The future of coupled modeling at NWS

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Overview

Planning at NWS

- Coupled ensemble modeling
  - NOAA Unified Modeling Committee whitepaper
  - A Strategic Vision for NOAA’s Physical Environmental Modeling Enterprise
  - 2017-2018 Roadmap for the Production Suite at NCEP
  - Strategic Implementation Plan
- NOAA – NCAR Memorandum of Understanding (MoA)

Coupled modeling

- The present and past
- The approach
- The progress
Planning Overview
A Hierarchy of Plans

1. UMC
   - Unified Modeling Committee: High-level NOAA Unified Modeling Overview
     - **Horizon**: 5-10 Years
     - **Scope**: NOAA

2. Vision
   - A Strategic Vision for the US National Physical Environmental Modeling Enterprise
     - **Horizon**: 5-10 Years
     - **Scope**: US Environmental Modeling Enterprise (Federal focus, integrated with Academia)

3. Roadmap
   - Roadmap for the Production Suite at NCEP
     - **Horizon**: 5-10 Years
     - **Scope**: NCEP Production Suite (Unified Forecast System)

4. SIP
   - Strategic Implementation Plan
     - **Horizon**: 0-3 Years
     - **Scope**: NCEP Production Suite (Unified Forecast System)

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(1) A broad “strategy document” from the NOAA Unified Modeling Committee (UMC; under the auspices of the NOAA Research Council); spans the entirety of the NOAA modeling enterprise, inclusive of bio-geo-chemical, social and physical.

(2) The NWS and OAR are developing a Strategic Vision Document looking out 10 years and bridging US Physical Environmental Modeling Enterprise with the higher level NOAA UMC effort.

(3) Also emanating from an NWS-OAR partnership, is a Roadmap document that lays out how we can move the NCEP Production Suite towards the vision described in the Vision Document.

(4) At a practical level, the Strategic Implementation Plan (SIP), describes NOAA’s concrete steps over the next 3 years to build the Next Generation Global Prediction System based on the Unified Forecast System, beginning with numerical weather prediction across scales and in partnership with the community (all stakeholders).
Unified Modeling Committee

NOAA-wide, long term
Under NOAA Research Council
Policy rather than requirements

Strategic Vision

Physical modeling at NOAA, 5-10 year vision
AA level approval
Effort pre-dates UMC

Finalized, awaiting signatures
Strategic Vision: Key Elements

Focus on products supporting mission requirements

Unified modeling and data assimilation
- Coupled, ensemble based, reforecast and reanalysis
- Including pre- and postprocessing, calibration, verification validation

Focus on community modeling
- Operations and research

Evidence-driven decisions
- Same standards for all who contribute

Transparent and robust governance
- Service requirements
- Technical requirements / solutions
- Prioritization

See SIP for community governance

Strategic Vision Fig. 1
Deconstructing the funnel

Past

Future

"external" community

Operational system development and implementation

Community Software - Updates

Implementable Research

Science and Technology Transition

Test Beds

Operational system development and implementation

Research Partners

Mission-oriented research and development to improve NOAA's operational and information services

NOAA Mission Research and Development

Science and Technology Transition

Test Beds

Operational system development and implementation

"external" community

General research and development
Related to NOAA’s mission.

Research Partners

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Test Beds
Strategic Vision: Temporal Domains

### Unified Forecast System

- **Unified Coupled Model**
- **Unified Data Assimilation**

#### Temporal Domains

- **Year+** (decadal centennial)
- **Year** (seasonal)
- **Month** (outlook/sub-seas.)
- **Week** (weather)
- **Day** (rapid refresh)
- **Hour** (WoF)
- **Now** (analyses)

#### Resolution Levels

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**Unified Forecast System = Coupled Ensemble + Reanalysis + Reforecast**
Roadmap

Production Suite, 5-10 years
AA level approval
Effort pre-dates UMC

Finalized, awaiting signatures
Starting from the quilt of models and products created by the implementing solutions rather than addressing requirements...

... we will move to a product based system that covers all present elements of the productions suite in a more systematic and efficient way.

Moving from atmosphere focus to holistic environmental approach.
**Roadmap: 5 year “end state”**

Focus on transition to Unified System

<table>
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<th>Element</th>
<th>Cadence</th>
<th>Range</th>
<th>Resol.</th>
<th>Ens.</th>
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<th>RR</th>
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<td>1979-present</td>
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<tr>
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<td>3 y</td>
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<td>3 km (r)</td>
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<td>2-4 h</td>
<td>1 km (r)</td>
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<td>1 y</td>
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<td>TBD (r)</td>
<td>---</td>
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</table>

SFS= Seasonal Forecast System  
SSFS= Sub-Seasonal (Outlook) Forecast System  
GFS= Global Forecast System  
RRFS= Rapid Refresh Forecast System  
WoFS = “Warn on Forecast” System

*Changing use of WCOSS*
*Needing ~ 37 PFlop machine*

Resolutions for atmosphere, other component models may have different resolutions.

(g) Global  
(r) regional  
Red: uncharted territory
Roadmap: 10 year “best system”

Focus on becoming best in the world

<table>
<thead>
<tr>
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<td>50</td>
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<td>---</td>
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<td>TBD (r)</td>
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</table>

S3SFS= (Sub-) Seasonal Forecast System
GFS= Global Forecast System
RRFS= Rapid Refresh Forecast System
WoFS = “Warn on Forecast” System

SFS / SSFS use single model
Needing ~ 730 PFlop machine

Resolutions for atmosphere, other component models may have different resolutions
Strategic Implementation Plan

SIP, execution at NCEP 1-3 year
Execution level approval / planning
Annual upgrade through SIP working groups

https://www.weather.gov/sti/stimodeling_nggps_implementation
NGGPS Goals and Objectives

Design/Develop/Implement NGGPS global atmospheric prediction model
- Non-hydrostatic scalable dynamics

Improve data assimilation and physics

Position NWS for next generation high performance computing

Engage community in model/components development

Reduce implementation time

Increase effectiveness of product distribution
- Post-processing, assessments, and display

World’s Best Global Forecast Guidance

¹From NWS Budget Initiative proposal to OMB
SIP for Unified Forecast System

Common Goal: Single integrated plan that coordinates activities of NOAA + external partners in common goal of building a national unified modeling system across temporal and spatial scales

- NGGPS: foundation to build upon
- Activities include R&D, testing/eval, V&V, R2O, shared infrastructure, etc.

Approach for SIP development:

- Began with existing core R&D partners to organize in functional area Working Groups (WGs) responsible for drafting respective functional SIP components
- End product (in final coordination) will be SIP version 1.0, a 3-year plan (FY 2018-2020)
- FY18 and following: SIP to be rolling 3-year plan to be updated annually
SIP Working Groups

**Unified Forecast System (UFS)**
- Steering Committee

**Communications and Outreach**
- Common messaging strategy

**Convective Allowing Models (CAMs)**
- Intermediate steps to CAM ensembles, Warn on Forecast; test/eval w/community

**System Architecture**
- NEMS evolution; community approach

**Infrastructure**
- Standards/doc; CM; code repository; etc.
- Role of testbeds; regression testing; etc.

**Verification & Validation (V&V)**
- V&V of ops forecasts vs. R&D testing/eval
- Unified/standard tools and data formats

**Dynamics and Nesting**
- FV3 transition on global wx/S2S/climate
- Nests for hurricanes (moving?)

**Model Physics**
- Common Comm. Physics Pkg (CCPP); stochastic, scale-aware physics

**Data Assimilation**
- NOAA, NASA integ. w/FV3; coupled DA
- Joint Effort for DA Integration (JEDI)

**Ensembles**
- Strategy across scales; model uncertainty

**Post-Processing**
- Comm. PP infrastructure; std formats/tools

**Component Model groups**
- Marine models + NOS coastal/bay models
- Aerosols and Atmospheric Composition
- Land Sfc Models (LSMs) + hydrology (OWP)

*New WG or addition (wrt NGGPS)*
Augmentation of existing NGGPS group
NOAA – NCAR MoA

NCAR - NWS – OAR
NCAR – NOAA MoA

Letter of Intent for collaboration between NCAR, NWS and OAR signed July 28, 2017

● “to develop a Memorandum of Agreement (MOA) that will describe how both organizations will work collaboratively toward the design and construction of a community unified modeling infrastructure. “

● Identified benefits include
  ➤ Synergies
  ➤ Common repositories
  ➤ Access to NOAA operational models

Team for writing MoA formed in November 2017

● Full MoA text agreed upon by all three organization
● Now in NOAA final legal review
The Present and Past
present

Coupled systems

- Climate Forecast System (CFS v2)
- HYCOM – CICE coupling
- Hurricane models (GFDL, HWRF)

http://cfs.ncep.noaa.gov/cfsr

![Diagram showing coupled systems and data exchange](image-url)
Operational HWRF

- High-Resolution (2km) near the storm
- Advanced hurricane physics
- Coupled to ocean model
- 1-way coupled to wave model (July 11, 2018)
- Custom coupler, 3-way coupling is being tested.

Three telescopic domains: 18km: 80x80°; 6km ~12x12° 2km inner-most nest 7x7°

Accurate intensity and structure forecasts from HWRF → Better wave and storm surge forecasts for landfalling storms
The Approach
Basic approach: coupling

This is not just a science problem

- Requirements for additional, traditionally downstream products
- "One-way" model coupling versus downstream model:
  - Increases forcing resolution of downstream models while reducing I/O needed to force models
  - Creates a better integrated test environment for holistic evaluation of model upgrades
  - Less implementations
  - Creates environment for investigating benefits of two-way coupling. Enables two-way coupling if science proves benefit

Negative aspects of coupling:

- More complex implementations
- Less flexibility to tailor product.
- Produce “too much”
Basic approach: coupling

Many potentially coupled model components already have products in the production suite:

- Where no products exist, science suggests benefit of coupling
- For the hourly forecast range, all still TBD
- DA is also moving (internationally) to coupling
- Space weather making its way into operations
- Ecosystems (marine) being considered (not in table)

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<th>Subsystem</th>
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<td>S/R</td>
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Y: present product  
S: science benefit  
R: unmet requirement  
?: TBD
### Basic approach: coupling “now”

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- **Green boxes:** light: tradition 1-wy downstream coupling
dark: two-way coupling in selected operations.

- **Grey boxes:** fixed data, not dynamic coupling

- **Black text:** presently in place.

- **Red text:** science has shown impact
Roadmap: Architecture

ESMF/NUOPC/NE MS architecture enables unified coupled modeling and DA

Consistent with broader NOAA (UMC) and US vision (National ESPC)

FV3, CCPP, CICE, MOM6 (HYCOM), WW3, GOCART, WRF-Hydro, JEDI, …..
Roadmap: Fully Coupled

Moving to coupled Data Assimilation

Range of work going from weakly to strongly coupled Data Assimilation

Commitment to go there, not mature enough for hard commitment

Joint Effort of DA Integration (JEDI)
The Progress
Team Efforts (I): Ice, Ocean, DA

The CICE consortium
- Started in October 2016
- Moving toward community modeling framework
- Icepack release this week!

Ocean modeling with ALE models
- MOM6 can be seen as a first attempt to merge existing models
- NOAA / NWS moving to MOM6 to merge MOM4 and HYCOM applications
- Can we go to a single community framework (ESPC discussions)?

Moving toward coupled Data Assimilation
- JCSDA Joint Effort for Data Assimilation Integration (JEDI), modular framework to streamline DA
- Agile code development techniques
- Marine-JEDI investments at NOAA
**Team Efforts (II) : Total Water**

Total coastal water prediction is identified as a major gap in our capabilities.

**Remember Harvey ….**

**Five themes in NOAA with own programs and authorizations,**

**Building first NOAA plan for total coastal water prediction.**

**Requirements, solutions, prioritization.**

<table>
<thead>
<tr>
<th>Requirement Theme</th>
<th>Auth. / Org/ Program</th>
<th>Present Geogr. Focus Area</th>
<th>Technical Aspects (req. / foci)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical Storm Surge</td>
<td>HFIP / OWP / NHC / MDL / EMC / RFCs / COASTAL act</td>
<td>Atlantic Coast, Gulf of Mexico, OCONUS</td>
<td>2D / 3D focus</td>
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<td>Major Error Sources</td>
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<td>Foci (other than coupling)</td>
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<td>Atm. forcing uncertainty</td>
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<td>Ensemble Forcing / DEM</td>
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<tr>
<td>Extratropical Storm Surge</td>
<td>OWP / OPC / NOS / EM C / RFCs / MDL</td>
<td>Continental US, AK, Puerto Rico, all US Pacific Areas of Interest</td>
<td>2D / 3D focus</td>
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<td>Forcing (atm + waves) / bathymetry</td>
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<td>Bathymetry (+DEM), high fidelity 2D surge model</td>
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<tr>
<td>Coastal Ocean and Lake Models (Operational Forecast Systems)</td>
<td>NOS</td>
<td>CONUS - AK - HI estuarine/coastal (head of tide to shelf) and Great Lakes</td>
<td>3D / 3D</td>
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<td>Forcing (global ocean, atm + rivers) / bathymetry</td>
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<td>3D circulation modeling, ecosystem forecasting</td>
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<tr>
<td>Water Quality</td>
<td>Ecological forecasting, HABHRCA</td>
<td>Atlantic coast, Gulf of Mexico coast, Pacific coasts, Great Lakes</td>
<td>3D / 3D</td>
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<td>3D flow details / contamination sources / biology</td>
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<td>Coupling to 3D circulation modeling</td>
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<tr>
<td>Inland National Water Model</td>
<td>OWP and RFCs</td>
<td>CONUS, Hawaii, Alaska, Puerto Rico</td>
<td>2D/3D</td>
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<td>Forcings/ bathymetry</td>
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<td>Water mass balance modeling</td>
</tr>
</tbody>
</table>
Great Lakes Modeling (I)

- Partnership with NOS, OAR and NWS
- Higher spatial resolution models (FVCOM) with extended forecast horizon
  - Enable other types of forecasts:
    - HAB forecasting (FY17)
    - Ice forecasting (FY20)
    - Wave coupling (ongoing)
Great Lakes Modeling (II)

Unstructured grid Wave model in ops.
1. Waves in ops., hourly update  2017
2. Couple to ice and circulation  Incr.
3. Couple to RRFS  2022 +
COASTAL Act

Preliminary findings

WAVEWATCH III – Adcirc coupling

IKE GFS05d_OC_DA_Wav
wind Date: 2008-09-09T01:00:00
Max. Val. = 36.2

IKE GFS05d_OC_DA_Wav - Only tide
Date: 2008-09-09T01:00:00
Max. Val. = 0.32

IKE GFS05d_OC_DA_Wav
hs Date: 2008-09-09T01:00:00
Max. Val. = 10.62

IKE GFS05d_OC_DA_Wav - Only tide
Max surge

Credit: S. Moghimi, A. Abdolali and Z. Ma
Atm. – wave coupling

Will be used in next implementations to move global wave model and global wave ensembles into GFS and GEFS (at least 1-way coupling).

Courtesy Jessica Meixner
Atm. – ocean – ice coupling

- Air-sea fluxes are computed in FV3
- Regridding from FV3 to MOM6 is done in coupler
- SST from MOM6 is used in FV3
- Sea ice fields are received by FV3, but are not used in FV3 yet

Changes in SST after 35 days

Courtesy Bin Li