2nd International Workshop on Waves, Storm Surges and Coastal Hazards

Global Wave Model Systems at NCEP

November 13, 2019

NOAA National Weather Service

Jose-Henrique Alves

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UFS Wave Group: *Jose-Henrique Alves, Jessica Meixner, Roberto Padilla, Bhavani Rajan, Deanna Spindler*

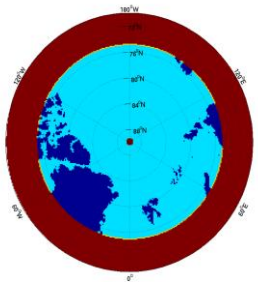
Outline

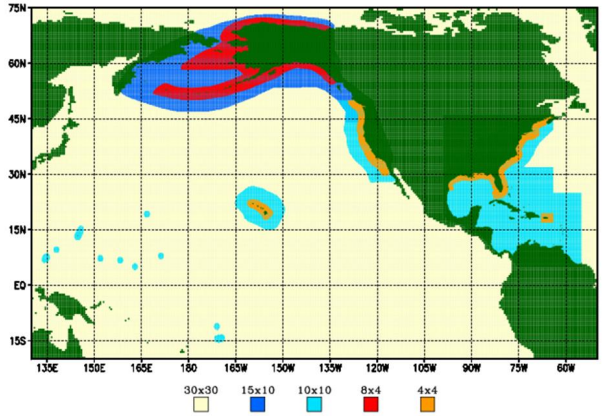
- NCEP's Operational Wave Guidance
- The new NGGPS/UFS paradigm
- Challenges for a wave model in a coupled world
- Wave Modeling Strategies → Upcoming Upgrades
- Results

Wave Guidance US National Weather Service

Global Wave Model (GWM)

- FV3-GFS winds, NCEP ice analysis
- 4 cyc/day, 9h ←→ 7-day
- WAVEWATCH III 9-grid mosaic



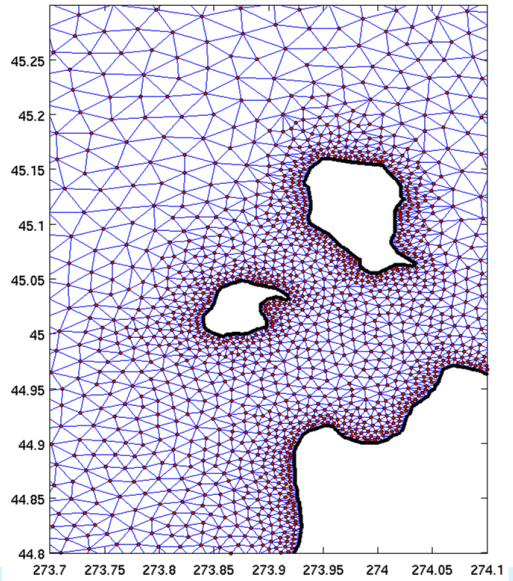


Global Wave Ensemble (GWES)

- GSM-GEFS winds, NCEP ice analysis
- 1 control + 20 perturbed members
- 4 cyc/day, 24h ←→ 10-day
- Single ½ deg grid, WAVEWATCH III

Great Lakes Wave Unstructured (GLWU)

- Forecaster winds, NIC ice
- 4 cyc/day → 6-day
- 20 cyc/day → 48h
- Unstructured grid, WAVEWATCH III

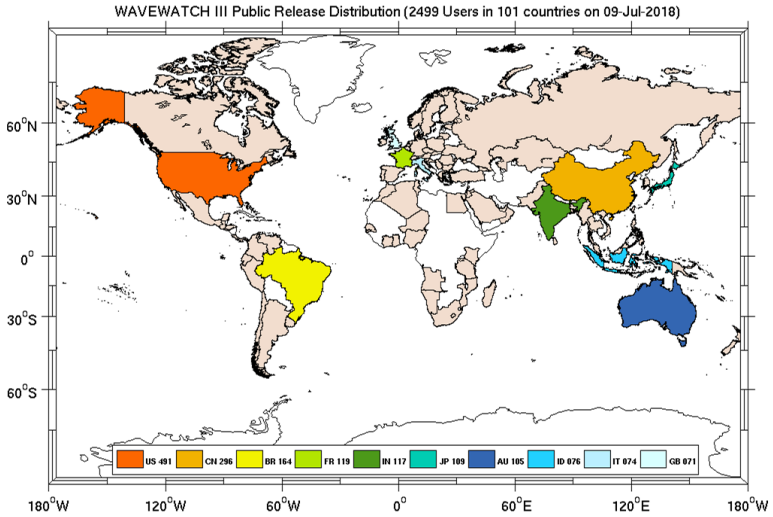


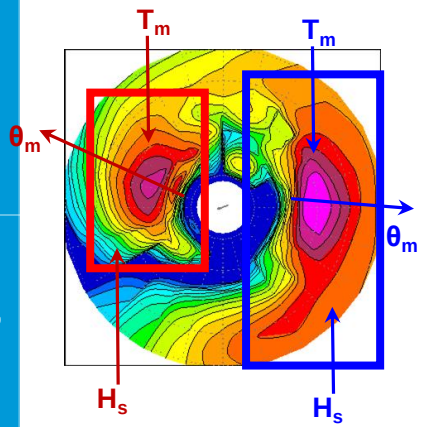
Nearshore Wave Prediction System (NWPS)

- On demand, forecaster winds
- Transitioning to WAVEWATCH III unstructured grids

WAVEWATCH III Modeling Framework

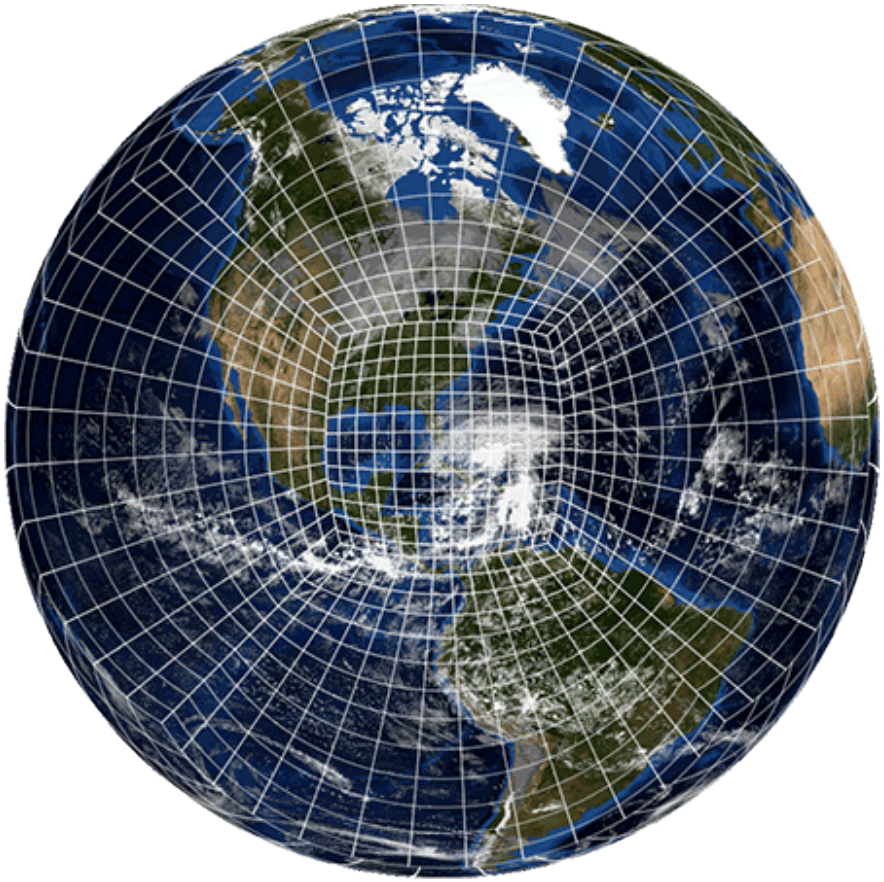
- WAVEWATCH III: state-of-the-art numerical model for wave prediction.
- Developed at NCEP in 90's, became community model recently,
  - Collaborators from all over the world,
  - >2,500 users in >100 countries (2018).
- WW3 is a spectral wave model,
  - Computes wave fields at fixed grid points
  - Statistical representation of waves via directional wave spectrum





- Model calculates how spectrum changes due to wind, currents and ice, computes mean wave parameters:
  - Significant wave height (Hs), total and partitions
  - Peak and Mean wave periods (Tp, Tm), total and partitions
  - Peak and mean wave directions (θp, θm), total and partitions

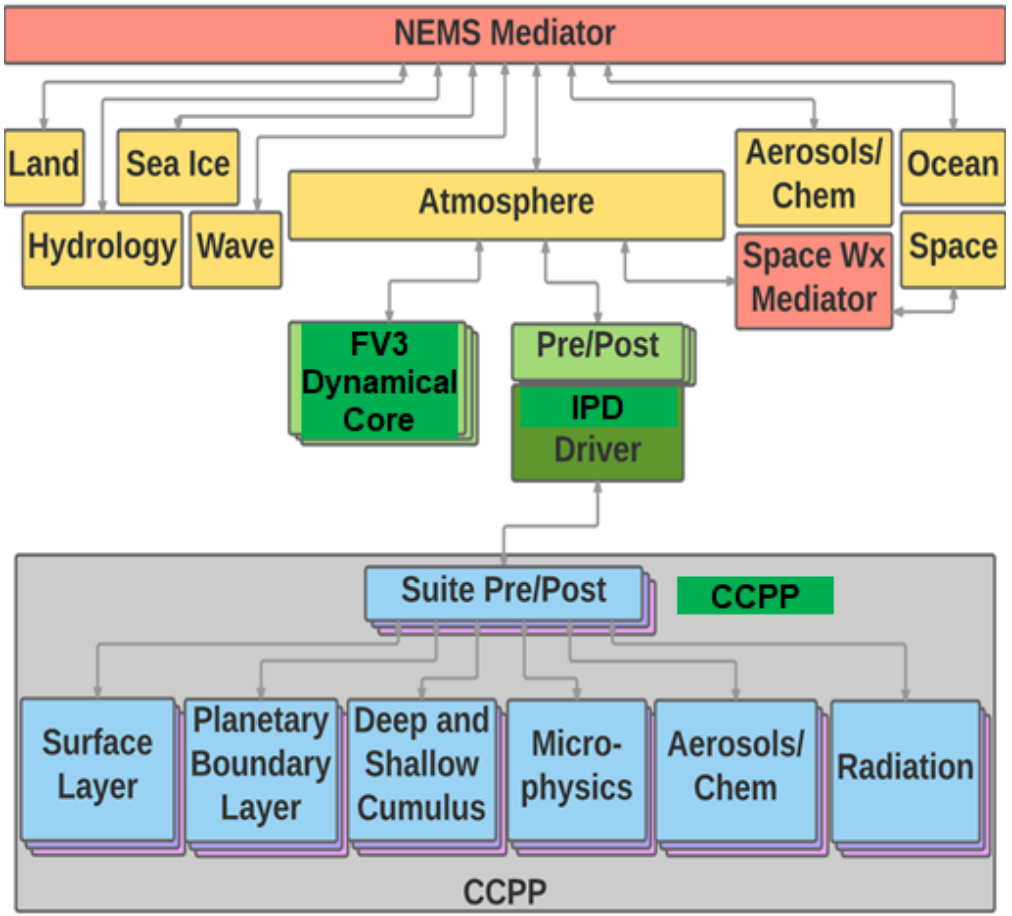
NCEP on the move: Cubed-Sphere GFS



- GFSv15 (June 2019)
- GFSv16 (2020)
  - FV3GFS C768 (~13km)
  - FV3GDAS C384 (~25km)
    - 80 member ensemble
  - 127 vertical levels, top extended to 80 km
- GEFSv12 (2020)
  - FV3GFS C384 (~25km)
  - 21 → 31 members
- Unification: Couple Waves GFSv16 & GEFSv12
  - Wave forecasts to 16 days

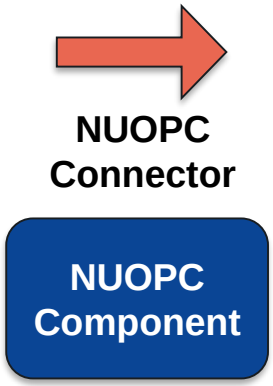
Next-Gen Global Prediction System (NGGPS)

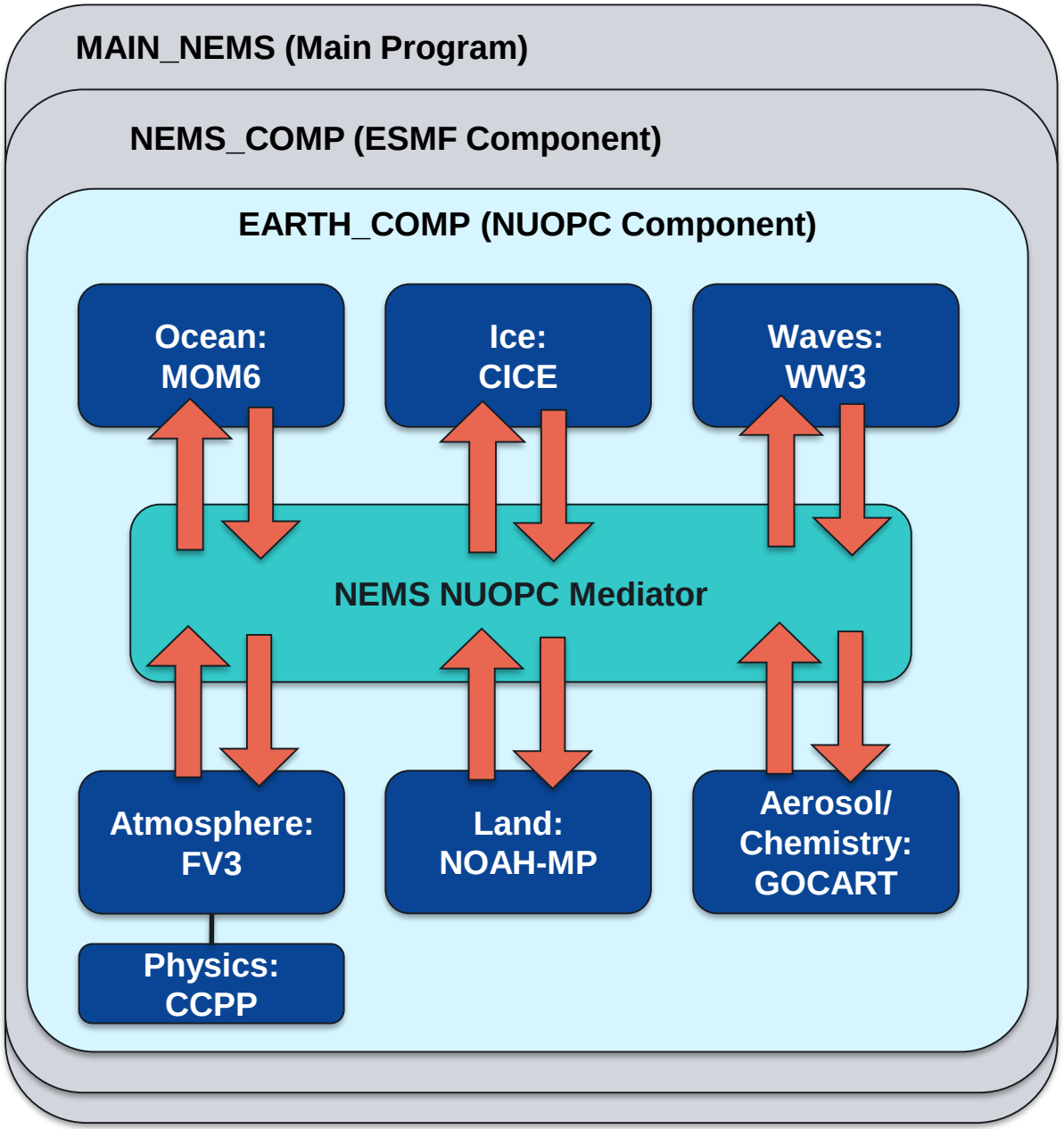
- Fully coupled, Unified Forecast System (UFS)
  - ocean, waves, sea ice, land surface, atmosphere, aerosols and atmospheric composition
- Built using NEMS/Earth System Modeling Framework
- Each component model will be community code



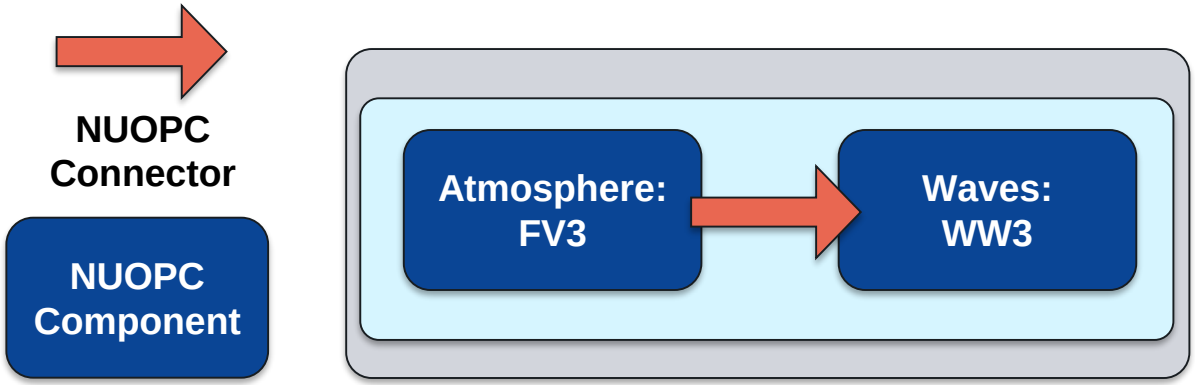
UFS
UNIFIED FORECAST SYSTEM

The plan for GEFSv13 (FY2023) is for waves to be two-way coupled with both the FV3GFS atmospheric model and MOM6 ocean model.





GFSv16/GEFSv12 Wave Coupling 2020



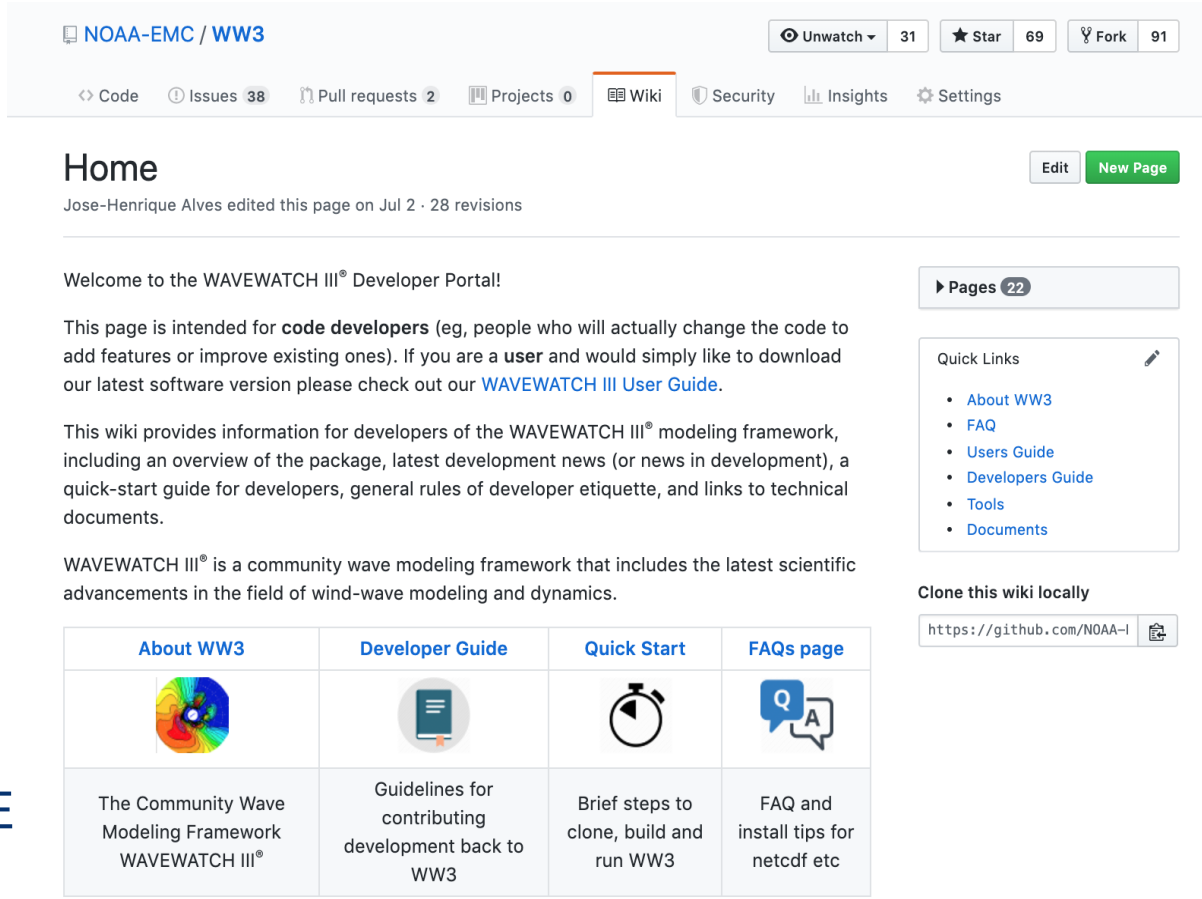
- One-way coupling via a NUOPC connector
- FV3ATM sends 10 m wind speeds (u,v) to WW3 at each coupling interval
  - For the first time step, WW3 reads winds from it's restart file (will be included in the next update of ufs-weather-model)

WAVEWATCH III Open Development

WAVEWATCH III

- 1st UFS model from EMC in Open Dev
- Apr 2019
- 1 central repo
  - NCEP
- 3 trusted repos
  - UKMet
  - Ifremer
  - ERDC/USACE
- 91 forks

https://github.com/NOAA-EMC/WW3



NCEP Global Wave Models and Unification

Challenges

- Unification/Coupling
  - Wave model is a component → shared resources
  - Coupling increases CPU & memory requirements
  - Stay close to atmospheric model resolution
- Wave model-specific
  - Adjustments to new wind model
  - Requirement to intake surface currents
  - Need to model entire Arctic: shrinking ice
  - Improve swell generation in high latitudes
    - Can't get away with coarse global scale grid

Model Development Strategy for Unification

Unification/Coupling

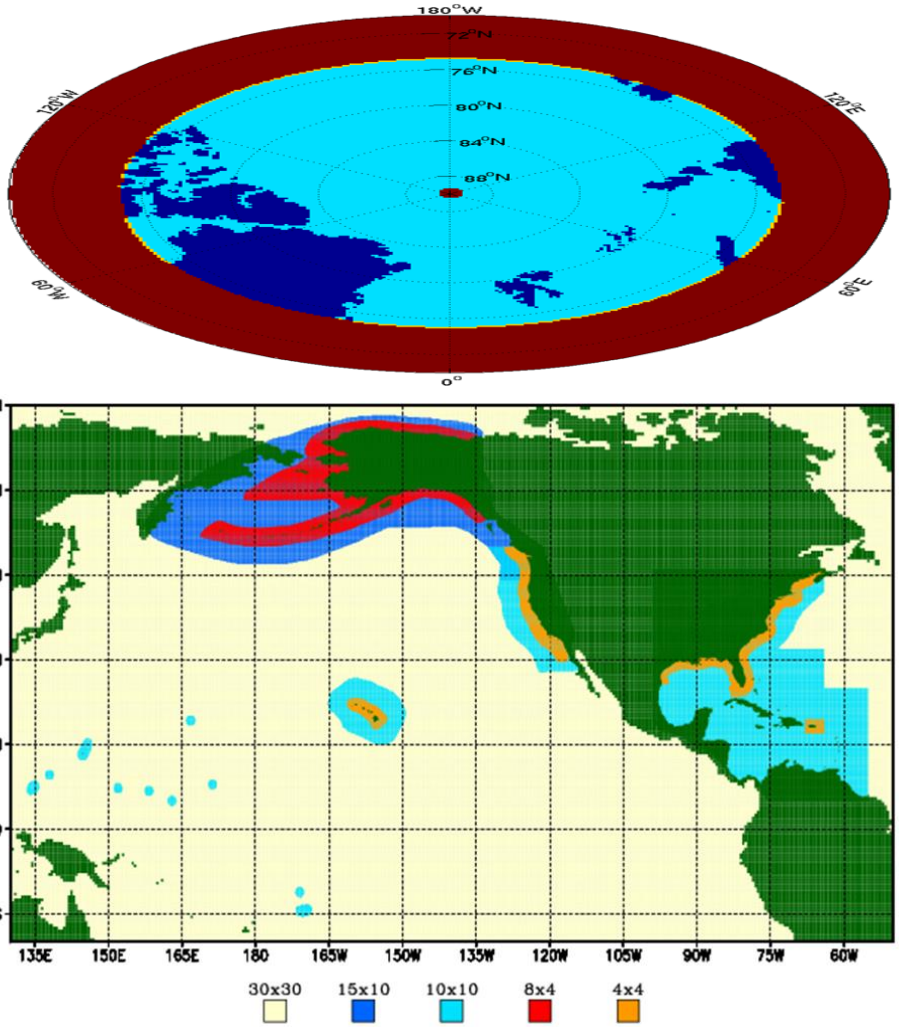
- Higher resolution grids
  - Stay close to atmospheric model resolution
- Less grids in mosaic → improved memory
  - Wave model is a component → shared resources
  - Coupling increases memory requirements

Wave model-specific

- Objective Physics Optimization/Higher Resolution Grids
  - Adjustments to new wind model
  - Improve swell generation in high latitudes
- Intake of RTOFS global currents
  - Requirement to intake surface currents
- Add polar-stereographic Arctic/Antarctic caps
  - Need to model entire Arctic: shrinking ice

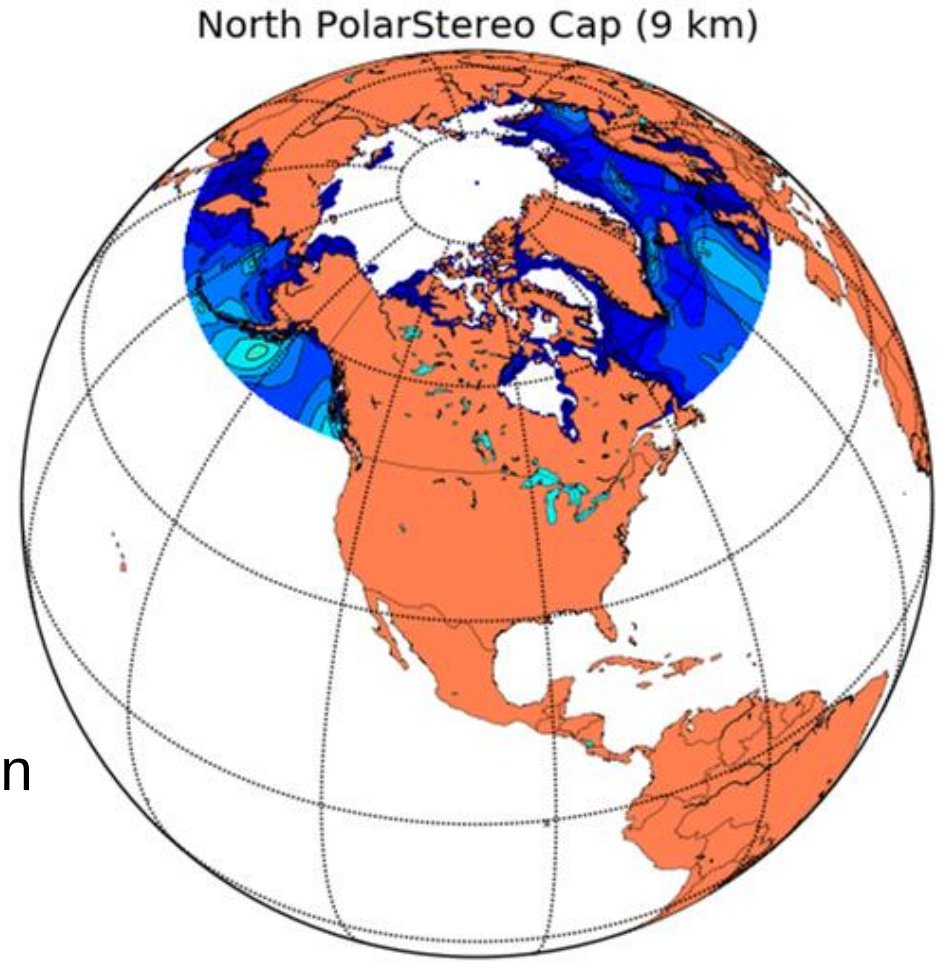
NCEP Operational Global Wave Model

- 9-grid mosaic:
  - Global ½ deg core,
  - ec_10, ec_4m,
  - wc_10m,
  - wc_4m,
  - ep_10m,
  - ak_10m15m,
  - ak_4m8m,
  - PS Arctic 18km.



GFSv16-wave Grid Mosaic

- 3-grid mosaic
  - Global1/6 deg core,
  - Two polar caps
    - Arctic 9km
    - Antarctic 9km
- Simplification of mosaic
  - From 9 to 3 grids
  - Memory management
- Higher resolution
  - Match FV3 grid closer
  - Improve swell generation
- Polar caps
  - Better representation of waves on shrinking ice



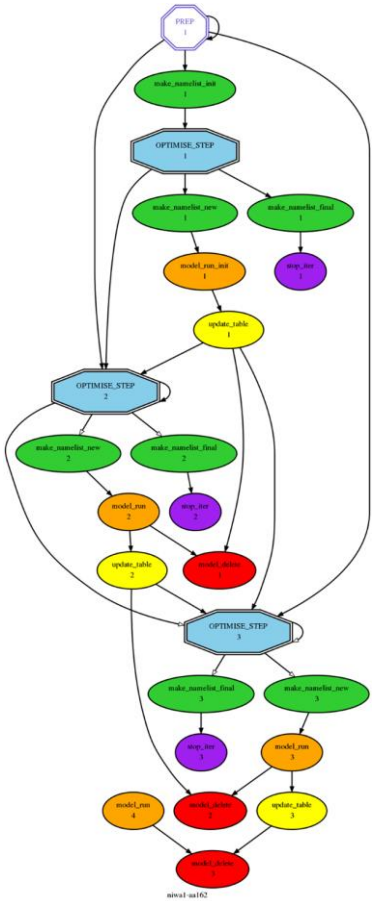
Improving NCEP's Wave Forecasts

- It's the wind, stupid?
- Operational center
  - Not much wave modelers can do, WYSIWYG
  - If that is as good as it gets, can we improve the wave model?
  - Improving winds not an option for me…
- Can I save the day by improving wave model?
  - Spatial and spectral grid resolution?
  - Source terms?
  - Surface currents?
  - Post-processing?

$$\sum S(\mathbf{i}) = S_{in}(\mathbf{i}) + S_{nl}(\mathbf{i}) + S_{ds}(\mathbf{i}) + ...$$

Objective Source-Term Optimization

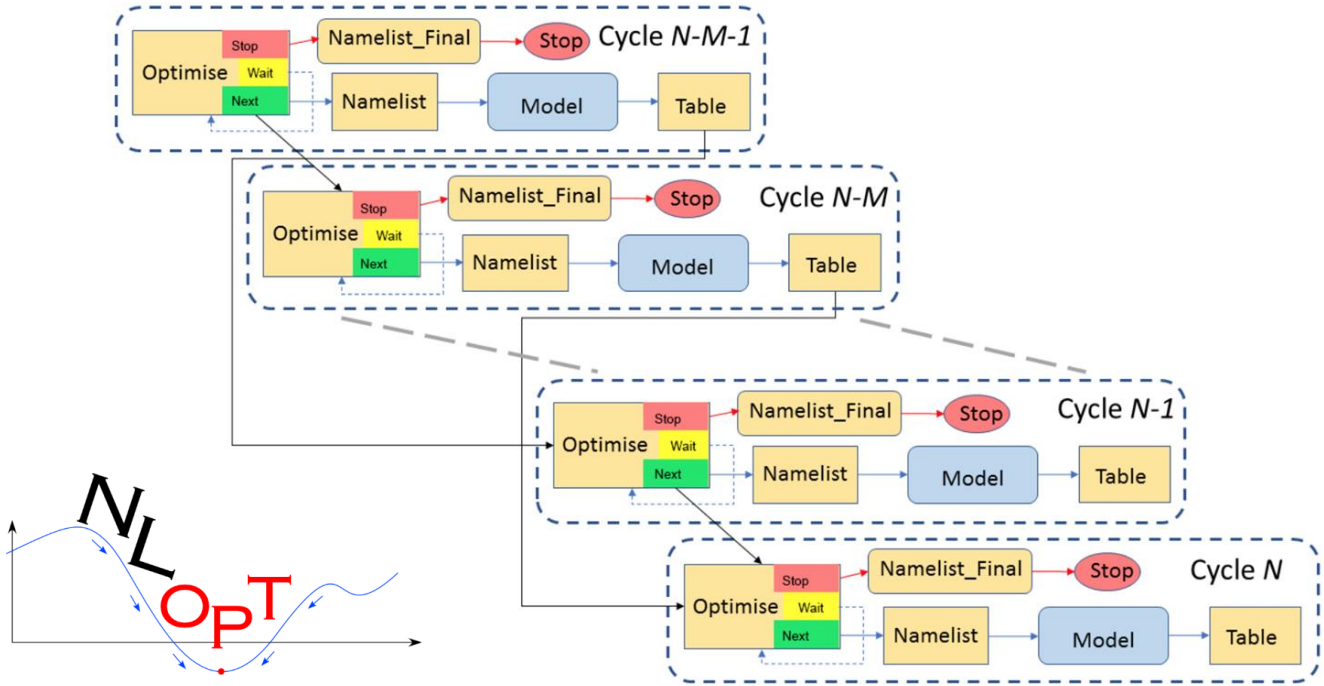
$$\sum S(\mathbf{i}) = S_{in}(\mathbf{i}) + S_{nl}(\mathbf{i}) + S_{ds}(\mathbf{i}) + \ldots\ldots$$



cylc

H. Oliver et al. 2019.

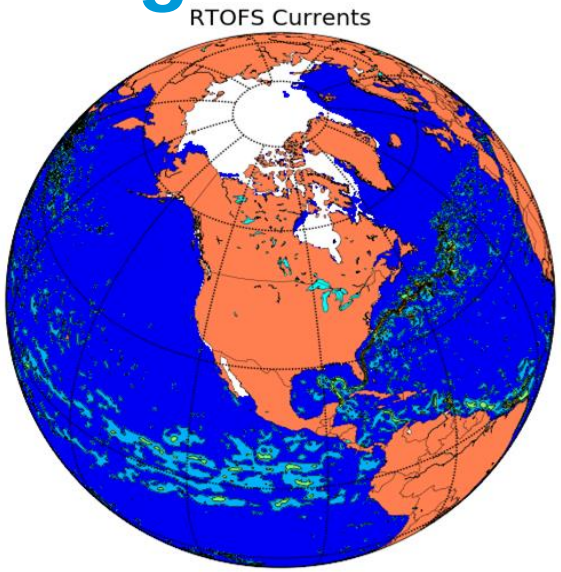
R. M. Gorman and H. J. Oliver: Automated model optimisation using Cyclops v1.0

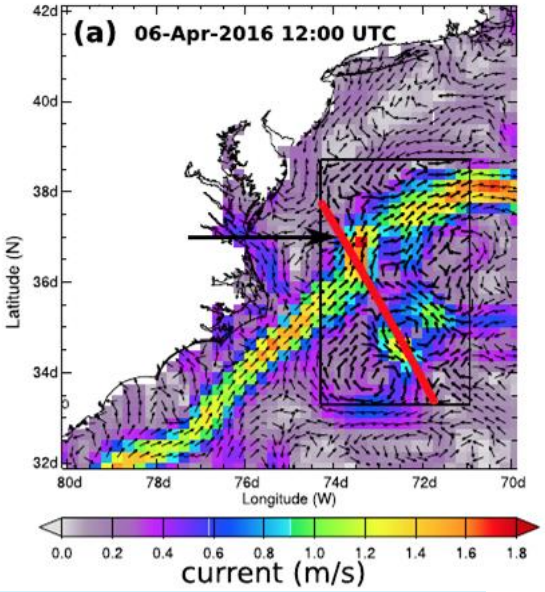


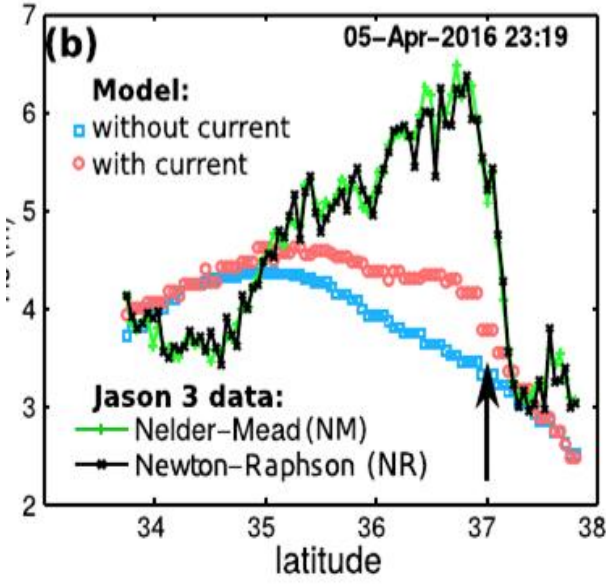
NLOpt nonlinear optimisation toolbox (Johnson, 2014).

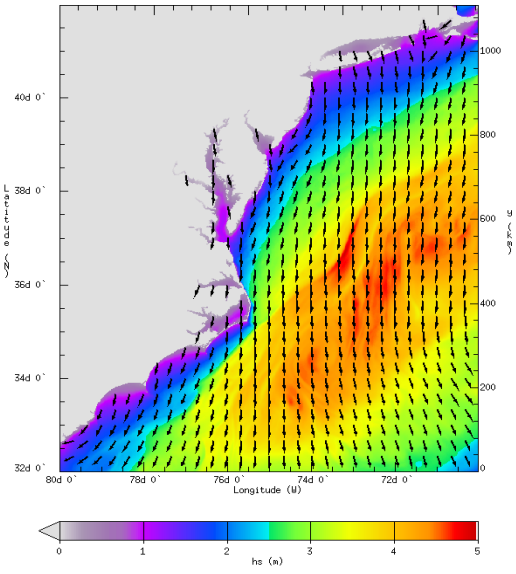
RTOFS surface current forcing

- Waves against current
  - Steeper
- Wind opposing current
  - Stronger forcing
- Fabrice: proper representation of currents, better wave field
- NCEP RTOFS
  - 1/12th deg global









Nonlinear Wave Ensemble Averaging using Neural Networks

R. Campos AOSC/UMD, J.-H. Alves, NCEP/EMC/SRG, V. Krasnopolski, NCEP/EMC, S. Penny, AOSC/UMD
OSTI-NOAA Project Award NA16NWS4680011

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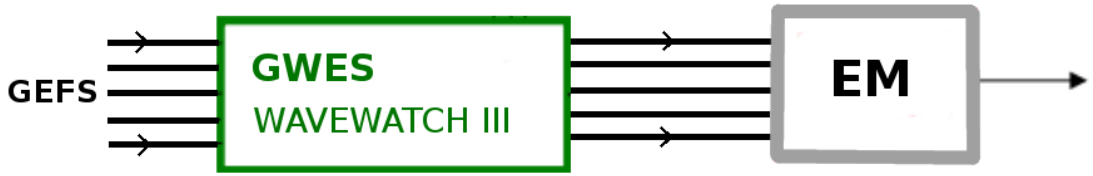

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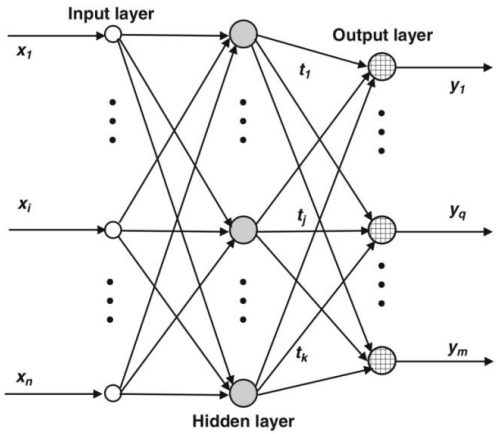
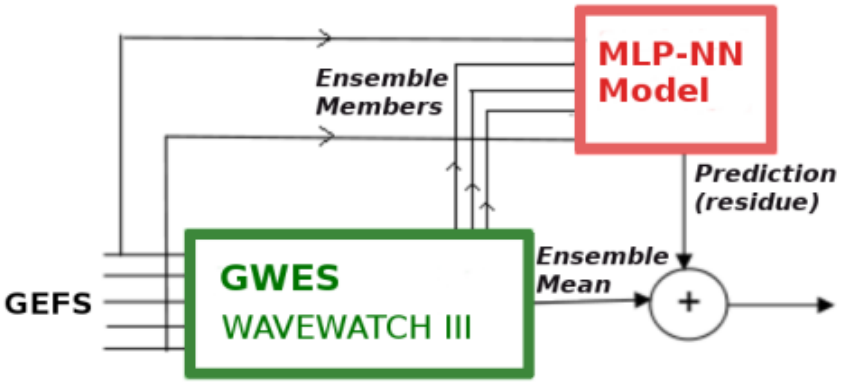
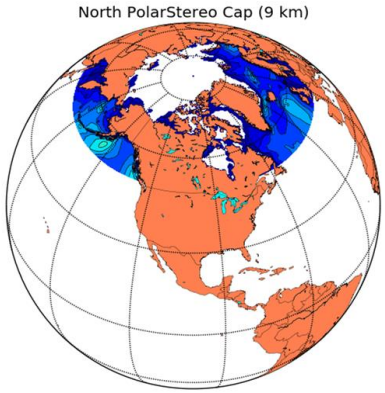


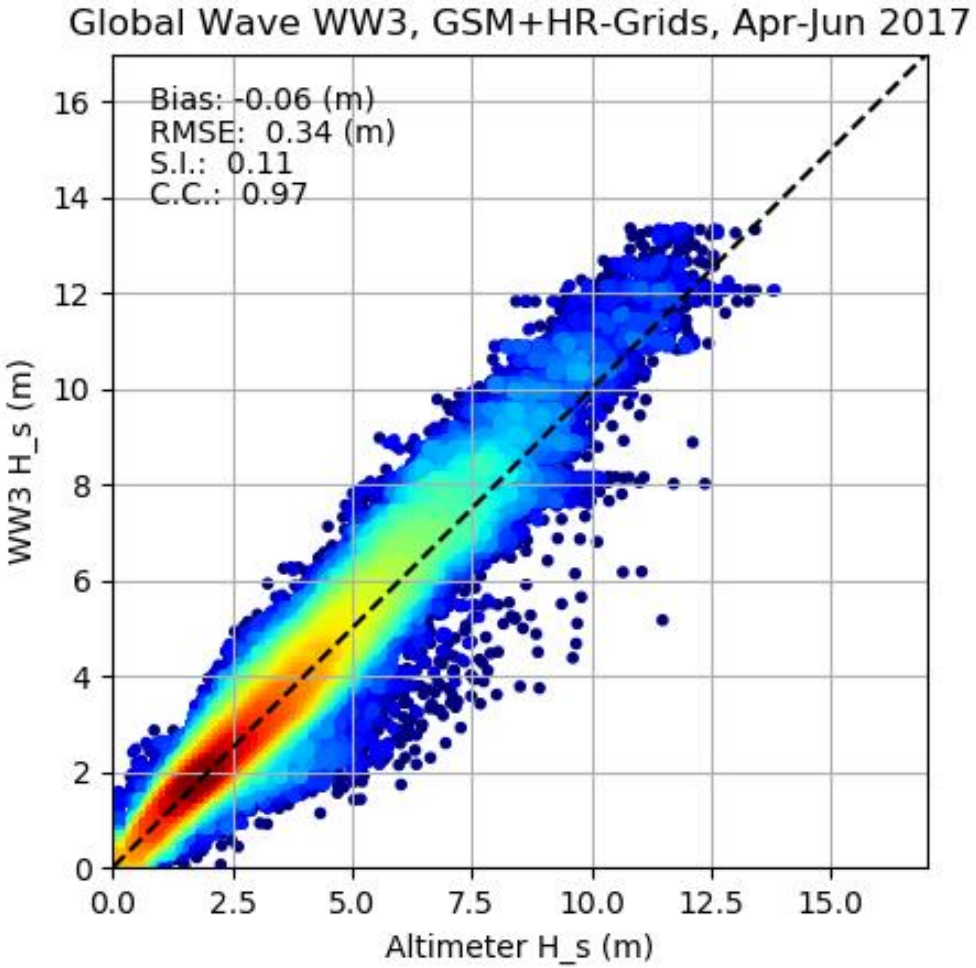


Improving NCEP Wave Forecasts Results

- Impacts assessment of
  - Higher-resolution grids
  - RTOFS currents
  - Source-term optimization
  - Post-processing → operational products
- Bulk validation of Hs for one year
  - Altimeter data (Jason-2, Cryosat, Saral/Altika)
  - Focus on 3-month periods for this talk

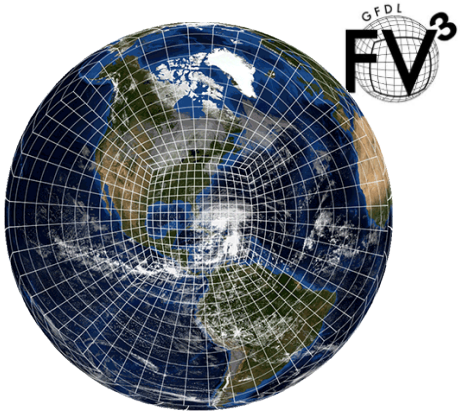
GFSv16-Wave Grid Mosaic

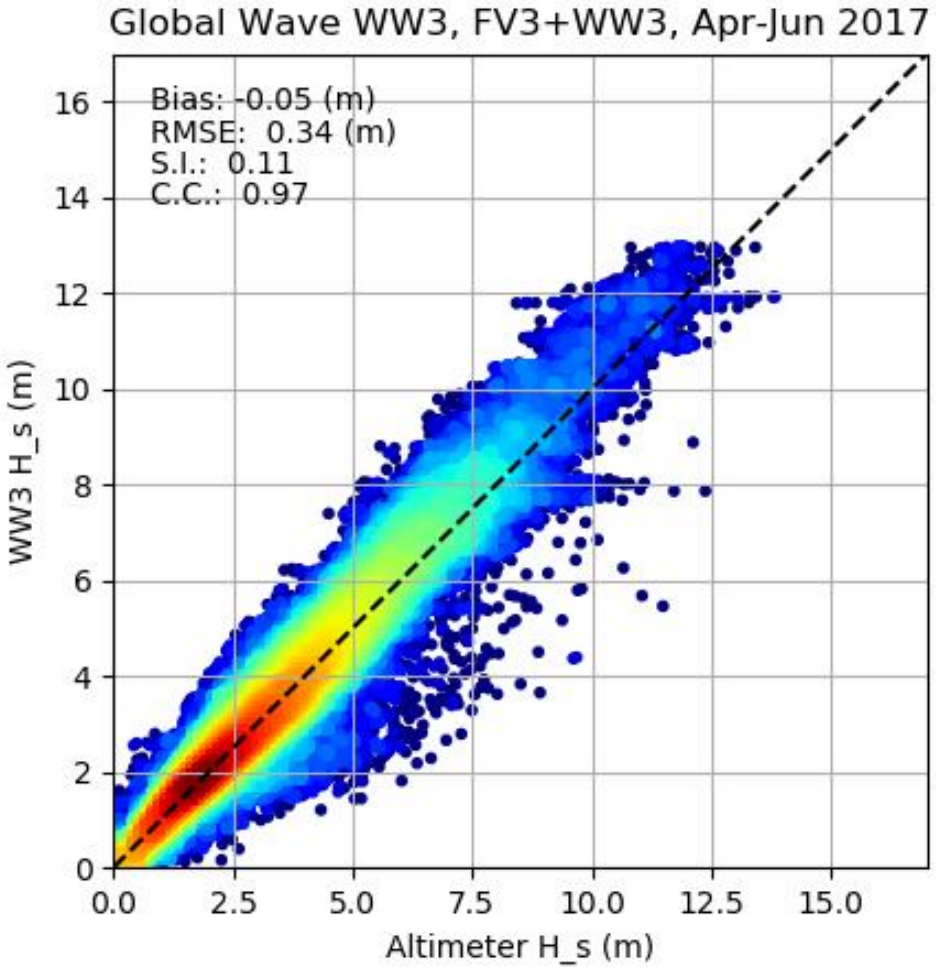




- GSM forcing
- Operational vs new grids
- Change in grid resolution → Larger impact on skill than change in wind
- More to it than the wind.

GSM vs FV3 Forcing





- New grids
- GSM vs FV3 forcing
- Change in grid resolution → Larger impact on skill than change in wind
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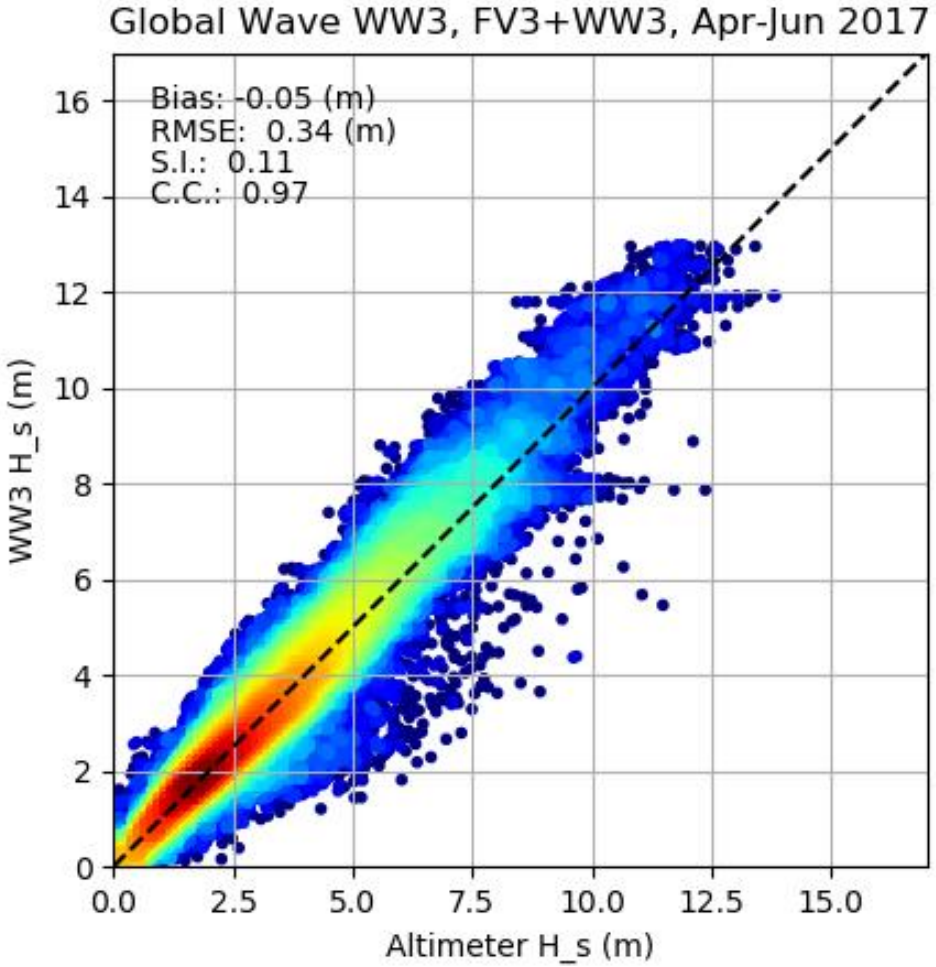
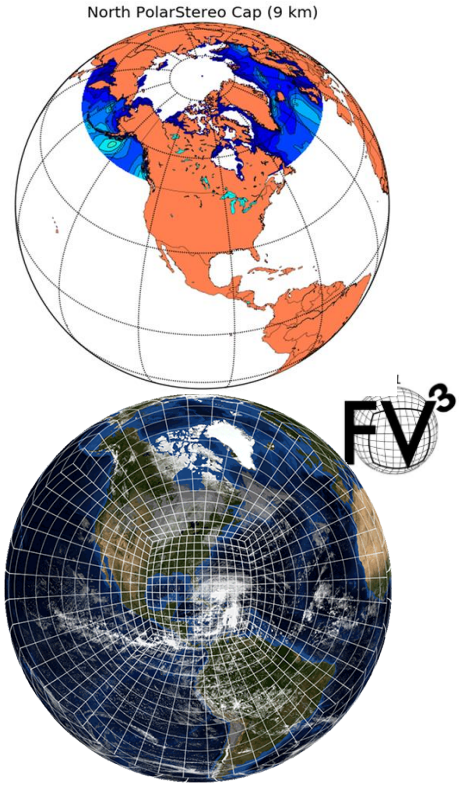
GFSv16-Wave Grid + FV3

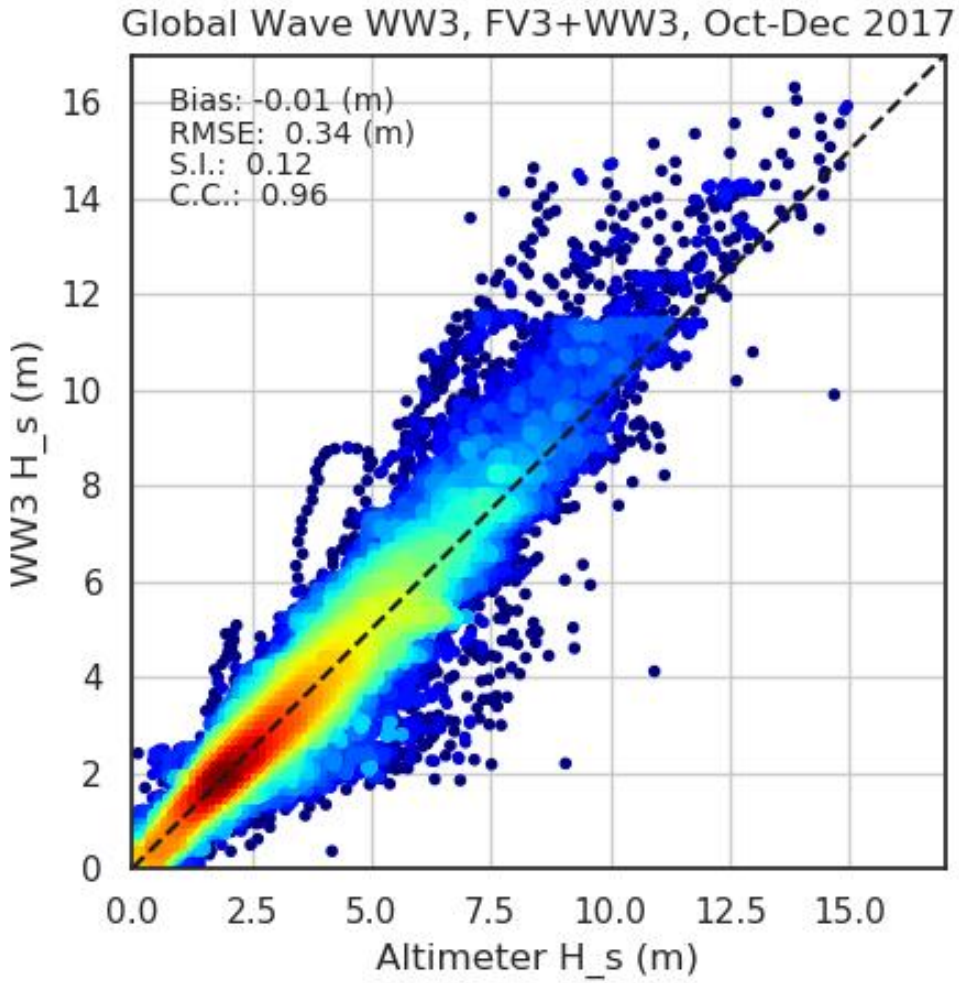


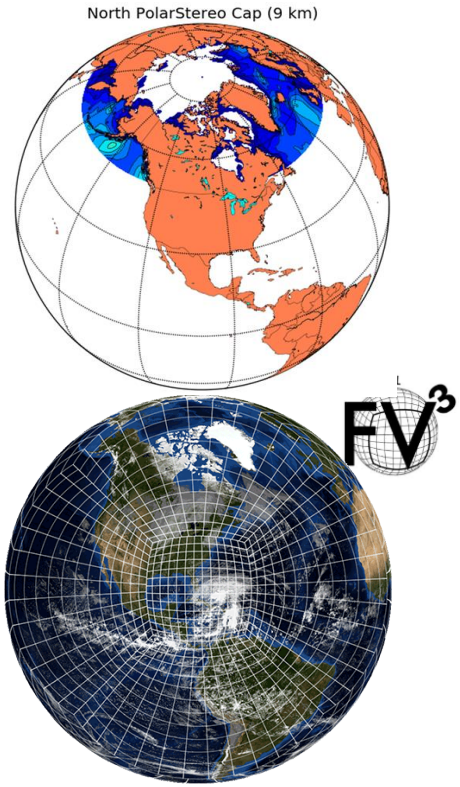


- Operational-GSM vs New grids+FV3

Apr-Jun 2017

GFSv16-Wave Grid + FV3

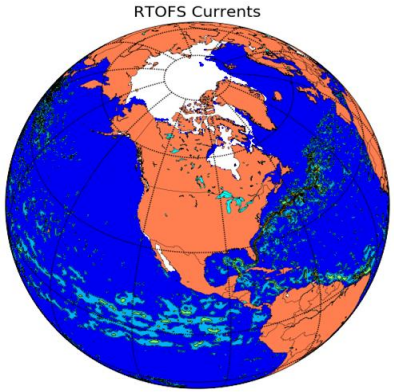


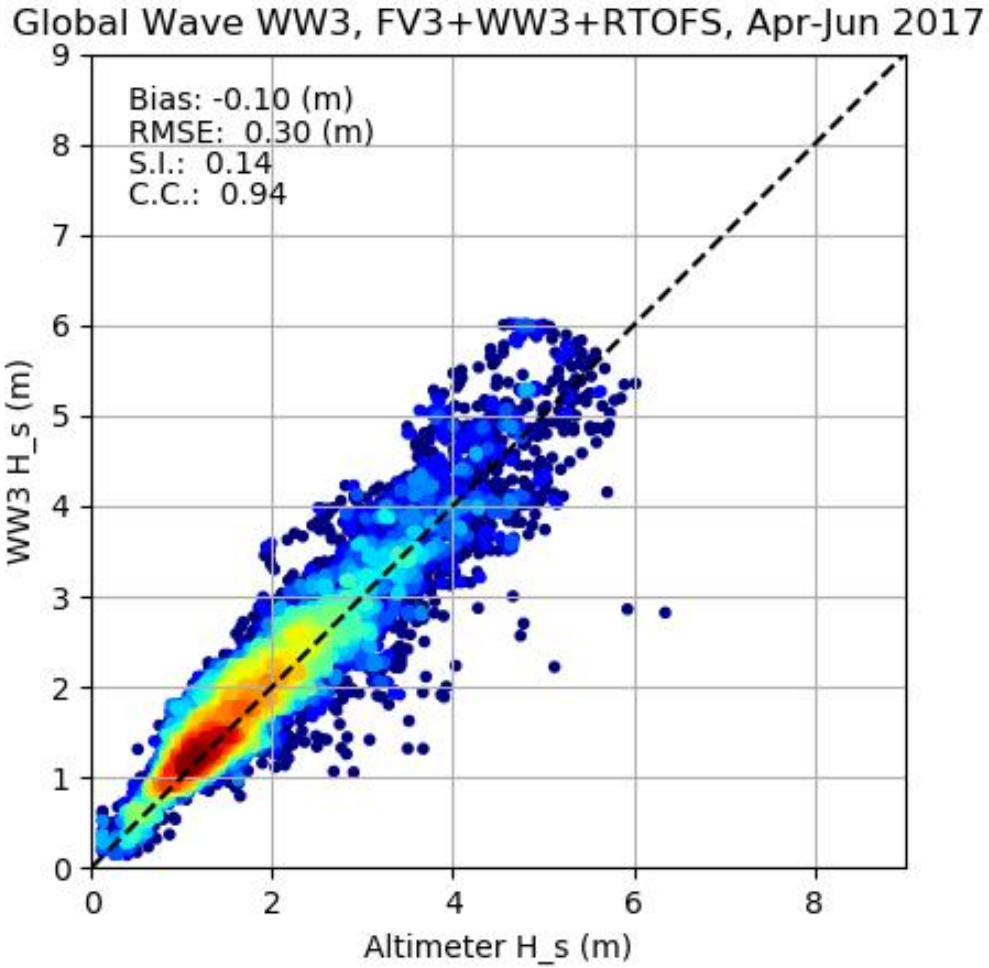


- Operational-GSM vs New grids+FV3

Oct-Dec 2017

RTOFS Currents, Gulf Stream





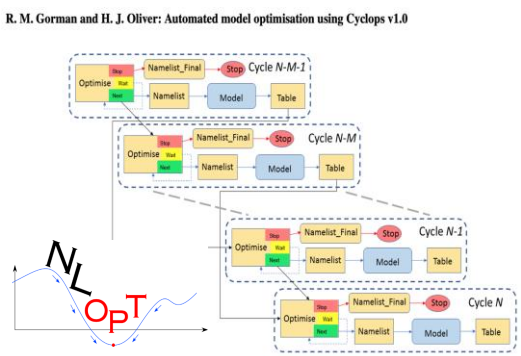
Objective Source-Term Optimization

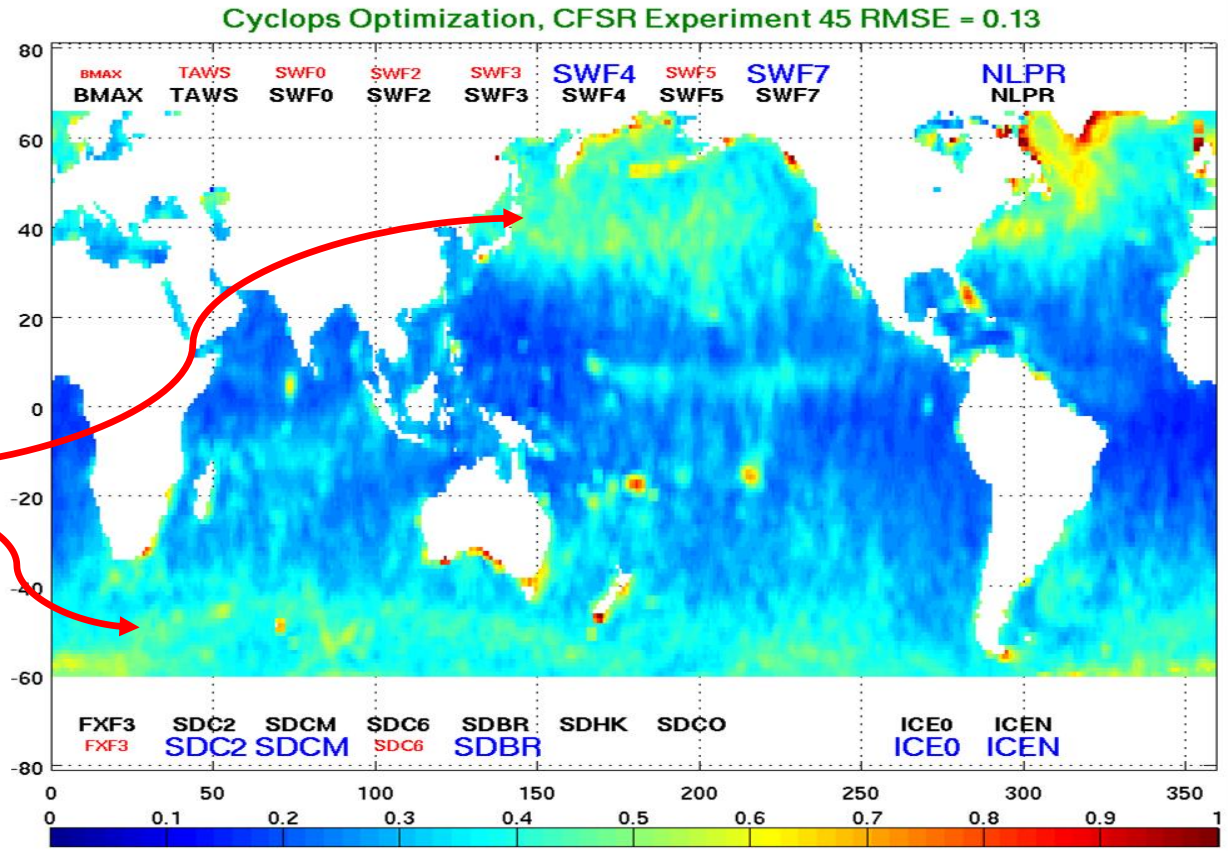
Global 1-year RMSE reduced

- 0.17m → 0.13m

High-latitude RMSE:

- ~1m → < 0.5m





Nonlinear Wave Ensemble Averaging using Neural Networks

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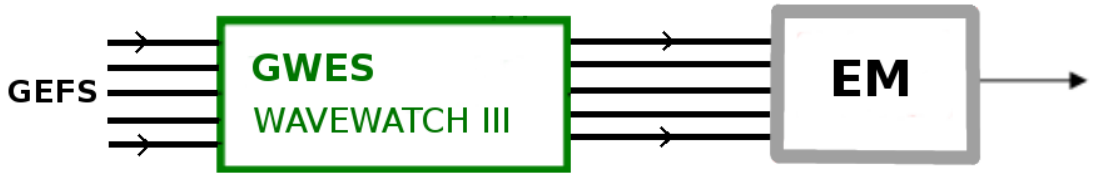

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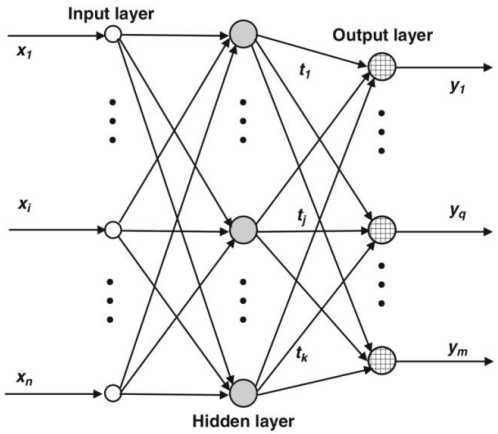

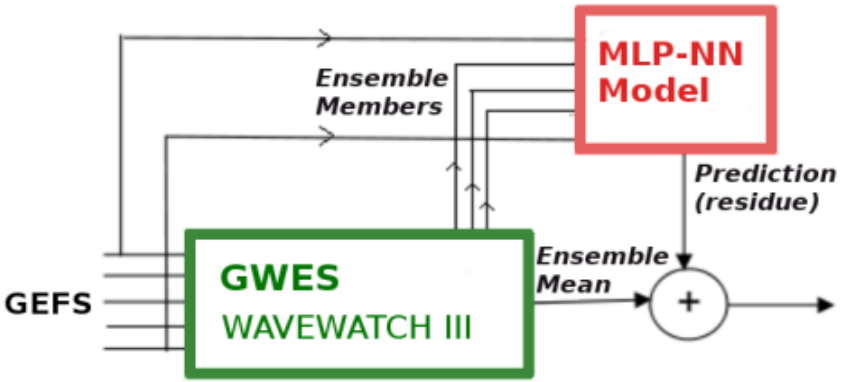

NN-Nonlinear Wave Ensemble Averaging

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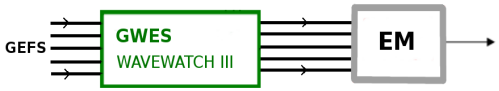

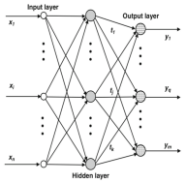

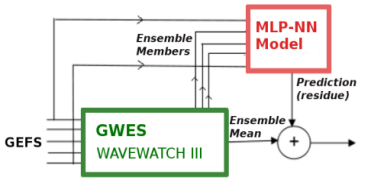

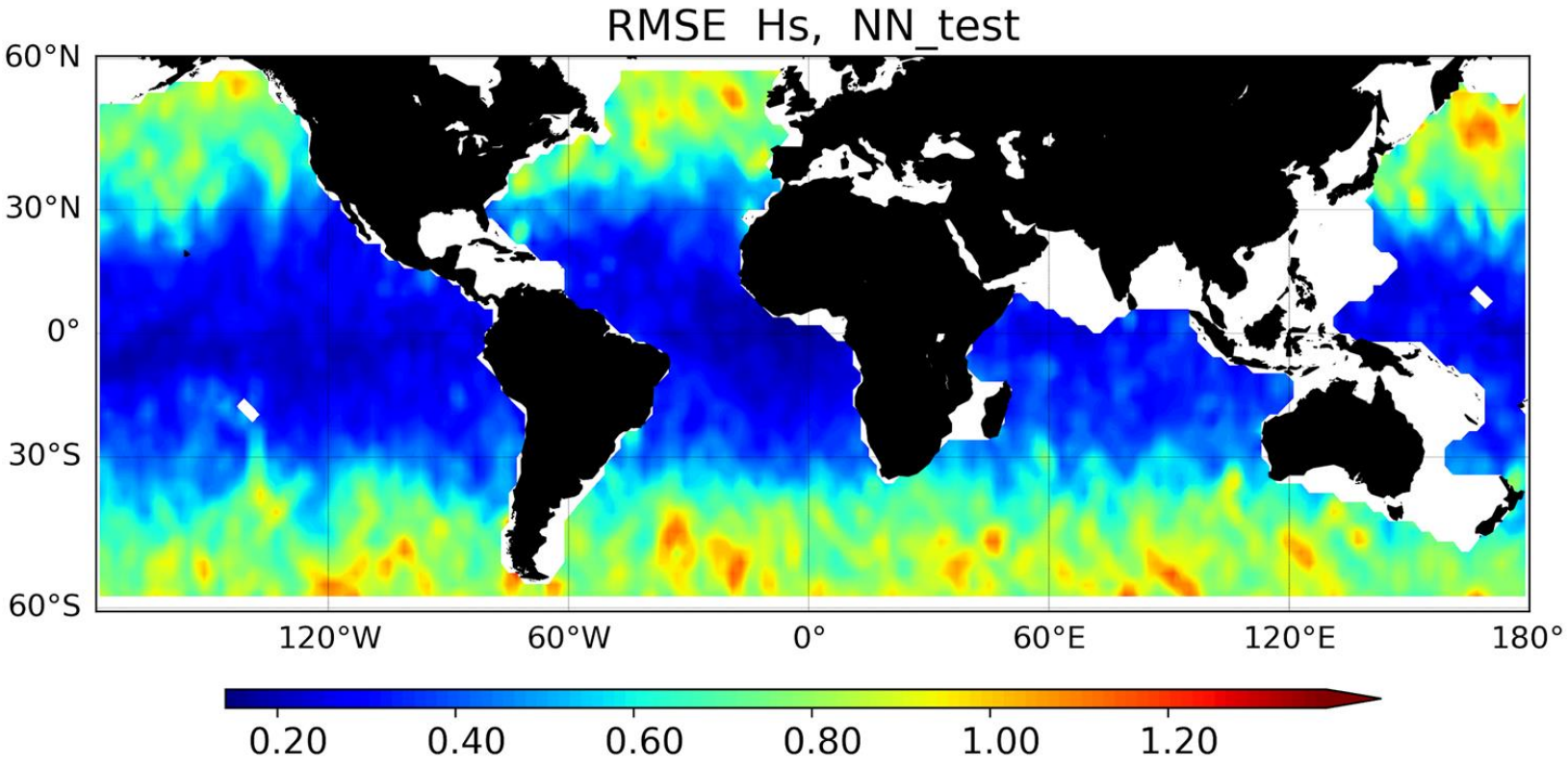

2017 Altimeter Data (SARAL, Cryosat, Jason 2/3)

Wave Modeling Framework for Unification

- NCEP's wave models for GFS/GEFS 2020
  - Effective solutions for model unification/coupling
  - Addressed wave-model specific requirements
- Higher resolution grids
  - Created proper coupling framework with FV3
  - Improved skill
- 9 to 3 grids in mosaic → improved memory
  - Effective use of shared resources in coupled system
- Objective Physics Optimization
  - Improved skill → swell generation in high latitudes
- Intake of RTOFS global currents
  - Improved skill, satisfied new stakeholder requirements