The GFS-GSI-based Global Forecast System Adapted at Central Weather Administration of Taiwan: Data Assimilation Development and Performance Evaluation

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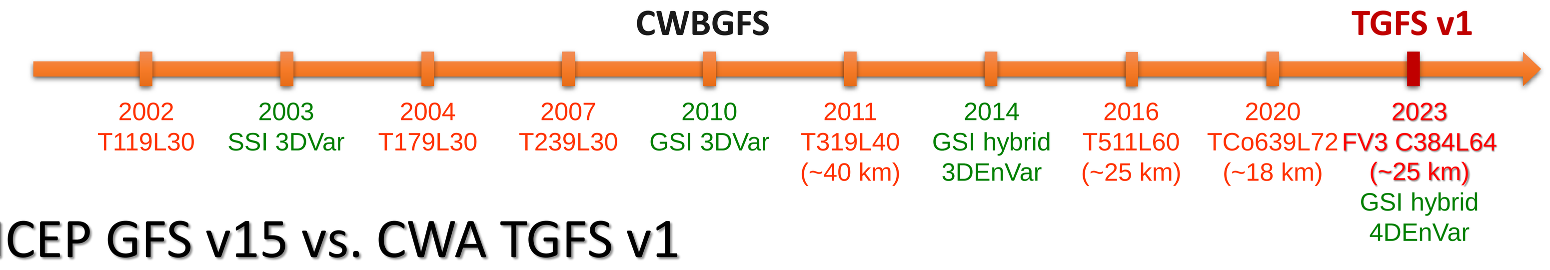
Introduction

The Taiwan Global Forecast System (TGFS) at CWA

- In collaboration with the U.S. National Centers for Environmental Prediction (NCEP), the Central Weather Administration (CWA) of Taiwan has adapted the NCEP's FV3 dynamical core based Global Forecast System (GFS) with the GSI-hybrid 4DEnVar data assimilation for operations at CWA.
- Development of the first operational version of the CWA-localized Global Forecast System, named "Taiwan Global Forecast System (TGFS)" version 1, has been completed, and it has started operations since September 2023.
- In TGFS v1, the deterministic model is run at a horizontal C384 (~25 km) resolution and the ensemble Kalman filter system is run at a C192 (~50 km) resolution, both of which are half of the current operational resolution at the NCEP.
- The observations assimilated in the hybrid data assimilation at CWA are similar but fewer than those assimilated at the NCEP.



NCEP GFS v15 vs. CWA TGFS v1

- CWA TGFS v1 is largely based on NCEP GFS v15.1, with the following main differences:

	NCEP GFS v15.1	CWA TGFS v1
Global grid setting	Deterministic: C768L64 (13 km) / Ensemble: C384L64 (25 km) (zonal tile arrangement)	Deterministic: C384L64 (25 km) / Ensemble: C192L64 (50 km) (Taiwan-centric tile arrangement)
Nested tile	N/A	Taiwan-area nested tile (4.8 km; forecast-only; initialized from global DA analysis)
Ensemble size	80	32 + 32 (12-h time-lagged forecast)
Cumulus scheme	New SAS	Global: CWA modified New SAS (Lin et al. 2022; based on Kwon and Hong 2017) Nested: CWA modified New Tiedtke
Land model and static data	NCEP fix data	Updated land-use, soil type (from WRF/MODIS), vegetation fraction (from EUMETSAT) Land model updates (based on NCEP GFS v16)
Gravity wave drag scheme		Fix a bug associated with air density
Assimilated observations	NCEP observation	NCEP observation – those not publicly available on NOAA NOMADS + CWA-processed **conventional data** (early run only) + CWA-processed **COSMIC-2 RO** + CWA-processed **Himawari-8 AHI radiance**
RO assimilation	Error specified using absolute values	Error specified using fractional values

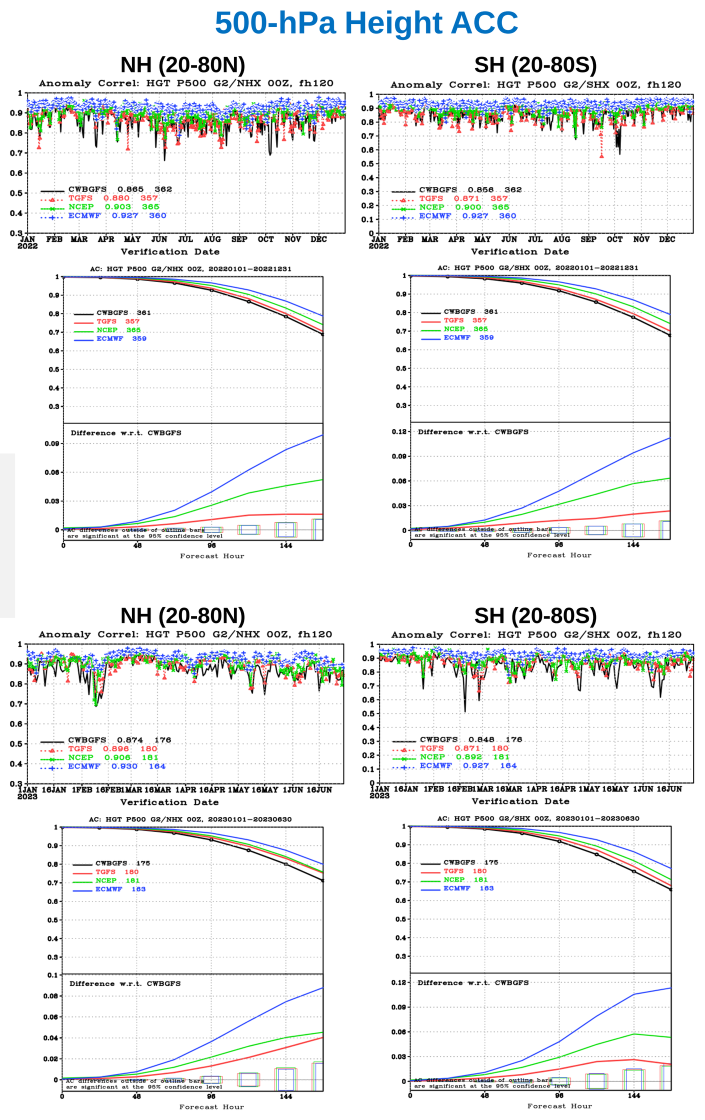
Performance evaluation

CWA TGFS semi-operational test (2022 & 2023H1)

500-hPa Height ACC

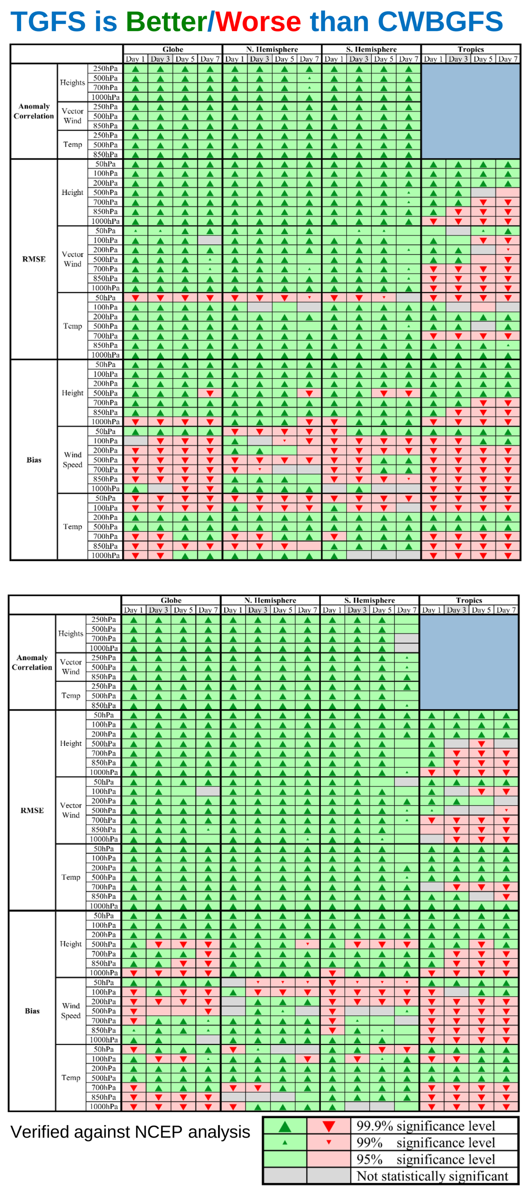
2022/01/01 – 2022/12/31

2023/01/01 – 2023/06/30



CWBGFS (OP-TCo639; 18km; DA at 25km)
CWA TGFS (C384T; 25km)
NCEP GFS (C768; 13km)
ECMWF IFS (9km)

Scorecard – Green/Red : TGFS is Better/Worse than CWBGFS



Verified against NCEP analysis

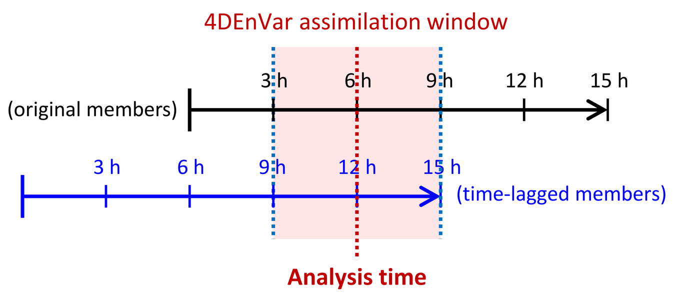
Time-lagged ensemble with hybrid 4DEnVar

- To increase the ensemble size of the flow-dependent error covariance used in the hybrid EnVar with a low cost, the "time-lagged ensemble" approach, as the idea proposed by Lorenc (2017), is used in TGFS.

Exp	Hybrid 3D/4DEnVar	Use time-lagged ensemble? (# members)
3D	3D	- (32)
3DLAG	3D	Yes (32+32)
4D	4D	- (32)
4DLAG	4D	Yes (32+32)

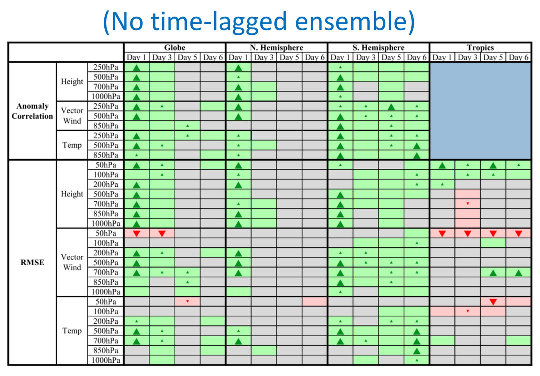
2019/10/01 00Z – 11/01 00Z , 7-day forecasts

4DLAG (Hybrid 4DEnVar + time-lagged ensemble)



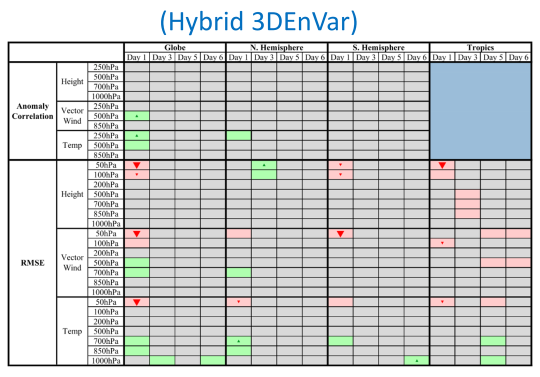
Impact of 4DEnVar vs. 3DEnVar

4D vs. 3D (No time-lagged ensemble)

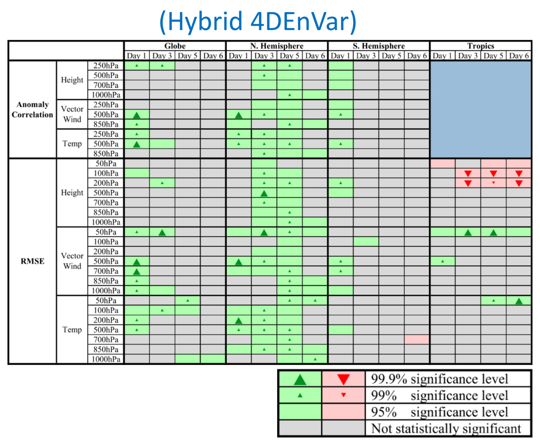


Impact of time-lagged ensemble

3DLAG vs. 3D (Hybrid 3DEnVar)



4DLAG vs. 4D (Hybrid 4DEnVar)

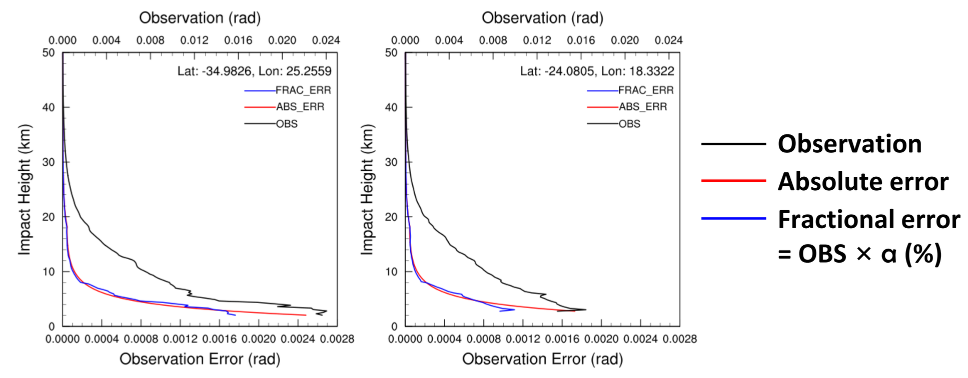


RO bending angle assimilation

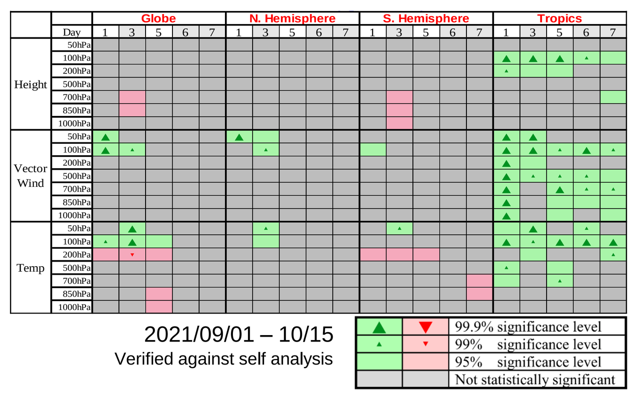
Fractional (relative) vs. absolute observation errors

CTRL : Absolute bending angle observation errors (GSI default)
FracErr : Relative (fractional) bending angle observation errors

Absolute vs. fractional obs errors (Two samples of RO profiles)



Scorecard (RMSE) – Green/Red : FracErr is Better/Worse than CTRL



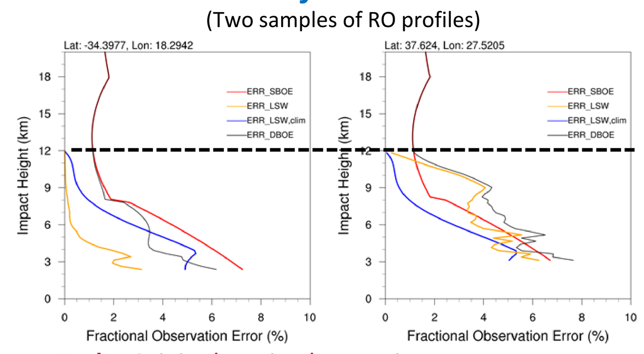
2021/09/01 – 10/15 Verified against self analysis

Local Spectral Width (LSW)-based dynamic observation errors

- Zhang et al. (2023) demonstrated a positive impact of LSW-based dynamic RO observation errors in a global NWP system.
- Inspired by the previous study, we propose a new statistically-consistent approach to formulate a bending angle observation error model, which by design meets the following assumptions:
  - The long-term average of the profile-dependent observation error variance always converges to the traditional (statistically determined) static observation error variance.
  - Upper-level RO data use exactly the static observation errors (i.e., not profile-dependent).
  - The observation errors of lower-level RO data are largely determined by their LSW values.

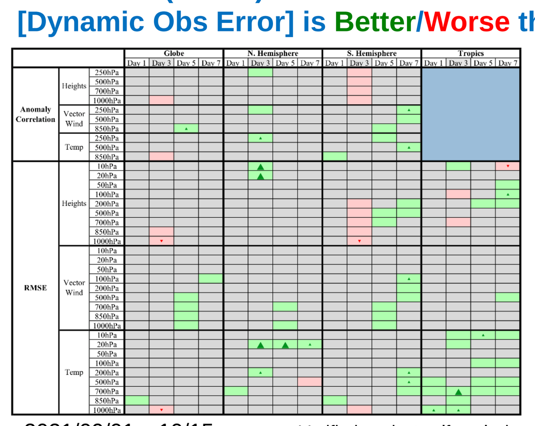
$$\sigma = \sqrt{\sigma^2_{static} + \sigma^2_{dyn} - \sigma^2_{dyn,\,clim}} \qquad \sigma_{static}: \text{Traditional static errors} \qquad \sigma_{dyn} = LSW/3 \qquad \sigma_{dyn,\,clim} = \sqrt{\overline{\sigma^2_{dyn}}}$$

Static vs. dynamic obs errors (Two samples of RO profiles)



Red: Original static observation error
Gray: The new dynamic observation error

Scorecard (RMSE) – Green/Red : [Dynamic Obs Error] is Better/Worse than [Static Obs Error]



2021/09/01 – 10/15 Verified against self analysis

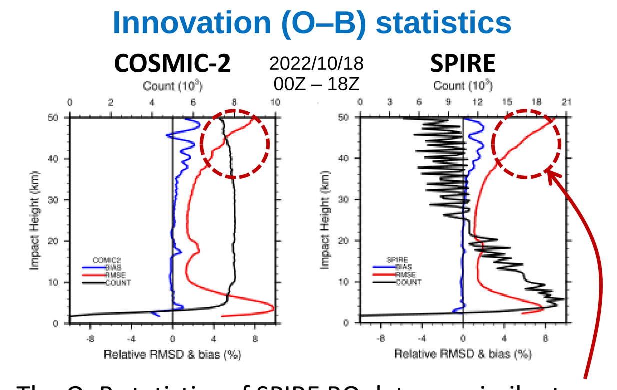
- To achieve an optimal impact of the dynamic observation errors, some GSI built-in QC criteria are relaxed in these experiments.

(This part of development has not been used in the operational TGFS v1.)

Commercial RO data

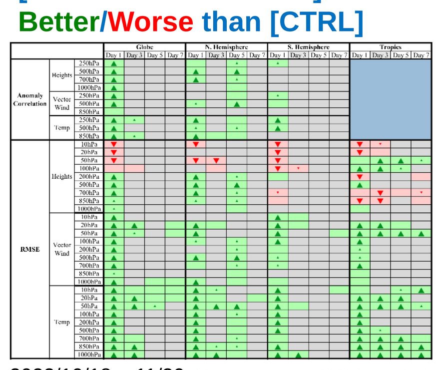
- In recent years, the number of RO observation data from commercial providers has increased rapidly, and NOAA and EUMETSAT have purchased several commercial RO datasets and released them via GTS.
- After some brief tests, the assimilation of SPIRE and PlanetIQ RO data has been enabled in TGFS v1.

Innovation (O–B) statistics



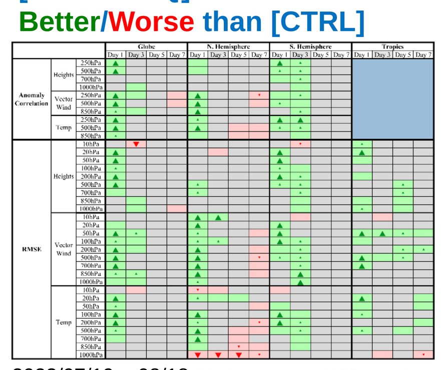
- The O–B statistics of SPIRE RO data are similar to other traditional RO data, except for upper-level data above ~30 km, which shows larger errors.

Scorecard (RMSE) – Green/Red : [w/ SPIRE + METOP-C] is Better/Worse than [CTRL]



2022/10/18 – 11/30 Verified against NCEP analysis

[w/ PlanetIQ] is Better/Worse than [CTRL]



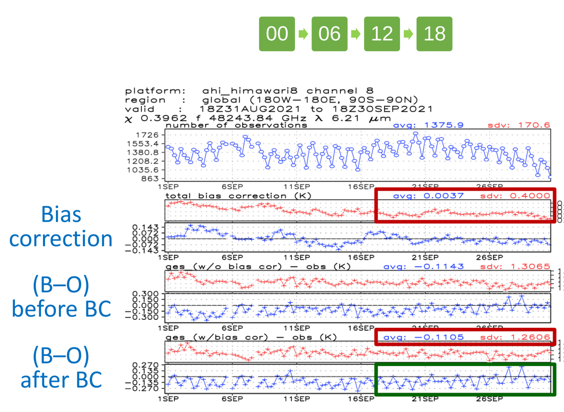
2023/07/19 – 08/18 Verified against NCEP analysis

- Commercial RO data above 30 km are discarded.

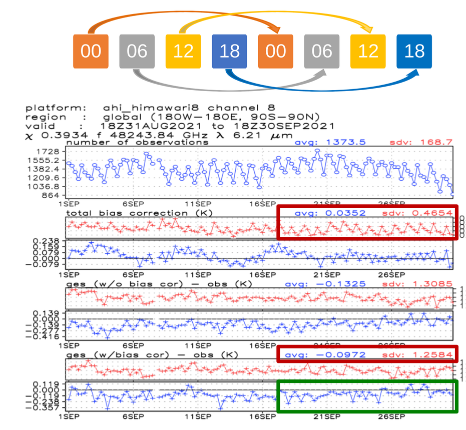
Himawari-8/9 AHI assimilation

- The Himawari-8/9 AHI geostationary infrared radiance data processed at CWA are assimilated in TGFS v1. The assimilation impact is just neutral (not shown).
- We tested a "daily cycle" bias correction approach for the geostationary satellite assimilation. It improves the effectiveness of the bias correction, but no significant impact on the forecast has been found.

Traditional 6-h cycle VarBC



24-h (daily) cycle VarBC for AHI

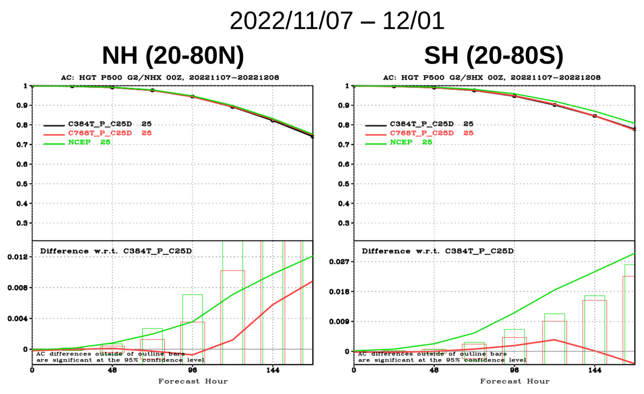


Next version: Increased resolution

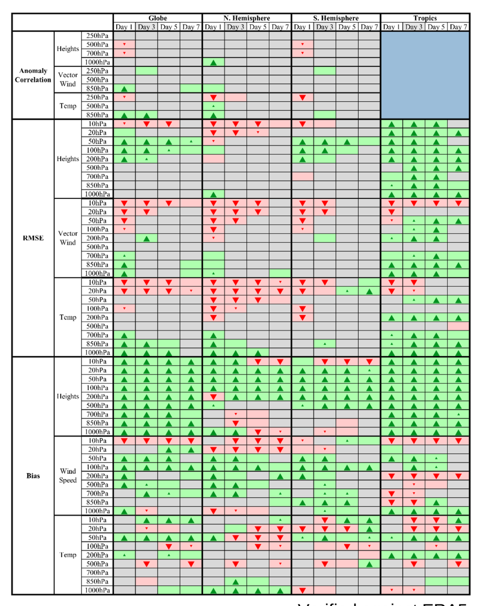
- With CWA's 6th-generation HPC, we started testing a deterministic C768 (13 km) / ensemble C384 (25 km) resolution version of TGFS (same resolution as NCEP).
- Preliminary results show only slightly improved forecast skills (mostly in tropics and bias scores). Further improvements are needed to justify the operation of the 13 km system.

Scorecard – Green/Red : C768T (13km) is Better/Worse than C384T (25km)

2022/11/07 – 12/01



TGFS v1 (C384T; 25km)
TGFS develop (C768T; 13km)
NCEP GFS (C768; 13km)



Verified against ERA5

Conclusions and references

- The CWA has successfully adapted and localized the NCEP's GFS and GSI systems (version 15.1) as the new operational global prediction system run at CWA, named TGFS.
- With several local modifications in the model and data assimilation components, the TGFS v1 has achieved a good forecast performance at the C384 (about 25 km) resolution.

References:

Lien, G.-Y., L.-F. Hsiao, C.-H. Lin, F.-J. Wang, Y.-H. Chen, J.-H. Chen, J.-S. Hong, D. Kleist, F. Yang, V. Tallapragada, 2023: The Operational Use and Local Development of UFS MRW-GSI System at Central Weather Bureau of Taiwan. *Unifying Innovations in Forecasting Capabilities Workshop (UIFCW) 2023*, Boulder, USA & Virtual Meeting, 24-28 July. [Video recording and presentation slide available at https://epic.noaa.gov/uifcw-summer-workshop-2023/]

Lin, C.-H., M.-J. Yang, L.-F. Hsiao, J.-H. Chen, 2022: The Impact of Scale-Aware Parameterization on the Next-Generation Global Prediction System in Taiwan for Front Predictions. *Atmosphere*, **13**(7), 1063. https://doi.org/10.3390/atmos13071063

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