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Evaluation on Indian Summer Monsoon in High Resolution Prototypes of NOAA's Unified Forecast System (UFS)

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- NOAA's Unified Forecast System (UFS)
 - Monsoon simulations from UFS Prototypes
 - Precipitation related to Indian monsoon in UFS Prototypes
 - Some diagnostic analyses
 - Summary and discussions



In Development: Coupled UFS Applications for global medium range, sub-seasonal and seasonal predictions

GFSv17/GEFS v13: Fully coupled system for medium-range and sub-seasonal predictions

- FV3+MOM6+CICE6+WWW3+GOCART Coupled Model
- Advanced Physics, Weakly Coupled DA
- FY26: Implement GFSv17/GEFS v13 Seasonal Forecast System (SFS v1.0)
- Fully coupled Unified Forecast System
- Seasonal ensemble forecasts with reanalysis and reforecasts
 - Advanced coupled DA

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• FY27+: Implement SFS v1.0



Goals/Scope of GFSv17

- Coupled forecast model (atm, land, ocn, ice, wav)
- Improved DA with JEDI for non-ATM components
- Towards consolidation of NCEP production suite
- Improve on known issues in GFSv16
- Increase ATM horizontal resolution to 9 km



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GFSv17 Development | Runs | Initial Conditions

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$GFSv16{\rightarrow}HR5$

JJA/DJF

			N. America			N. Hemisphere					S. Hemisphere									
			Day 1	y Day 4	Day 7	Day 10	Day 13	Day 16	Day 1	Day 4	Day 7	Day 10	Day 13	Day 16	Day 1	Day 4	Day 7	Day 10	Day 13	Day 16
LIDE	Heights	250hPa		I													1			
HRO VS		500hPa																		
GFSv16		700hPa											\square							
Second Control Control		1000hPa			1-	\vdash							\square		V					
27.3301.02014	Vector Wind	250hPa			1-	\vdash	1				1-					1 .	1-	+		
Anomaly Correlation		500hPa			1-	+	+				1—	-	-		Ā			1		
JJA		850hPa	17			+	+			-	1-	-	-	\vdash	F		1	+	-	
	Temp	250hPa	17		+-	+	+		17	-	-	-	-			-		-	-	
		500hPa	f		+-	\vdash							\vdash				-			
		850hPa									-	1			۷		1			
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			Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day
			1	4	7	10	13	16	1	4	7	10	13	16	1	4	7	10	13	16
HD5 VC		250hPa						_			_		_							_
HKJ VS	Heights	500hPa				<u>, s</u>			*	*	_				•	-				
GFSv16		700hPa		*	_			0		*	_		_	_						
		1000hPa								-	_	*		_						
nomaly Correlation	Vector Wind	250hPa	*								_									
Coefficient		500hPa											_	_						
		850hPa							*											
DJF	Temp	250hPa								A.										
		500hPa	*						*											
L		850hPa																		
	MSLP	MSL										-								

HR4 is better than GFSv16 at the 99.9% significance level
 HR4 is better than GFSv16 at the 99% significance level
 HR4 is better than GFSv16 at the 95% significance level
 No statistically significant difference between HR4 and GFSv16

JJA HR5 shows statistically significant improvement over GFSv16

DJF HR5 shows statistically significant improvement over GFSv16, reaching longer lead times

Fully Coupled GEFSv13 for Operations

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		Components	V12 (Sep 23. 2020)	V13 (targeting FY26)							
<i>उ</i> म्र <u>ौ</u>		Dynamics	FV3 (Finite-Vol Cubed-Sphere) GFSv15	FV3 (Finite-Vol Cubed-Sphere) GFSv17							
		Physics	saSAS, GFDL-MP, K-EDMF, oroGWD	saSAS, Thompson-MP, sa-TKE-EDMF, uGWD							
	Atmos	Initial perturbation	EnKF f06 (previous cycle)	EnKF f00 (early cycle)							
Ŕ		Model uncertainty	5-scale SPPT and SKEB	5-scale SPPT, SKEB, SPP, CA							
		Boundary (ocean surface)	NSST + 2-tiered SST	NSST							
		Resolutions	C384L64 (25km)	C384L127 (25km)							
哭	Lond	Model	NOAH-LSM	NOAH-MP							
	Land	Initial perturbation	N/A	Soil moisture							
	Ocean	Model		MOM6 (0.25°L75)							
		Initial perturbation		SOCA-Ens							
		Model uncertainty	Ν/Δ	5-scale oSPPT and ePBL							
	lce	Model		CICE6 (0.25°)							
		Initial perturbation		SOCA-Ens							
	Wave Model		WW3 (1-way) (0.5°)	WW3 (2 way) (0.25° lat/lon grid)							
	Aerosol Model		GOCART (1-way)	GOCART (1-way)							

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GFSv13 Development | Runs | Initial Conditions

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AC and RMSE (Lead Days 1-10)



EP6 is significantly better than GEFSv12 for the vast majority of instances

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Evaluation on Indian Summer Monsoon from UFS Prototypes

- Model outputs: a) HR1--HR3a (C768); HR3b--HR5 (C1152) Ops GFSv16 (C768)
 b) EP5 (GEFS ensemble prototype)
- Season: a) HR: Summer 20200601 to 20200830 every 3-days (31 cases)
 b) EP5: May-Sep of 2018, 2019 and 2021 (run every week)

• Observations or analyses:

- -- Winds: GFSv16 analysis, ERA5
- -- Precipitation: CPC CMORPH daily and hourly precipitation analysis CDR GPCP daily precipitation analysis



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Evaluation on Indian Summer Monsoon: Monsoon Index and Rainfall ž



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A East Asian - Western North Pacific monsoon index Δ Webster-Yang monsoon index **∆** South Asia monsoon index

∆ Dynamic Indian monsoon index

- △ Extended Indian Monsoon Rainfall (EIMR)
- **∆ South Asia Rainfall**
- **∆ Indian Continent Rainfall**
- **∆ Webster-Yang Rainfall**



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Forecast:Lead day 10Valid time:20200610 to 20200908 (every 3day)

Anl Data: Winds: GFSv16anl; ERA5, Precipitation: CPC COMORPH; CDR GPCP

∆ East Asian - Western North Pacific monsoon index: (U850 (5°N-15°N, 90°E-130°E) - U850 (20°N-30°N, 110°E-140°E))

△ Webster-Yang monsoon index: (U850-U200 averaged over 0°N-20°N, 40°E-110°E)

 Δ South Asia monsoon index: (V850-V200 averaged over 10°N-30°N, 70°E-110°E)

∆ Dynamic Indian monsoon index: (U850 (5°N-15°N, 40°E-80°E) - (U850 20°N-30°N, 70°E-90°E))



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East Asia-WNP Index: HR vs Analyses



HRs: Strong/weak bias before/after East Asian monsoon onset (July 25, 2020). HR5 has the best performance compared to all prototypes and GFSv16.

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△ East Asian - Western North
 Pacific monsoon index
 (U850 (5°N-15°N, 90°E-130°E) U850 (20°N-30°N, 110°E-140°E))

 △ Webster-Yang monsoon index
 (U850-U200 averaged over 0°N-20°N, 40°E-110°E)

 ∆ South Asia monsoon index (V850-V200 averaged over 10°N-30°N, 70°E-110°E)

 △ Dynamic Indian monsoon index
 (U850 (5°N-15°N, 40°E-80°E) -(U850 20°N-30°N, 70°E-90°E))



Webster-Yang Index: HR vs Analyses



△ East Asian - Western North
 Pacific monsoon index
 (U850 (5°N-15°N, 90°E-130°E) U850 (20°N-30°N, 110°E-140°E))

△ Webster-Yang monsoon index (U850-U200 averaged over 0°N-20°N, 40°E-110°E)

 ∆ South Asia monsoon index (V850-V200 averaged over 10°N-30°N, 70°E-110°E)

 △ Dynamic Indian monsoon index
 (U850 (5°N-15°N, 40°E-80°E) -(U850 20°N-30°N, 70°E-90°E))



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South Asia Index: HR vs Analyses

South Asia Monsoon Index 10Jun-08Sep 2020 15 - 0- · ERA5 GFSv16anl OpsGFSv16 12 HR3Ł HR4 HR5 9 6 0 0707 0716 0725 0830 0619 0628 0803 0812 0821 0908

HRs: Reasonable simulation; OpsGFSv16: Strong bias. HR5 greatly reduced the strong bias.

△ East Asian - Western North
 Pacific monsoon index
 (U850 (5°N-15°N, 90°E-130°E) U850 (20°N-30°N, 110°E-140°E))

 △ Webster-Yang monsoon index
 (U850-U200 averaged over 0°N-20°N, 40°E-110°E)

∆ South Asia monsoon index (V850-V200 averaged over 10°N-30°N, 70°E-110°E)

 △ Dynamic Indian monsoon index
 (U850 (5°N-15°N, 40°E-80°E) -(U850 20°N-30°N, 70°E-90°E))

Dynamic Indian Monsoon Index: HR vs Analyses Valid: 10Jun-08Sep2020



HRs perform as good as operational GFSv16

∧ East Asian - Western North Pacific monsoon index (U850 (5°N-15°N, 90°E-130°E) -U850 (20°N-30°N, 110°E-140°E))

∆ Webster-Yang monsoon index (U850-U200 averaged over 0°N-20°N, 40°E-110°E)

∧ South Asia monsoon index (V850-V200 averaged over 10°N-30°N, 70°E-110°E)

∆ Dynamic Indian monsoon index

(U850 (5°N-15°N, 40°E-80°E) -(U850 20°N-30°N, 70°E-90°E))



Forecast: Lead day 10 Valid time: 20200610 to 20200908 (every 3day)



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Precipitation Analysis Data

-- CPC COMORPH: Daily precipitation analysis (0.25deg) -- CDR GPCP: Daily precipitation analysis (1 deg)

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Valid: 10Jun-08Sep2020

Precipitation: Webster-Yang monsoon domain



 Δ Before July 25, HRs show lower rainfall (especially early July);

∆ After July 25, HRs are close to CMORPH and much closer to GPCP



South Asia/EIMR: HRs overestimate before 25 July and close to Obs late. GFS has the highest bias; Indian Continent: Basically, all models overestimate during the whole summer, except for some days.

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Webster-Yang monsoon index: Precip (mm/d) Day5 FCST Valid: 05Jui

Valid: 05Jun-03Sep2020



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South Aisa/EIMR : Precip (mm/d)



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Indian_Continent: Precip (mm/d)



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Precipitation: HR5 - CMORPH



 Δ HR5 has higher precipitation over northern India, and lower precipitation over other regions.

 Δ The lowest precipitation in HR5 appears in the west coast of India.

Precipitation related to Monsoon Index: Diurnal Variation

Forecast: Lead day 0-16 (3-hourly) Valid time: 20200610 to 20200908 (every 3day)

Analysis Data: Precipitation (3-hourly): CPC COMORPH (0.25 deg)

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Precipitation related to Monsoon Index: Week1 and 2

Week1: HR5 - CMORPH Week2: HR5 - CMORPH Pr (mm/d): HR5-CMORPH Ave@WK1 01Jun2020-30Aug2020 Pr (mm/d): HR5-CMORPH 01Jun2020-30Aug2020 Ave@WK2 30N · 30N 25N -25N -20N 20N 15N 15N 10N -10N -5N 5N · EQ-55E 60E 65E 70E 75E 80E 85E 90E 95E 100E 105E 110E 60E 65E 70E 75E 80E 85E 90E 95E 100E 105E 110E 50F 50F -12-10 -8 -6 -4 -2 -1 -12-10 -8 2 4 6 8 10 12 14 -6 8 10 12 14

 \triangle Week1: HR5 is higher precipitation over northern India, and lower in the west of India. \triangle Week2: Further lower precipitation in HR5 in the west of India.

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Precipitation related to Monsoon Index: Diurnal Variation



Diurnal Precipitation over Indian Continent

Indian Continent Rainfall Pr over (10°N-25°N, 75°E-85°E)

Day-10 forecast

∆ HRs overestimate rainfall during daytime.

 △ HRs are close to CMORPH in the early evening but overestimate again after midnight.

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Precip related to Monsoon Index in EP5r2: Diurnal variation



Indian Continent Rainfall: Pr over (10°N-25°N, 75°E-85°E)

 Δ EP5r2 overestimates rainfall in summer of 2018 and summer of 2021; Δ EP5r2 shows less diurnal variation.

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Precipitation in EP5r2: Week 3-4



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Evaluation on Indian Summer Monsoon from UFS





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Summary and Discussions

Indian summer monsoon from UFS was evaluated with four monsoon indices and their related rainfall simulations.

Basically, all UFS prototypes showed reasonable simulations of monsoon indices, and strong biases for some monsoon indices before the monsoon onset and weak biases during the monsoon peak.

I HR overestimated rainfall during the whole summer, except for some short periods and higher bias appears over northern India and near the Himalayas.

 HR showed reasonable diurnal variation of rainfall but overestimated rainfall during daytime. However, EP5 exhibited much less diurnal variation.

More diagnostics would be necessary to further explore and understand Indian monsoon simulation in UFS.



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