Exploring Impacts of the Tomorrow.io Microwave Sounder (TMS) Constellation

Ryan Honeyager[1], Jonathan J. Guerrette[1], S. Joseph Munchak[1], Xiaoxu Tian[1,2]

[1] The Tomorrow Companies, Inc.

[2] NOAA/NCEP/EMC - Axiom Consultants, Inc.

IPWG-11 | July 17, 2024

Contact Info: ryan.honeyager@tomorrow.io

Effort sponsored by the U.S. Government under Other Transaction Number FA8730-22-9-0009 between The Tomorrow Companies, Inc. and the Government. The U.S. Government is authorized to reproduce and distribute reprints for Governmental purposes notwithstanding any copyright notation thereon.

Tomorrow Microwave Sounder (TMS)

- Next-generation of TROPICS-like sensor design
- Up to 18 CubeSat sounders launch 2024-2026
- 2200 km swath, with horizontal resolution of:
  - 14 x 17 km @ nadir (204 GHz)
  - 26 x 28 km @ nadir (91 GHz)
- Two imaging channels (1 and 12)
- Seven temperature-sounding channels (F band)
- Three water vapor-sounding channels (G band)

Channel	Center Freq. (GHz)	Bandwidth (GHz)	NEDT (K)
1	91.65	2	0.95
2	118.75±3.5	1	0.85
3	118.75±2.625	0.75	0.90
4	118.75±1.875	0.75	0.90
5	118.75±1.25	0.5	0.90
6	118.75±0.75	0.5	0.90
7	118.75±0.375	0.25	1.00
8	118.75±0.125	0.25	1.20
9	184.41	2	0.80
10	186.51	2	0.80
11	190.31	2	0.80
12	204.8	2	0.80

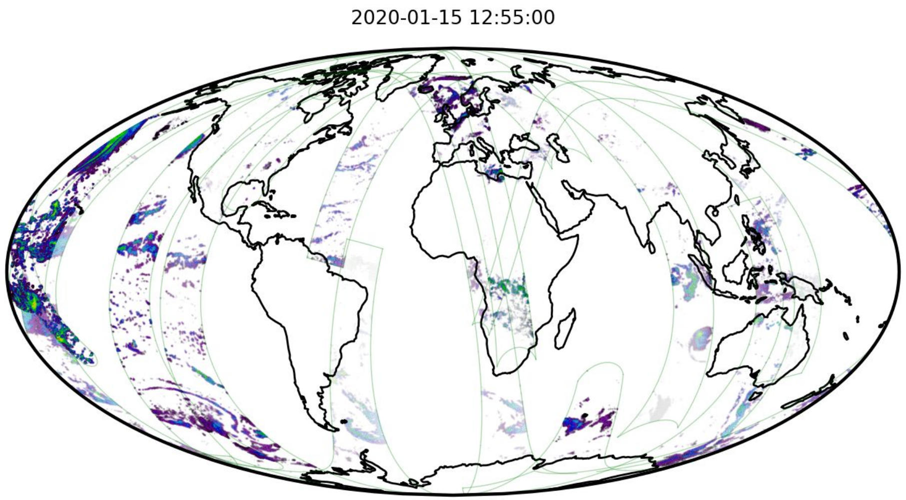
TMS Observation System Simulation Experiments

We simulate our sounders and add them to a "baseline" system, with similar instruments as NOAA's Global Data Assimilation System (GDAS) to:

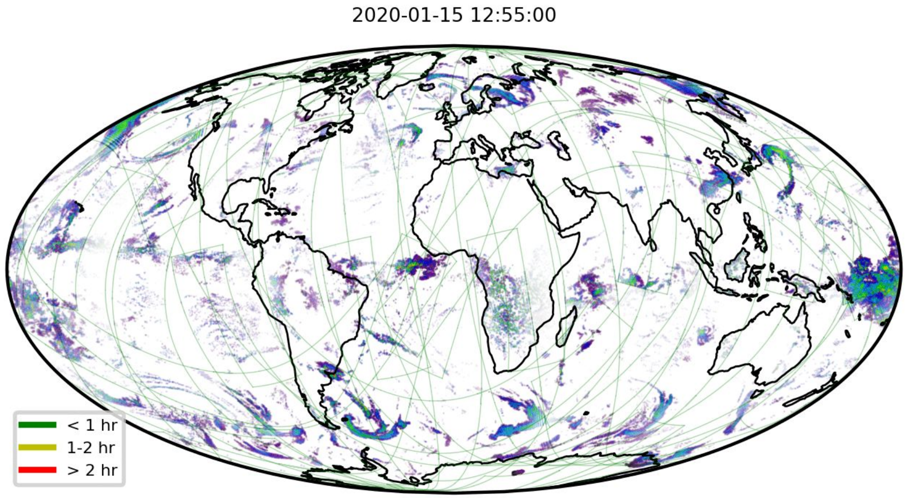
1. Develop the science and algorithms needed to assimilate TMS observations

2. Assess the impact of our observations on forecasts

Existing Multi-Agency MW Sounder Constellation



Tomorrow.io MW Sounder Constellation



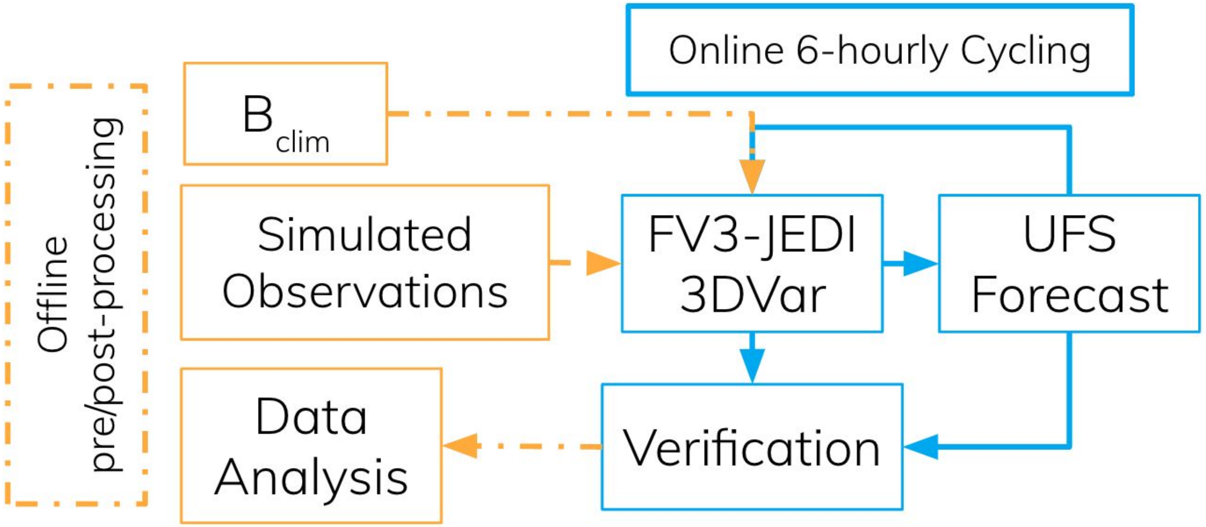
Top right: T.io sounders. Bottom right: NOAA and NASA microwave sounders. One hour of coverage is shown.

tomorrow.io

Experiment Setup

- Nature run (NR): GMAO DYAMOND Phase II
  - C2880 grid (~3km), 181 vertical levels
  - 50 days of simulation (Jan - Mar 2020), with hourly outputs
- Instruments mostly match those in NOAA's Global Data Assimilation System (GDAS).
  - Observations are perturbed to match GDAS error statistics and are subject to Desroziers et al. (2005) error tuning.
- Assimilation: FV3-JEDI
  - 3DVar with NR-trained static B matrix
  - B-matrix validated against 20-member GEFS ensemble during NR spin-up

Components of our setup for mid-range global weather experiments.



- Forecasts: UFS-ATM
  - C768 grid (~13 km)
  - 64 vertical levels

Observation Error Model

Observation error (weight assigned to observations for DA purposes):

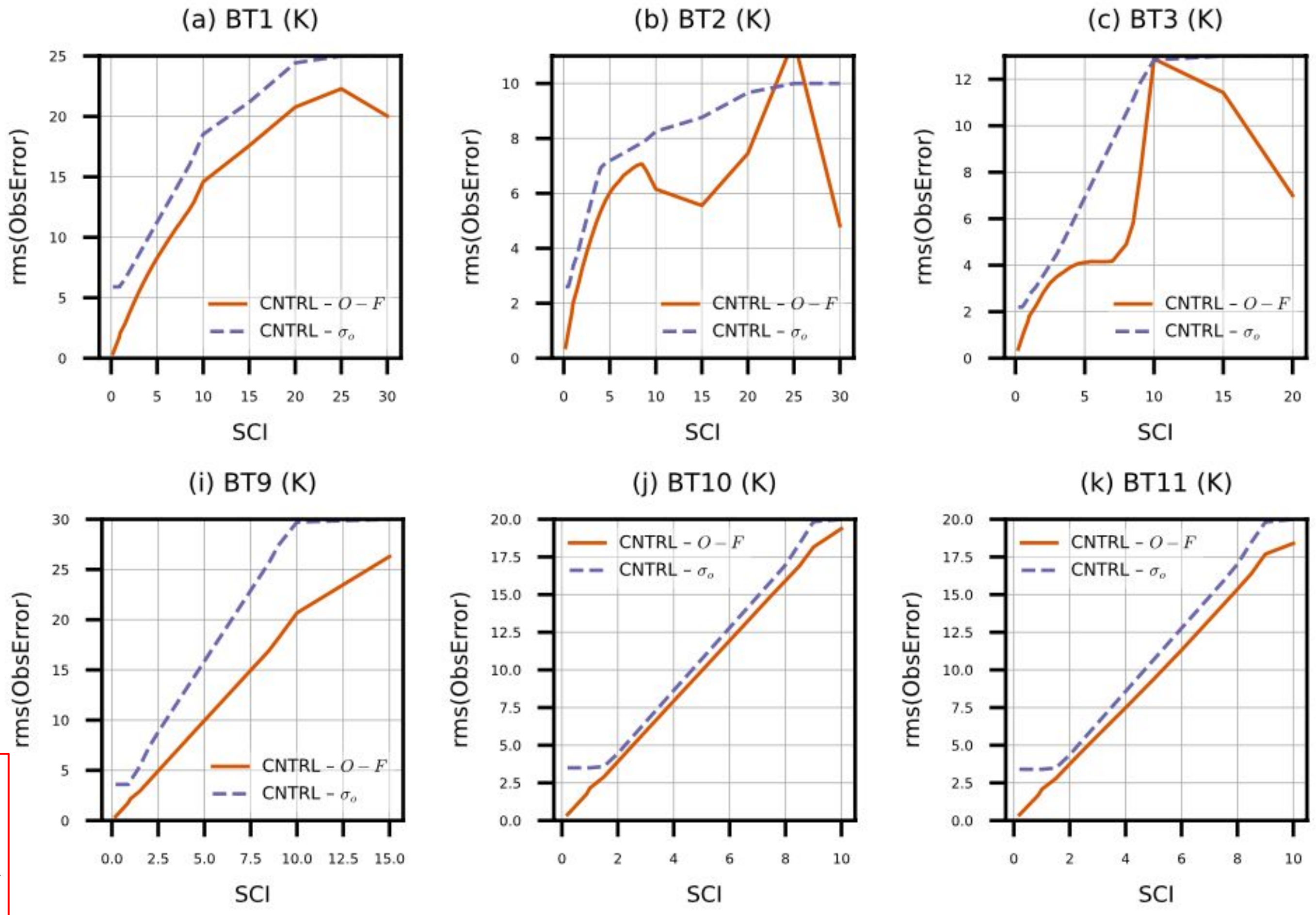
The RMS of 6-hr O-F should match our parameterization for observation error (σ_0).

We employed a symmetric cloud impact (SCI) predictor to gauge hydrometeor impact following the Okamoto et al. (2013; 2023) developments in the IR assimilation community.

$$SCI = (|TB_{clear} - TB_{obs}| + |TB_{clear} - TB_{model}|) / 2$$

$$\sigma_o = \begin{cases} \sigma_{clear} & SCI \le SCI_{clear} \\ (\sigma_{cloudy0} - \sigma_{clear}) \frac{SCI - SCI_{clear}}{SCI_{cloudy0} - SCI_{clear}} & SCI_{clear} < SCI \le SCI_{cloudy0} \\ (\sigma_{cloudy1} - \sigma_{cloudy0}) \frac{SCI - SCI_{cloudy0}}{SCI_{cloudy1} - SCI_{cloudy0}} & SCI_{cloudy0} < SCI \le SCI_{cloudy1} \\ \sigma_{cloudy1} & SCI_{cloudy1} < SCI \end{cases}$$

Obs error at various channels with the symmetric cloud impact model



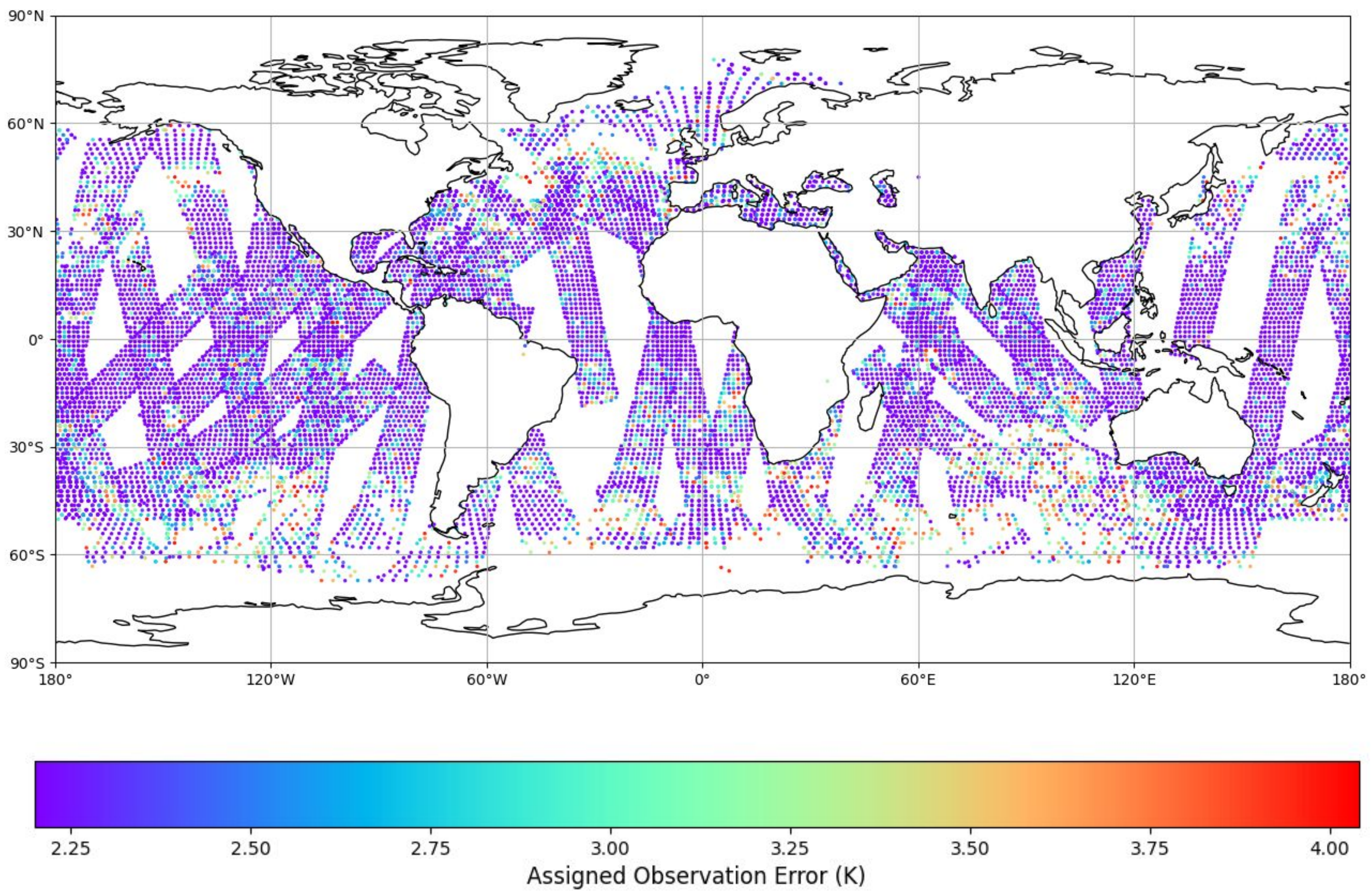
Observation QC Model

These filtering steps address issues with 3DVAR, FV3, model resolution, and CRTM. We remove:

1. Edges of swath
2. Land-sensitive observations
3. Large O-B errors
4. Cloud-contaminated observations at high sounding channels
5. Large discrepancies in O vs. B hydrometeor impact, cloud phases and heights

We further thin observations to a reduced Gaussian grid.

Assimilated Observations - Four TMS Satellites - 6 hr Cycle - Channel 3



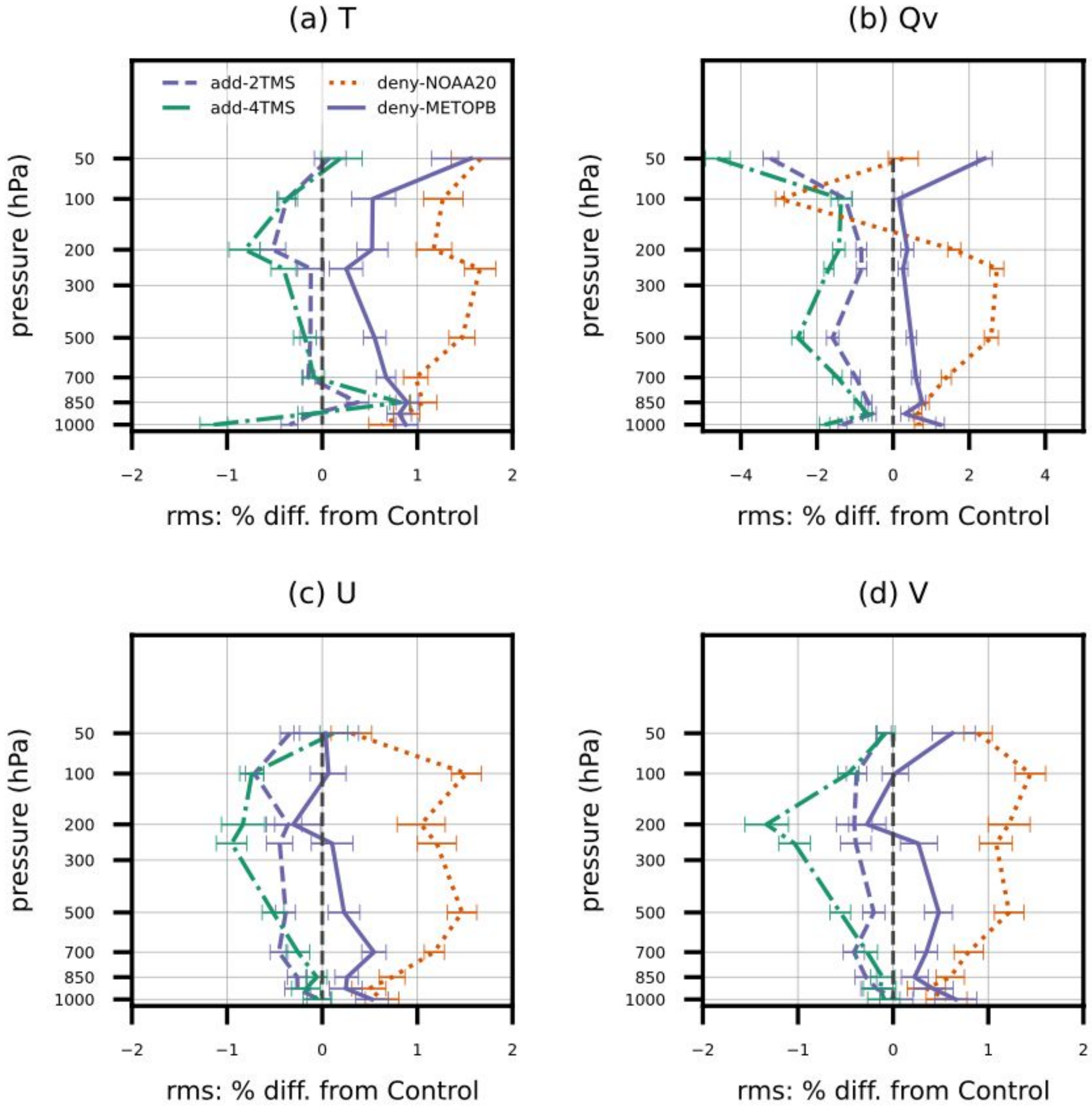
Overall 6 h TMS Impact

Our "Control" run is a global six week-long experiment using most observations assimilated in GDAS circa 2020.

We compare this to:

- Control + Two TMS satellites
- Control + Four TMS satellites
- Control without NOAA-20 (ATMS)
- Control without Metop-B (AMSU-A and MHS instruments)

Left of zero = **reduction** in forecast error

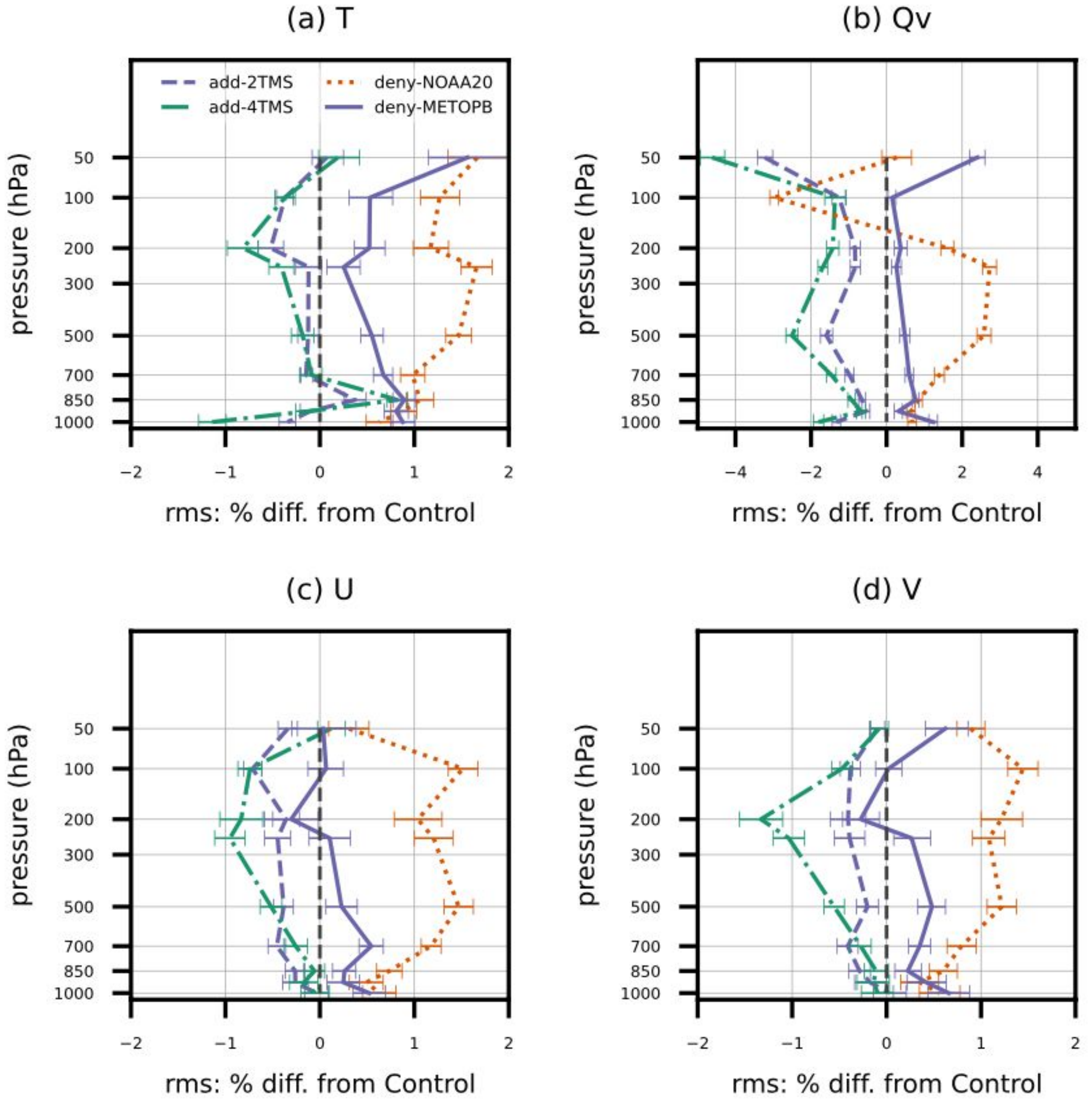


Overall 6 h TMS Impact

Takeaways:

1. TMS makes direct observations of atmospheric water vapor (Qv) and temperature (T). This improves forecasts directly.

2. Improvements in these fields affect weather development and also improve forecasts of wind fields (U and V).

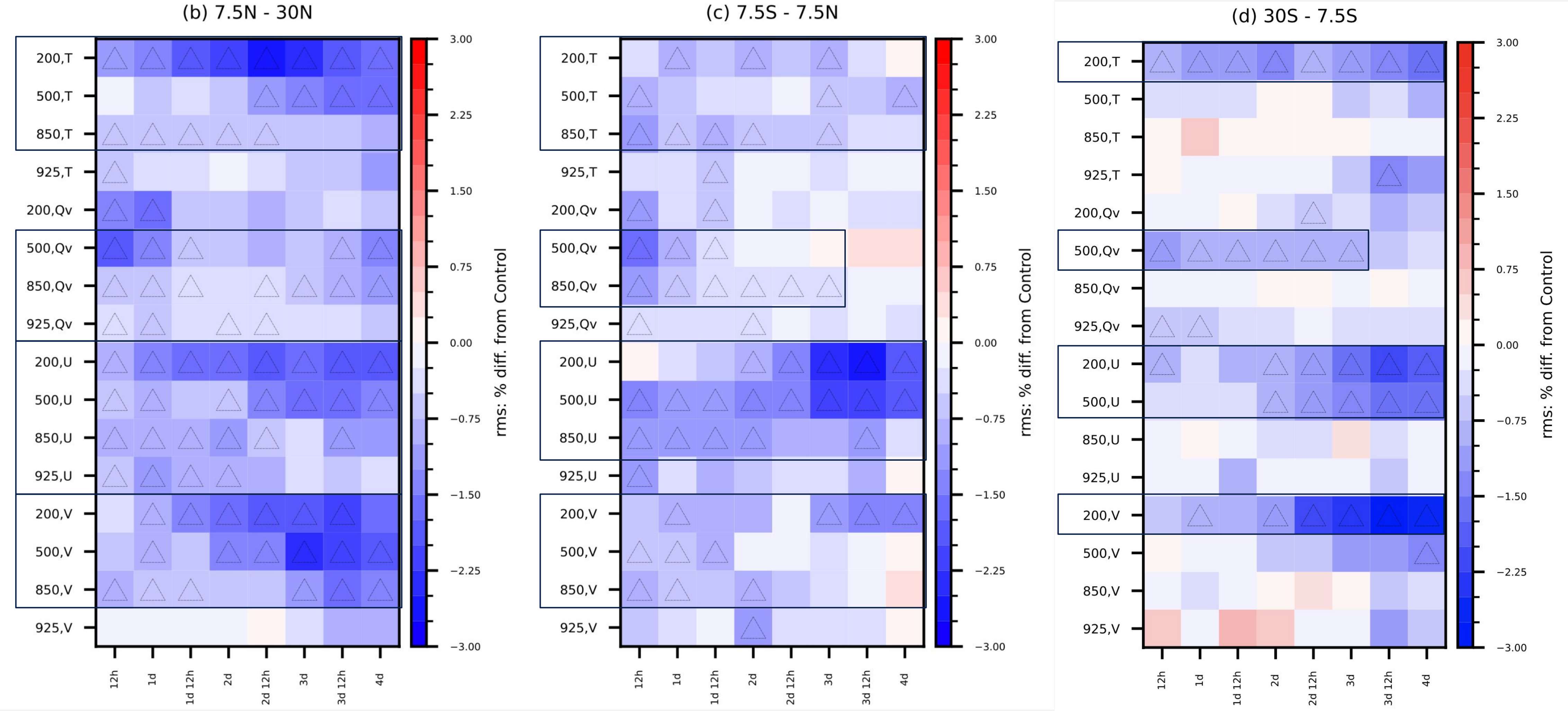


Forecast Impacts: add-2TMS, tropics

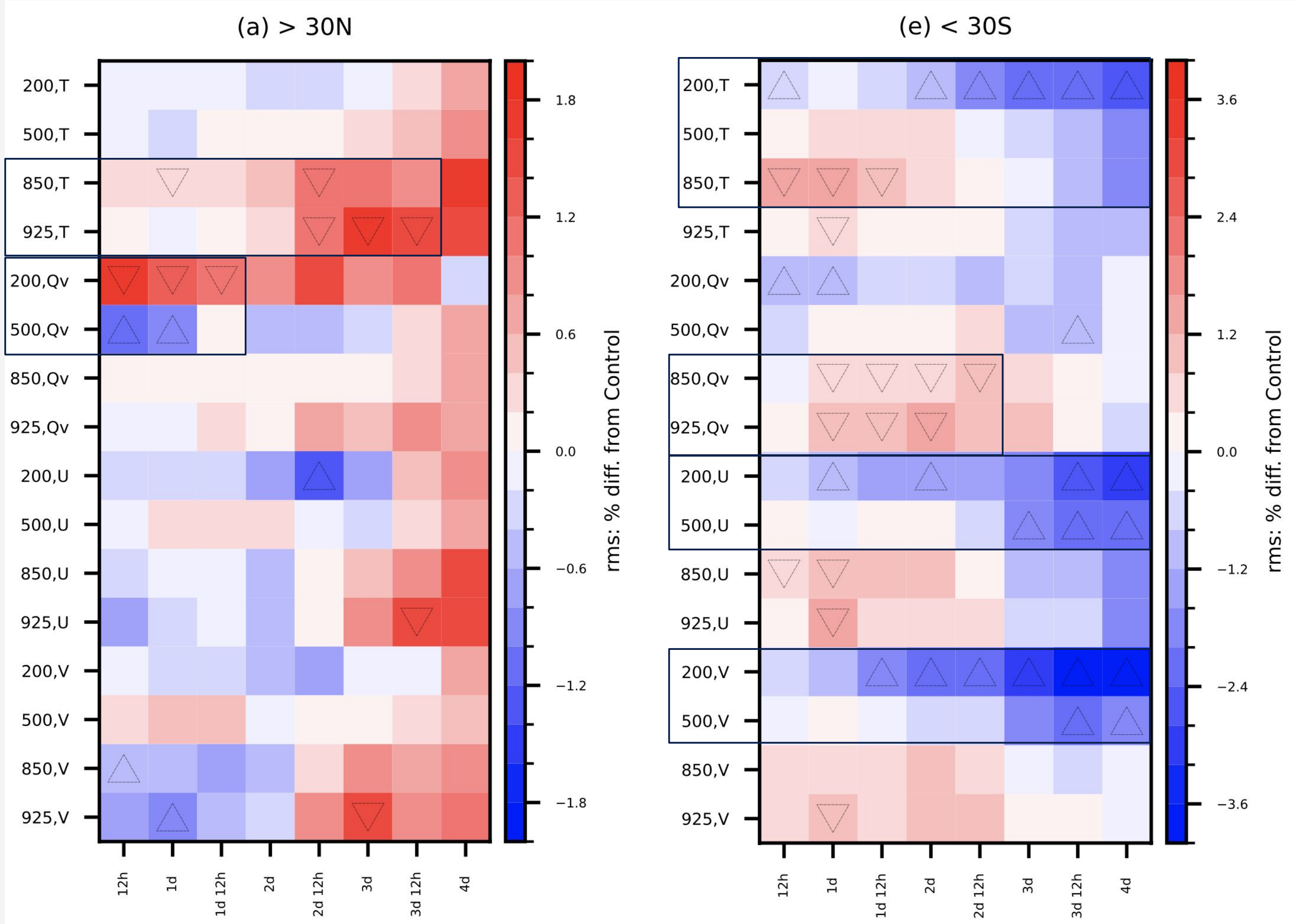
~95% confidence of **improvement**

~95% confidence of **degradation**

37 forecast samples, initialized from 00z on 22 Jan to 28 Feb



Forecast Impacts: add-2TMS, extratropics



~95% confidence of **improvement**

~95% confidence of **degradation**

37 forecast samples, initialized from 00z on 22 Jan to 28 Feb

- We have extended to 3DEnVar DA, and are awaiting a GSI-validated B matrix formulation and improved performance for 4DEnVar.
- Instrument algorithm development remains a work in progress for:
  - T-sounding channels in all-sky conditions
  - WV-sounding outside tropics
- We are refining our all-sky error model for lower-level T-sounding channels 2 and 3 in extratropics.

Summary

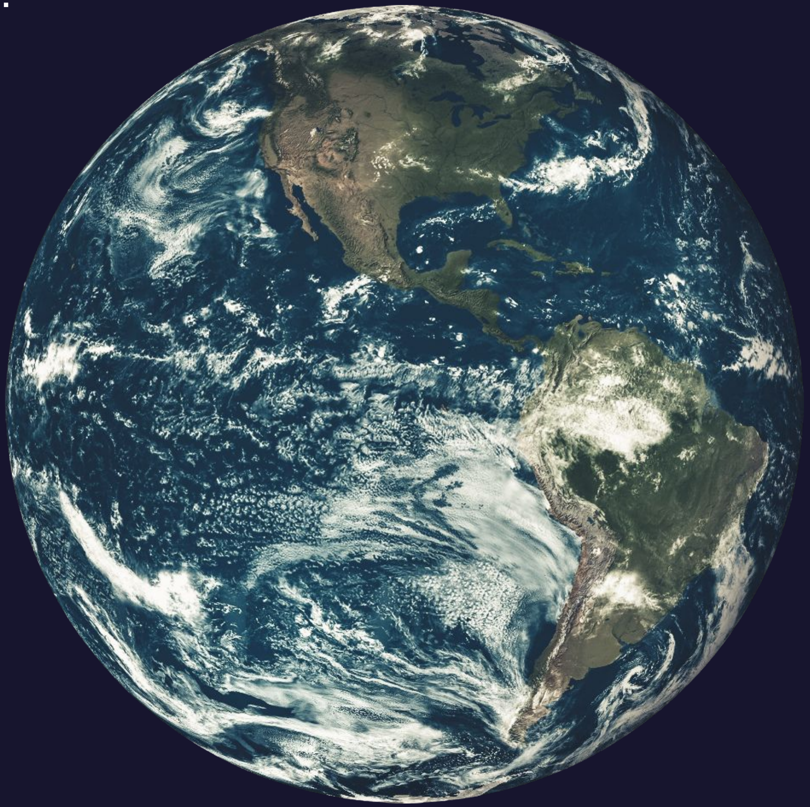
1. The Tomorrow.io Microwave Sounders (TMS) are launching soon!

2. An OSSE-based methodology has allowed us to develop candidate error models for TMS and other TROPICS-like instruments.

3. This is one of the first OSSE attempts using JEDI, and it reflects recent progress for that in-development system.

4. TMS observations will significantly improve forecasts, particularly in the tropics.

5. Forecast improvements increase as more satellites are launched. Further experiments will try to find a saturation point for NWP.



Unlock the Power of NextGen Weather Data

Predict, prepare, and adapt to weather and climate impact like never before with advanced, rapid-refresh data. Captured from Tomorrow.io's first-of-its-kind weather radar satellite constellation, our groundbreaking approach paves the way for organizations around the globe to access previously unreachable critical weather insights.

Pre-launch sample datasets, ATBDs, and instrument coefficient packages are available. Talk with us.