NATIONAL WEATHER SERVICE

NOAA Unified Forecast System

-- Focusing on Physics Updates

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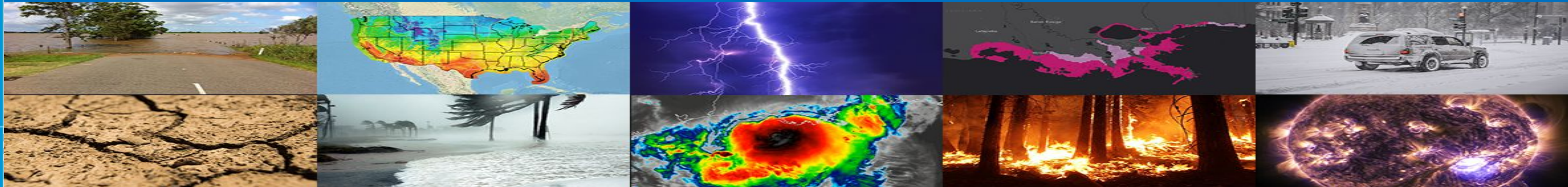
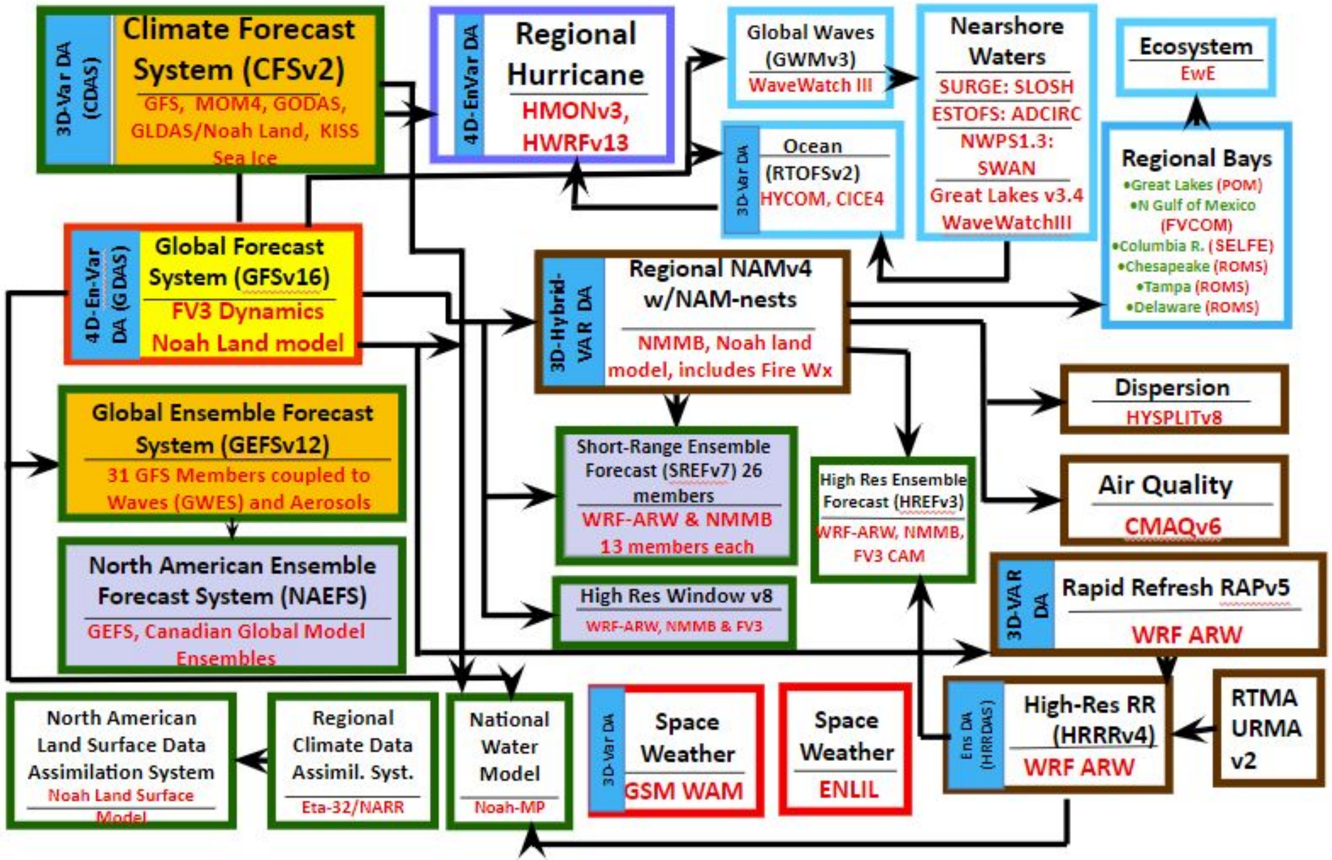
38th WGNE-38 and JWGFVR Conference, 27 Nov to 01 Dec 2023, São José dos Campos, SP, Brazil

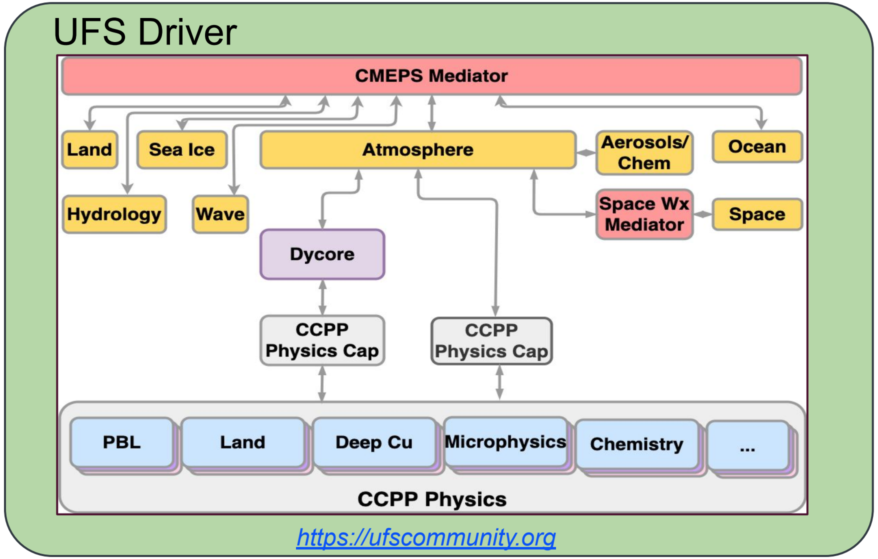


Current State of NCEP Production Suite



- NCEP operates more than 38 distinct modeling systems to meet the stakeholder requirements
- Quilt of Models developed to meet the service needs over a long period of time
- Simplification of NCEP Production Suite is critical to reduce redundancy and improve efficiency

NOAA is collaborating with the US weather and climate science community to develop the next generation fully coupled earth system modeling capability for both research and operational forecast applications across different temporal and spatial scales.



- CMEPS mediator
- FV3 dycore
- CCPP physics
- MOM6 ocean
- Noah-MP LSM

- WAVEWATCH III wave
- CICE6 sea-ice
- GOCART aerosols
- CMAQ air quality

The UFS Community

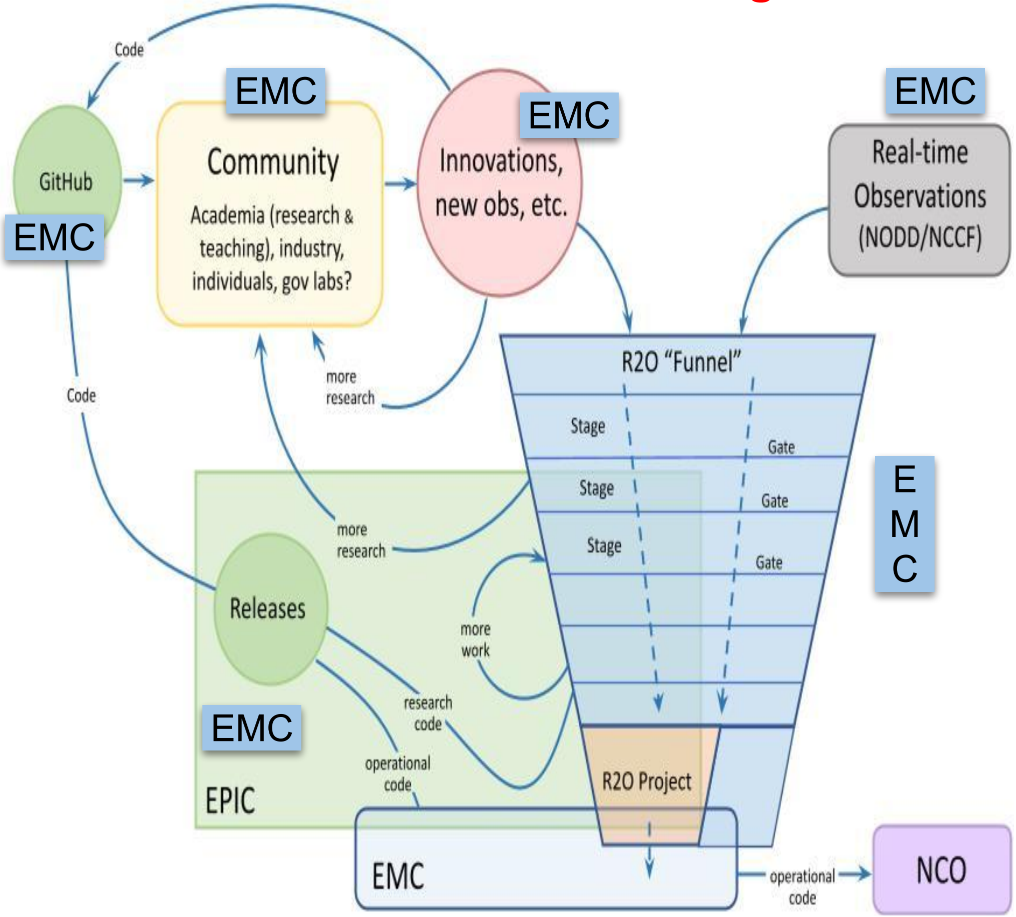
NOAA Programs that Support UFS

- **NWS/OSTI Modeling Programs:** NGGPS, Weeks 3&4, HFIP
- **OAR/WPO Programs:** EPIC, JTTI, S2S, Atmospheric Composition
- **Disaster Supplementals FY18, FY19, FY22 and Bipartisan Infrastructure Legislation FY22**

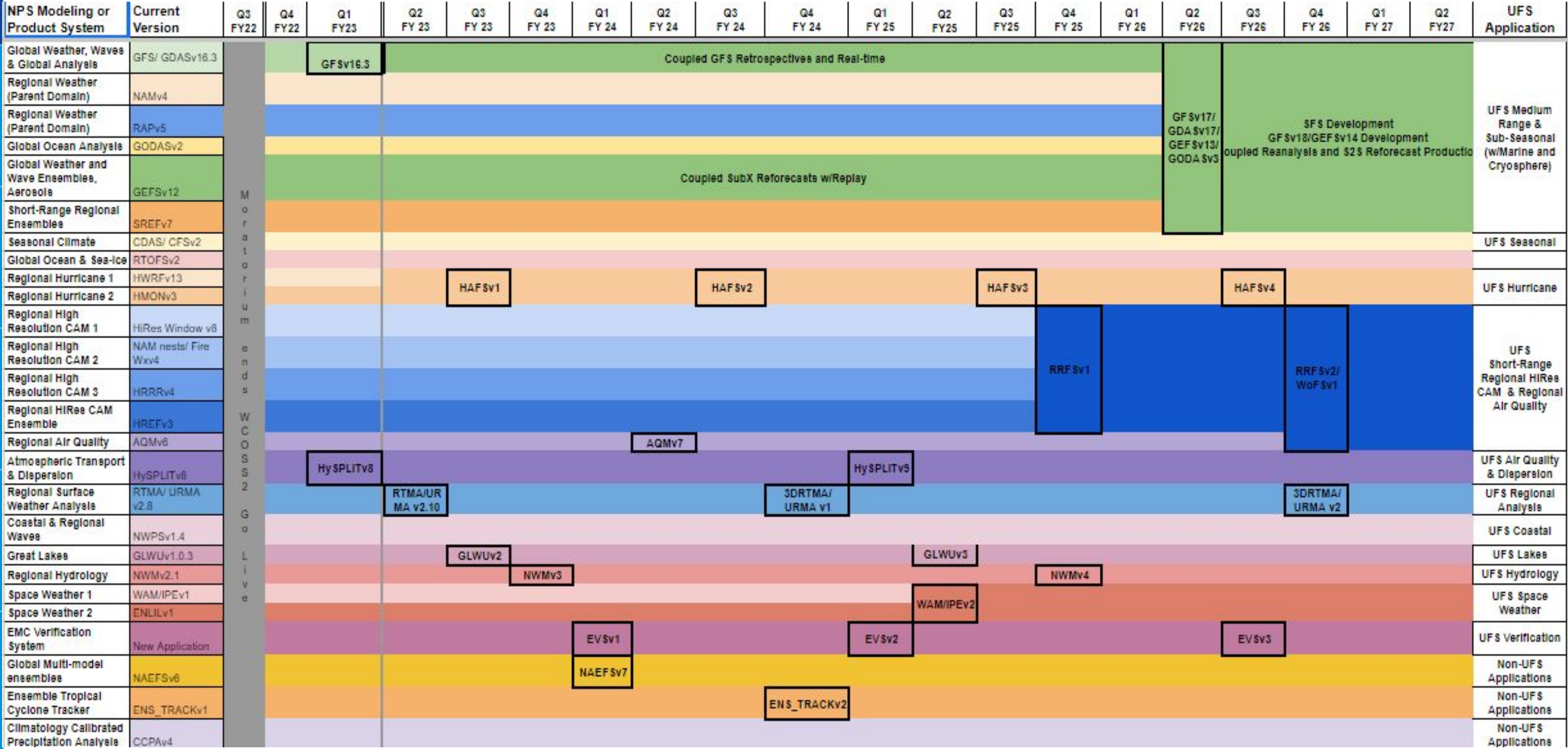
UFS Research-to-Operations (UFS R2O) Project

- **Three year project (FY20-23) with 5-year vision**
- Developing the next-generation global and regional forecast systems and transition to NOAA operations in **FY23 and beyond**
- Jointly supported by NOAA NWS and OAR
- Community team (NOAA, NCAR, JCSDA, Academia)
- Website: https://vlab.noaa.gov/web/ufs-r2o

EMC is involved in all stages



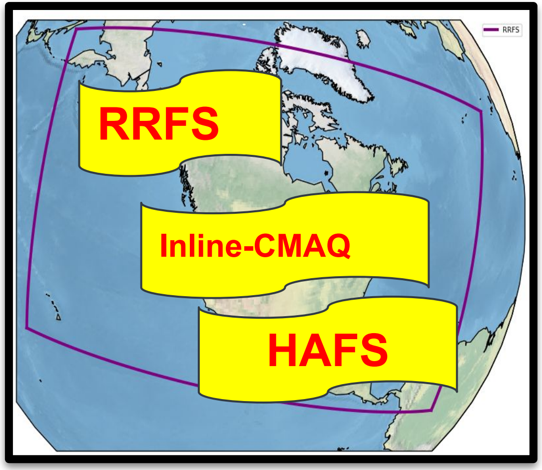
Notional Schedule for Transition to UFS Applications

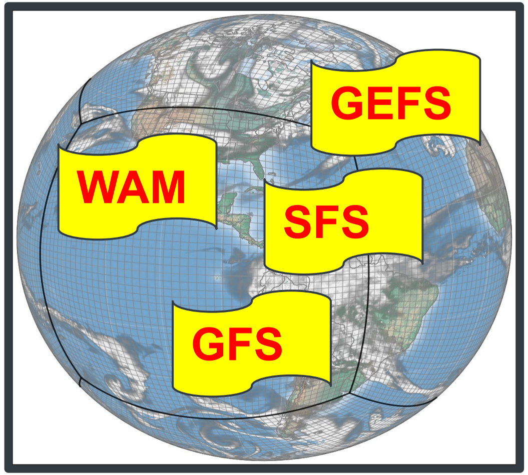


Guidance for Atmos Physics Development for UFS Applications:

- Develop and improve physics parameterizations for UFS applications to **reduce model systematic biases and maximize model prediction skills**.
- **Unify physics parameterizations** for all applications across different spatial and temporal scales to speed up the R2O transition of physics innovations and to reduce the cost of operational systems maintenance.

SRW/CAM





MRW/S2S

Atmos Physics Parameterizations in Major UFS Applications: Current Status

	GFSv17 (13km) & GEFSv13 (25km)	RRFSv1 (3-km) (multi-physics ensemble as of 11/10/2023)	HAFSv1 (6/2 km)	AQMv7 (12km) aka Inline-CMAQ
Deep Convection	sa-SAS	GF and sa-SAS	sa-SAS	sa-SAS
Shallow Convection	sa-SAS	MYNN-EDMF	sa-SAS	sa-SAS
Microphysics	Thompson MP	Thompson MP & NSSL MP	A: GFDL MP B: Thompson MP	GFDL MP
Radiation	RRTMG	RRTMG	RRTMG	RRTMG
Surface Layer	GFS	MYNN & GFS	GFS	GFS
PBL	sa-TKE-EDMF	MYNN-EDMF & TKE-EDMF	sa-TKE-EDMF	sa-TKE-EDMF
Land	NOAH-MP	RUC	NOAH LSM	NOAH LSM
oro and non-oro GWD	uGWP v1	N/A	uGWP.v0 (oro)	uGWP.v0
SS-GWD & TOFD	Yes	Yes	Yes	No

Physics Development for the Global Model: GFSv16/GEFSv12 --> UFS-based GFSv17/GEFSv13

Items highlighted in blue color had also been included in HAFS.v1

Introduced

- a **two-moment cloud microphysics** scheme (GFDL MP --> **Thompson MP**)
  - Improved the cloud radiation interaction capabilities
  - Introduce Semi-Lagrangian Sedimentation for improved stability and cost
- a **new land model** (NOAH LSM --> NOAH-MP LSM)
- **new small-scale gravity wave** and **turbulent orographic form drag** parameterizations
- a **new** parameterization for **convective organization**, and a new **Prognostic**-Stochastic and Scale-Adaptive **Cumulus Convection Closure**
- **new stochastic physics** in the ocean, land-surface and the atmosphere
- a **new positive definite tracer advection (TVD)** scheme in convection and PBL
- new capability for **coupling between aerosols and physics**
- **new land/ocean/lake masks, new ice climatology, and surface composites over fractional grid**

Improved

- **cumulus convection** schemes and **boundary layer** schemes to address model systematic biases
- **gravity wave drags and mountain blocking**
- **coupling of the land model and surface layer** schemes.

Example: Updating Thompson Microphysics For Global Applications

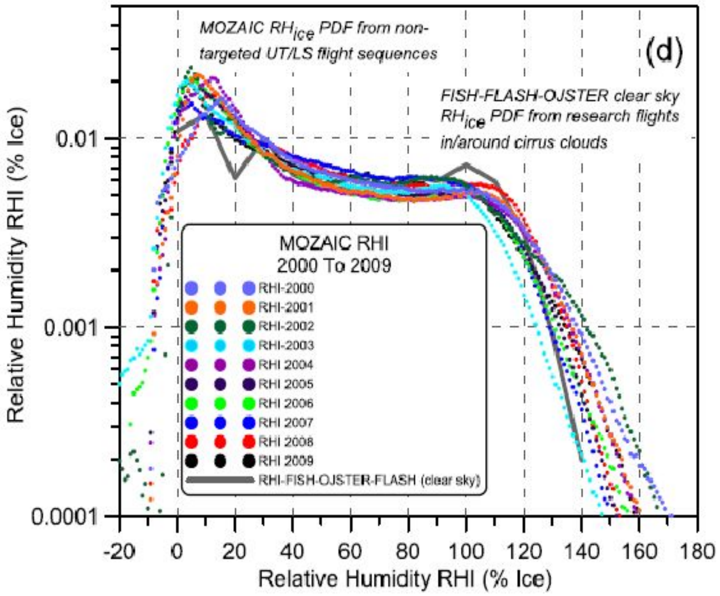
- In current NCEP operation, GFS &GEFS ==> GFDL MP; RAP & HRRR ==> Thompson MP; NAM ==> Ferrier-Aligo MP. FA was also used by HWRF before HAFS implementation.

- In 2020 after GFSv16 was finalized for operation, a decision was collectively made by EMC and the UFS Physics WG to **adopt Thompson MP for all UFS-based applications** (except for HAFS-B).

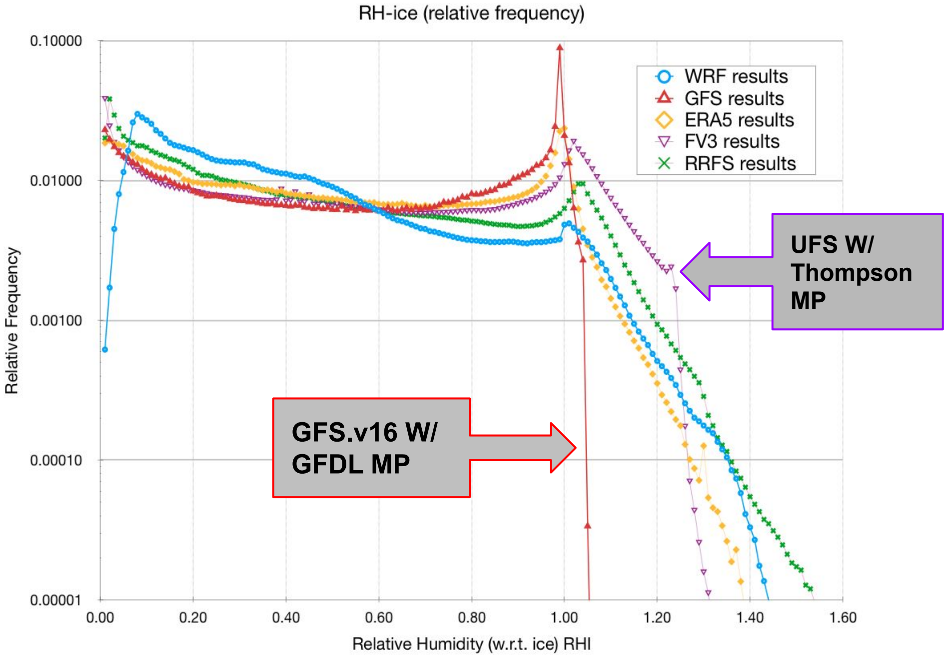
- Thompson MP has been widely used in the WRF community for regional model applications. Adapting it for NCEP global model applications has proved to be challenging.

- Significant efforts have been made 1) to **eliminate computational instability of Thompson MP** in global models which have larger physics time steps than regional high-res models. **Subcycling microphysics and semi-Lagrangian sedimentation** for rain and graupel were both developed to maintain computational instability; 2) to **improve simulation of ice clouds in the tropics** to achieve better radiation and energy balances.

Supersaturation and Supercooled cloud water



Observed frequency distribution (PDF) of RH relative to ice (RHI) from MOZAIC flight-level obs.



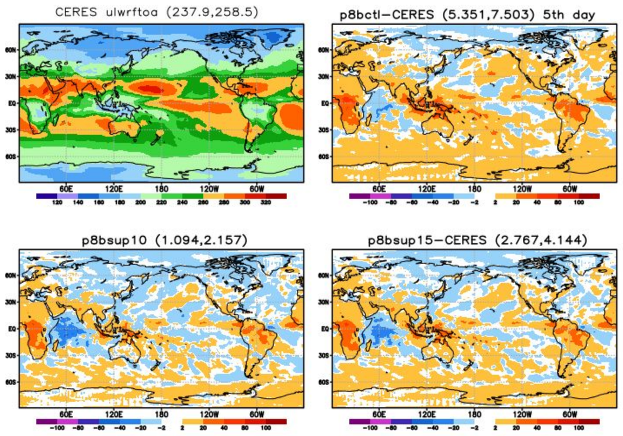
RHI PDF from various models (Credit: Greg Thompson). **Supercooled cloud water is a hazard to aviation !**

UFS Microphysics Development -- Challenges

Integrated hydrometeors (global, tropical:30S-30N)

g/m2	GFSv16 GFDL MP	GFSv17 Prototype Thompson MP	IFS
Cloud liquid	(77.6, 57)	(54,45.14)	(54.6, 50.13)
Cloud ice	(35.47, 23.82)	(8.67,12.32)	(20.17,15.14)
Snow	(17.57,13.75)	(54.3,40.97)	(49.63,43.14)
Ice + snow	(53.04,37.57)	(62.97,53.29)	(69.8,58.28)
Ice + snow + cloud liquid	(130.64, 94.57)	(117.42,98.43)	(124.4,108.41)

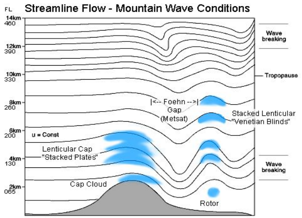
These difference in hydrometer loadings affect radiative heating and energy balances



UFS p8b experiment: OLR varies with RHic for supersaturation

UL: CERES obs
UR: RHi=125% (default)
LR: RHi=115% (final for GFSv17)
LL: RHi=110%

Unified Gravity-Wave Drag Parameterization



Large-Scale Orographic GWD

Low-level flow blocking

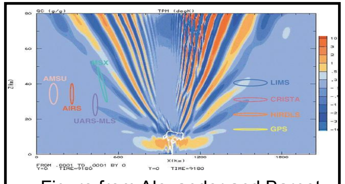
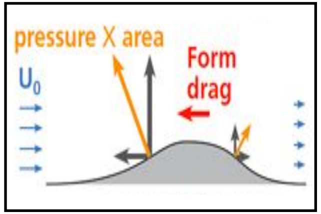


Figure from Alexander and Barnet (JAS,2007)

Non-stationary GWD

Small-scale GWD



Turbulent orographic form drag

uGWD.v0 in current ncep operation:
Kim & Arakawa (1995) O-GWD & Block,
Yudin et al (2020) N-GWD

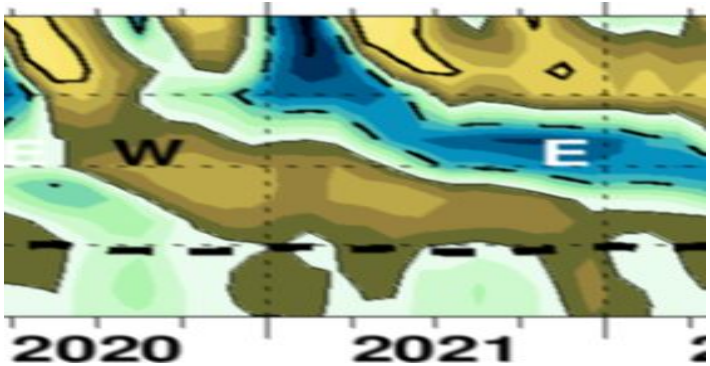
Different scaling factors need to be tuned and applied for different model grid resolution.

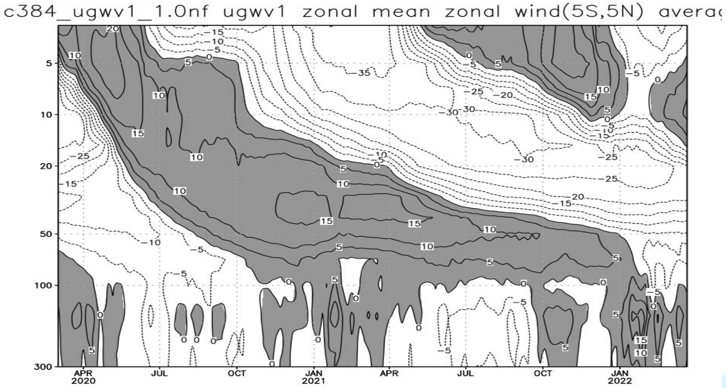
uGWDv1 (aka the GSL suite) for the UFS:
Kim and Doyle (2005) O-GWD & Block
Yudin et al (2021) N-GWD
Tsiringakis et al. (2017) SS-GWD,
Beljaars et al. (2004) TOFD

O-GWD & Block have been optimized to match COORDE intercomparison benchmark. Source functions for triggering N-GWD still need to be set differently for models with different resolutions

"Best" scaling factors for capturing the QBO and jet streams and for improving overall NWP forecast skills

	O-GWD	Blocking	N-GWD
C768	2.5	7.5	0.5
C384	5	5	1.0
C192	10	3.5	1.8

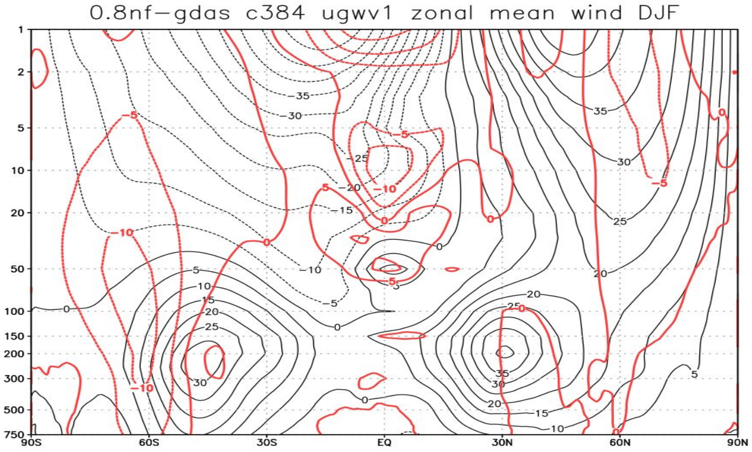




25-km model

DJF Zonal Mean Zonal Wind

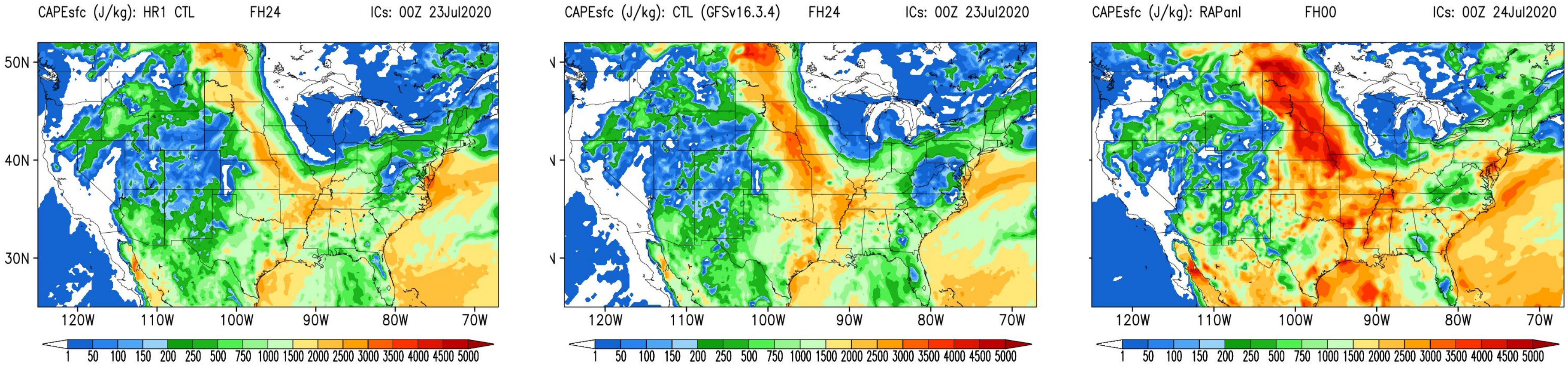
Black: C384 forecast; Red: forecast minus GDAS analysis



Improving CAPE for GFS.v17

Addressing Forecasters' Concerns

CAPE (J/kg) **Valid: 00Z 24 JUL 2020**



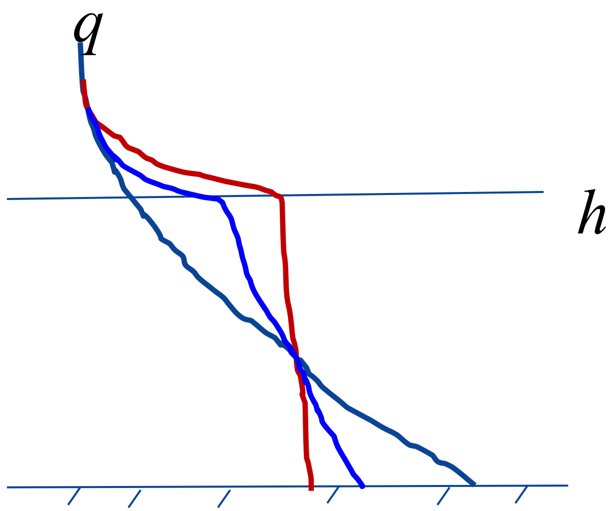
GFSv17 atmos-only Prototype

GFS.v16

RAP ANL

GFSv17 is less than Ops GFS.v16, and both are much less than RAP analysis

Sensitivity of CAPE to entrainment enhancement in TKE-EDMF PBL scheme



Dark Blue: no non-local mixing
Red: a full non-local mixing
Blue: reduced non-local mixing by enhanced entrainment rate

- Increase entrainment rate in updraft to reduce PBL mixing (1.3 c_ε --> 2.0 c_ε)
- Further adjust entrainment rate in updraft as a function of vegetation fraction (σ_f) and surface roughness length (z_0)

$$\varepsilon_u = c_\varepsilon \left[\frac{1}{z + \Delta z} + \frac{1}{(h - z) + \Delta z} \right]$$

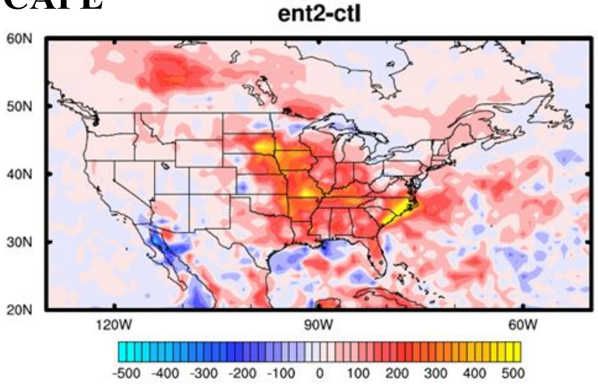
$$f_1 = \frac{\sigma_f - 0.1}{0.9}, \quad f_2 = \frac{z_0 - 0.1}{0.9}$$

$$c_\varepsilon' = \left(1 + \sqrt{\min(\max(f_1, 0), 1)}\right)\left(1 + \min(\max(f_2, 0), 1)\right) c_\varepsilon$$

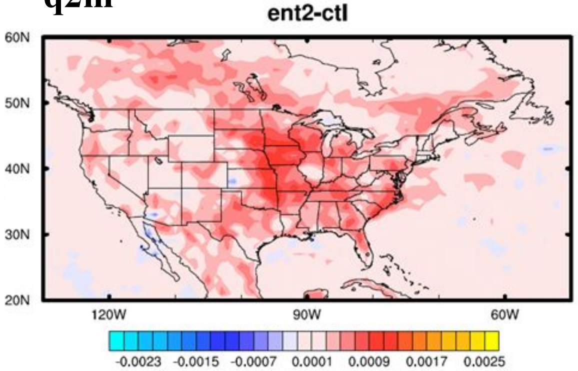
Improved CAPE and Q2m

5-Day Fcst 20200716-20200830

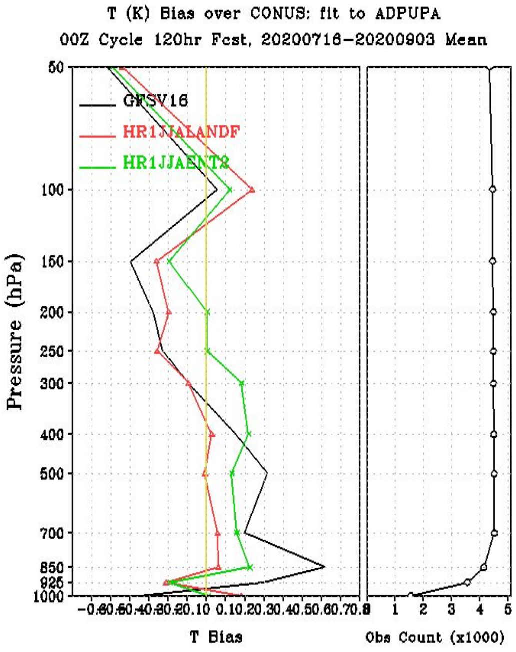
CAPE

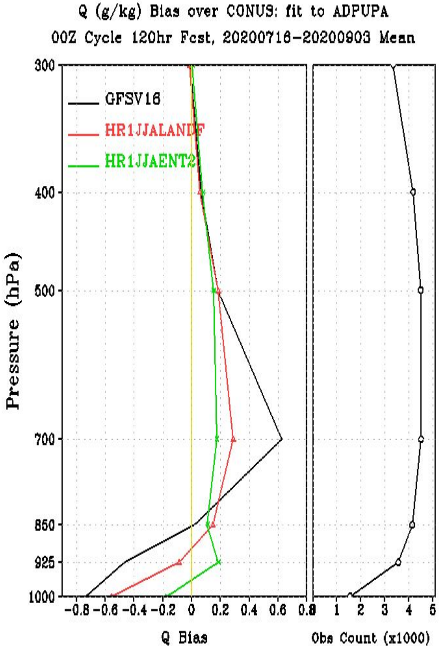


q2m



Improved T and Q profiles over CONUS





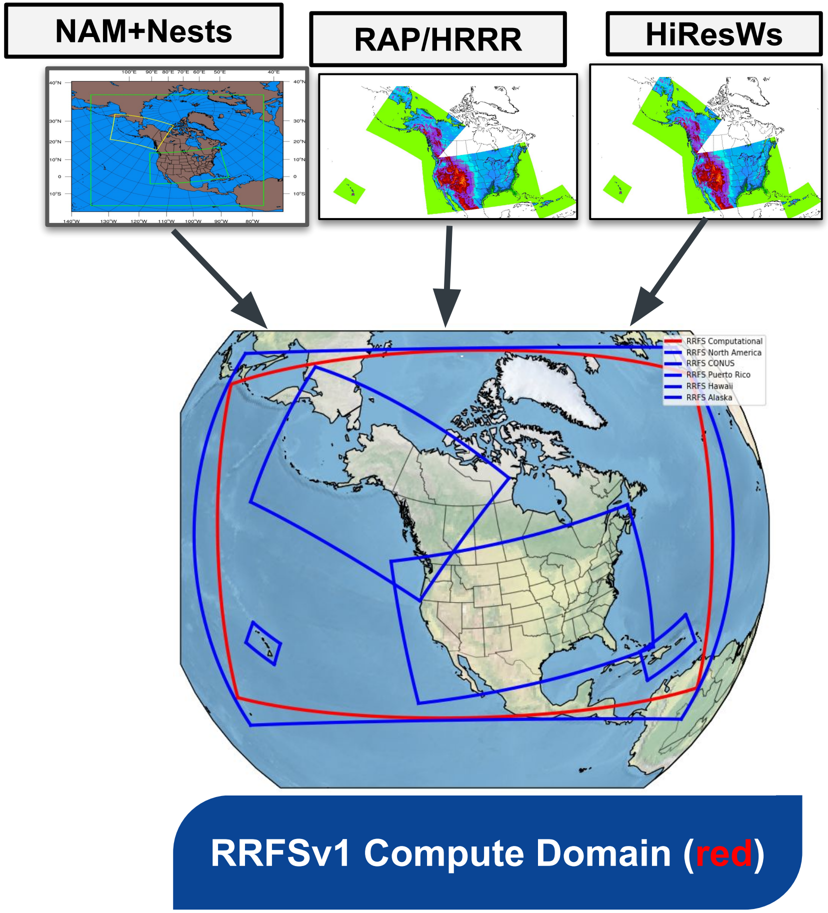
HR1JJALANDF: Control

HR1JJAENT2: increased entrainment rate

RRFS, 3km resolution

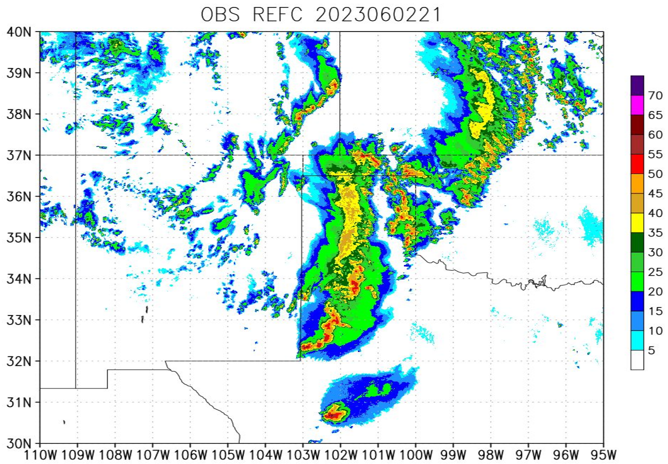
Overprediction of heavy precipitation and radar reflectivity in the regional Rapid Refresh Forecast System in weekly forced convective environment

Sensitivity to parameterized deep convection

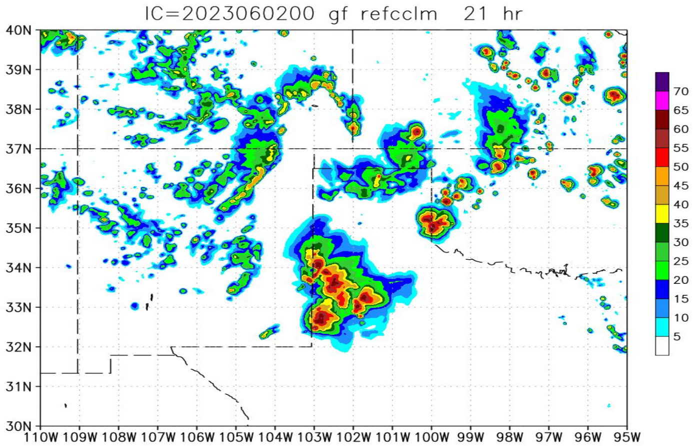


Radar Reflectivity, 2023060221

OBS

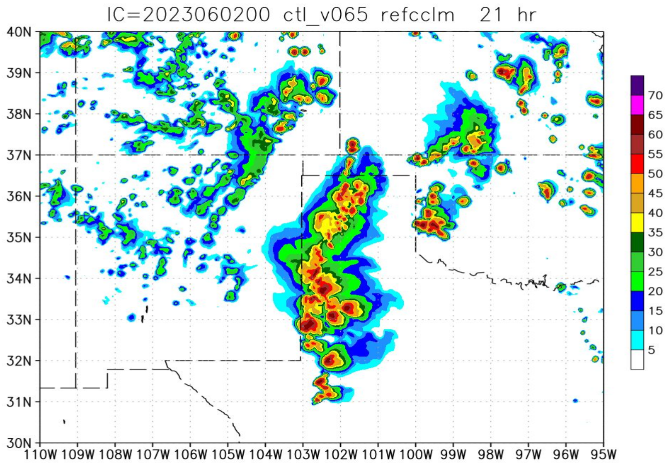


Grell-Freitas Convection

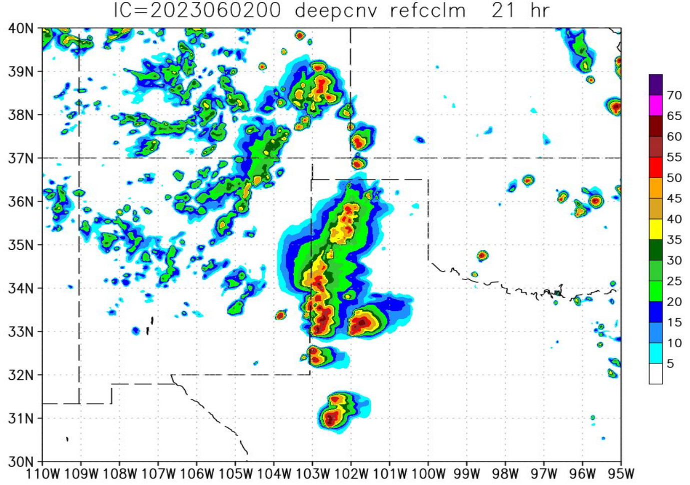


CTL
W/O parameterized convection

21h Fcst

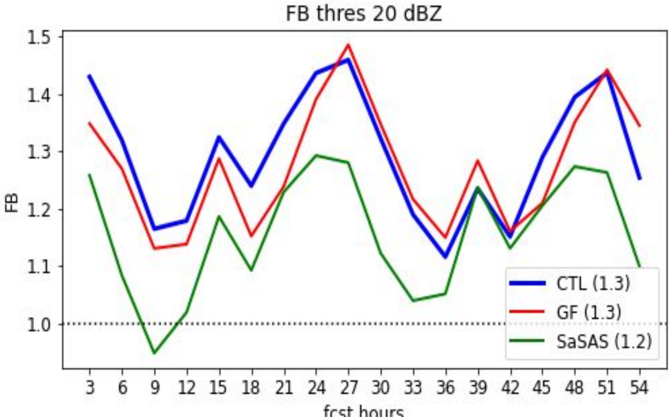


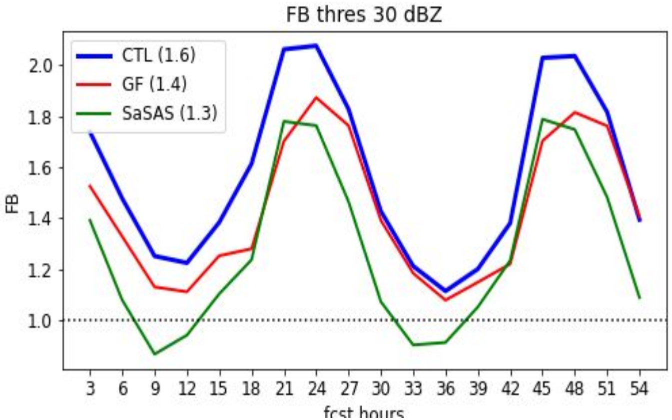
sa-SAS Convection

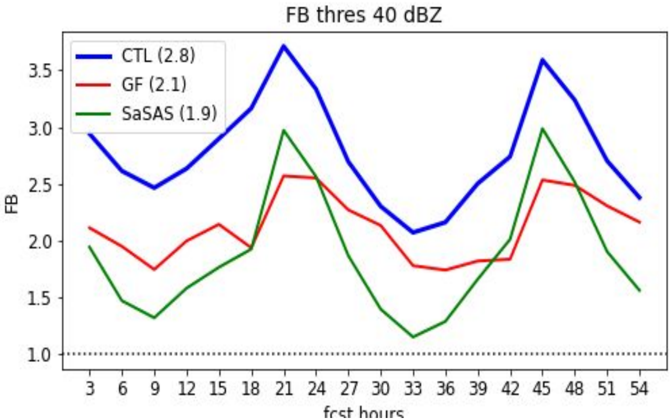


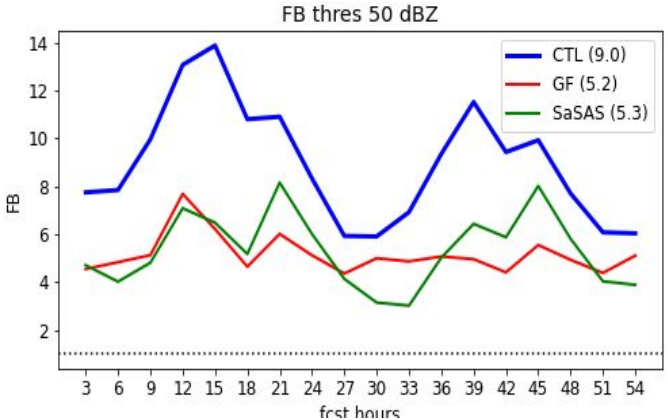
Reduced reflectivity bias with parameterized Deep Convection

- 28 Cases from 2023051100 to 2023061100; 00Z only
- ICs: From RRFS real-time parallel DA



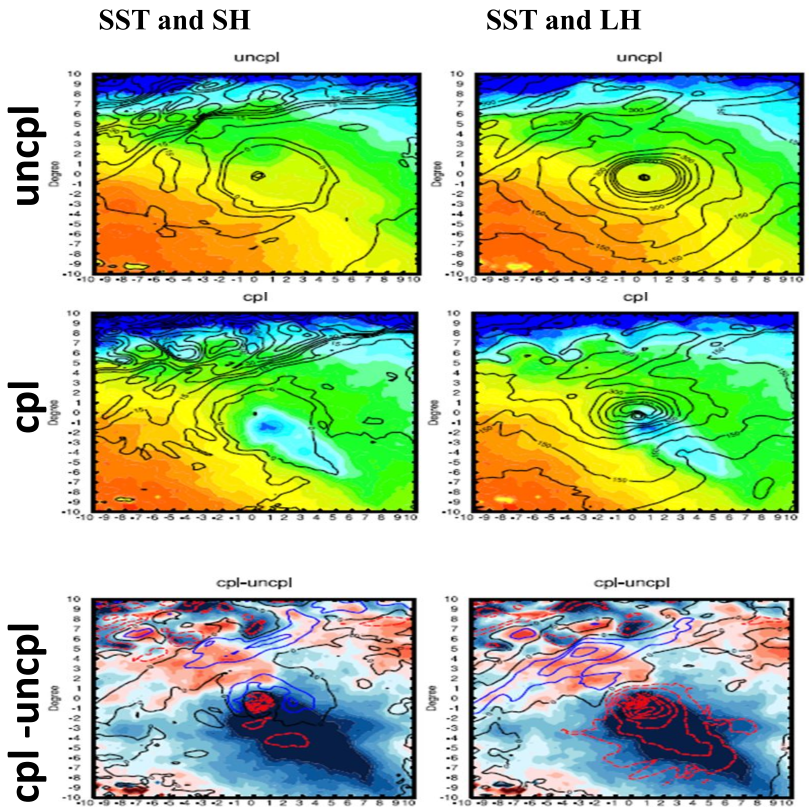




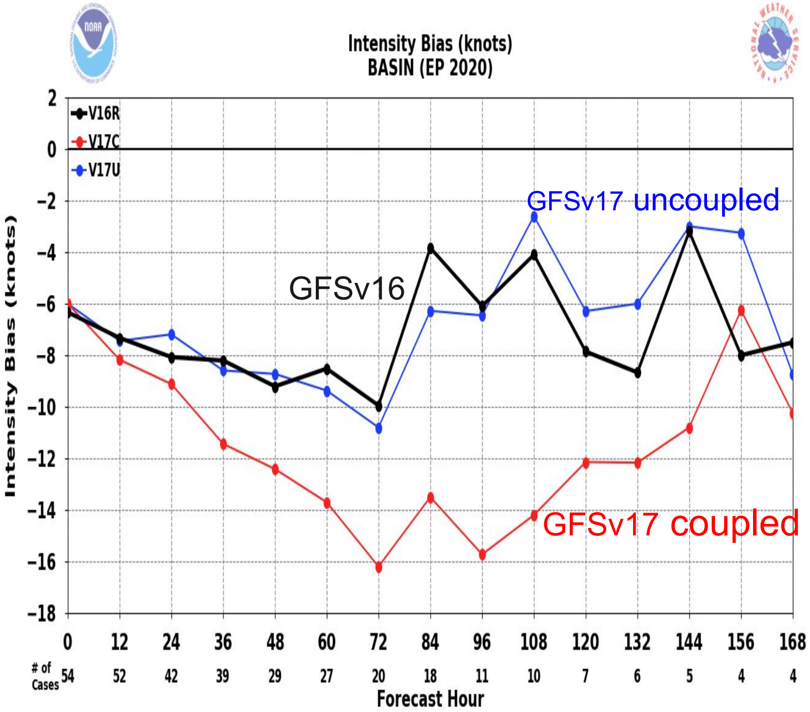


Weakening Hurricane Intensity in Coupled Model (GFSv17, 13-km)

Hurricane Teddy, IC 20200913, 132h Fcst

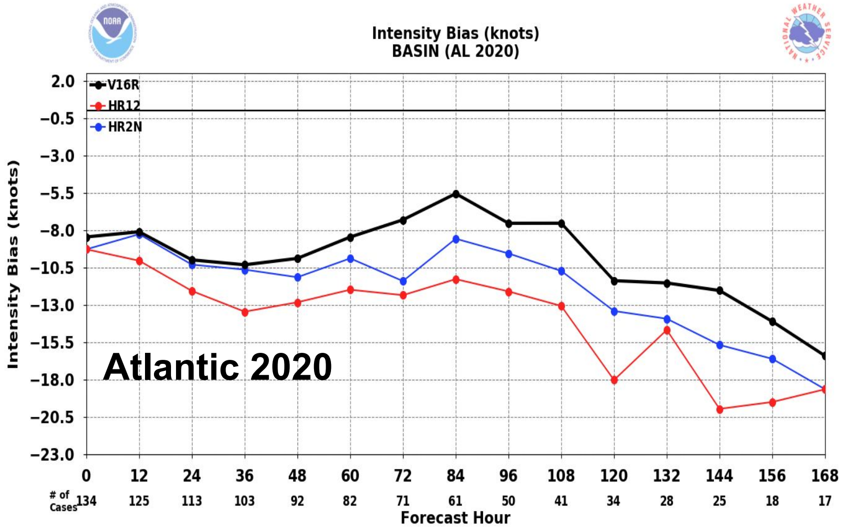


2020 Hurricane Season (Eastern Pacific)

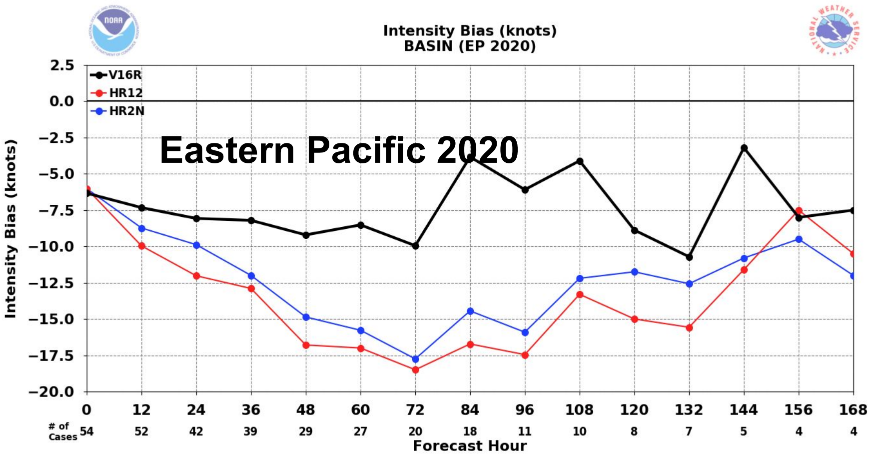


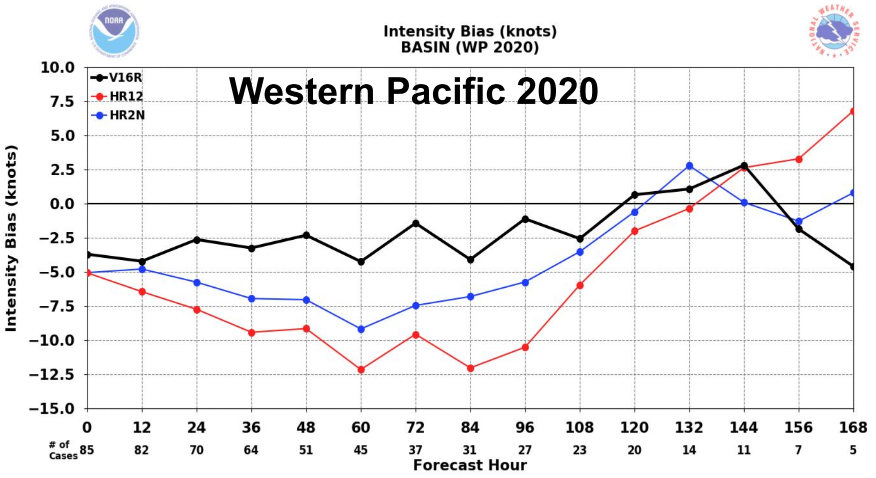
Reduced hurricane intensity biases in coupled GFSv17 by

- introducing environmental wind shear effect on convective updraft and downdraft and TKE-dependent entrainment enhancement
- Update Wave-Atmosphere interaction (ongoing)



V16R--GFSv16; HR12— HR1 coupled; HR2N—HR2 coupled





Final Thoughts on Physics Unification -- Opportunities and Challenges

- Efforts have been made in the past few years in the UFS and UFS-R2O community to develop scale adaptive physics parameterizations that can be used in UFS applications across different spatial and temporal resolutions, but challenge remains.

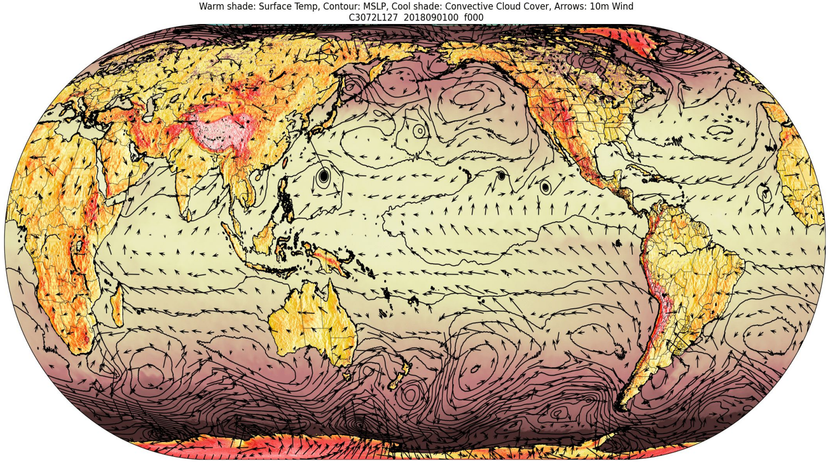
- Schemes that have been traditionally developed for global models at ~10-km and coarser resolution do not work well out of the box for regional high-resolution models. Likewise, schemes used by regional high-resolution models do not always work well in global models.

- To achieve unification, physics parameterizations that have strong dependence on model grid size need to be evaluated in both UFS global and regional applications.

- Schemes like microphysics, convection, PBL, and GWD needs further development to become truly scale aware

Thank you

A fully coupled UFS serves as a foundation for future operational global forecast systems at NOAA/NWS/NCEP ranging from weather to subseasonal to seasonal scales.



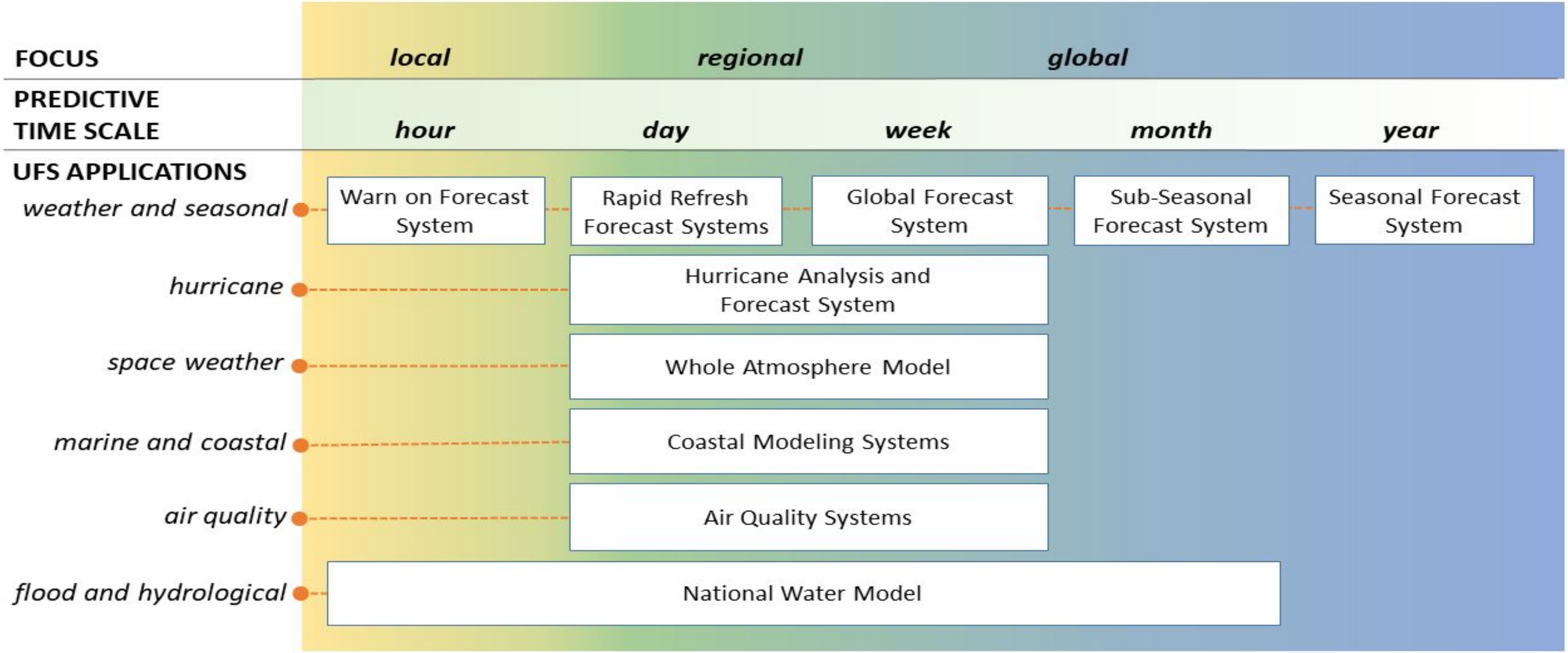
UFS Earth System Model Components:

- FV3 (Atmosphere)
- MOM6 (Ocean)
- CICE6 (Sea Ice)
- WW3 (Waves)
- NOAH-MP (Land)
- GOCART (Aerosols)

MRW/S2S: Building a Six-Way Global Coupled Unified Forecast System
For future GFS, GEFS and SFS

Extra Slides

The Goal: Transition to UFS Applications and Simplify NCEP Production Suite



Developing Scale Aware/Adaptive Physics Parameterizations for UFS Applications

- Further development of scale-aware convection parameterizations
- Unify cloud cover and cloud-radiation interaction through a prognostic cloud scheme where subgrid-scale cloud is treated as a source term
- Unify aerosol-cloud-radiation interactions for both global and regional models
- Develop scale-aware stationary and non-stationary GWD parameterizations
- PBL schemes: MYNN-EDMF vs TKE-EDMF
- Land model: NOAH-MP
- Experimenting with unified PBL, shallow and deep convection schemes such as SHOC CLUBB and UNICON etc