Improving Small-scale Tropical Precipitation Forecast by Assimilating Frequent Satellite Microwave Observations

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Objective: This is first study in global scales that explores challenges and advantages of high-frequency satellite microwave observations using NICAM-LETKF.

1. Introduction

- Traditional weather forecasting utilizes a 6–12-hour assimilation of the satellite microwave radiances.
- High-frequency data assimilation (Fig. 1) has the potential to improve predictions in shorter time scales (days to hours), synoptic scales, and mesoscale weather events.

2. OSSE framework in NICAM-LETKF

- The NICAM-LETKF data assimilation system (Terasaki et al., 2015, 2017) is used to perform OSSE (Fig. 1). RTTOV is used as an observation operator to convert model state variables to AMSU-A microwave radiances.

Table 1: NICAM model settings

Model	NICAM
Horizontal resolution	**Glevel-7 (56 km)**
Vertical resolution	78 layers (Up to 50 km)
Cloud Microphysics	Single moment scheme (NSW6 with Roh scheme)
Cumulus parameterization	**None**
Ocean model	1-layer bulk scheme nudged with NCEP FNL ocean data
Land scheme	MATSIRO

Table 2: Data assimilation settings

DA algorithm	**LETKF (32 ensembles)**
Error covariance inflation	**RTPS (Relaxation To Prior Spread); Tuning 6H(0.5), 3H (0.6), 2H (0.6), 1H(0.6), 1H_AOEI (0.5)**
Horizontal localization	250 km
Vertical localization	**Tuning : 6H(0.5), 3H (0.4), 2H (0.4), 1H(0.3), 1H_AOEI(0.3)**
Observations	Conventional observations and **satellite AMSU-A radiances**
Observation operator	**RTTOV version 13**

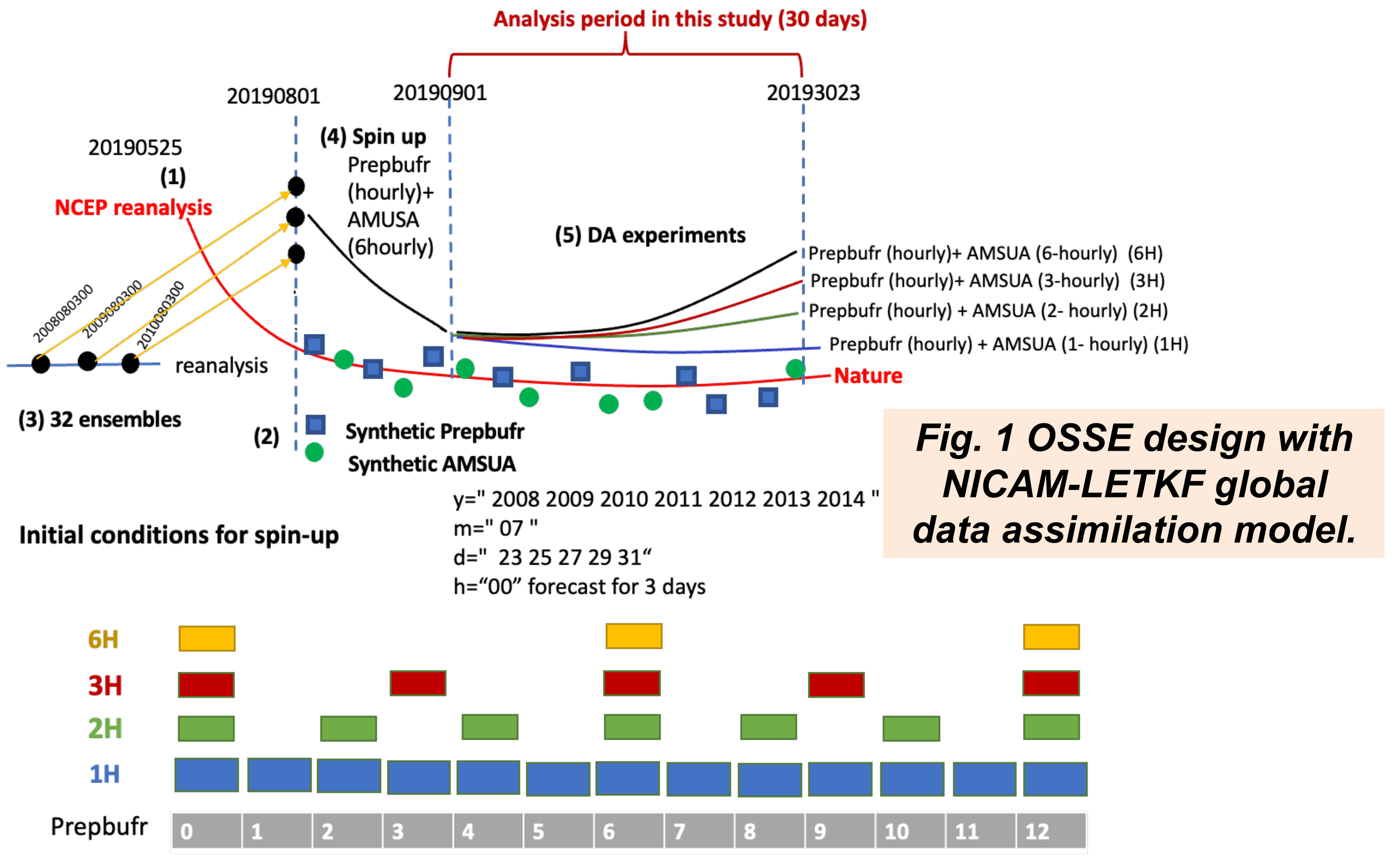


Fig. 1 OSSE design with NICAM-LETKF global data assimilation model.

Four experiments 6H, 3H, 2H, and 1H were conducted with 32

6H: 6-hourly satellite data assimilation; **3H:** 3-hourly satellite data assimilation
2H: 2-hourly satellite data assimilation; **1H:** 1-hourly satellite data assimilation

1H (Rinfl): 1H experiment with manual/offline observation error tuning
1H (AOEI): 1H experiment with AOEI/online observation error tuning

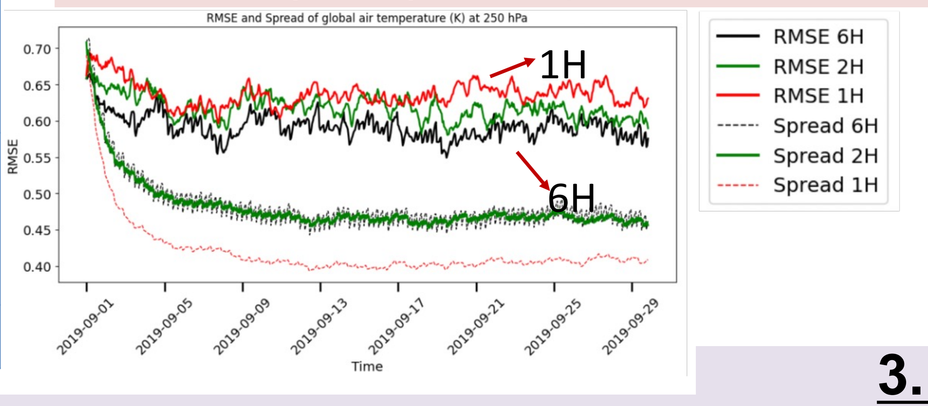


Fig. 2 Time series of global averaged air temperature root mean square errors (RMSE; K; solid line) and spread (K; dash line).

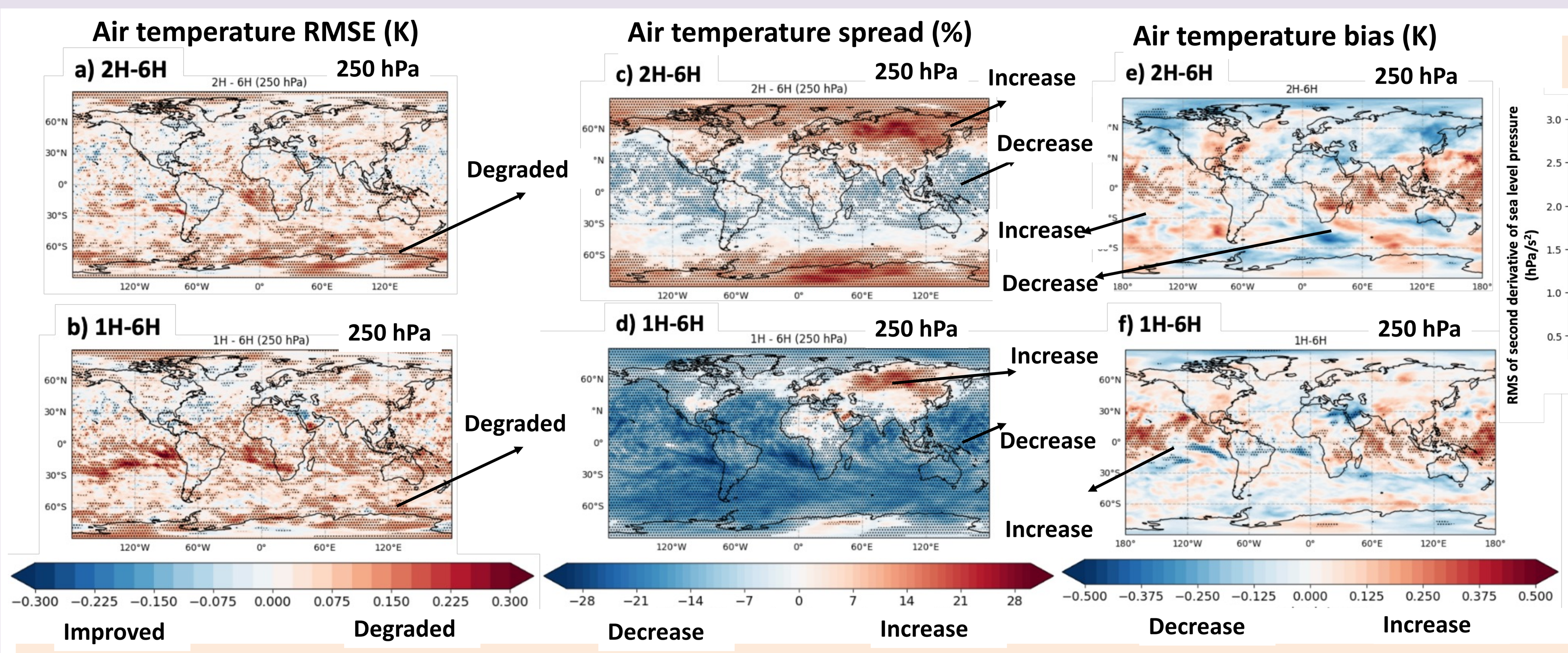
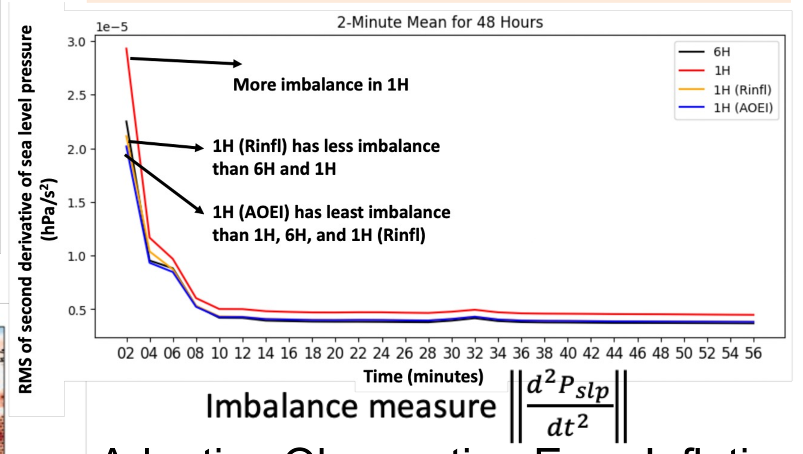


Fig. 3 Difference in Air temperature (K) root mean square error (RMSE; a-b), spread (c-d), bias (e-f), and second derivative of vertical velocity as imbalance measure (g-h) of 2H & 1H experiments with 6H. Hashed region shows 95 % significant difference calculated using t-test.

Fig. 4 Imbalance measure (hPa/s²)



Imbalance measure $\left\|\frac{d^2P_{slp}}{dt^2}\right\|$

Adaptive Observation Error Inflation (AOEI; Minamide and Zhang 2017) Estimate observation error variance from the innovations

$$\sigma^2_{\text{est-o}} = (d^o_b)^2 - \sigma^2_{H(x_b)},$$

$$\sigma_o^2 = \max\left\{\sigma^2_{\text{pre-o}}, \sigma^2_{\text{est-o}}\right\},$$

3. Improving 1H analysis

- ✓ As compared to 6H, all experiments 2H and 1H degraded global average air temperature RMSE (Fig. 2 and 3), but 1H has > 10% higher (RMSE) as compared to 6H and 2H.
- ✓ Large bias and RMSE of air temperature are shown over tropics, mid-latitudes, and sub-polar regions (Fig. 3).
- ✓ A second time derivative of sea level pressure (hPa/s²) represents a dynamic imbalance in the 1H and 2H as compared to 6H (Fig. 4), which could cause larger errors and bias in the air temperature in the synoptic scales.
- ✓ Inflating observation errors reduce the spurious fluctuations in the initial states caused by imbalance (Minamide and Zhang 2017; He et al. 2020; Fig. 4)
- ✓ Spatial improvements in air temperature RMSE are noted in the 1H (AOEI) experiments.
- ✓ 1H (AOEI) outperforms 1H (Rinfl) in reducing imbalance and air temperature RMSE (Fig. 4 and 5)

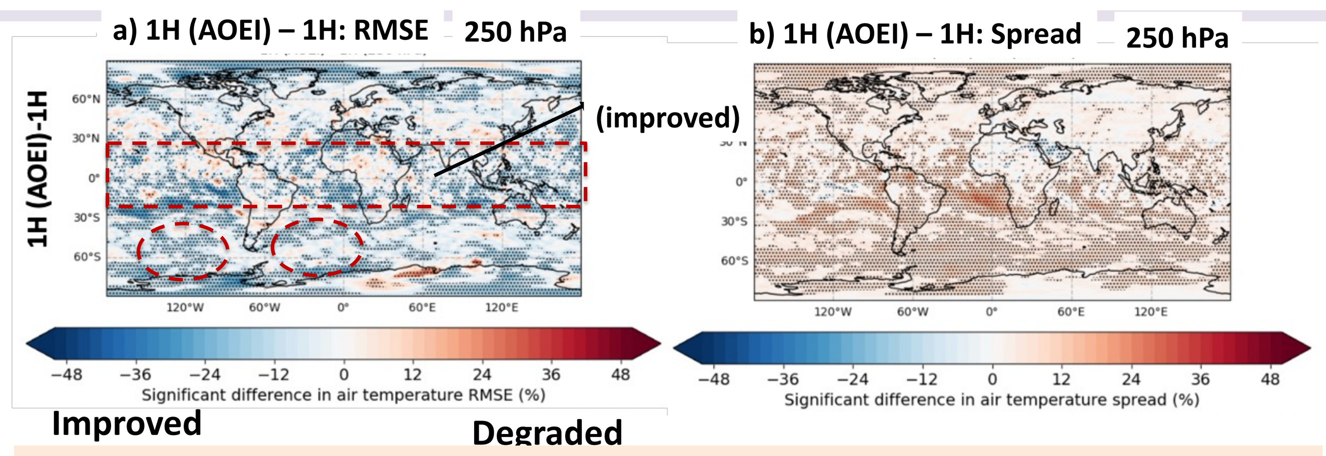


Fig. 5 Spatial changes in the air temperature RMSE and spread w.r.t 1H (%). Hashed region shows 95 % significant difference.

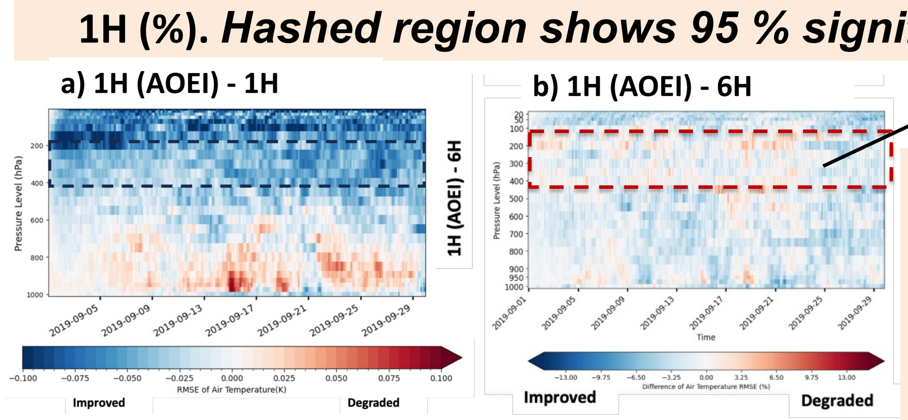


Fig. 6 Vertical and temporal air temperature RMSE change in 1H (AOEI) w.r.t 1H and 6H.

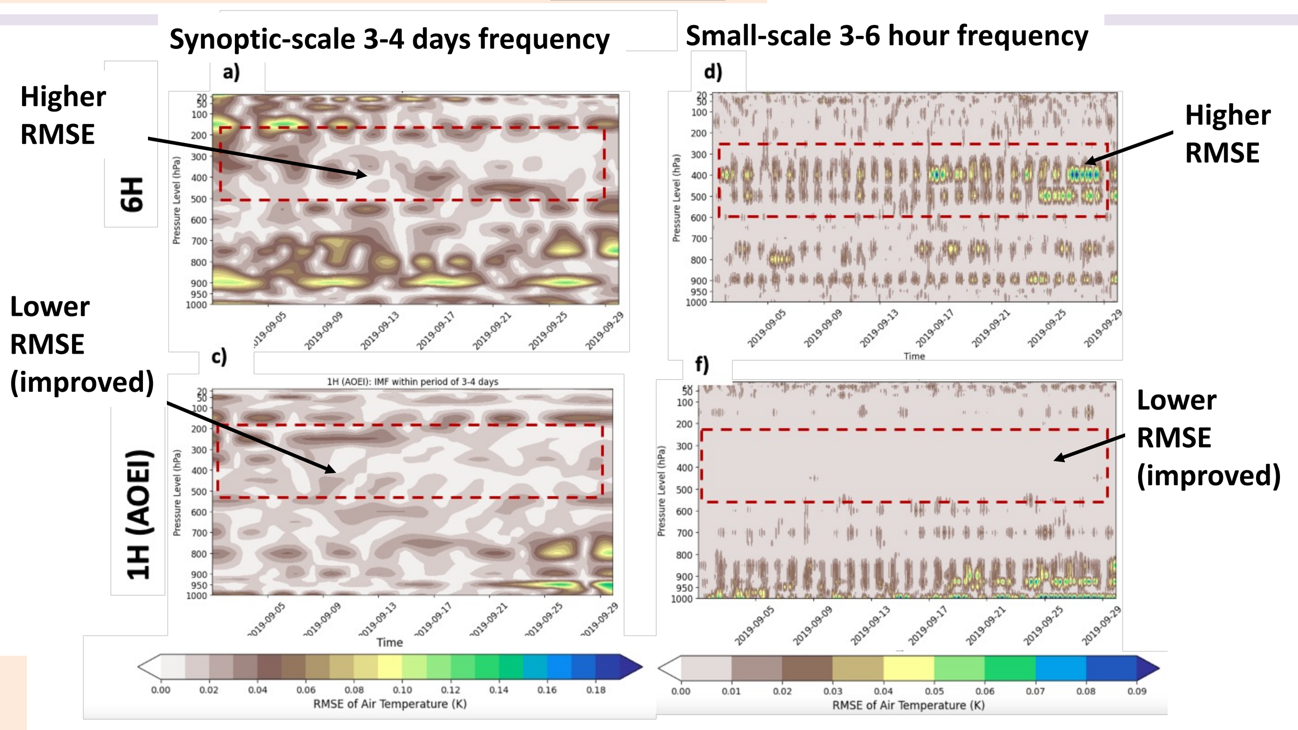
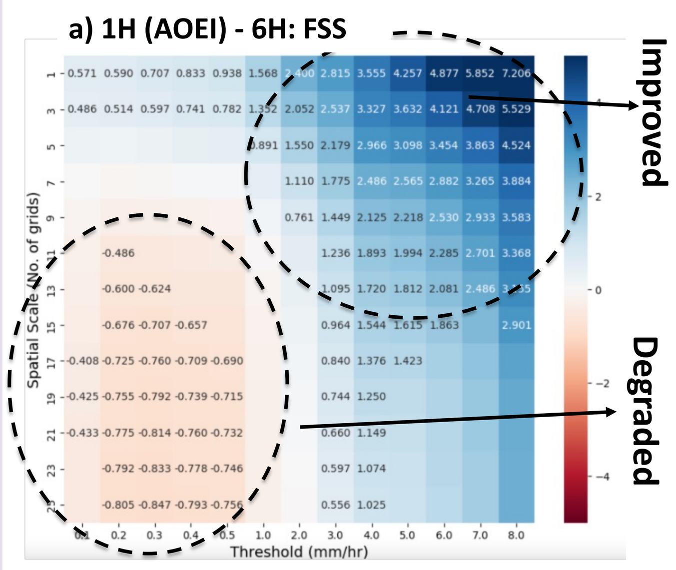


Fig. 7 Vertical and temporal air temperature RMSE (K) for 3-4 day and 3-6 hour temporal scales.

4. Improved precipitation forecast

- ✓ High frequency assimilation improves high intense precipitation forecasts globally.



- ✓ Improved 1H (AOEI) experiment shows significantly better forecast of the small to medium heavy precipitation events globally, which can be explain by improvements in the FSS measure.

Fig. 8 Improvement in the fractional skill score (FSS; %) of the 1-hour forecast precipitation rate (mm/hr) 1H (AOEI) w.r.t 6H. Shown improvements are 95% significant.

- ✓ Threat score (TS) of 6H, 1H (AOEI), and 2H (AOEI) experiment precipitation forecast is shown for global and tropical regions.
- ✓ A higher threat score indicates that the forecast correctly predicted a higher proportion of the observed precipitation events. This means the forecast of 1H (AOEI) has a higher level of skill in predicting precipitation events.

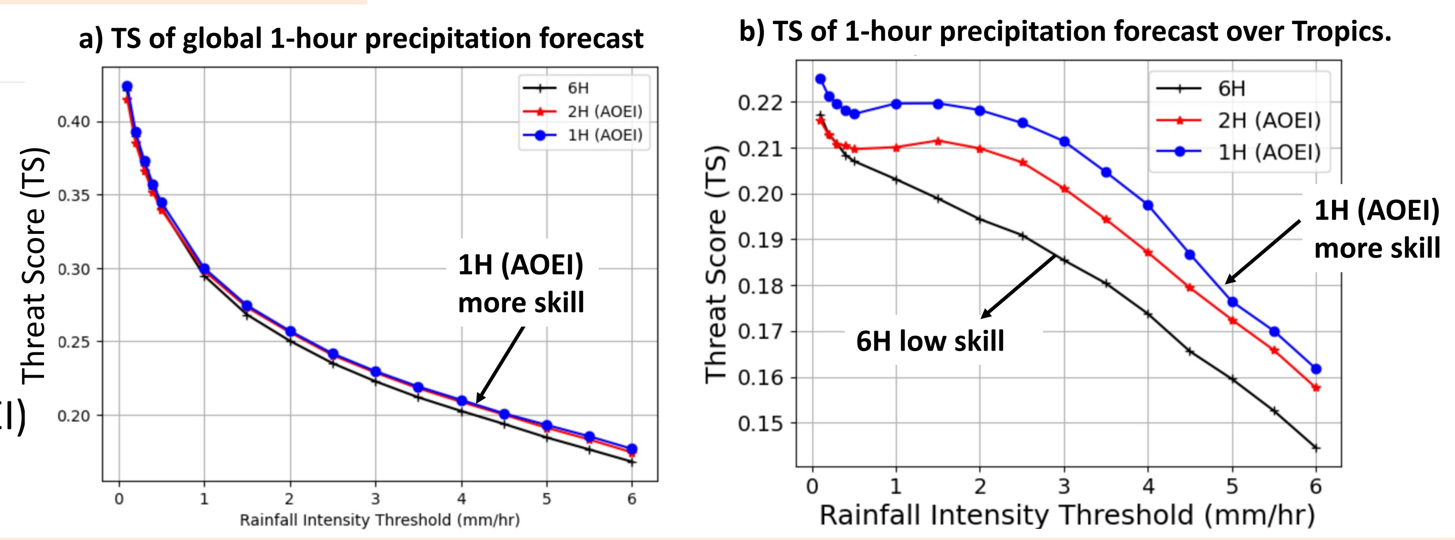


Fig. 9 Threat score between Nature precipitation and 1H (AOEI), 2H (AOEI), & 6H 1-hour precipitation forecast a) over entire globe and b) over tropics (20N:20S & 130E: 160E).

5. Conclusions:

1) This study shows that with the assimilation of frequent and dense satellite microwave observations induce dynamical imbalance which can be addresses by AOEI.
2) Frequent microwave observations improve small scale intense systems globally, epecially improves tropical precipitation forecast.

Reference: **Konduru, R. T.**, Otsuka, S., Liang, J., and Miyoshi, T. (2023) Diagnostic Scale Decomposition of RMSE in Data Assimilation: Insights from OSSEs with NICAM-LETKF., The 6th International Workshop on the Nonhydrostatic Models (NHM-WS-2023), proceedings D-3, Hokkaido University, Sapporo, Japan.
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Terasaki, K., Sawada, M. and Miyoshi, T., 2015. Local ensemble transform Kalman filter experiments with the nonhydrostatic icosahedral atmospheric model NICAM. *Sola*, *11*, 23-26.