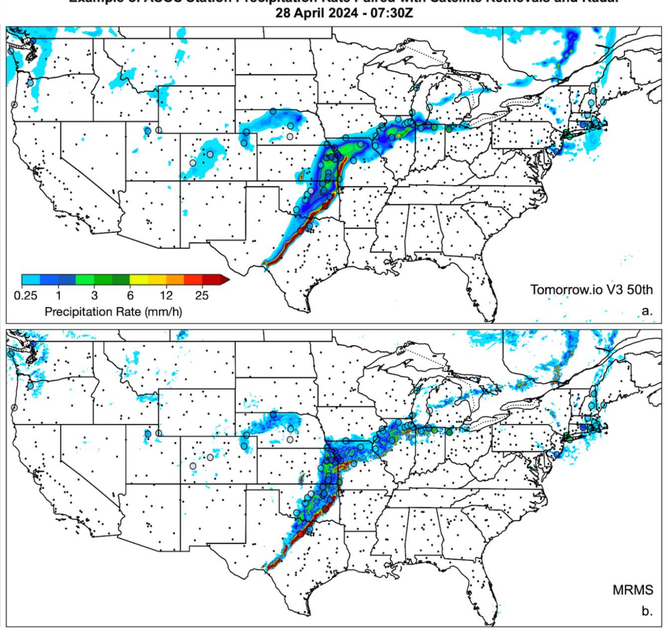


Results: Retrospective Analysis

CONUS (ASOS) Test Split Average (07/2023 - 10/2024)

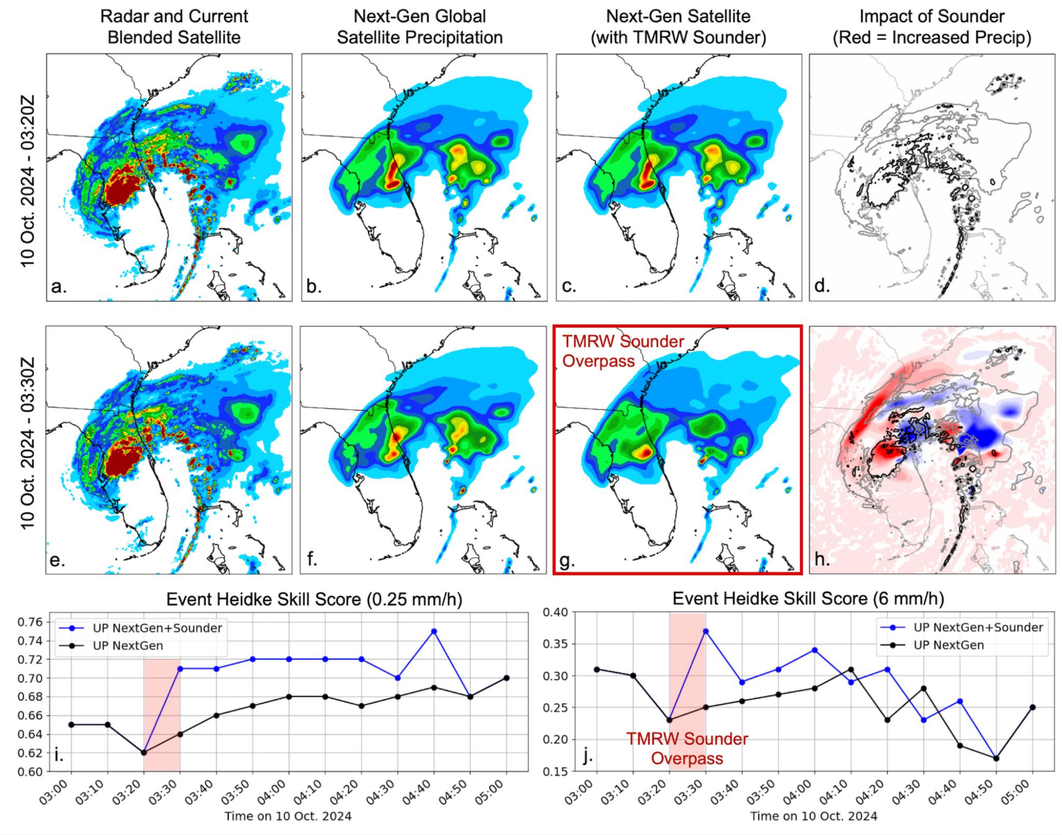
	Product	POD	FAR	CSI	BIAS	HSS
0.25 mm/h	IMERG	0.54	0.71	0.23	2.34	0.21
	V2 T.io	0.68	0.66	0.29	2.41	0.29
	V3 T.io 50	0.70	0.58	0.36	1.96	0.40
	V3 T.io 75	0.76	0.63	0.34	2.52	0.35
	MRMS	0.70	0.48	0.43	1.51	0.50
0.5 mm/h	IMERG	0.47	0.66	0.24	1.71	0.24
	V2 T.io	0.60	0.58	0.32	1.68	0.34
	V3 T.io 50	0.63	0.52	0.38	1.50	0.43
	V3 T.io 75	0.70	0.58	0.36	1.94	0.40
	MRMS	0.59	0.40	0.43	1.06	0.51
1 mm/h	IMERG	0.38	0.63	0.22	1.21	0.24
	V2 T.io	0.49	0.50	0.31	1.15	0.36
	V3 T.io	0.53	0.46	0.37	1.08	0.44
	V3 T.io	0.61	0.52	0.37	1.45	0.43
	MRMS	0.48	0.36	0.38	0.78	0.47
3 mm/h	IMERG	0.27	0.68	0.16	1.01	0.21
	V2 T.io	0.31	0.60	0.20	0.94	0.26
	V3 T.io 50	0.40	0.46	0.29	0.79	0.37
	V3 T.io 75	0.52	0.55	0.31	1.24	0.40
	MRMS	0.41	0.46	0.31	0.73	0.40
6 mm/h	IMERG	0.15	0.73	0.10	0.66	0.13
	V2 T.io	0.20	0.54	0.15	0.64	0.20
	V3 T.io 50	0.24	0.47	0.19	0.45	0.26
	V3 T.io 75	0.35	0.56	0.23	0.83	0.31
	MRMS	0.32	0.48	0.24	0.63	0.32
12 mm/h	IMERG	0.04	0.82	0.03	0.25	0.04
	V2 T.io	0.05	0.58	0.05	0.19	0.06
	V3 T.io 50	0.21	0.37	0.17	0.35	0.23
	V3 T.io 75	0.29	0.51	0.21	0.63	0.28
	MRMS	0.29	0.48	0.22	0.65	0.29

Example of ASOS Station Precipitation Rate Paired with Satellite Retrievals and Radar 28 April 2024 - 07:30Z



Skill metrics for remotely-sensed precipitation retrievals using ASOS station precipitation rate as ground truth. Examples to visualize the comparison of station and gridded precipitation rates across the CONUS domain for 1 out of 170 cases evaluated from the testing split to generate the table statistics are shown on the right. 50th percentile of Tomorrow.io V3 retrievals and MRMS.

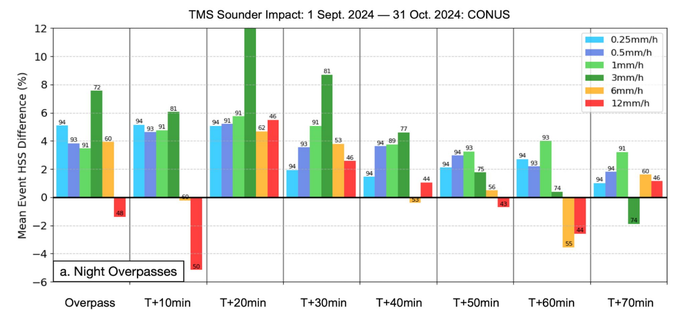
Results: Microwave Sounder Impact



MRMS precipitation rate during Hurricane Milton landfall on 10 Oct. 2024. The difference between precipitation retrieval from the control experiment and the experiment with sounder observations enabled as input are shown in panel d and indicate an increase in precipitation as a result of including the sounder data.

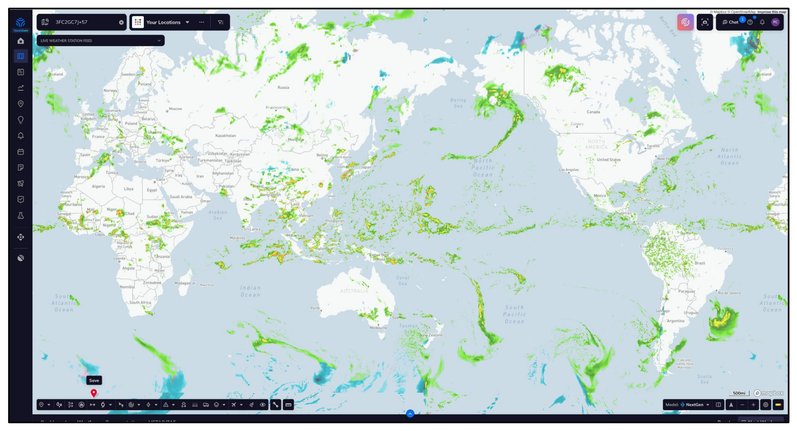
Results: Operational Data Denial

TMS Sounder impact on CONUS precipitation retrievals between 1 Sept. 2024 and 31 Oct. 2024. Data denial performance is quantified against MRMS according to latency since overpass.



Results: Operational System

Realtime retrievals support operational global precipitation estimation on Tomorrow.io's platform and API. Subhourly result data is delivered from satellites to customers in ~15 min, incorporating groundlink and processing time.



What's Next

- Retrained on 2 years of on-orbit TMS
- Re-framed network to be TMS-centric to maximize utilization and optimize revisit/latency handling
- Improved impact from TMS and improved overall skill

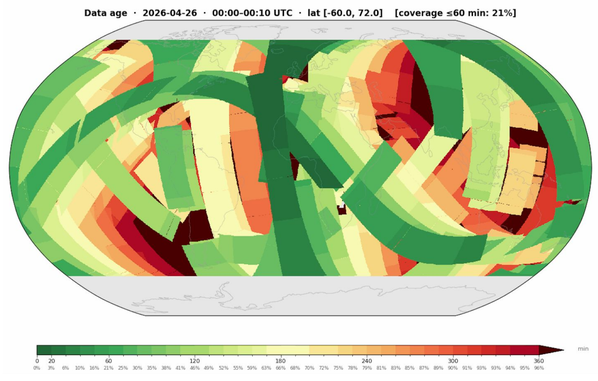


Figure shows the TMS observation latency at network ingest.

All data within a 6h window is ingested, with overpass time included as channels

Importantly, even with latency, the updated network leverages TMS observation of the precipitation environment that is not available from geostationary imagery alone.

Conclusions

- Tomorrow.io's near-global satellite precipitation retrieval network provides accurate near-real time estimates for regions lacking terrestrial radar coverage.
- This performance is further enhanced by ingesting near real-time data from Tomorrow.io's microwave sounder constellation.
- These advancements will contribute to global precipitation monitoring, enabling communities, corporations and governments worldwide to better understand, prepare for, and respond to precipitation extremes.

Reference

Forest Cannon, Simon Pfreundschuh, Brandon Taylor, et al. Deep Learning for Multi-Satellite Precipitation Retrievals: Impact of Tomorrow.io's Microwave Sounders. Journal of Hydrometeorology, 27, 453–471,