NATIONAL WEATHER SERVICE

Development of Global and Regional Coupled UFS Applications at NWS/NCEP

Avichal Mehra[1]

[1]NOAA/NWS/NCEP/EMC

Unifying Innovations in Forecasting Capabilities Workshop
College Park, MD

Outline

- Overview of UFS Coupled Applications
- UFS MRW-S2S Global Application: Description
- UFS MRW-S2S: Current Status and Results
- UFS HAFS Regional Application: Description
- UFS HAFS: Current Status and Results
- Future Directions & Summary

Current UFS-based Coupled Developments

- **Each of these is a working coupled application which is either operational or actively being developed**

FV3GFS – WW3
Impact of waves on atmospheric stress at ocean surface

FV3GFS – CHEM
Atmosphere and Aerosols interaction

ADCIRC – WW3 – NWM
Wave, Surge and Inundation coupling

DATM – MOM6 – CICE6
Ocean Ice coupled model with Data Atmosphere for developing Marine DA.

FV3HAFS- HYCOM
Hurricane Analysis and Forecast System

FV3GFS – MOM6 – CICE6 – WW3 – NOAH-MP – GOCART
Global MRW-S2S Applications

Global UFS-Coupled Development Objectives

1. **Establish forecast priorities spanning the Medium-Range (0-2 weeks) to S2S (3 weeks to 2 years) time scales, within the NOAA mission space.**

2. **Identify scientific goals that will ensure that the Medium-Range Weather(MRW) and S2S applications will meet identified forecast priorities with increased forecast skill.**

3. **Design and conduct an evaluation of MRW/S2S applications to improve performance on forecast priorities, in coordination with users and stakeholders.**

Acknowledgement to UFS Coupled Prototype Active Developers

Atmospheric Physics

NCEP/EMC: Shrinivas Moorthi, Jongil Han, Michael Barlage, Helin Wei, Anning Cheng, Bing Fu, Wei Li, Ruiyu Sun, Rongqian Yang, Qingfu Liu, Weizhong Zheng, Sajal Kar, Alexei Belochitski, Yihua Wu, Eric Sinsky, Bo Yang, Hong Guang, Xu Li, Fanglin Yang
ESRL/GSL: Dom Heinzeller, Shan Sun, Michael Toy, Ben Green, Tanya Smirnova, Joseph Olson
ESRL/PSL: Philip Pegion, Lisa Bengtsson, Clara Draper, Jian-Wen Bao, Songyou Hong, Dustin Swales
DTC: Weiwei Li, Ligia Bernardet
Catholic University of America: Valery Yudin

Coupled Model Component Development

NCEP/EMC: Jessica Meixner, Jiande Wang, Lydia Stefanova, Shrinivas Moorthi, Jun Wang, Denise Worthen, Robert Grumbine, Bing Fu, Ali Abdolali, Bin Li, Minsuk Ji, Matthew Masarik, Walter Kolczynski, George Gayno, Arun Chawla, Avichal Mehra
ESRL/GSL: Shan Sun, Ben Green
ESRL/PSL: Phillip Pegion, Lisa Bengtsson
GFDL: Brandon Reichl, Alistair Adcroft, Robert Halberg, Stephen Griffies, Rusty Benson, Marshall Ward, Matthew Harrison
NCAR: Rocky Dunlap, Mariana Vertenstein, Alper Altuntas, Gustavo Marques, Gokhan Danabasoglu, Keith Lindsay
NRL/ESMF: Gerhard Theurich
GMU: Cristiana Stan, Ben Cash, Jim Kinter, Lawrence Marx
FSU: Eric Chassignet, Alan Wallcraft, Alexandra Bozec
NASA: Akella Santha
Univ. Alaska: Katherine Hedstrom
U. Mich.: Christiane Jablonowski
Univ. Victoria: Andrew Shao

Atmospheric Composition

NCEP/EMC: Raffaele Montuoro, Li Pan, Partha Bhattacharjee, Walter Kolczynski, Jeff McQueen, Ivanka Stajner
ARL: Barry Baker, Patrick Campbell, Rick Saylor
ESRL/GSL: Li (Kate) Zhang, Shan Sun, Georg Grell
CSL: Siyuan Wang, Jian He, Stuart McKeen, Gregory Frost
NESDIS/STAR: Xiaoyang Zhang, Ethan Hughes, Shobha Kondragunta

Coupled Model Evaluation

NCEP/EMC: Lydia Stefanova, Jiande Wang, Partha Bhattacharjee, Sulagna Ray, Wei Li, Michael Barlage, Weizhong Zheng, Robert Grumbine, Huug van den Dool, Avichal Mehra
CPC: Wanqiu Wang, Yanyun Liu, Jieshun Zhu
ESRL/PSL: Zachary Lawrence, Amy Solomon, Maria Gehne, Chris Cox
GMU: Cristiana Stan, V. Krishnamurthy, Eunkyo Seo

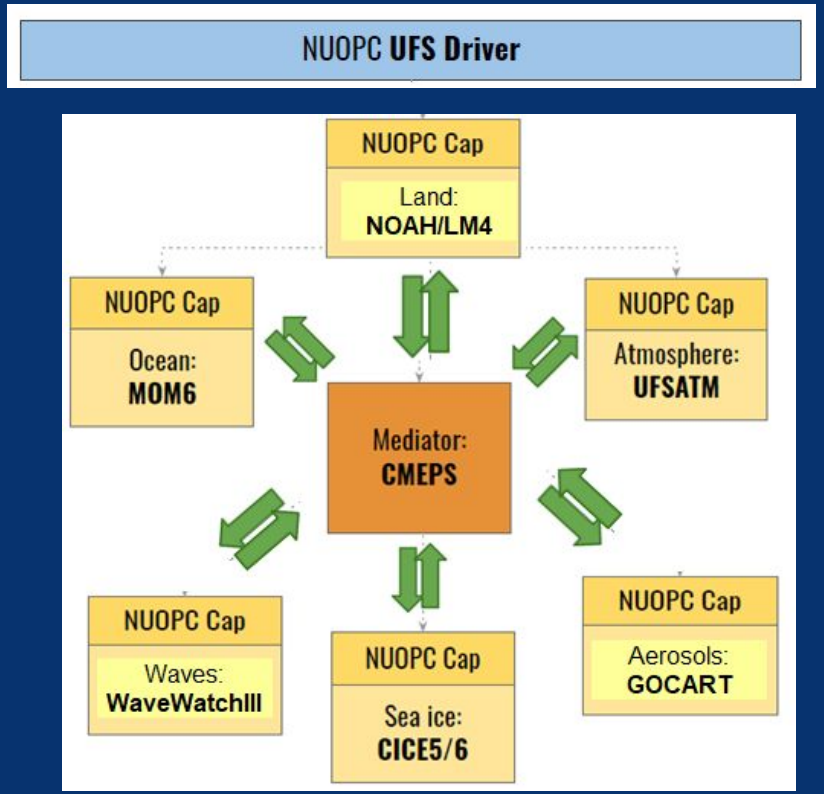
Operational Targets for Global UFS-Coupled

GFS v17/GEFS v13: Fully coupled system for MRW and Subseasonal predictions

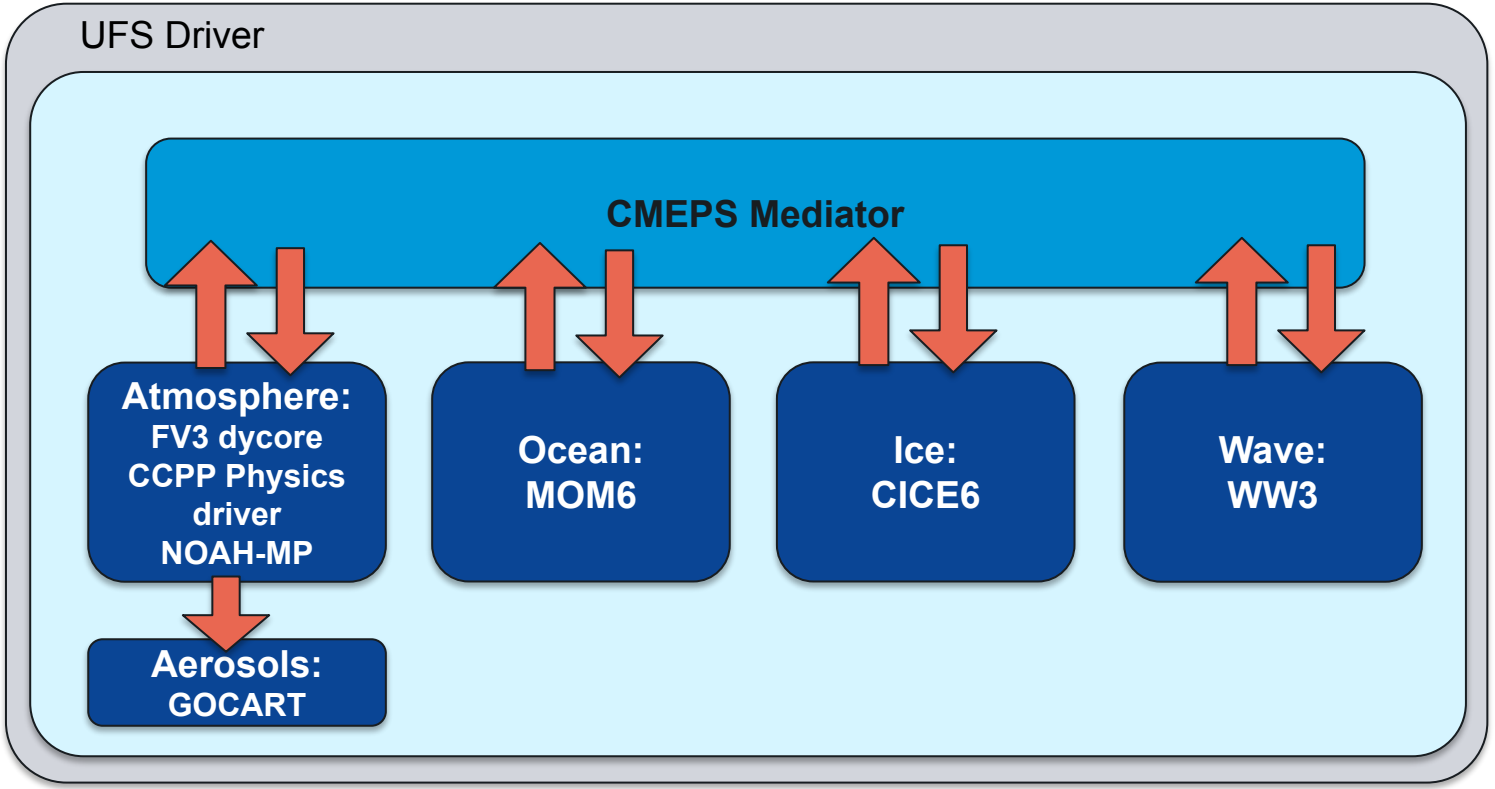
- FV3+MOM6+CICE6+WW3+NOAH-MP+ GOCART Coupled Model
- Advanced Physics, Weakly Coupled DA
- **FY24: Implement GFS v17 & GEFS v13**

Seasonal Forecast System (SFS v1.0)

- Fully coupled Unified Forecast System
- Seasonal ensemble forecasts with reanalysis and reforecasts
- Advanced coupled DA
- **FY26: Implement SFS v1.0**



MRW-S2S Application Planned Prototype 8 Model Configuration



Prototypes 1-8 Main Features

- **UFS_p1:** Initial prototype
- **UFS_p2**
  - Updated ocean ICs
  - Slow/fast coupling time step updated
- **UFS_p3.1**
  - Updated ice ICs
  - River runoff
  - Fluxes from ice no longer merged with ocean
- **UFS_p4**
  - CCPP physics driver
  - Wave coupling
- **UFS_p5**
  - CMEPS mediator
  - CICE6 ice model
- **UFS_p6**
  - Fractional grid
  - 127 vertical levels in atm (up from 64)
  - Updated physics
- **UFS_p7**
  - Updated atm, land, wave ICs
  - Updated physics
- **UFS_p8**
  - Updated atm, land, wave ICs
  - Updated physics
  - New workflow
  - New mesh cap for waves

Prototypes Overview

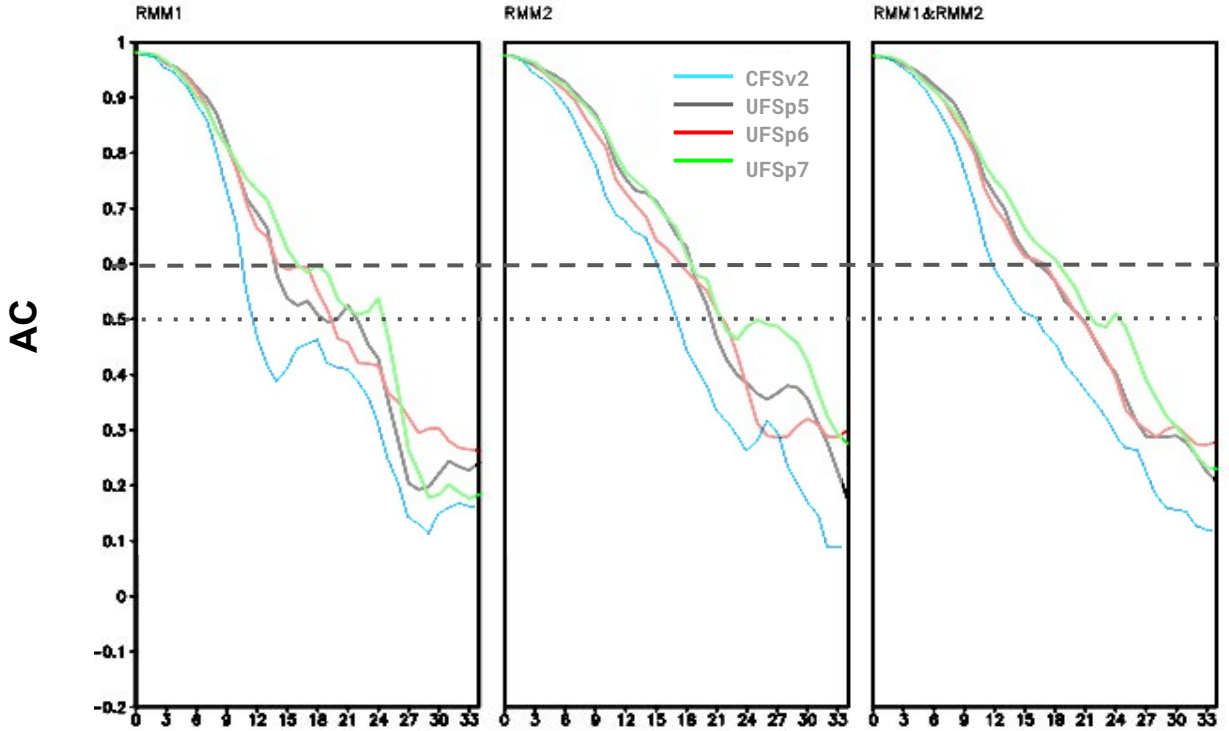
For more details see the spreadsheet here.

All items in **red** represent modifications to the previous prototype

	Initial Conditions					
	FV3 GFS	MOM6	CICE	WW3	Ice Model	Mediator
UFS_P1	CFSR	CFSR	CFSR	n/a	CICE5	NEMS
UFS_P2	CFSR	**CPC 3Dvar**	CFSR	n/a	CICE5	NEMS
UFS_P3.1	CFSR	CPC 3Dvar	**CPC ice analysis**	n/a	CICE5	NEMS
UFS_P4	CFSR	CPC 3Dvar	CPC ice analysis	**Generated with CFS forcings**	CICE5	NEMS
UFS_P5	CFSR	CPC 3DVar	CPC ice analysis	Generated with CFS forcings	**CICE6**	**CMEPS**
UFS_P6	**CFSR Frac grid**	CPC 3DVar	CPC ice analysis	Generated with CFS forcings	CICE6	CMEPS
UFS_P7	**GEFS, NOAH-MP land, Frac grid**	CPC 3DVar	CPC ice analysis	**Generated with GEFS forcings**	CICE6	CMEPS
UFS_P8	**GEFS, NOAH-MP land, Frac grid**	CPC 3DVar	CPC ice analysis	Generated with GEFS forcings	CICE6	CMEPS

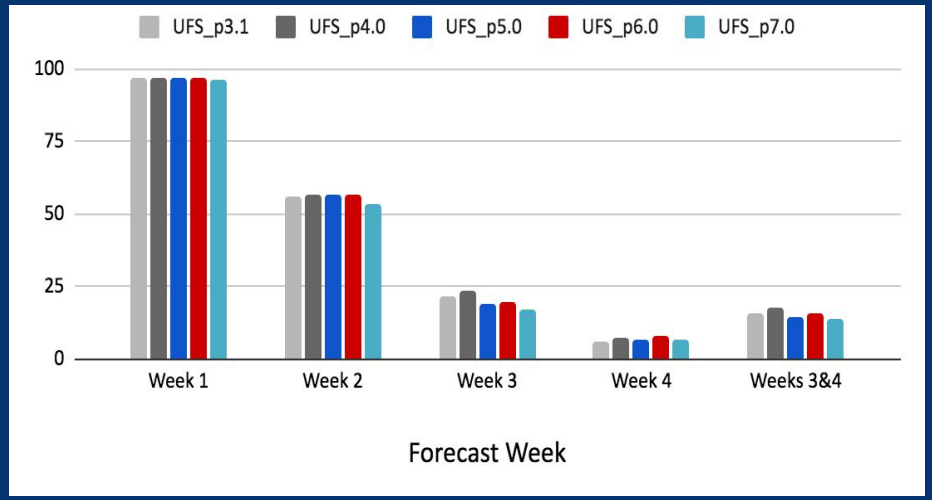
UFS-Coupled Improvements in MJO-Skill

Correlation Skill for MJO Indices RMM1 and RMM2 and Bivariate Correlation Skill for MJO index

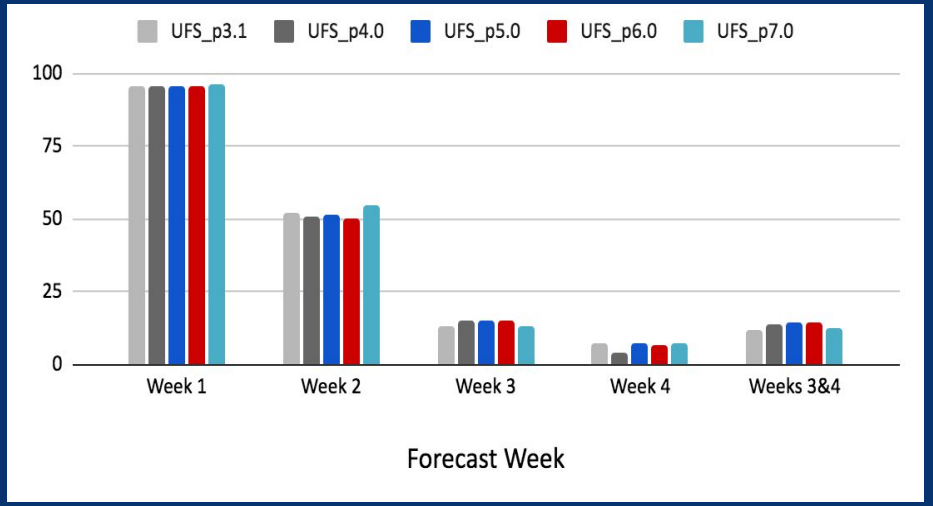


UFS-Coupled Improvements in z500 AC scores

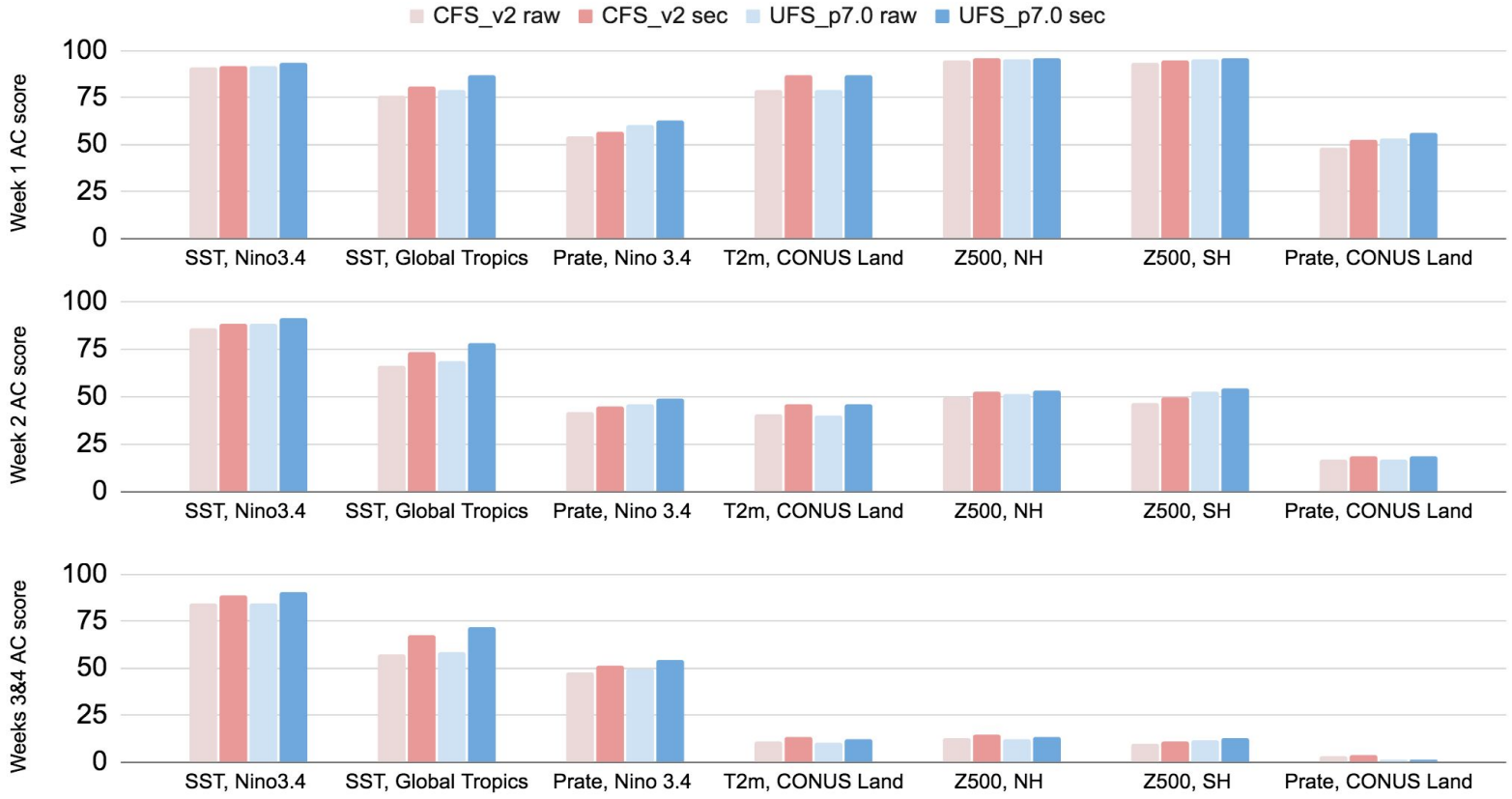
NH z500 AC



SH z500 AC



UFS-Coupled Prototype Summary of AC scores

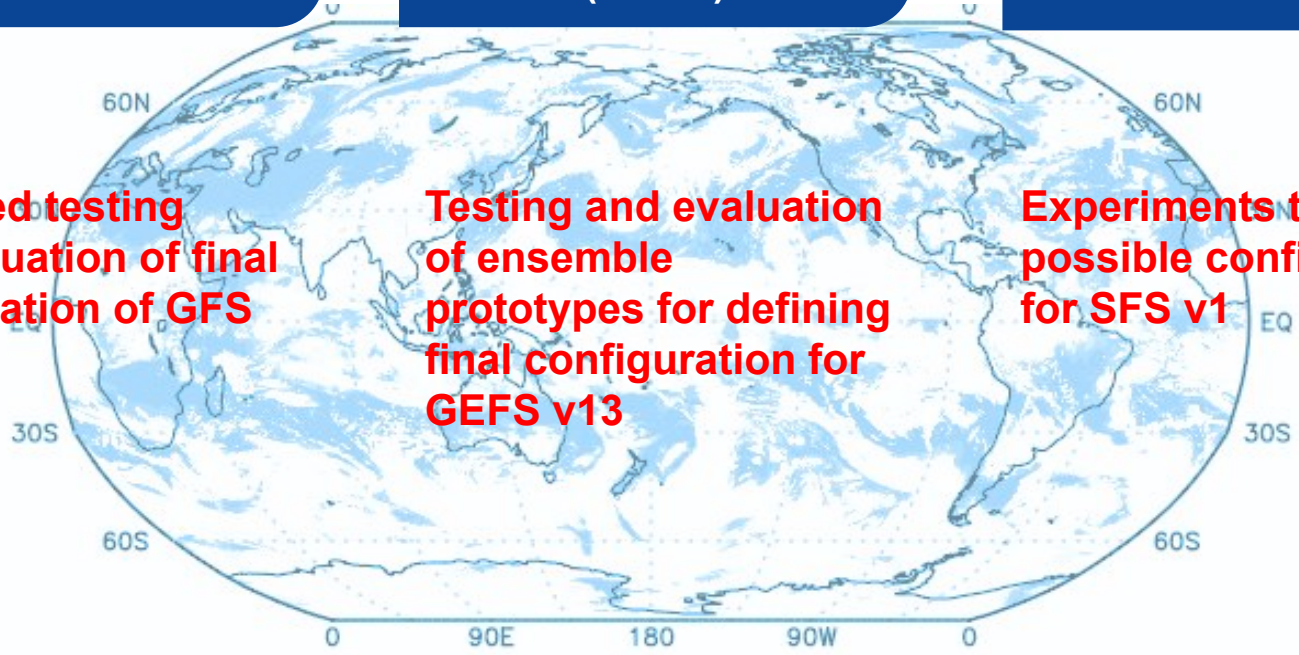


Global UFS-Coupled: Future Work/Priorities

Global Forecast System (GFS)

Global Ensemble Forecast System (GEFS)

Seasonal Forecast System (SFS)



Advanced testing and evaluation of final configuration of GFS v17

Testing and evaluation of ensemble prototypes for defining final configuration for GEFS v13

Experiments targeting possible configuration for SFS v1

Current UFS-based Coupled Developments

- **Each of these is a working coupled application which is either operational or actively being developed**

FV3GFS – WW3
Impact of waves on atmospheric stress at ocean surface

FV3GFS – CHEM
Atmosphere and Aerosols interaction

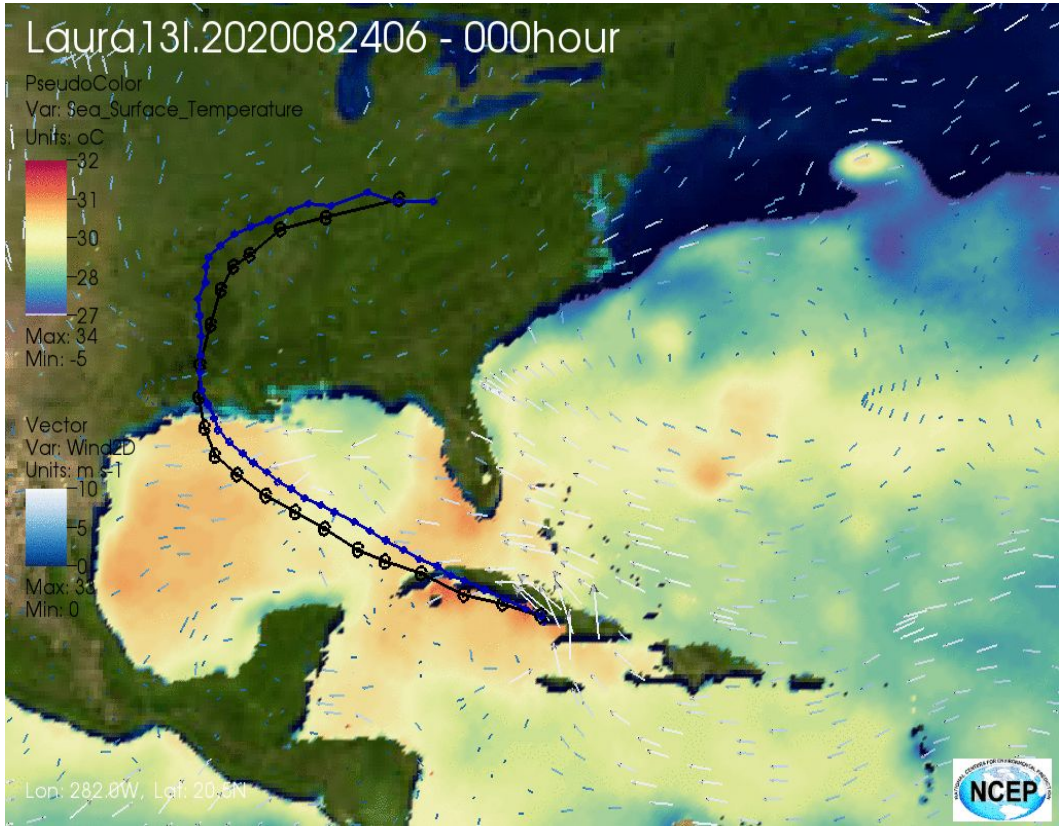
ADCIRC – WW3 – NWM
Wave, Surge and Inundation coupling

DATM – MOM6 – CICE6
Ocean Ice coupled model with Data Atmosphere for developing Marine DA.

FV3HAFS- HYCOM
Hurricane Analysis and Forecast System

FV3GFS – MOM6 – CICE6 – WW3 – NOAH-MP – GOCART
Global MRW-S2S Applications

Hurricane Analysis and Forecast System (HAFS)



HAFS Development Objectives

- Use cloud resolving resolutions within nests (static, telescopic and moving) and coupled domains
- Improve physics schemes by using observations to enhance the accuracy of coupled simulation of physical processes for TC's
- Advance inner-core and satellite DA algorithms for TCs; ingest new observations and adopt advanced DA algorithms

Acknowledgement to HAFS model active developers

Atmospheric model dynamics/configurations/workflow

NCEP/EMC Avichal Mehra, Bin Liu, JungHoon Shin, Vijay Tallapragada, Biju Thomas, Zhan Zhang
AOML/HRD Kyle Ahern, Ghassan Alaka, S. Gopalakrishnan, William Ramstrom, Xuejin Zhang,
DTC Evan Kalina, Kathryn Newman, Mrinal Kanti Biswas, Linlin Pan
GFDL Joseph Mouallem, Lucas Harris, Timothy Marchok

Ocean/Wave coupling through CMEPS

NCEP/EMC Maria Aristizabal, Jessica Meixner, John Steffen,
AOML/HRD Lew Gramer
AMOL/PhOD Hyun-Sook Kim
NRL/ESMF Dan Rosen, Gerhard Theurich

Data Assimilation

NCEP/EMC Li, Bi, Xu Li, Daryl Kleist
AOML/HRD Jason Sippel, Sarah D. Ditchek
OU Xuguang Wang, Xu Lu
UM/CIMAS Altug Aksoy, Dan Wu
UMD Kenta Kurosawa, Jonathan Poterjoy
SUNY/U at Albany Ryan Torn, Eun-Gyeong Yang

Model Pre- and Post-processes

NCEP/EMC Bantwale Enyew, Qingfu Liu, Yonghui Weng, Chuan-Kai Wang, Lin Zhu

Atmospheric Physics

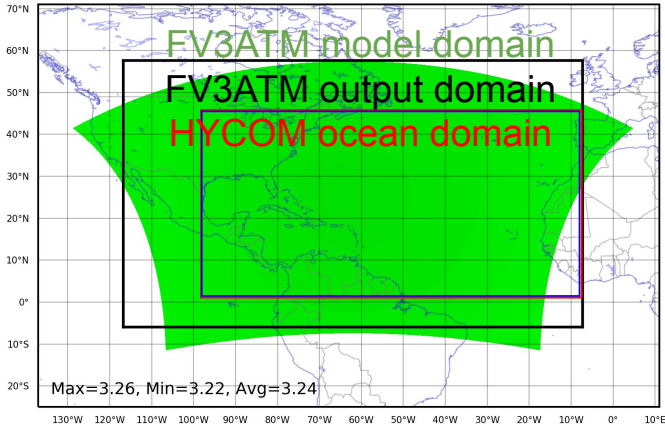
NCEP/EMC Jongil Han, Xu Li, Chunxi Zhang, Weiguo Wang, Fanglin Yang
AOML/HRD Andrew Hazelton, Xiaomin Chen

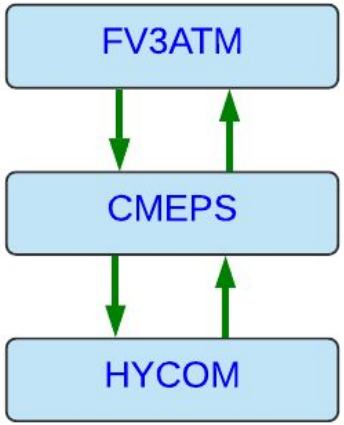
Verification/Evaluation

NCEP/EMC Jiayi Peng, Olivia Ostwald
NHC Michael Brennan, Ben Trabing, David Zelinsky

The HAFSv0.2A Configuration (~ 2021)

- **The hafs.v0.2.0 version (finalized 05/12/2021) was used**
  - Available from https://github.com/hafs-community/HAFS
- **The FV3ATM component**
  - Regional ESG C3089 grid (~3-km) with L91 (10 hPa top) levels
  - GFSv16 netcdf files for IC; 3-hrly GFSv16 grib2 files for LBC
  - dt_atmos=90s; k_split=3; n_split=5; radiation time step: 1800s; LBC blending with nrows_blend=10
  - The HAFS_v0_gfdlmp_tedmf_nonsst physics suite was used
    - GFDL microphysic; RRTMG radiation; Scale-aware SAS convection; Noah LSM; GFS surface layer with HWRF exchange coefficients; Modified GFSv16 scale-aware TKE-EDMF PBL scheme (with modified surface layer mixing length scale, sfc_rlm=1); Turn on orographic GWD but keep convective GWD off; NSST component turned off
  - Utilize inline post to generate grib2 products within the forecast model
  - Fix boundary-crawler issue and turn off two thickness parameters in the GFDL tracker (from Tim Marchok, GFDL)
- **The HYCOM component**
  - Updated CMEPS/NUOPC based atmosphere-ocean coupling
  - Updated 1/12-degree NATL domain (1-45.78N, 261.8-352.5E), L41
  - Ocean IC's from RTOFSv2 with persistent oceanic LBC
  - Atmospheric forcing from GFSv16 grib2 files for non-overlapping area



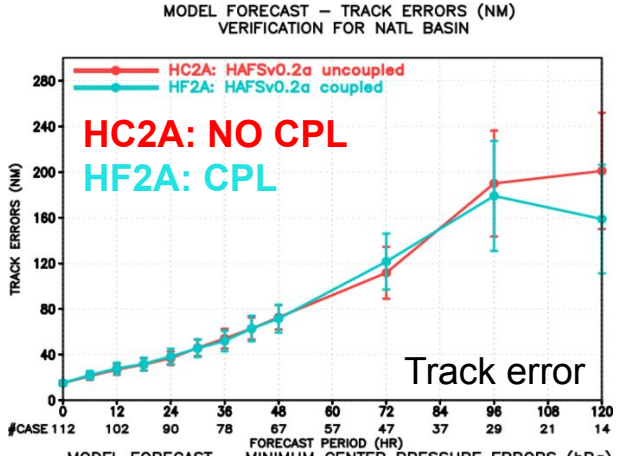


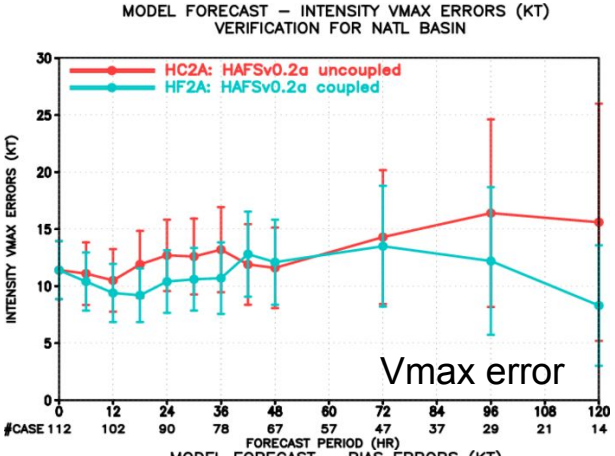
ATM to OCN: air-sea momentum, sensible and latent heat fluxes, net shortwave and longwave radiation fluxes, surface pressure, and precipitation

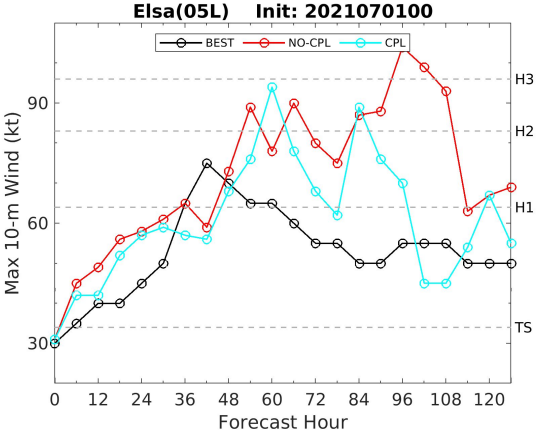
OCN to ATM: SST

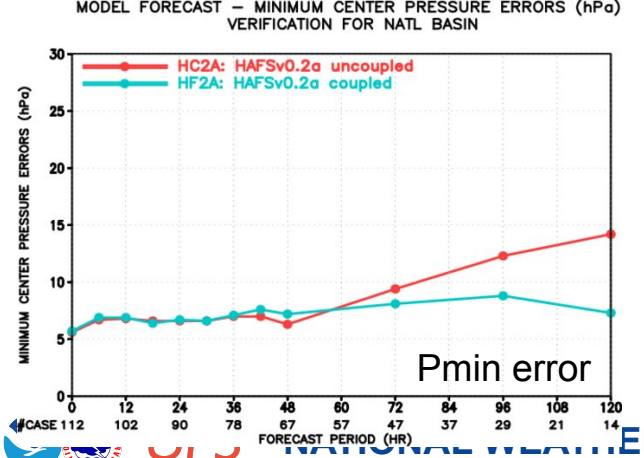
Coupled vs Uncoupled HAFSv0.2A

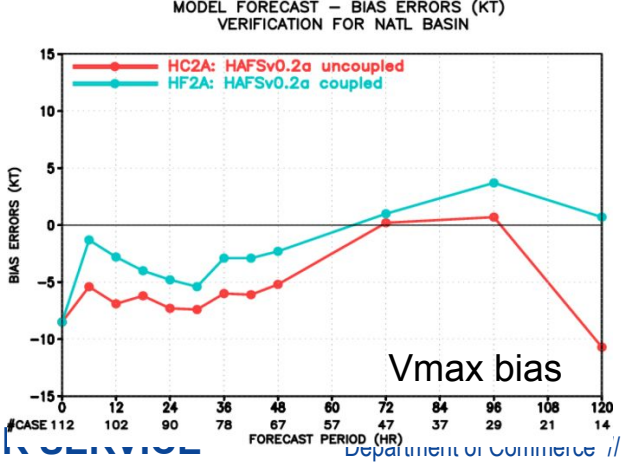
Impact of Ocean Coupling

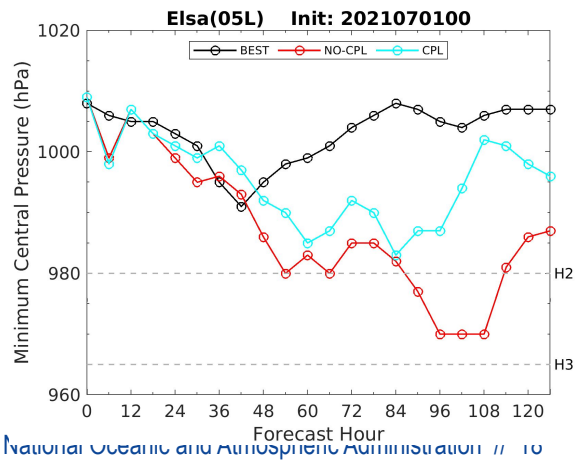






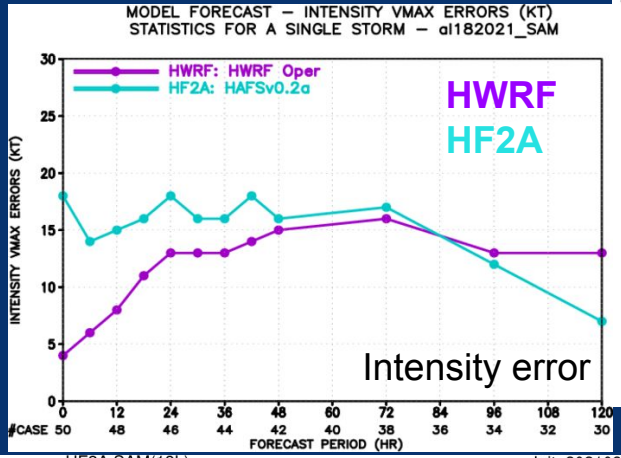


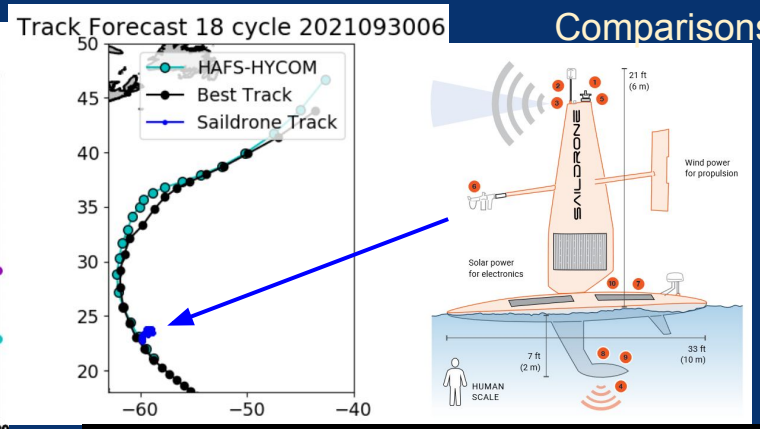


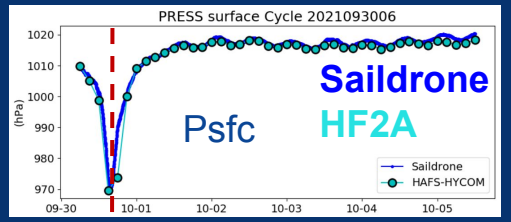


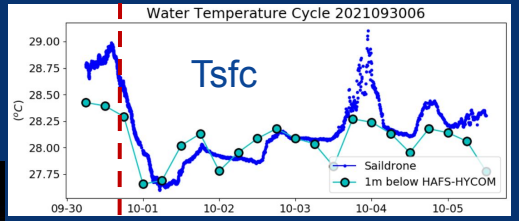
HAFS v0.2A Forecast for Hurricane Sam (18L2021): Saildrone comparisons

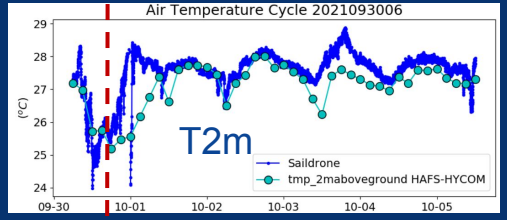
Comparisons with Saildrone observations

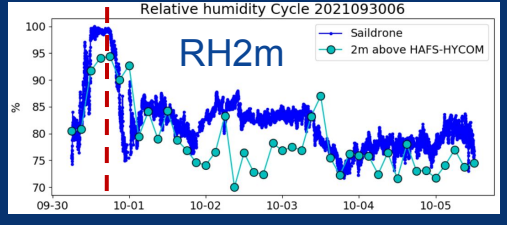


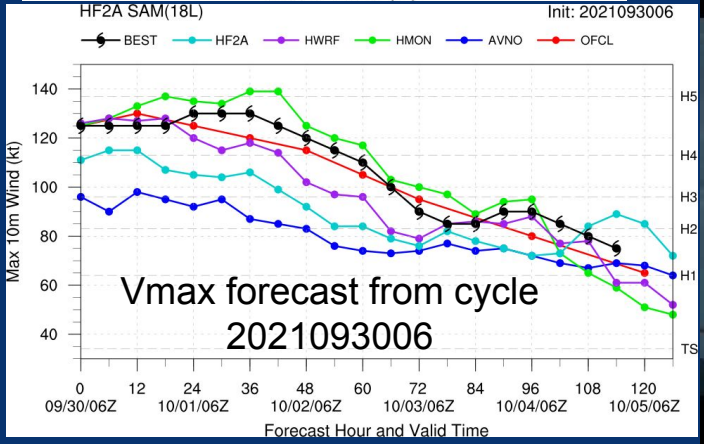












Courtesy: AOML/HRD

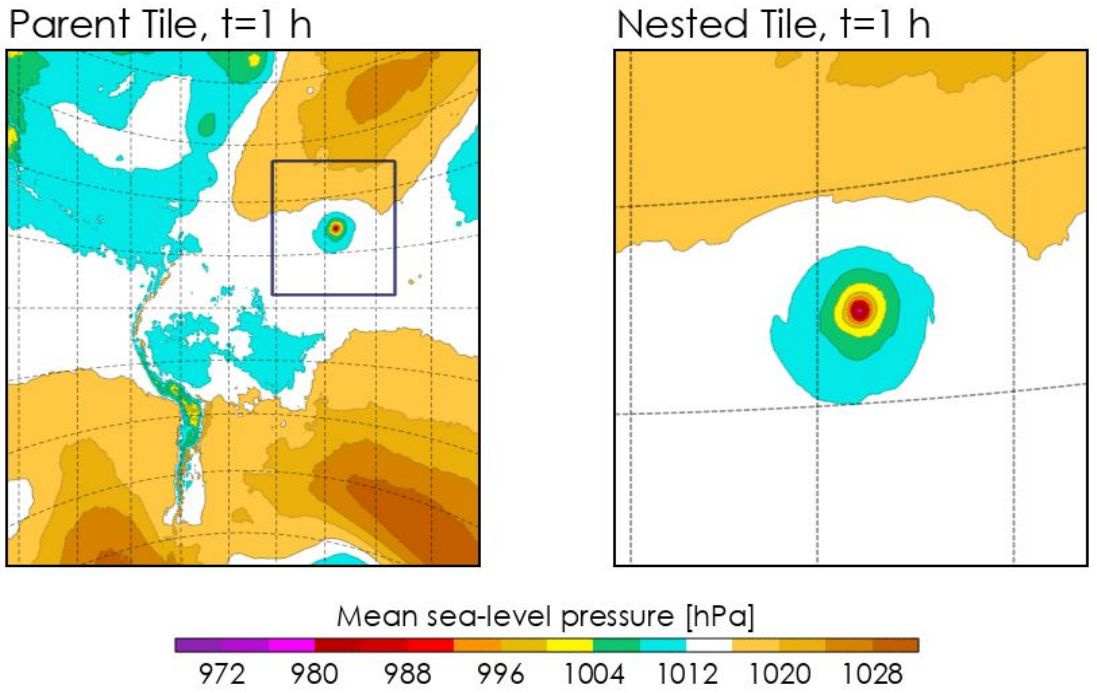
HAFS Moving Nest Development Strategy

Moving Nest Current Status (completed)

- Single moving nest on tile 6 in global domain
- Atmospheric prognostic variables shifted
- Atmospheric diagnostic variables recomputed
- Surface/terrain parameters moved
- Tested for C96 and C768 with 3X refinement
- Workflow for moving nest
- Preprocessing high-resolution orography and surface static fields
- Storm tracking algorithm
- Physics optimization for variable resolutions

Ongoing Development

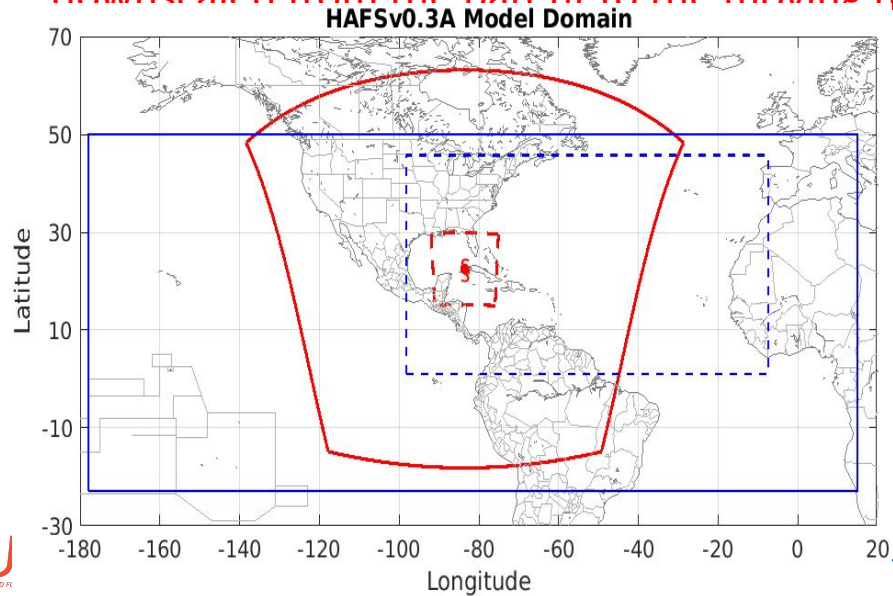
- Moving & telescopic nest code merge into HAFS repository (completed)
- Configure regional moving nest (completed)
- Multiple moving nest
- Flexible refinement
- Data assimilation for moving nest
- Post-processing and visualization
- Track generation for moving nest (completed)

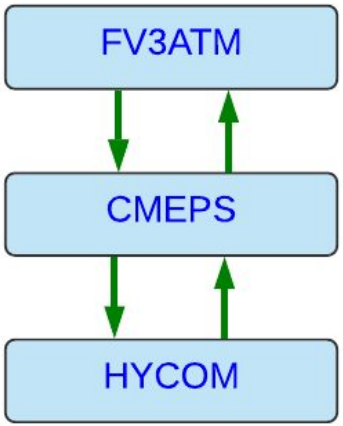


Courtesy: Bill Ramstrom and Xuejin Zhang (AOML/HRD)

The HAFSv0.3A Moving Nest Configuration (~2022 & FY23 IOC)

- **HYCOM ocean coupling**
  - Using a large 1/12-degree HYCOM NHC Domain (1-45.78N, 261.8-352.5E) with 41 vertical levels
  - Ocean IC's from RTOFSv2 with persistent oceanic LBC
  - Atmospheric forcing from GFSv16 grib2 files for non-overlapping area
  - CMEPS based coupling with the FV3ATM parent domain and with SST being downscaled from the parent to the moving nest domain

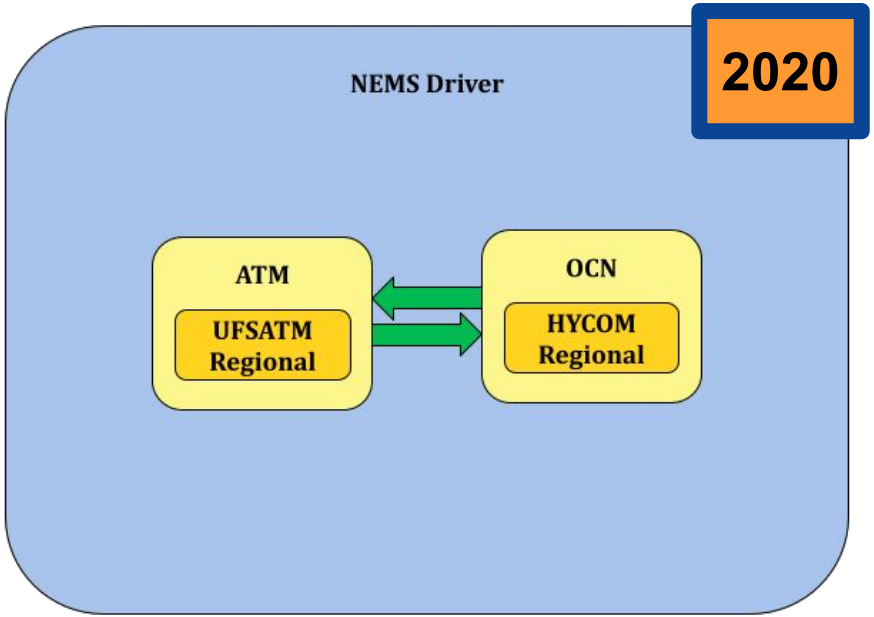




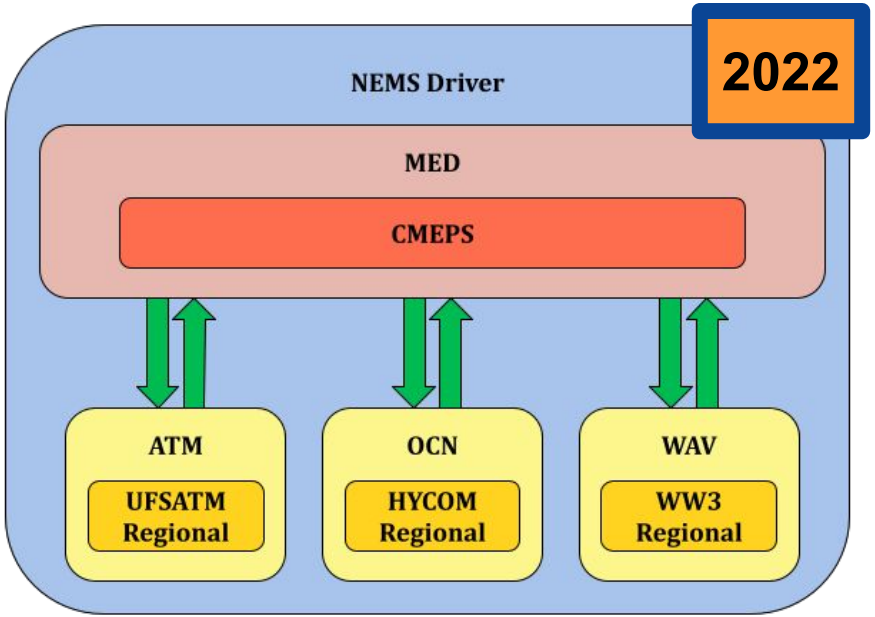
ATM to OCN: air-sea momentum, sensible and latent heat fluxes, net shortwave and longwave radiation fluxes, surface pressure, and precipitation

OCN to ATM: SST

HAFS with UFSATM-HYCOM-WW3 Coupled Components



UFSATM-HYCOM two-way coupling through NUOPC Connectors

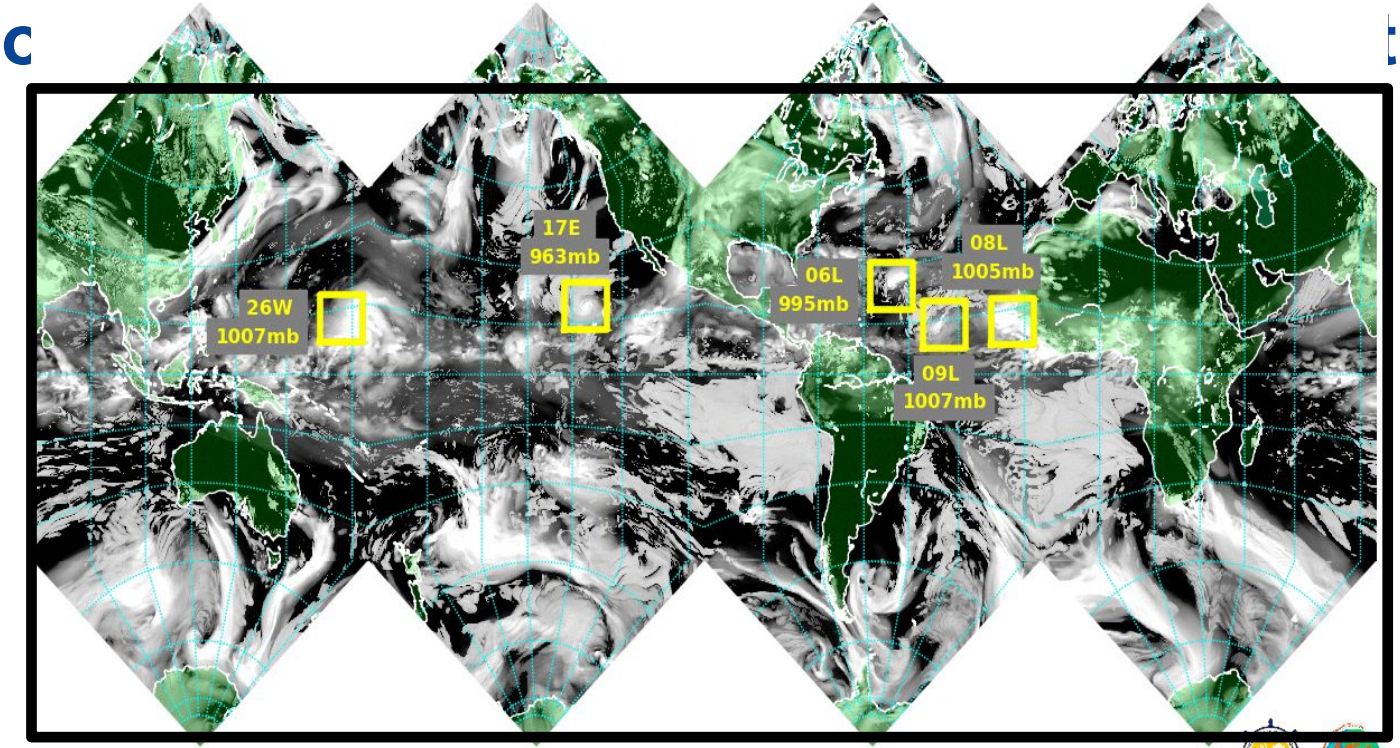


UFSATM-HYCOM-WW3 two-way coupling through the CMEPS mediator

Ongoing and Future Work

- Enable ocean coupling for HAFS with storm-following moving nest capability
- Transition from HYCOM to MOM6 for ocean coupling
- Include wave coupling impacts with WW3 to establish a three-way atmosphere-wave-ocean coupled HAFS, and move towards earth-system coupled HAFS for TC forecasting
- Develop inner-core vortex initialization and data assimilation for both the atmosphere and ocean components, and eventually establish air-sea coupled data assimilation system for HAFS
- Finalizing the Initial Operational Capability (IOC) for HAFS in FY23

Lc tion



Developing and advancing the Hurricane Analysis and Forecast System is one of the key strategies to address the next generation HFIP's science and R2O challenges.

Summary

- Coupled UFS Applications are being targeted for operational implementation in FY23 and beyond.
- There are many contributions from the community including for the component models, atmospheric physics, coupling of models, data assimilation, infrastructure, and more.
- EMC looks forward to continued collaboration with the broader community.

Thank you!