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

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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

| 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 |
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

UFS Driver

CMEPS Mediator

Atmosphere: FV3 dycore
CCPP Physics driver
NOAH-MP

Ocean: MOM6

Ice: CICE6

Wave: WW3

Aerosols: GOCART
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.

<table>
<thead>
<tr>
<th></th>
<th>Initial Conditions</th>
<th>Ice Model</th>
<th>Mediator</th>
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<td><strong>UFS_P1</strong></td>
<td>CFSR</td>
<td>CICE5</td>
<td>NEMS</td>
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<td>CPC 3DVar</td>
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<td>CICE6</td>
</tr>
</tbody>
</table>

For more details see the spreadsheet [here](#).
UFS-Coupled Improvements in MJO-Skill

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

![Graph showing correlation skill for MJO indices RMM1, RMM2, and RMM1 RMM2 with different models CFSv2, UFSp5, UFSp6, UFSp7.](image)
UFS-Coupled Improvements in z500 AC scores

NH z500 AC

SH z500 AC
UFS-Coupled Prototype Summary of AC scores

Week 1 AC score

Week 2 AC score

Weeks 3&4 AC score

Legend:
- CFS_v2 raw
- CFS_v2 sec
- UFS_p7.0 raw
- UFS_p7.0 sec
Global UFS-Coupled: Future Work/Priorities

Global Forecast System (GFS)

- Advanced testing and evaluation of final configuration of GFS v17

Global Ensemble Forecast System (GEFS)

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

Seasonal Forecast System (SFS)

- Experiments targeting possible configuration for SFS v1
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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](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
  - \(dt\_\text{atmos}=90\text{s}; k\_\text{split}=3; n\_\text{split}=5\); radiation time step: 1800s; LBC blending with \(n\_\text{rows}\_\text{blend}=10\)
  - 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

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**FV3ATM model domain**

**FV3ATM output domain**

**HYCOM ocean 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
Coupled vs Uncoupled HAFSv0.2A
Impact of Ocean Coupling

HC2A: NO CPL
HF2A: CPL

Track error
Vmax error
Pmin error
Vmax bias
HAFS v0.2A Forecast for Hurricane Sam (18L2021): Saildrone comparisons

Comparisons with Saildrone observations

Vmax forecast from cycle 2021093006

Intensification error

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

Diagram: HAFSv0.3A Model 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
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!