tomorrow.io

Evaluation of the Tomorrow.io Microwave Sounder constellation with a JEDI-UFS-based and GDAS-inspired NWP system

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UIFCW25
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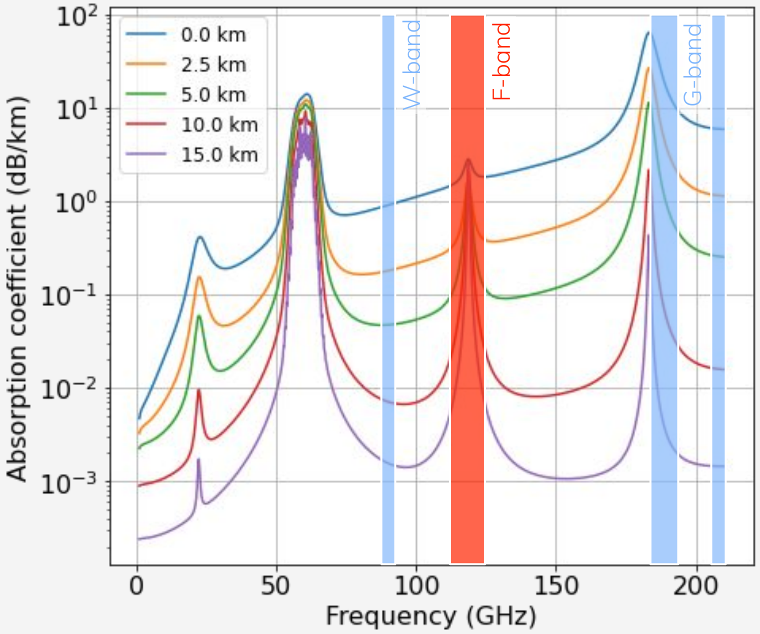
Tomorrow.io Microwave Sounders (TMS 1.1)

Heritage: NASA/MIT-LL TROPICS Microwave Sounder (v1.0)

- 12 channels from 91-204 GHz (2 window, 7 O_2, 3 H_2O)
- Calibration: deep space, noise diodes, and an internal calibration target (ICT)
- **Digital spectrometer (ASIC)** for F-band (114-122 GHz, ch. 2-8)
- **Direct detect** W-band (ch. 1) and G-band (ch. 9-12)
- 2200 km swath (±60°)



ADC Backend | ASIC Backend

See [Munchak et al. (2025) in preprint]() for more details. DOI: 10.22541/essoar.175250254.43121152/v1

Tomorrow.io Sounders Constellation 2025

- Successful Launch
- Operational
- Commissioning (Cal/Val)
- Recovery Not Expected
- Building for Launch

S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12+
Transporter-11 LTAN 22:38 Aug 16, 2024		Bandwagon-2 45° Dec 21, 2024		Transporter-13 LTAN 10:26 Mar 14, 2025		BW-3 45° Apr 20, 2025	Q4 2025		2026		2026+

IOC - Initial Operational Capability

EOC - Early Operational Capability

FOC - Full Operational Capability

Planned Revisit	683	219	125	105	79	63

TMS revisit rate in minutes — Goal is sub-hourly (<60min)

Relative to NOAA / NASA programs of record:

Modest Improvement	Notable Improvement	Significant Improvement

Objectives for this work

1. Proven TMS assimilation methodologies, easy to use/adapt by the community (continually improving)

2. Research-level estimates of TMS benefits in NWP, to be later evaluated in an operational context

Observing System Experiments (OSEs) Configurations

Heterogeneous observation data (External + T.io)

Microwave Sounders:
AMSU-A, ATMS, MHS, TMS

In-Situ:
Sondes, Stations, Buoys

Satellite-Derived:
AMV Winds, GNSS-RO

UV Profilers:
OMI, OMPS

IR Sounders:
CrIS, IASI

IR Imagers:
ABI, AHI, SEVIRI

TMS Observing System Experiment
January 1-31, 2025

Future assessments,
~Q1/Y26

Data Assimilation

- FV3-JEDI (SkyLab 8 code tags); work in progress at NOAA-EMC and JCSDA; Tomorrow.io workflow
- 3DEnVar; B-matrix uses 30-member C192 forecasts initialized from GEFS
- Obs availability and QC modeling reflect upstream efforts, i.e., a snapshot of EMC's GDASApp repository circa Jan 2025.

↑ ↓

Forecast

- UFS-ATM – GFSv16.2
- Global C768 (13-km) mesh, 127 levels

Jonathan Guerrette, Ryan Honeyager, Stephen Munchak, Xiaoxu Tian: All-sky assimilation impacts of the Tomorrow.io Microwave Sounder constellation on global weather forecasts. *Submitted to QJRMS.*

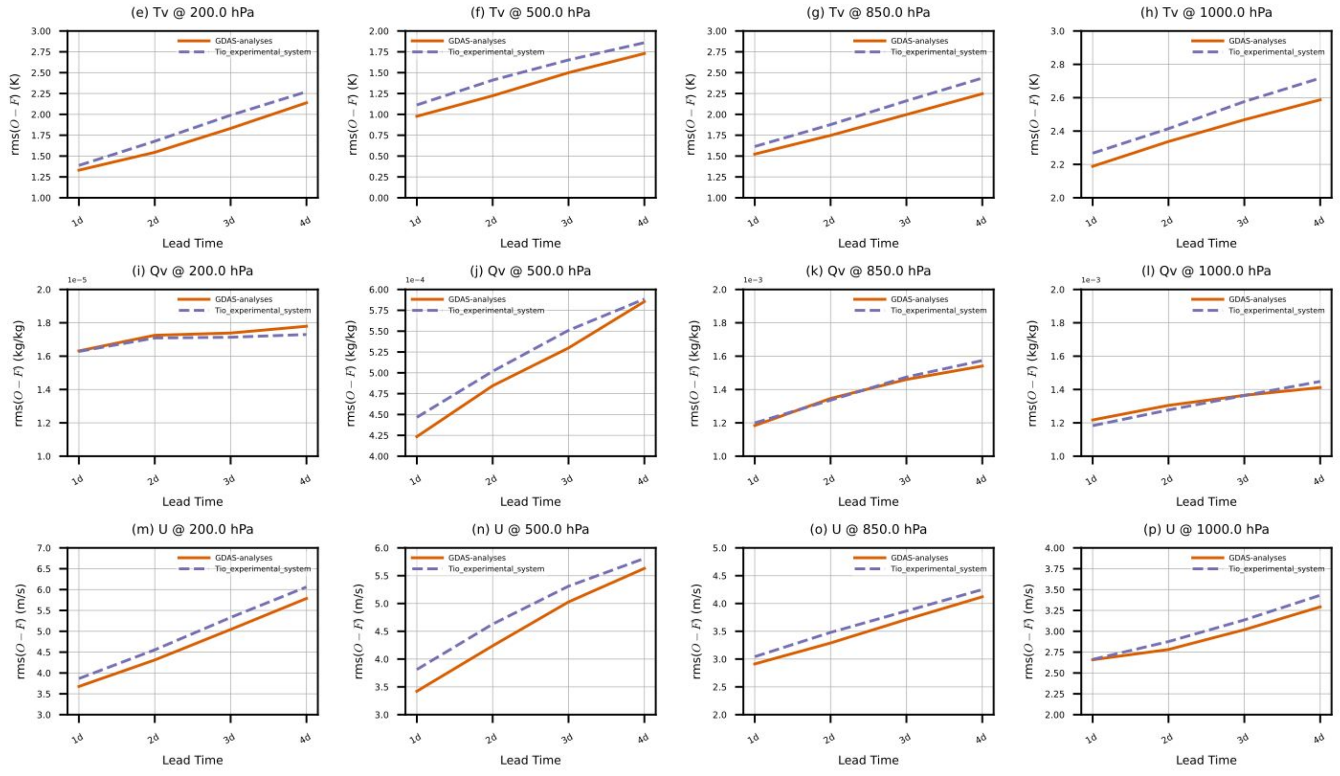
Forecast skill (ADPUPA): Tio-experimental and GDAS

200 hPa | 500 hPa | 850 hPa | 1000 hPa

T_v

Qv

U



Period: January 2025

y-axis: RMSE w.r.t. ADP Upper Air (ADPUPA)

x-axis: forecast lead time of 1–4 days

Tio-experimental (dashed)

GDAS (solid)

All-sky Observation Configuration

Error Model:

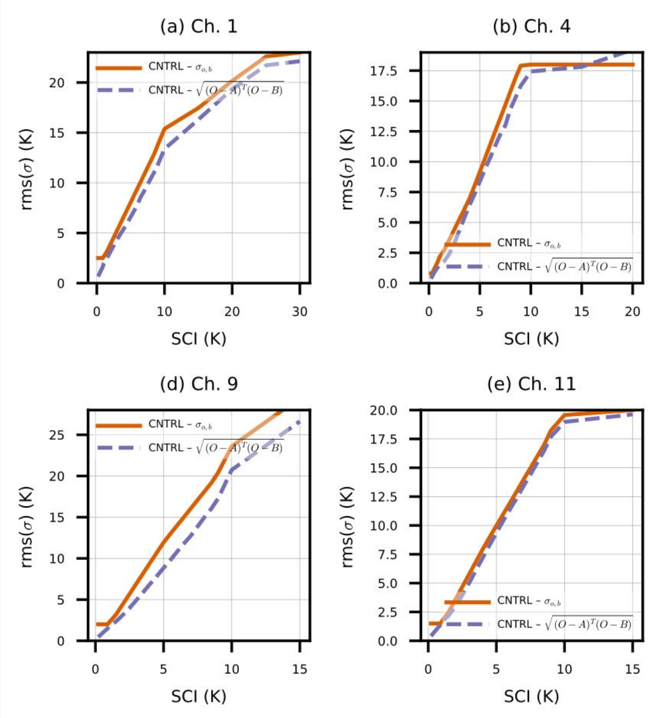
Errors are prescribed as proportional to the per-channel symmetric cloud impact (**SCI**) predictor (Okamoto et al. 2013, 2023):

$$\mathrm{OCI} = \mathrm{BT}_{\mathrm{clr}} - \mathrm{BT}_{obs}$$
$$\mathrm{MCI} = \mathrm{BT}_{\mathrm{clr}} - \mathrm{BT}_{mod}$$
$$\mathrm{SCI} = 0.5\,(|\mathrm{OCI}| + |\mathrm{MCI}|)$$

Quality Control:

Remove locations where **OCI** and **MCI** differ significantly

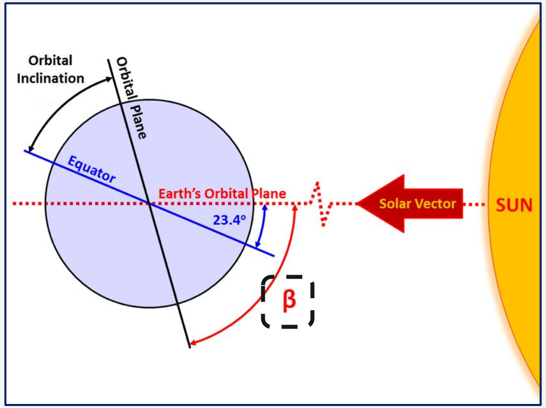
Obs error (σ_o, **solid**) and Desroziers et al. (2005) diagnostic (**dashed**)

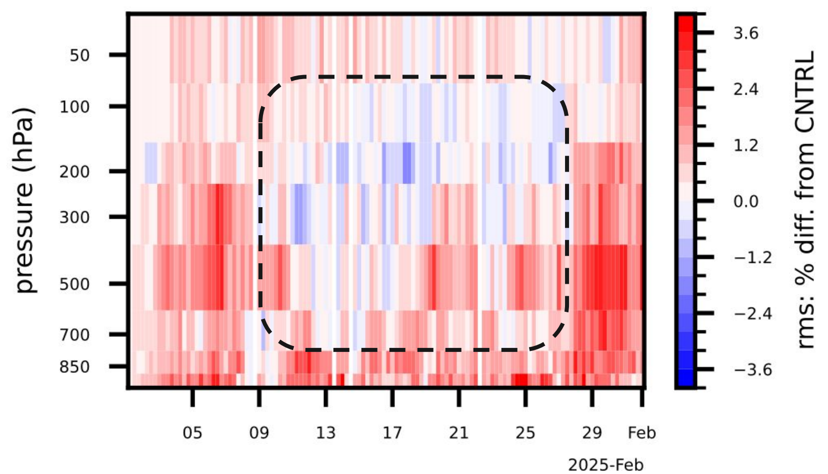


Period: January 2025

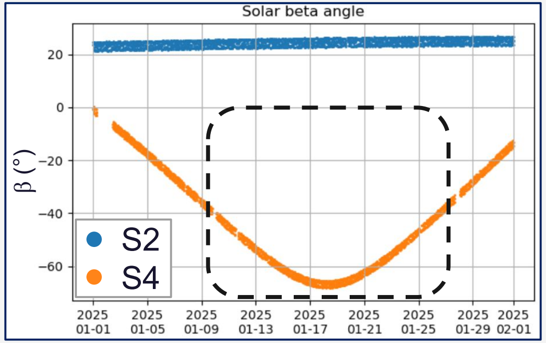
Thermal Loading and Bias Correction

- Early cycling results (bottom) showed a lull in TMS impacts on 6-h temperature forecasts between 700-100 hPa in mid-January
- The lull coincides with a solar β angle extremum, when the fraction of an orbit in sunlight is maximized (satellite is getting cooked)
- 45° orbits: β angle cycles are sinusoidal with 58-day period





6-h forecast delta RMSE (%) caused by denying S2 and S4 from a control experiment for TEMPERATURE w.r.t. GDAS analyses
RED=GOOD
BLUE=BAD



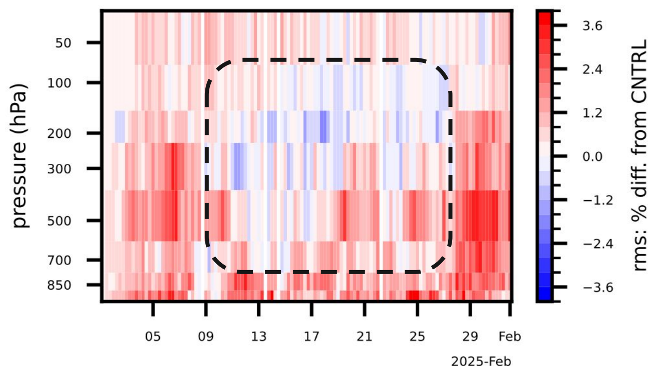
Period: January 2025

Thermal Loading and Bias Correction

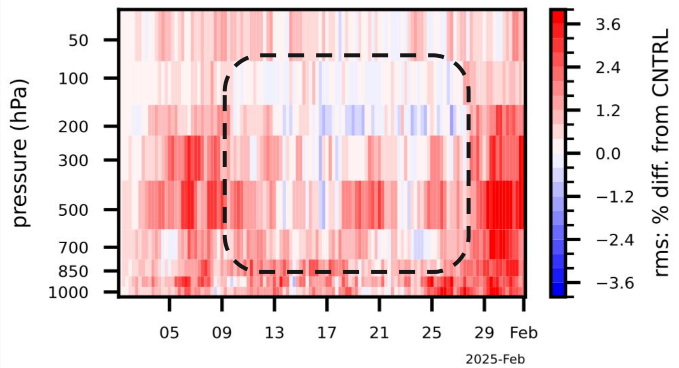
Delta RMSE (%) caused by denying S2 and S4 from a control experiment for TEMPERATURE w.r.t. GDAS analyses
RED=**GOOD**
BLUE=**BAD**

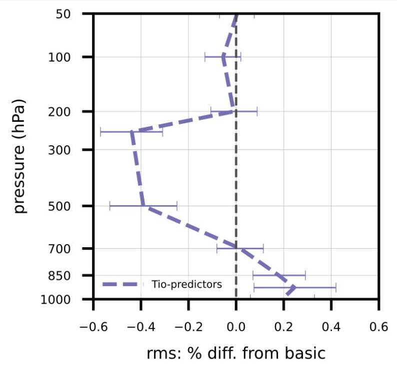
Delta RMSE (%) by adding the intra-orbit predictors
NEGATIVE=**GOOD**
POSITIVE=**BAD**

NOAA EMC's ATMS-like VarBC



add intra-orbit bias predictors





- Intra-orbit bias predictors yield moderate RMSE reductions during the extreme β-angle period
- L1B improvements around thermal loading are in progress

Period: January 2025

Control and Denial OSEs

CNTRL assimilates all data from our complete configuration

Denial experiments remove select microwave sounders

Table 3. PMWSs assimilated in each experiment, with indication of temperature (T) and/or humidity (H) sounding capability.

Instrument	TMS (T+H)		ATMS (T+H)		AMSU-A (T)					MHS (H)		
Satellite → / Experiment ↓	S02	S04	NOAA-20	NOAA-21	NOAA-15	NOAA-18	NOAA-19	Metop-B	Metop-C	NOAA-19	Metop-B	Metop-C
CNTRL	×	×	×	×	×	×	×	×	×	×	×	×
deny-2TMS			×	×	×	×	×	×	×	×	×	×
deny-2ATMS	×	×			×	×	×	×	×	×	×	×
deny-MetopC	×	×	×	×	×	×	×	×		×	×	

Impacts on 6-h background fits to ATMS

Approx. clear-sky signals

Qv

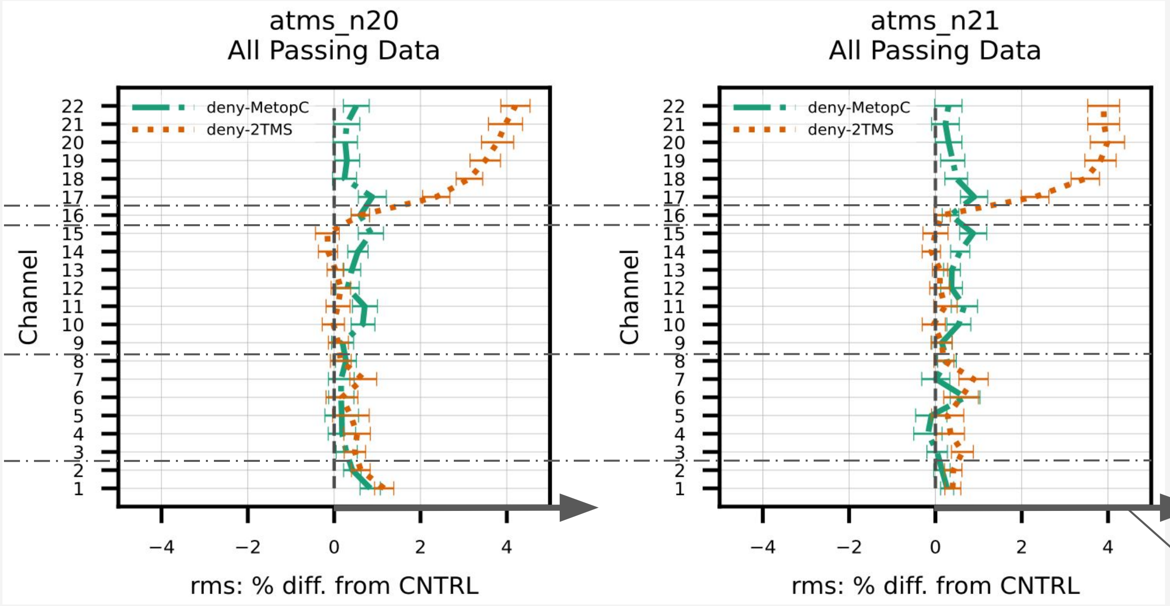
Window

Strato. T

Tropo. T

Window

Ch. 1-8, and 16-22 have hydrometeor signals too



Data denial cases:

Metop-C AMSU-A+MHS

2TMS (S2+S4)

NOTE: smallish Metop-C impacts may be due to nearby orbiting Metop-B and 3DEnVar, clear-sky MHS methodology from GDAS, boxcar SRFs in CRTM, or noise performance

Positive impact on CNTRL

- Largest TMS impacts (**RED**) are on ATMS water vapor channels, increasing from surface (ch. 17) to middle-upper troposphere (ch. 22, ~400 hPa)
- Primary temperature improvements are from the surface (ATMS ch. 1-3) to middle-upper troposphere (ATMS ch. 4-7, ~950–350 hPa)
- TMS has fewer stratospheric T channels than AMSU-A/ATMS; consistent with forecast response

0-to-4 day forecasts

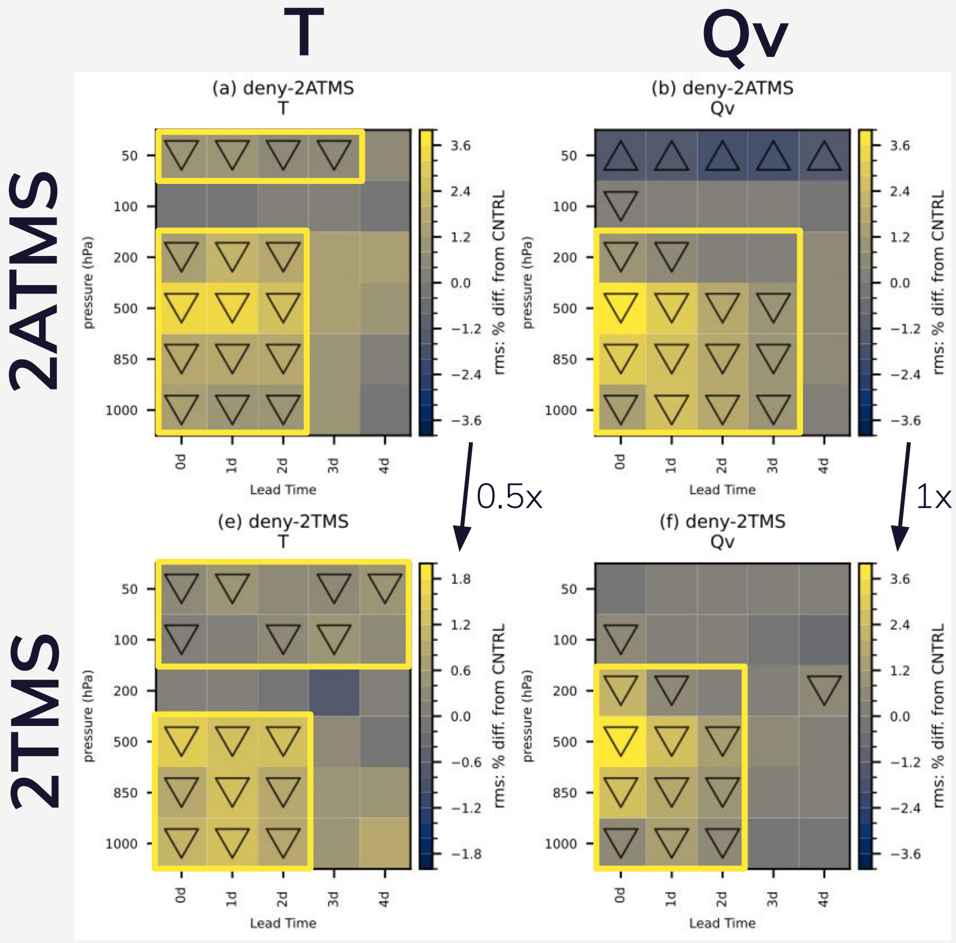
Verification metric:
delta RMSE (%) from CNTRL, as measured between C768 (13km) UFS forecasts and GDAS analyses

Experiments:
deny-2ATMS
deny-2TMS

▽ POSITIVE impact on CNTRL

△ NEGATIVE impact on CNTRL

▽/△ ~95% confidence



Summary

All this and more in a manuscript submitted to QJRMS.
Preprint available on request.

- Effective bias correction, all-sky error, and QC methodologies are established for TMS. All methods freely available as JEDI yaml stubs. Please reach out.
- Community source code (UFS, JEDI) provides effective proving ground
- In our research-quality NWP:
  - TMS has a significant impact at weather forecast lead times **up to three days in the tropics**
  - TMS yields **similar Qv improvements as ATMS**
- Contributing VarBC code back to the public UFO repository

Tomorrow.io presence at UIFCW

- **Forest Cannon**. Impact of Tomorrow.io's Satellite Constellation on Global Precipitation Observation and Prediction.
- **Randy Chase**. ICgen: A method to generate initial conditions from Tomorrow.io's constellation of microwave sounders using score based data assimilation.
- **Maxfield Green**. Tomorrow.io operates a km-scale weather prediction model adapted from generative corrective diffusion.
- **Mariah Pope**. The NOAA Anemoi Experience: scalable and user-friendly tools for training AI weather prediction models.