The Operational Use and Local Development of UFS MRW-GSI System at Central Weather Bureau of Taiwan

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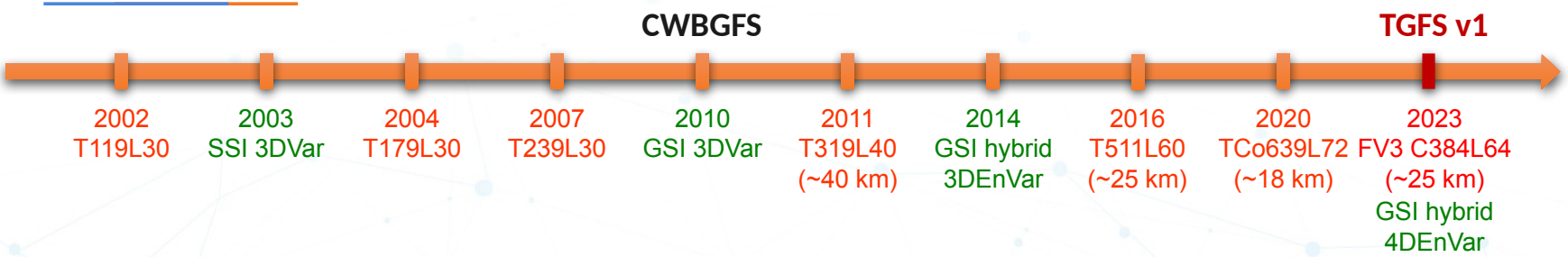
CWB Global NWP system



In collaboration with NCEP/EMC since 2016,
CWB has adapted the NCEP GFS v15 as its new operational global NWP system

- **2019**: Port GFS v15 (FV3GFS) model code
- **2020**: Port GSI code (for GFS v15) and the complete data assimilation workflow
- **2021**: Start semi-operational (near-real-time) run / research & performance tuning
- **2022**: Research & performance tuning / Port to CWB's 6th-generation HPC (Fujitsu FX1000; ARMv8.2-A)
- **2023**: Research & performance tuning / Operation → **Taiwan Global Forecast System (TGFS) v1**
- **Continuous research & performance tuning**

CWB TGFS v1 grid configuration

Deterministic system

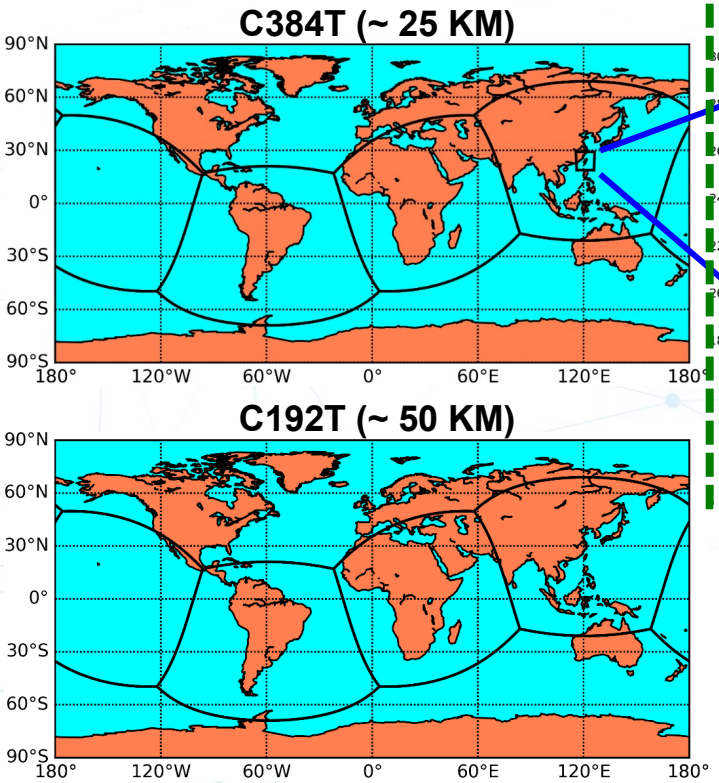
hybrid 4DEnVar

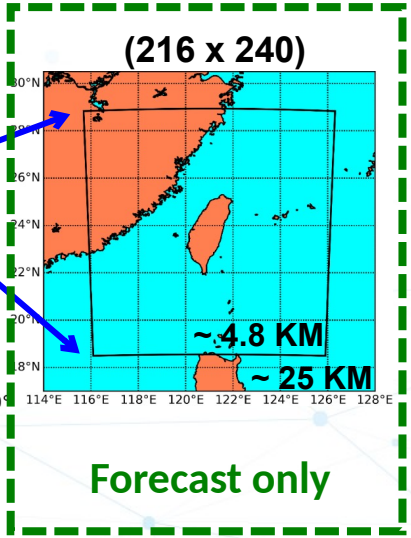
using time-lagged ensemble (global domains)

Ensemble system

EnKF

(32 members)





Forecast only

cf. NCEP:

C768 (~13 km) for deterministic

C384 (~25 km) for ensemble

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NCEP GFS v15 vs. CWB TGFS v1

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

	NCEP GFS v15.1	CWB TGFS v1
Global grid setting	Det: C768L64 (13km) / Ens: C384L64 (25km) (zonal tile arrangement)	Det: C384L64 (25km) / Ens: C192L64 (50km) (Taiwan-centric tile arrangement)
Nested tile	N/A	Taiwan-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	Modified New SAS: Lin et al. (2022) [based on Kwon and Hong (2017)]
Cumulus scheme for the nested tile	N/A	New Tiedtke
Surface static data	NCEP fix data	Updated land-use, soil type (from WRF/MODIS), vegetation fraction (from EUMETSAT)
Gravity wave drag scheme		Fix a bug associated with air density
Planetary boundary layer scheme	K-EDMF	Fix a bug associated with Prandtl number
Assimilated observations	NCEP observation	NCEP observation – those not publicly available on NOAA NOMADS + CWB-processed **conventional data** (early run only) + CWB-processed **COSMIC-2 RO** + CWB-processed **Himawari-8 AHI**
Hybrid 4DEnVar time bin width	1 h	3 h
RO assimilation	Error specified using absolute values	Error specified using fractional values

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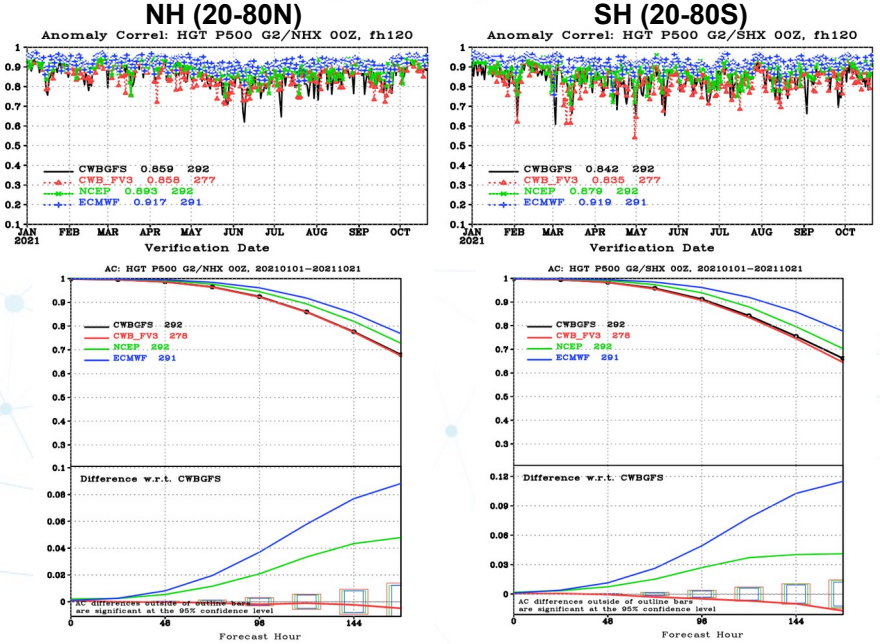
RO assimilation	Error specified using absolute values	Error specified using fractional values

Main inferiorities to NCEP GFS:
1) **Lower resolution (25 vs. 13 km)**
2) **Fewer ensemble members (32(+32) vs. 80)**
3) **Fewer observations assimilated**

TGFS v1 semi-operational test: 2021

2021/01/01 ~ 2021/10/21

500-hPa Height ACC



- CWBGFS (18 km; DA at 25 km with "EC bogus data")
- TGFS (C384; 25 km)
- NCEP GFS (C768; 13 km)
- ECMWF IFS (9 km)

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

			Globe				N. Hemisphere				S. Hemisphere				Tropics			
			Day 1	Day 3	Day 5	Day 7	Day 1	Day 3	Day 5	Day 7	Day 1	Day 3	Day 5	Day 7	Day 1	Day 3	Day 5	Day 7
Anomaly Correlation	Height	250hPa	▼	▼	▾	▼					▲	▼						
		500hPa	▵	▼		▾					▲	▼						
		700hPa	▲			▾	▲	▵			▲			▾				
		1000hPa	▲	▲			▲	▲			▲	▲						
	Vector Wind	250hPa	▲	▼	▼	▼	▲				▲	▼	▾					
		500hPa	▲	▼	▾		▲				▲	▼						
		850hPa	▼	▼								▼						
	Temp	250hPa	▲				▲			▾	▲							
		500hPa	▼	▼	▼	▼	▼	▾			▲	▼	▾					
		850hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲				
RMSE	Height	50hPa	▾	▲	▲	▲			▲	▲	▲	▲	▲	▲	▼	▼	▼	
		100hPa	▼	▲	▲	▲			▲	▲		▲	▲	▲	▼	▼		▲
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		1000hPa	▲	▲	▲	▲	▲	▲	▵		▲	▲	▵		▼	▼	▼	▼
	Vector Wind	50hPa	▼	▼	▼	▼	▲	▲	▲	▲	▲	▼	▼	▼	▼	▼	▼	▼
		100hPa	▲	▼	▼	▼	▲	▲	▲		▲	▼	▼	▼	▲		▼	▼
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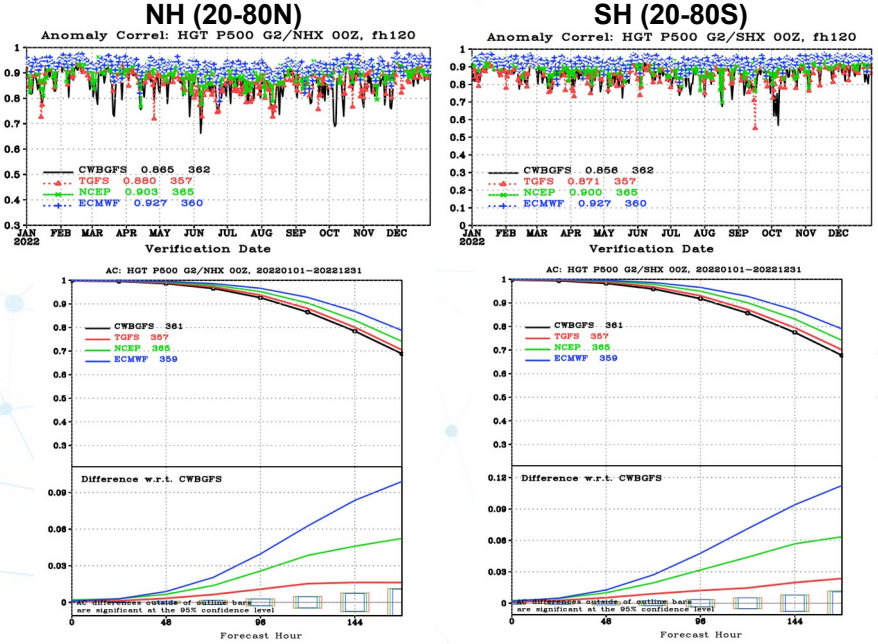
		500hPa	▲	▼	▼	▼	▲	▲			▲	▼	▼	▼	▼	▼	▼	▼
		700hPa	▼	▼	▼	▼	▲	▲			▵	▼	▼	▼	▼	▼	▼	▼
		850hPa	▼	▼	▾	▼	▲	▲			▲	▼	▼	▼	▼	▼	▼	▼
		1000hPa	▲	▼			▲	▲	▲	▵	▵	▼	▾	▾	▼	▼	▼	▼
	Temp	50hPa	▵	▼	▼	▼	▲	▲	▼	▼	▾	▼	▼	▼	▼	▼	▼	▼
		100hPa	▵	▼	▼	▼	▲	▲	▼	▼	▲	▼	▼	▼	▼	▼	▼	▼
		200hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▼	▼	▼
		500hPa	▼	▼	▼	▼	▲	▼	▼	▼	▲	▼	▼	▼	▼	▼	▼	▼
		700hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▼	▼	▼
		850hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
		1000hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
Bias	Height	50hPa	▼	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▼	▲	▼
		100hPa	▼	▲	▲	▲	▼	▲	▲	▲	▲	▲	▲	▲	▼	▼	▲	▲
		200hPa	▼	▲	▲	▲	▼	▲	▲	▲	▲	▲	▲	▲	▼	▼	▲	▲
		500hPa	▲	▲	▼	▼	▲	▲	▲	▲	▲	▼	▼	▼	▲	▼	▲	▼
		700hPa	▲	▲	▲	▼	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▲	▼
		850hPa	▲	▲	▲	▼	▲	▲	▲	▲	▲	▲	▲	▲	▼	▼	▼	▼
		1000hPa	▼	▲	▲	▼	▲	▲	▲	▲	▲	▲	▲	▲	▼	▼	▼	▼
	Wind Speed	50hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▼	▲	▲
		100hPa	▼	▼	▼	▼	▲	▲	▲	▲	▼	▼	▼	▼	▼	▼	▼	▾
		200hPa	▲	▲	▲	▲	▲	▲	▵		▼	▼	▼	▼	▼	▼	▲	▵
		500hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▼	▼
		700hPa	▲	▲	▲	▵	▲	▲	▲		▲	▲			▼	▼	▼	▼
		850hPa	▼				▲	▼	▼	▼	▲				▼	▼	▼	▾
		1000hPa	▼	▾			▲	▲	▲	▲	▲	▲	▲	▲	▼	▼	▼	▼
	Temp	50hPa	▼	▼	▼	▼	▲	▲	▼	▼	▲	▲	▲	▲	▼	▼	▼	▼
		100hPa	▼	▼	▼	▼	▲	▲	▼	▼	▲	▲	▲	▲	▼	▼	▼	▼
		200hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▼	▼	▼
		500hPa	▼	▼	▲	▲	▼	▼	▼	▼	▲	▲	▲	▲	▼	▼	▼	▼
		700hPa	▼	▼	▲	▲	▼	▼	▼	▼	▲	▲	▲	▲	▼	▼	▼	▼
		850hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▼	▼	▼
		1000hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲

▲	▼ 99.9% significance level
▵	▾ 99% significance level
	95% significance level
	Not statistically significant

Verified against NCEP analysis

TGFS v1 semi-operational test: 2022 2022/01/01 ~ 2022/12/31

500-hPa Height ACC



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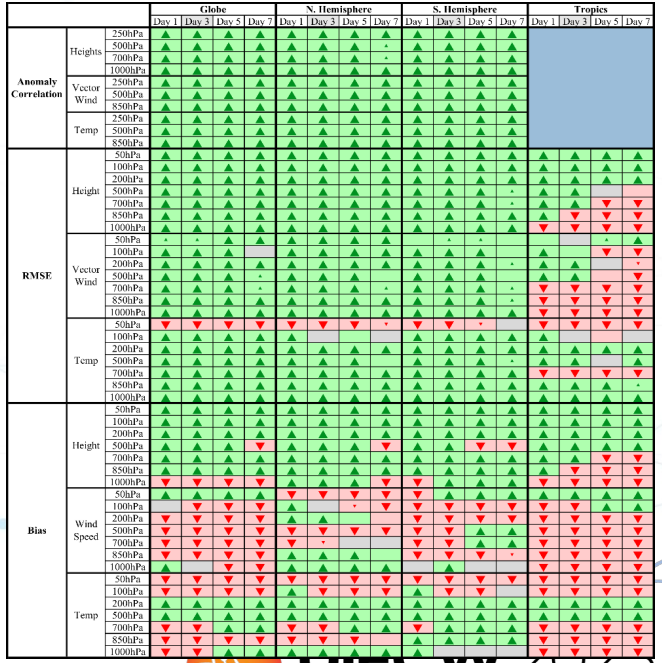
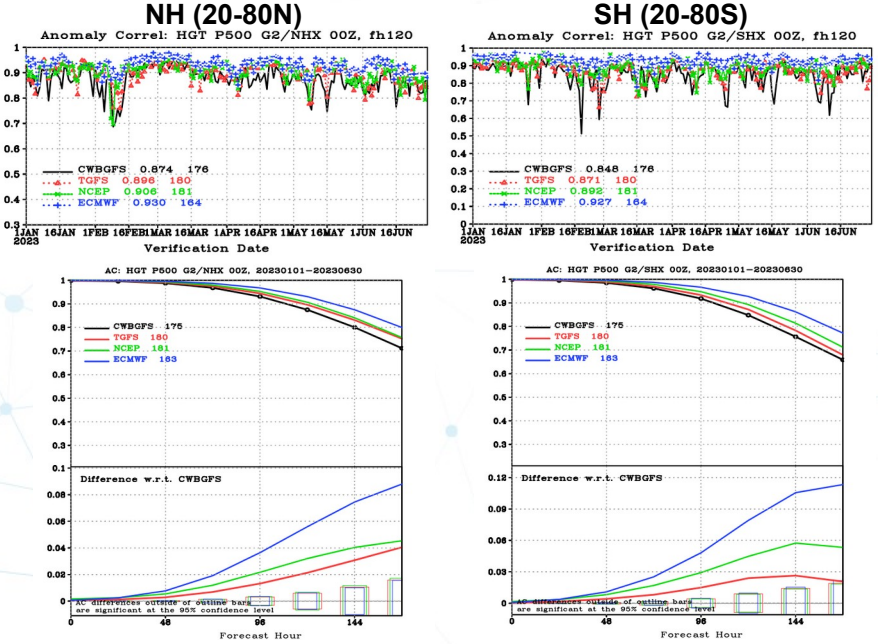


Verified against NCEP analysis

TGFS v1 semi-operational test: 2023H1

2023/01/01 ~ 2023/06/30

500-hPa Height ACC



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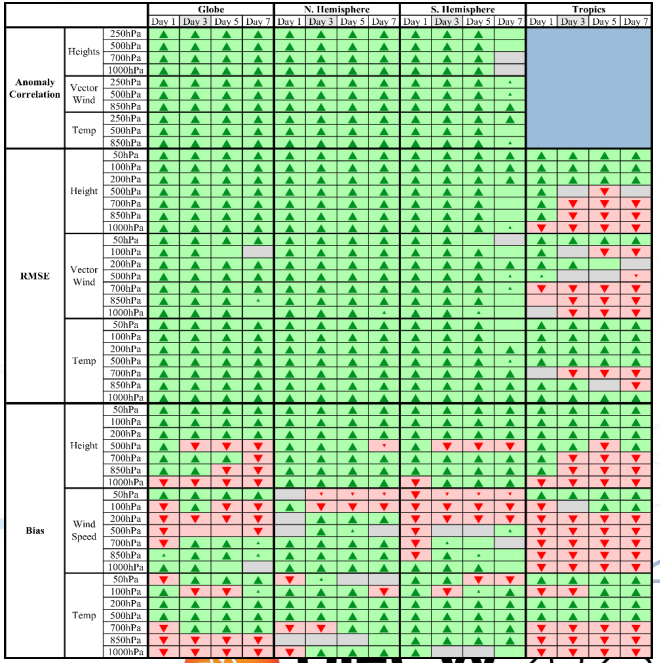
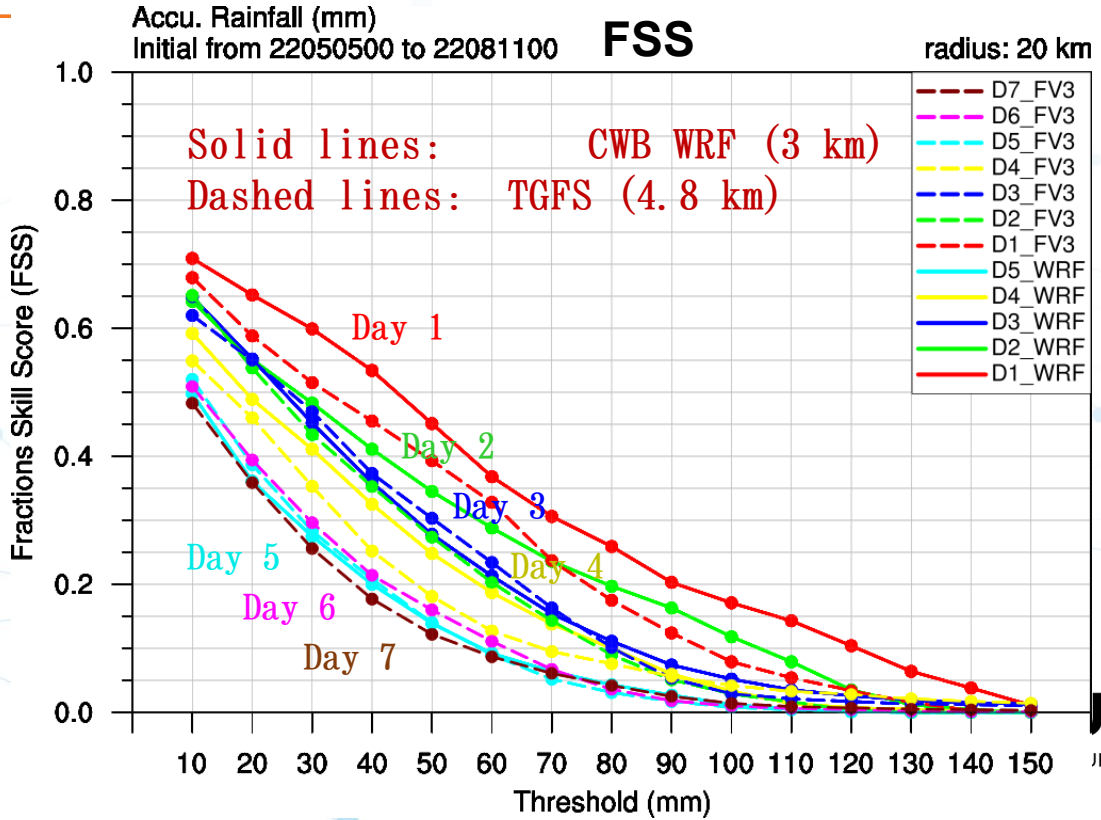
Scorecard – Green/Red : TGFS is Better/Worse than CWBGFS



Verified against NCEP analysis

TGFS v1 semi-operational test: Taiwan nested tile



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Improvement of NSAS cumulus scheme

[**Lin et al. (2022)**, based on **Kwon and Hong (2017)**]

Scorecard – Green/Red :
EXP is better/worse than CTRL

Verification data: ERA5
Time period: 20210904~20211009

			Globe				N. American				N. Hemisphere				S. Hemisphere				Tropics			
			Day 1	Day 3	Day 5	Day 7	Day 1	Day 3	Day 5	Day 7	Day 1	Day 3	Day 5	Day 7	Day 1	Day 3	Day 5	Day 7	Day 1	Day 3	Day 5	Day 7
Anomaly Correlation	Heights	250hPa	▲																			
		500hPa							▲													
		700hPa					▲															
		1000hPa					▲															
	Vector Wind	250hPa		▲												▲						
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		850hPa	▲	▲			▲				▲				▲							
	Temp	250hPa	▲	▲	▲	▲									▲	▲						
		500hPa					▲								▲							
		850hPa													▲							
	MSLP	MSL																				
RMSE	Heights	10hPa																				
		20hPa																				
		50hPa	▲	▲	▲		▲	▲	▲		▲	▲	▲		▲				▲	▲	▲	▲
		100hPa	▲	▲	▲		▲	▲	▲		▲	▲	▲		▲				▲	▲	▲	▲
		200hPa	▲	▲			▲	▲			▲	▲			▲				▲	▲	▲	▲
		500hPa					▲	▲	▲										▼			
		700hPa					▲															
		850hPa					▲															
		1000hPa					▲															
	Vector Wind	10hPa																				
		20hPa																				
		50hPa	▲	▲	▲			▲	▲						▲				▲	▲	▲	▲
		100hPa	▲	▲	▲				▲			▲							▲	▲		
		200hPa		▲			▲								▲	▲						
		500hPa					▲								▲							
		700hPa	▲				▲												▲			
		850hPa					▲				▲				▲							
		1000hPa		▲								▲								▲	▲	
	Temp	10hPa																				
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		100hPa					▲				▲				▲							
		200hPa	▲	▲			▲				▲				▲				▲	▲	▲	
		500hPa					▲								▲					▲	▲	
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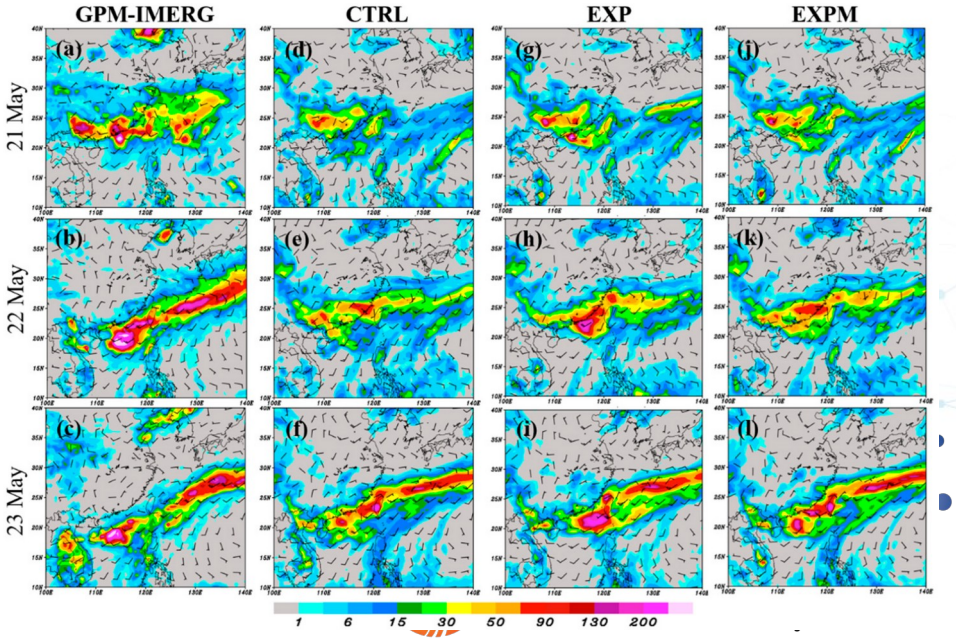


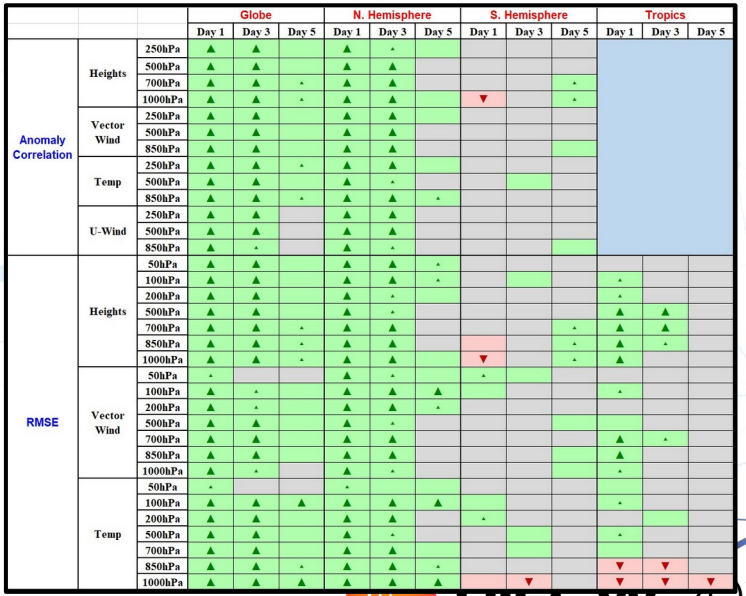
Improvement of land processes

1. **Update surface static data:**
   - **Land-use & soil type: WRF/MODIS**
   - **Vegetation fraction: EUMETSAT**

   (much newer and higher-resolution than the GFS default static datasets)

2. **Improve the land model:**
   (based on some revisions in GFS v16)
   - Revise ground heat flux calculation over snow cover
   - Introduce vegetation impact on surface energy budget over urban areas

Scorecard (RMSE) – Green/Red :
UPDATE is Better/Worse than CTRL
2022/12/01 ~ 2022/12/31

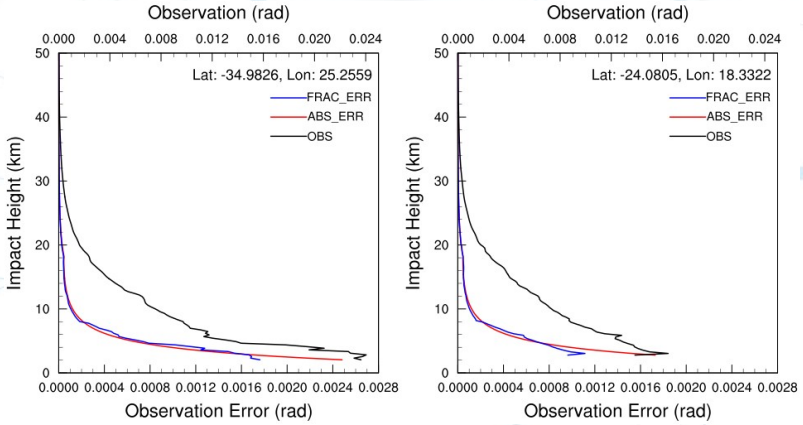


Verification data: ERA5

Improvement of GNSS RO observation error specification

Experiment	Observation error
CTRL	Absolute (GSI default)
FracErr	Fractional

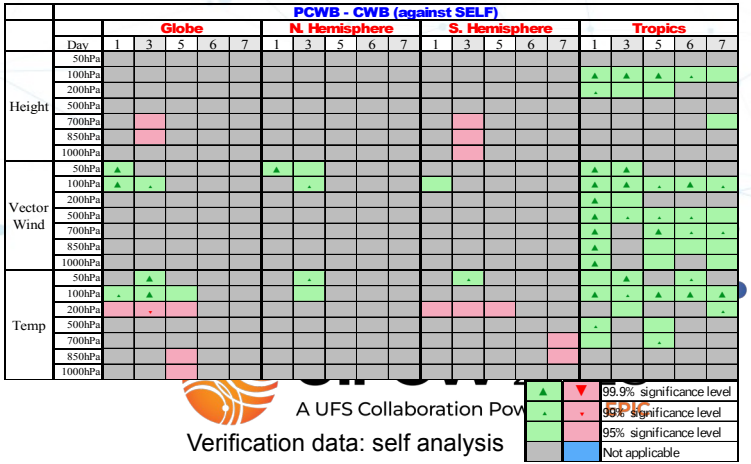
RO absolute vs. fractional errors



(RO observation samples)

- **Observation**
- **Absolute error**
- **Fractional error = OBS × a (%)**

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



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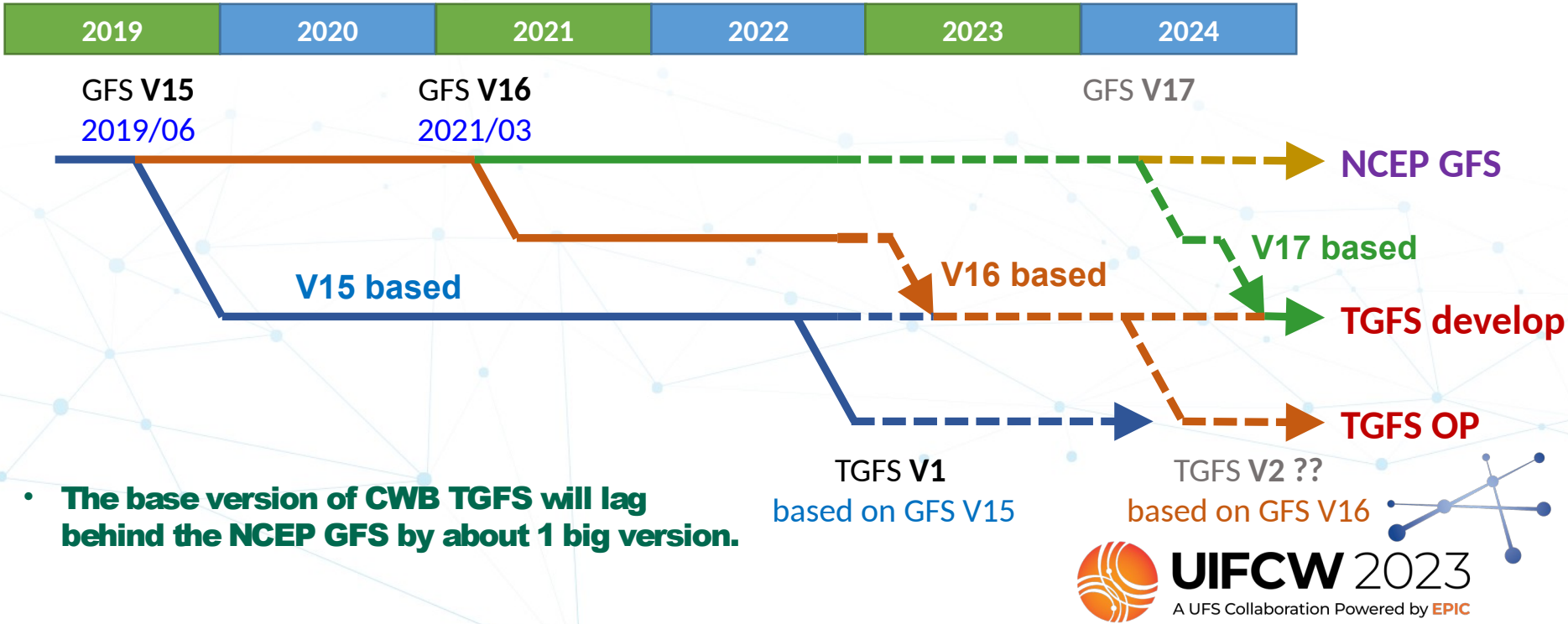
Verification data: self analysis

Relation between NCEP GFS and CWB TGFS



- **The base version of CWB TGFS will lag behind the NCEP GFS by about 1 big version.**

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Summary & Discussion

- In collaboration with NCEP/EMC since 2016, CWB has adapted the NCEP GFS v15 as its new operational global NWP system.
- Since the model component of the system has later become part of the UFS Medium-Range Weather (MRW) Application, the CWB may be regarded as one of the UFS MRW's early adopters for research and operations in the Western Hemisphere.
- The CWB-localized GFS (TGFS) has achieved a good forecast performance.
- Despite the thorough documentation of the GFS/UFS-related programs, to build the entire operational workflow of the system (including the hybrid EnVar data assimilation) in an environment outside NOAA computers (like CWB) is still not a trivial task, due to the complicated nature of the operational system.
    - However, we worked based on EMC's original operational code and did not watch closely the UFS community releases.
- Based on this CWB-localized system, we have established several collaborations with Taiwanese universities/ research institutes, so a "sub-community" in Taiwan may emerge.
- We greatly thank the UFS project and efforts spent by NOAA/NCEP to provide these great tools, that allow us to build and use a start-of-the-art NWP system at CWB.