NCEP Global Forecast System

Current and Future Plans for Advancing Global Forecast Capabilities With Special Emphasis on Physics Enhancements

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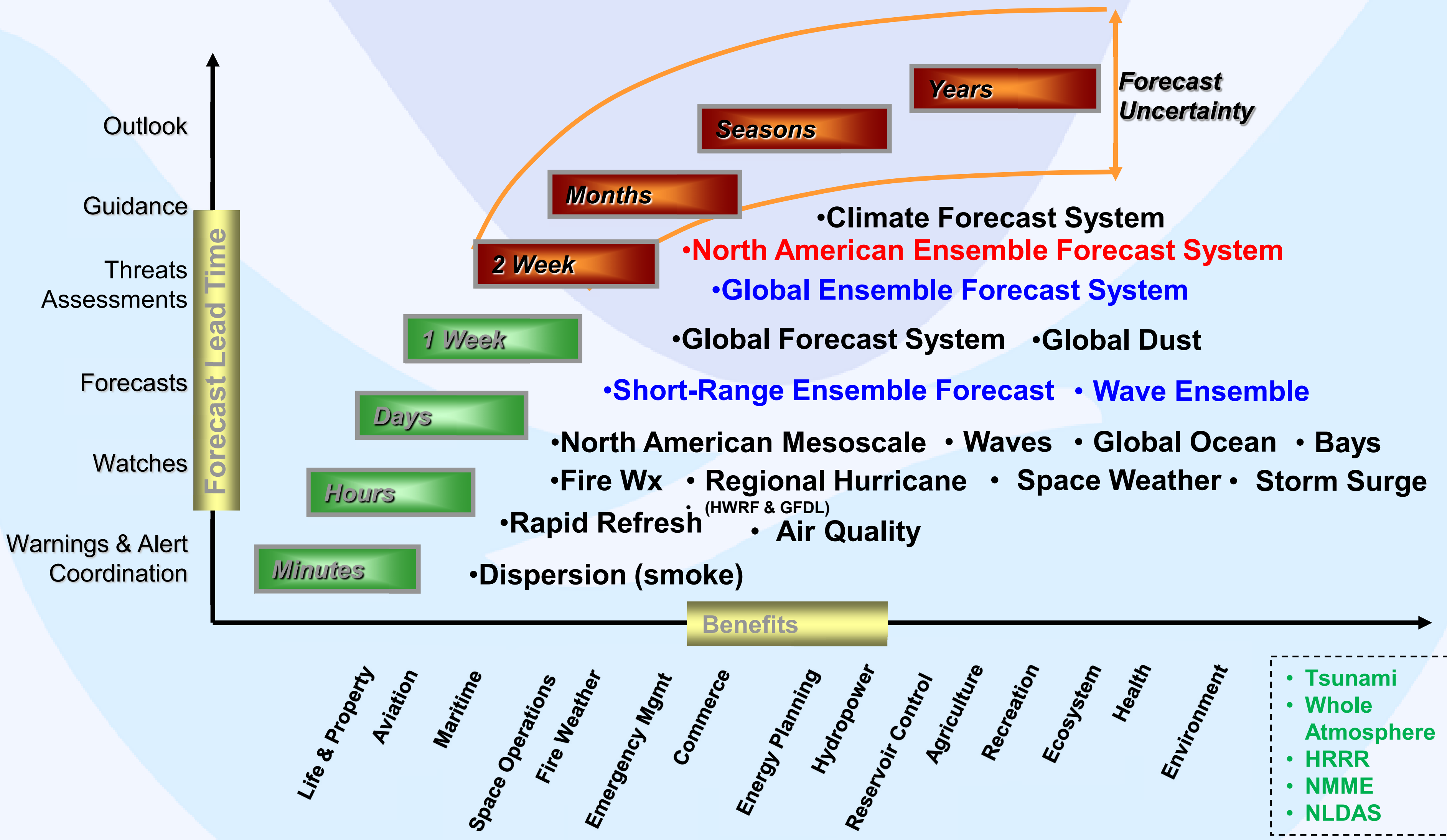
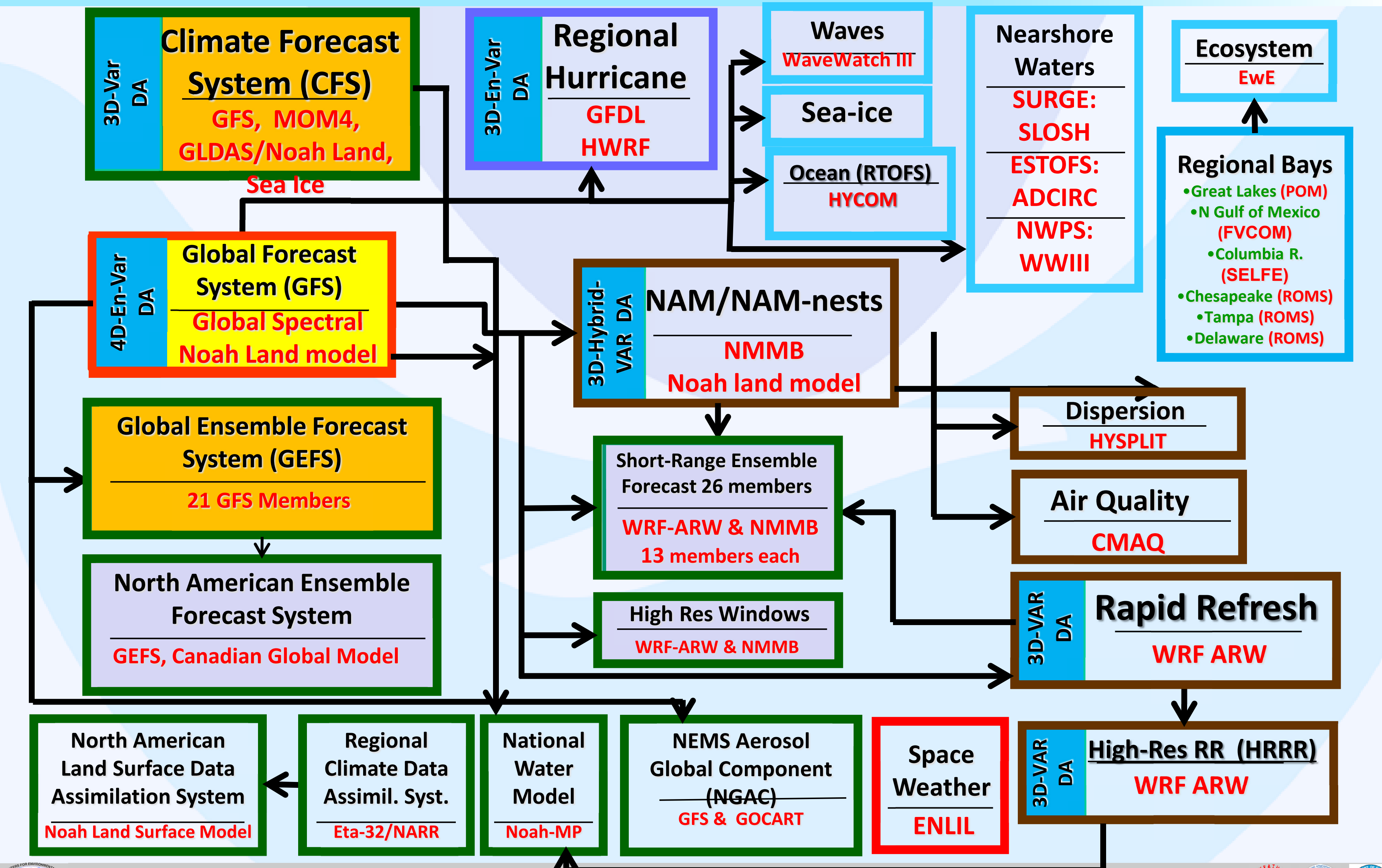
Outline

- Further improvements to the Global Spectral Model
  - Q2FY17& Q2FY18: NEMS/GSM
- Transition to Non-Hydrostatic Global Modeling (NGGPS)
  - Adoption of GFDL FV3 dynamic core for operational needs:
  - FY19: Initial implementation in operations at NCEP
- Unified Global Coupled System for medium range, sub-seasonal and seasonal applications
- Convection allowing global to local scale modeling
  - unifying global and regional modeling capabilities at NCEP
- Physics improvements: **Special Emphasis on representation of drag processes in GFS**
- Evidence based decision making process

Seamless Suite, spanning weather and climate

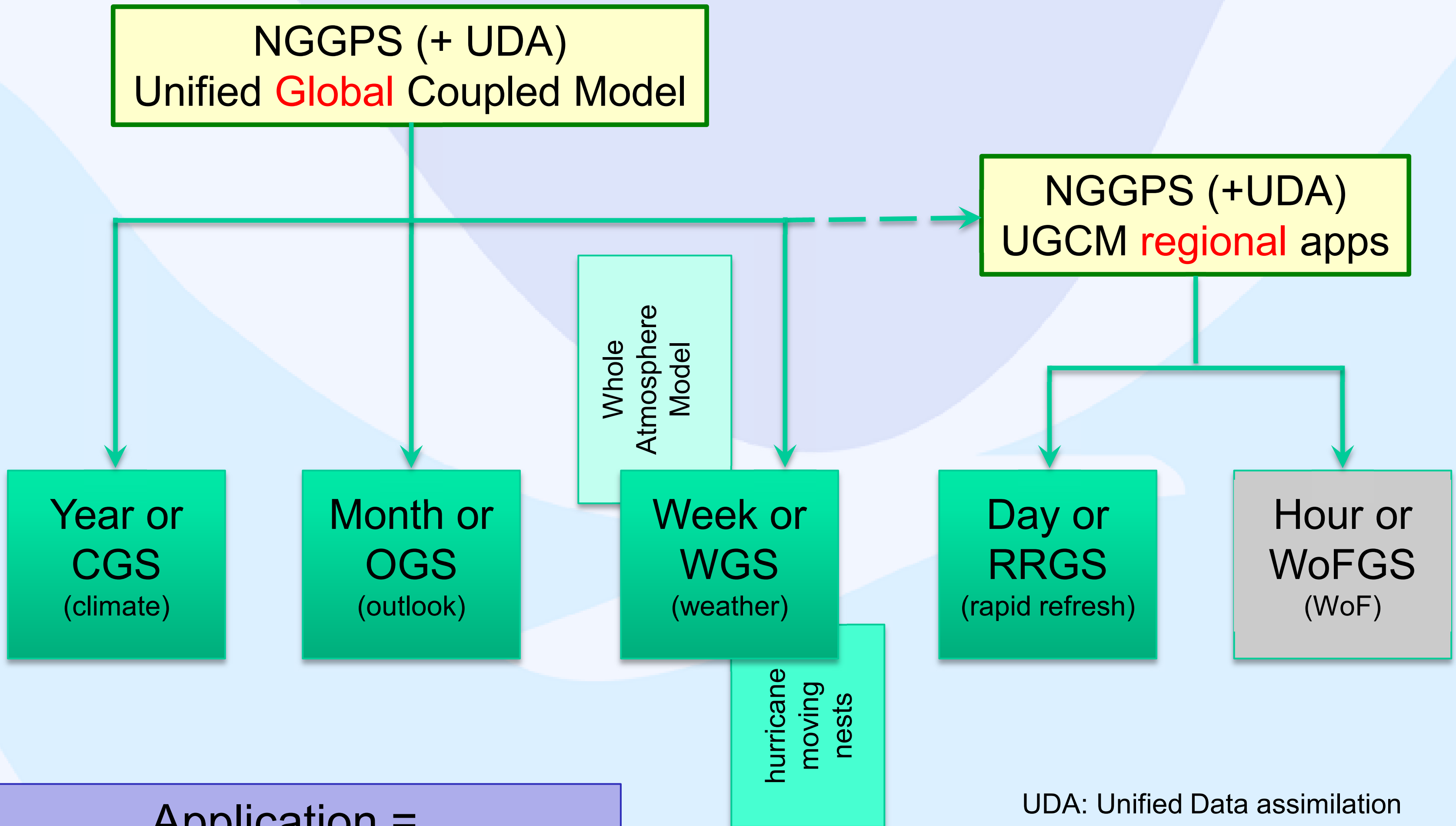


What we have …..



3D-Var DA
Climate Forecast System (CFS)
GFS, MOM4, GLDAS/Noah Land, Sea Ice
3D-En-Var DA
Regional Hurricane
GFDL
HWRF
Waves
WaveWatch III
Sea-ice
Ocean (RTOFS)
HYCOM
Nearshore Waters
SURGE:
SLOSH
ESTOFS:
ADCIRC
NWPS:
WWIII
Ecosystem
EwE
Regional Bays
•Great Lakes (POM)
•N Gulf of Mexico (FVCOM)
•Columbia R. (SELFE)
•Chesapeake (ROMS)
•Tampa (ROMS)
•Delaware (ROMS)
4D-En-Var DA
Global Forecast System (GFS)
Global Spectral
Noah Land model
3D-Hybrid-VAR DA
NAM/NAM-nests
NMMB
Noah land model
Global Ensemble Forecast System (GEFS)
21 GFS Members
Short-Range Ensemble Forecast 26 members
WRF-ARW & NMMB
13 members each
Dispersion
HYSPLIT
Air Quality
CMAQ
North American Ensemble Forecast System
GEFS, Canadian Global Model
High Res Windows
WRF-ARW & NMMB
3D-VAR DA
Rapid Refresh
WRF ARW
North American Land Surface Data Assimilation System
Noah Land Surface Model
Regional Climate Data Assimil. Syst.
Eta-32/NARR
National Water Model
Noah-MP
NEMS Aerosol Global Component (NGAC)
GFS & GOCART
Space Weather
ENLIL
3D-VAR DA
High-Res RR (HRRR)
WRF ARW

What we want ….



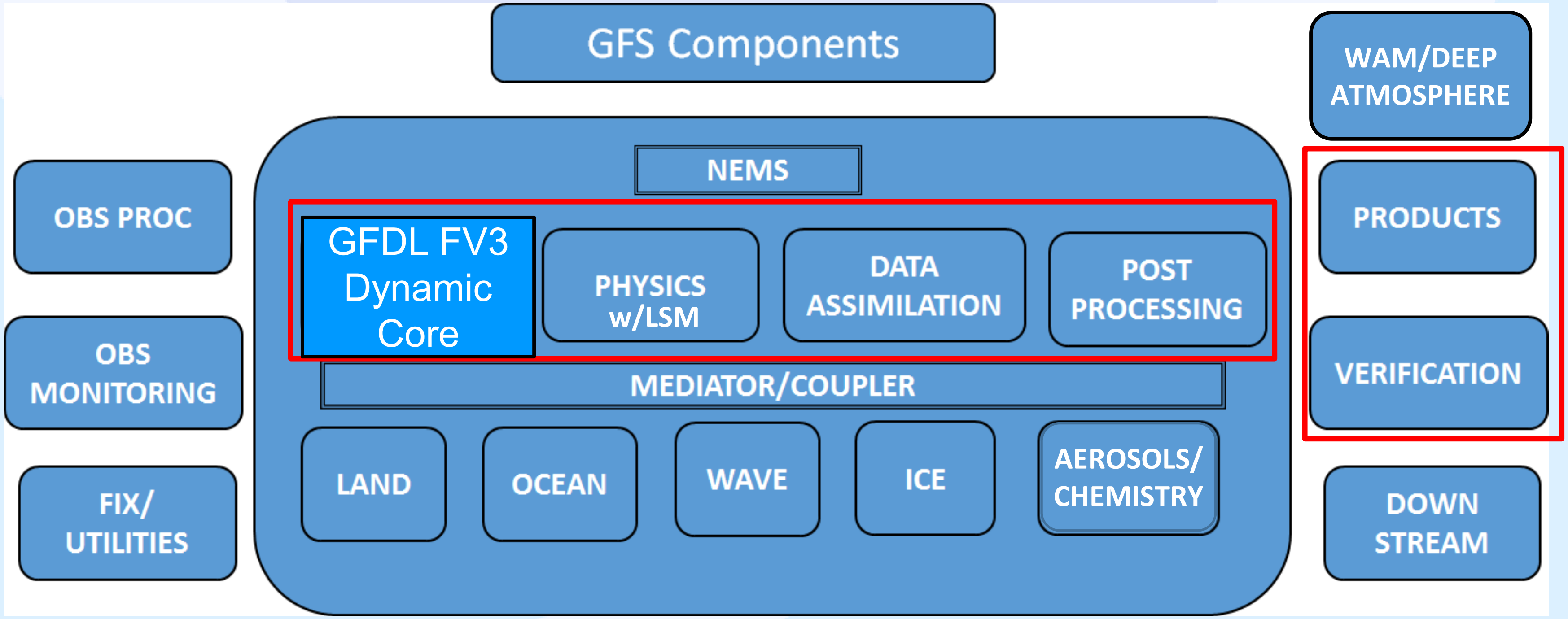
Application =
Coupled Ensemble
+ Reanalysis + Reforecast

UDA: Unified Data assimilation
CGS: Climate Guidance System
OGS: Outlook Guidance System
WGS: Weather Guidance System
RRGS: Rapid Refresh Guidance System
WoFGS; WoF Guidance System

NGGPS: The future of advanced global weather prediction at NCEP

- NWS Initiative on developing Next Generation Global Prediction System
- **GOAL: Global Weather Prediction: Becoming Second to None**
- **GFDL FV3:** An advanced non-hydrostatic dynamic core selected by NGGPS, implement it to meet operational needs for the foreseeable future
- Evidence based decision making process to ensure scientific integrity and excellence

Major Components of GFS



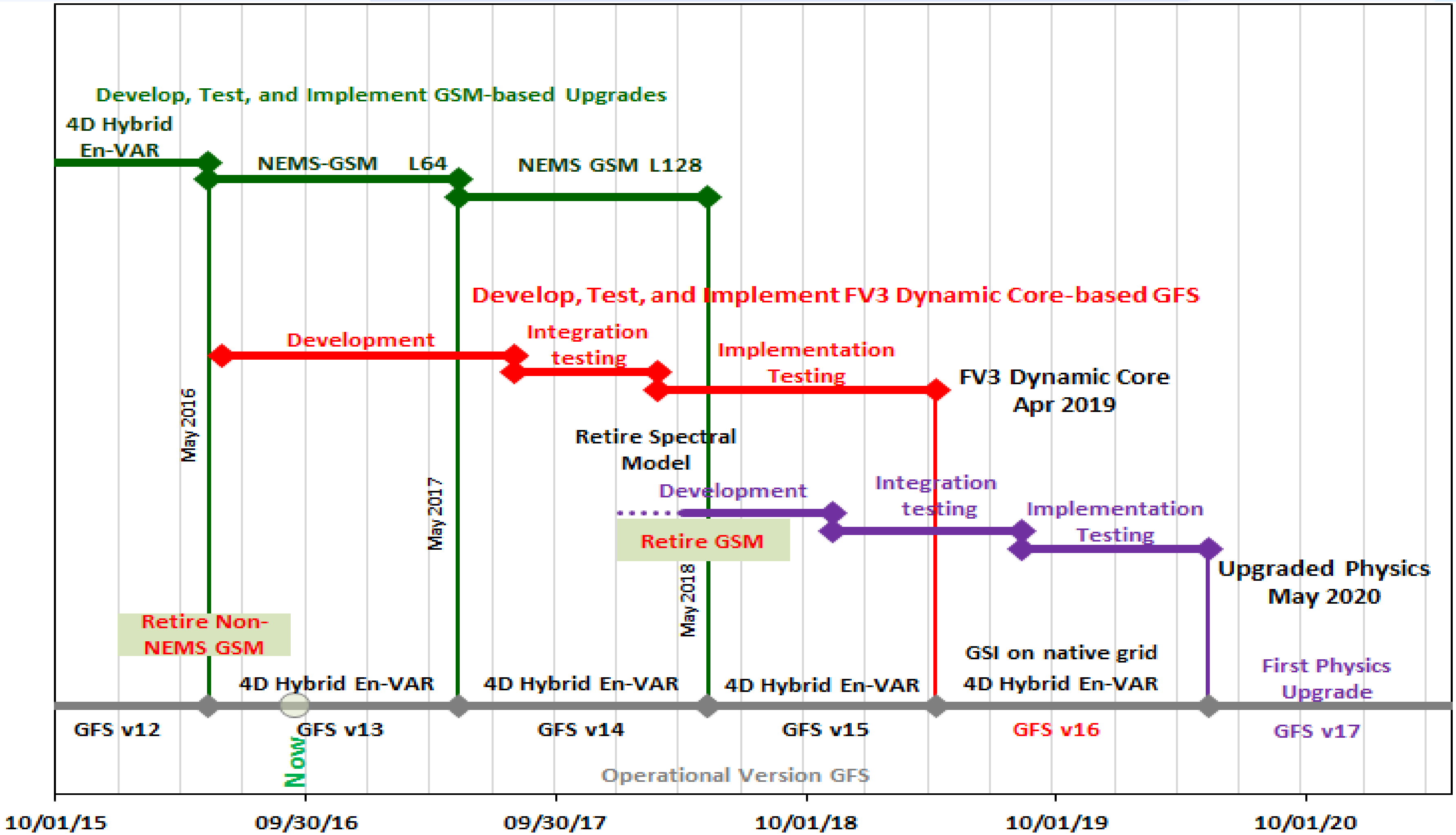
- NEMS infrastructure is the most critical component for R&D, community support, R2O and T2O.

Dependencies

Critical dependencies:

- Decision on new Dycore ***--- Done (GFDL FV3)***
- Readiness, adaptability, expandability and efficiency of NEMS and NUOPC ***--- In Progress***
- Involvement and support from external model developers (and NOAA labs) ***--- In Progress***
- Computational efficiency and adaptability ***--- In Progress***
- Infrastructure and support for R2O (GMTB) ***--- Established***
- Computational and human resources ***--- In Progress***
- Data management and enhanced evaluation tools
- Scientific results and endorsements from stakeholders

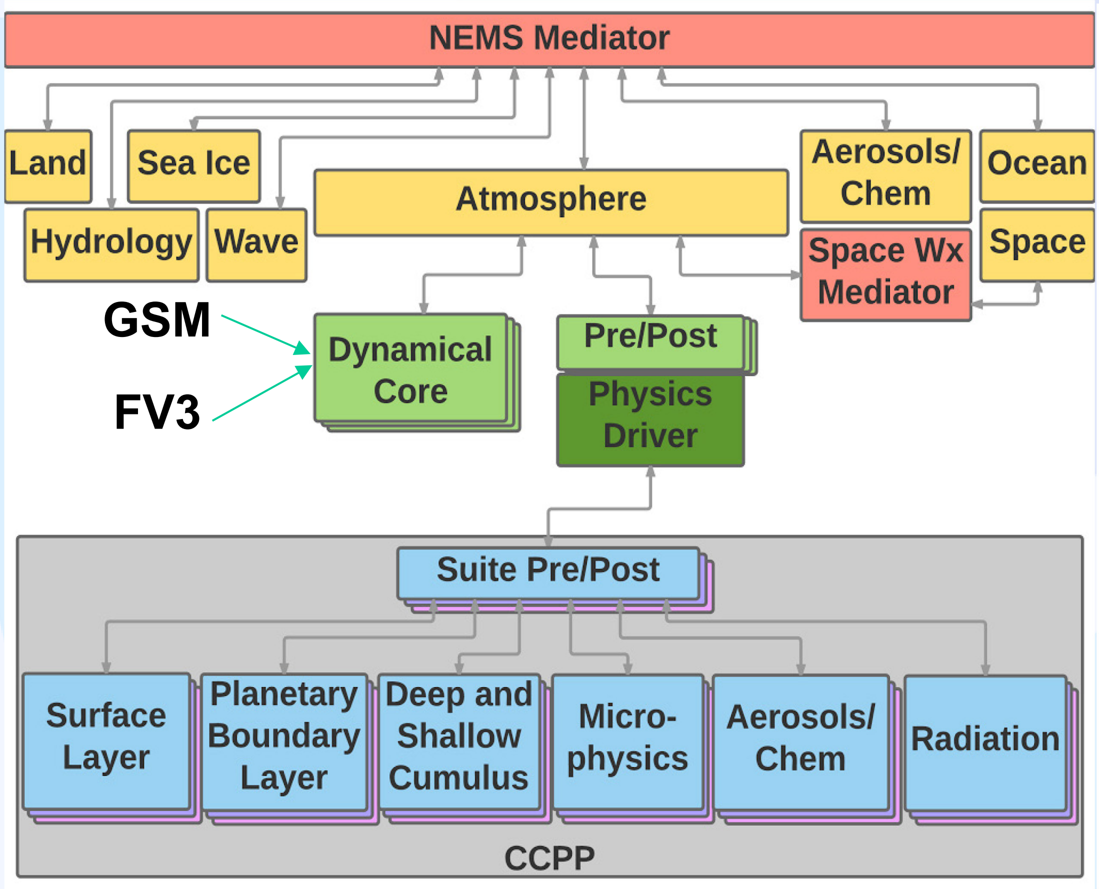
GFS Upgrade Strategy FY17-FY20

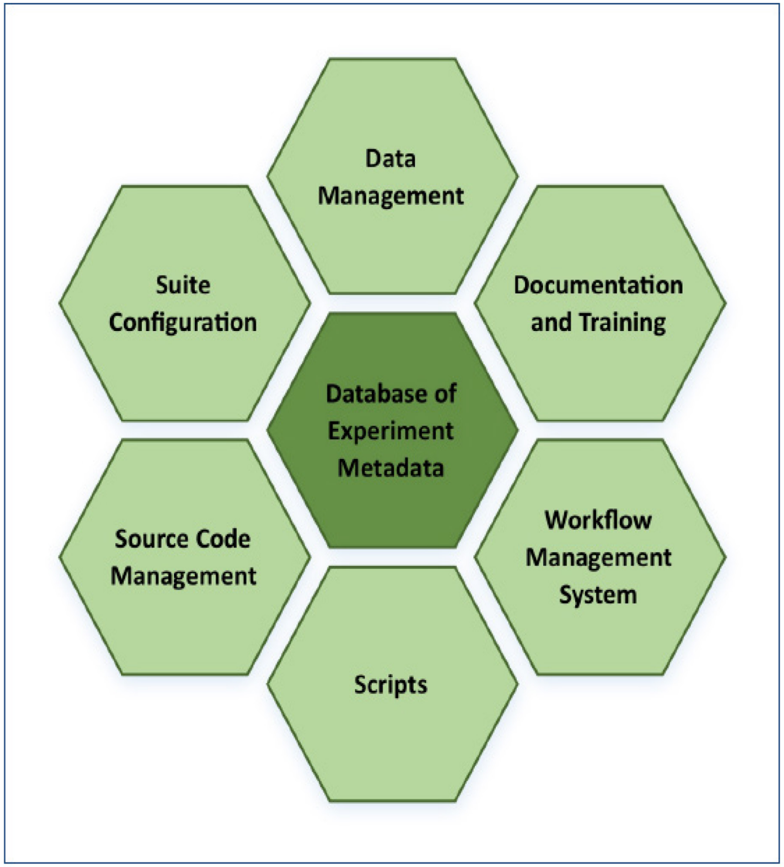


Integration of new NGGPS Dycore in NEMS: Initial Development Phase

- **Form a dedicated team of scientists at EMC to integrate the new GFDL FV3 dycore into NEMS in close collaboration with model developers (and NOAA labs)**
  - Create a specific project plan for adoption into NEMS
  - Train EMC staff on all aspects of the new system
- **Benchmark and prepare for initial implementation**
  - Configure the system to match the operational GFS configuration
  - Create and execute a test plan to reproduce operational GFS results
  - Include FY18 upgrade components and conduct parallel evaluation
  - Create FY19 implementation plan with comprehensive evaluation strategy
- **EMC global branch will maintain the operational code**
  - Master version on local repository
  - Agile development for NCEP needs

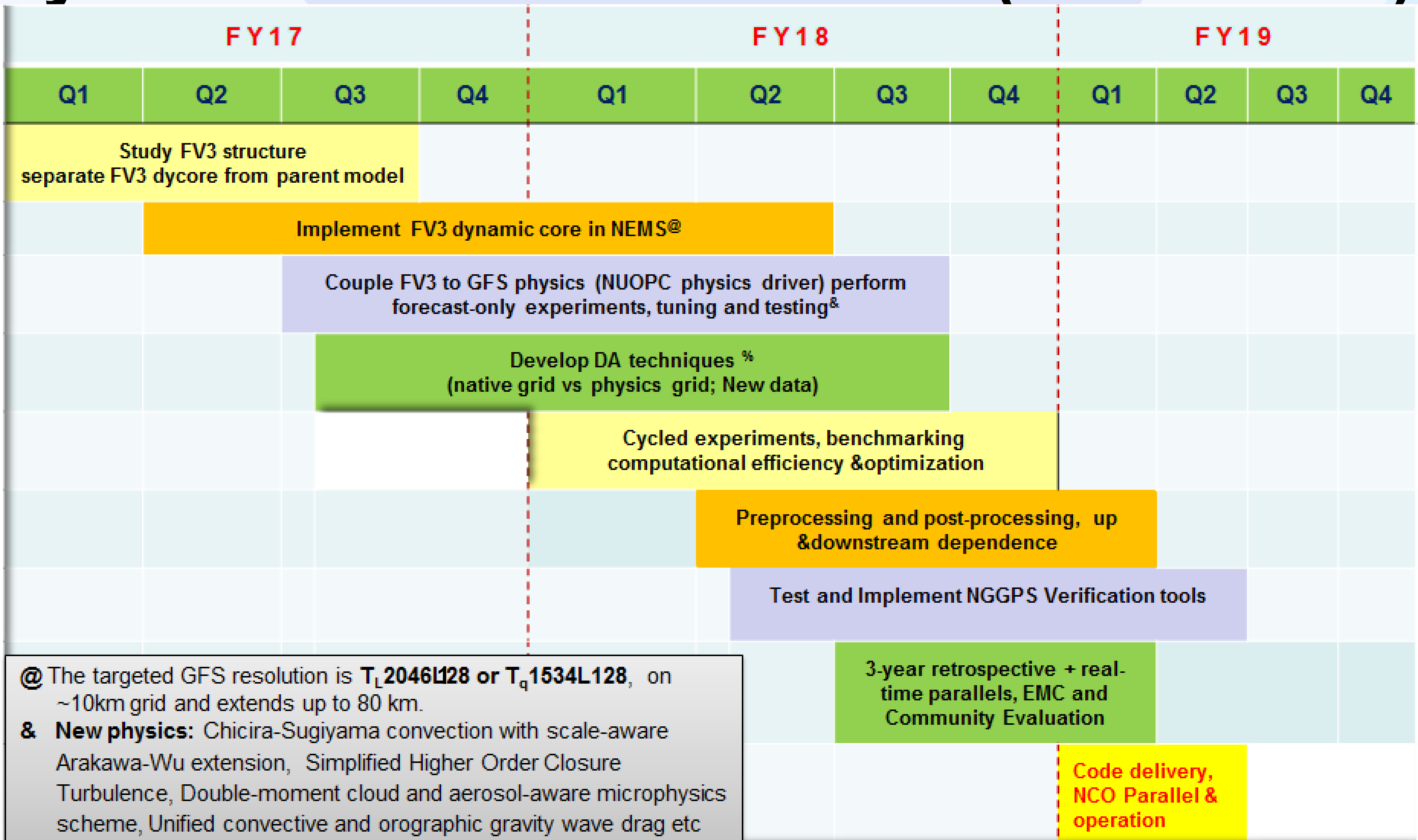
Schematic of NEMS GFS and NITE





NWP Information Technology Environment (similar to IFS Prep) to facilitate ease of R2O using NEMS infrastructure and standardized workflow

Stage 1: Implementation Plan of FV3 Dynamic Core in NEMS GFS (FY17-FY19)



@ The targeted GFS resolution is **T_L2046L128 or T_q1534L128**, on ~10km grid and extends up to 80 km.

& **New physics:** Chicira-Sugiyama convection with scale-aware Arakawa-Wu extension, Simplified Higher Order Closure Turbulence, Double-moment cloud and aerosol-aware microphysics scheme, Unified convective and orographic gravity wave drag etc

% T_L678L128 4D-EnVAR data assimilation

Physics: Two-Stream Strategy

NUOPC Physics Driver in NEMS using Community Common Physics Package (EMC, GFDL, ESRL, GMTB)

Physical Processes	Operational Physics (Evolved)	Advanced Physics* (CCPP)
Radiation	RRTMG	RRTMG (scale and aerosol aware, w/sub-grid scale clouds)
Penetrative convection and Shallow convection	SAS RAS	Scale-aware Chikira-Sugiyama & Arakawa-Wu; Grell-Freitas
Turbulent transport (PBL)	Hybrid EDMF	CS+SHOC (unified convection & turbulence)
Cloud microphysics	Zhao-Carr WSM-6	Double Moment scheme (Morrison, Thompson Barahona)
Gravity wave drag	Orographic GWD Stationary convective GWD	Unified representation of GWD
Ozone physics	NRL simplified scheme	Modified NRL scheme
Land surface model (LSM)	Noah	Noah and LIS
SST	Reynolds/RTG SST	NSST

***Includes aerosol chemistry (NGAC) module**

4D Hybrid En-Var Data Assimilation Interface for FV3 GFS

- Develop community GSI based cycled 4D-EnVAR hybrid DA system for FV3 (EMC, ESRL, GFDL, JCSDA)
  - Account for staggered grid of FV3 (winds and scalar on different position), and the non-orthogonal vertical coordinate (different for dynamics and physics due to mass adjustment) and non-hydrostatic dynamics
  - Physics grid vs. native grid considerations
  - Ensemble configurations (EnKF) to include stochastic physics

Post-Processing, Products & Verification

Further enhancements to NCEP UPP

- In-line post-processing (including diagnostic products) within NEMS
- Faster MPIIO for improved efficiency
- Products tailored to meet forecaster needs

Unified Verification package

- Transition EMC global verification package (vsdb) to MET and METViewer (supported by NCAR, GMTB and NOAA/ESRL/GSD).
- Develop procedures for inclusion of new verification metrics including process oriented metrics, metrics for ocean, ice, land, aerosols and system coupling
- Develop high performance database for large amounts of model and observational data that is suitable for NCEP's operational environment
- User support, training, documentation

Connect the pieces together for operational implementation (Q2FY19)

- End-to-end operational configuration for NGGPS implementation (EMC, GFDL, ESRL, NCO) for implementation
  - Adopt Unified Post-Processing, product generation and verification software
  - Conduct thorough analysis of scientific and computational performance with full 3-year retrospective and real-time experiments (MEG, stakeholder evaluation and feedback)
  - Test and evaluate the impact on upstream and downstream production suite dependencies

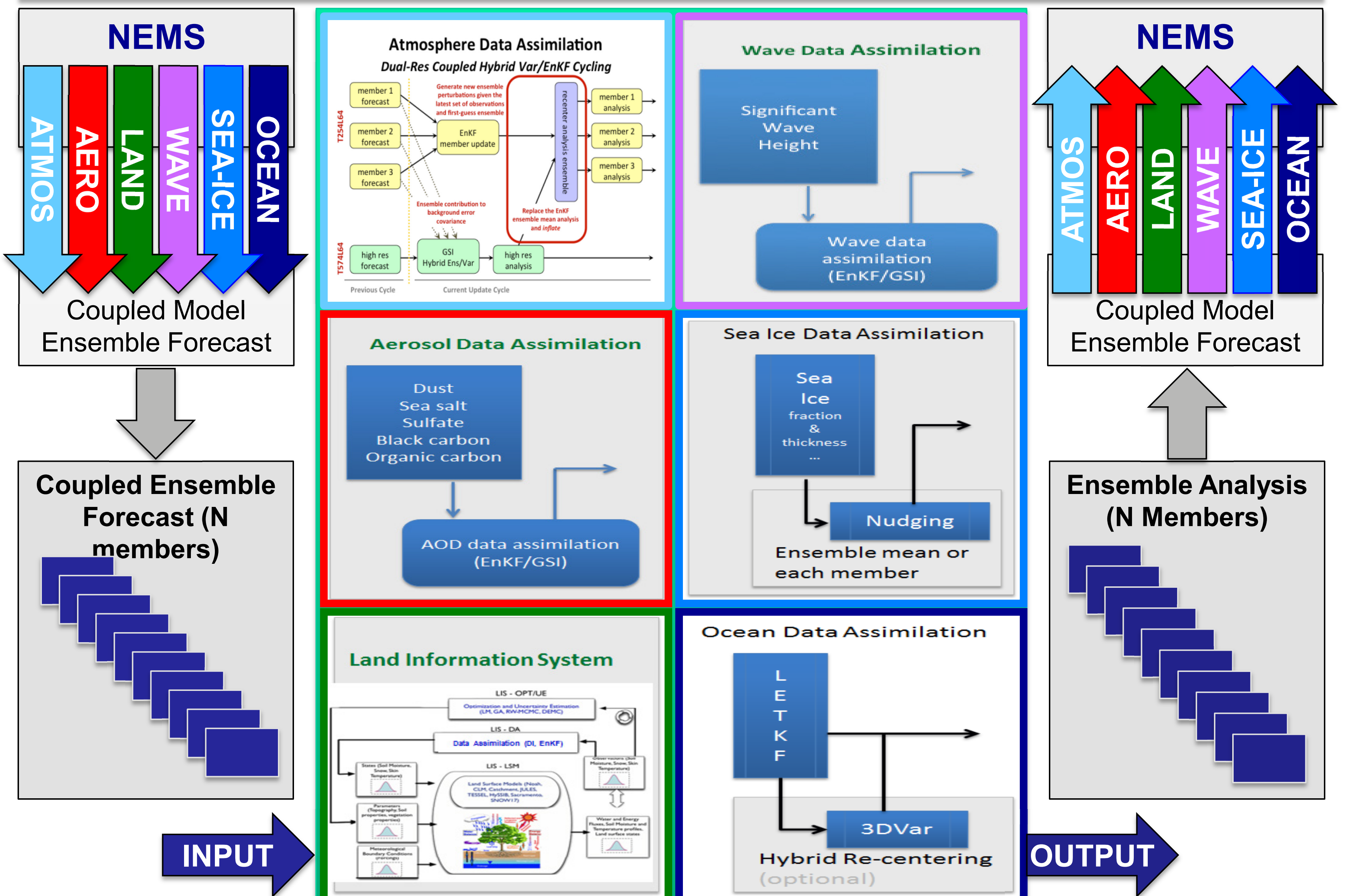
Stage 2: FV3/NEMS based Global Ensemble Forecast System (FY17-FY20)

- Transition GEFS into FV3 based GFS (EMC, ESRL)
  - Parallel efforts to develop ensemble generation techniques (STTP, Stochastic Physics etc.)
  - Extend GEFS to weeks 3&4 (possible ocean/sea-ice/wave coupled system)
  - Reanalysis and Reforecast Needs
  - Shared infrastructure, post-processing and product generation techniques

Stage 3: FV3/NEMS based Climate Forecast System (FY17-FY22)

- Transition CFS into FV3 based GFS coupled to many earth system components with strongly coupled DA (EMC, many others) using NUOPC Mediator
  - Parallel efforts to develop Unified Global Coupled System (See presentations from Saha and DeLuca and Iredell)
  - Explore scientific value of coupled system for weather, and sub-seasonal forecast guidance
- Implement Aerosol Forecast Capability (NGAC) into GFS
- Implement Whole Atmosphere Model (WAM)

NCEP Coupled Hybrid Data Assimilation and Forecast System

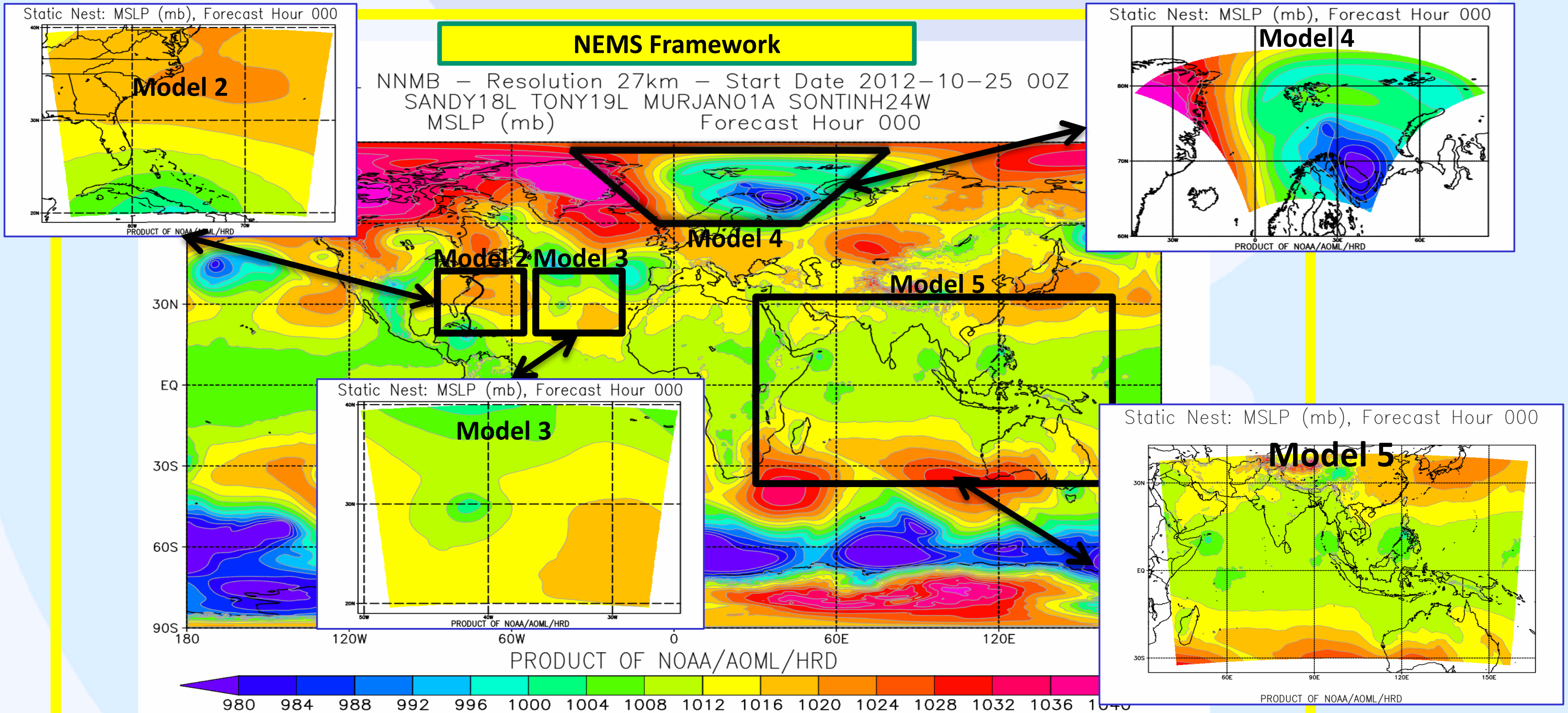


Adapted from Saha

Stage 4: FV3/NEMS based Global-Meso Unification (FY17-FY22)

- Develop efficient nesting techniques for high resolution convective scale weather forecasts
  - Next Generation Generalized Nesting Framework (NGGNF, EMC-GFDL-AOML)
  - NUOPC based coupling of high-resolution nests coupled to the global model
  - Static, moveable, one-way and two-way interactive nests for various applications including hurricanes
  - Multiple instantiations of nests to generate convective allowing model ensembles
  - Nests coupled to ocean/wave/surge/land/hydrology/air-quality etc. for unified production suite satisfying various service requirements

Example: Generalized Nesting By Coupling



*Example of Core, Grid, and Projection Independent, dynamical (up/)downscaling using and **advancing** ESMF re-gridding*

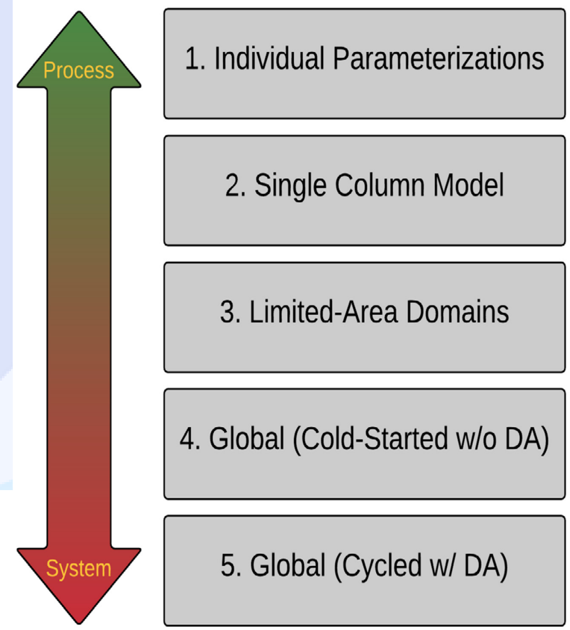
Focus: Addressing Problems with GFS

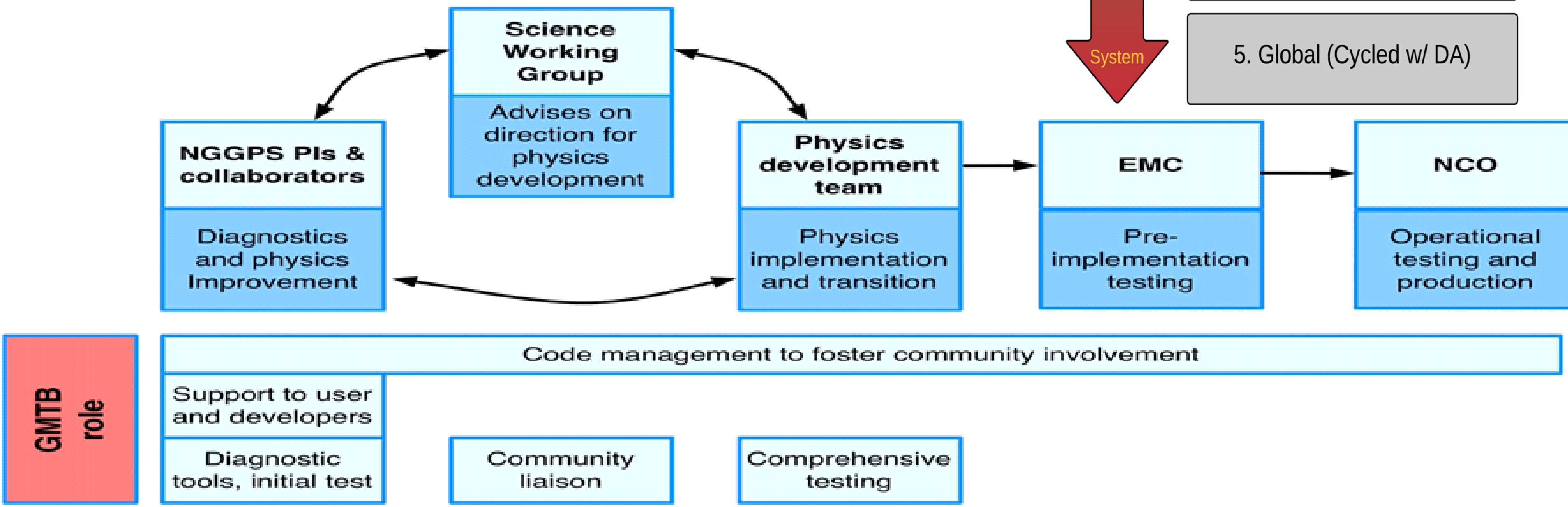
- Gap in deterministic skill with ECMWF, Met Office
- No Initialization of near surface fields in GFS
  - Moisture profiles not fit to radiosondes
- GFS inversions not strong enough
- Biases in low level winds over CONUS
- Southern plains too warm 12Z 2 m temperatures
  - Great Plains still too warm and dry in summer; CAPE underestimated
- US precipitation skill, biases: skill lower than other centers
- Bogus hurricanes near Central America: tendency to spin up convection just off shore in tropics
- Forecasts fail to maintain ascent in western equatorial Pacific, Indonesian region
  - Problems in forecasting MJO
- GFS too fast, too weak with mid-latitude systems
- Inconsistent forecasts, even at short ranges
- Upper stratosphere errors
- ………

Global Modeling Test Bed for enhanced R2O support

- **Common Community Physics Package**
  - Refactor and modularize GFS physics
  - Support PIs work in diagnostics and testing
  - Support code management
- **Interoperable Physics Driver**
  - same physics used by different models
  - Support NGGPS level 2 testing

Hierarchical Testing of Physics

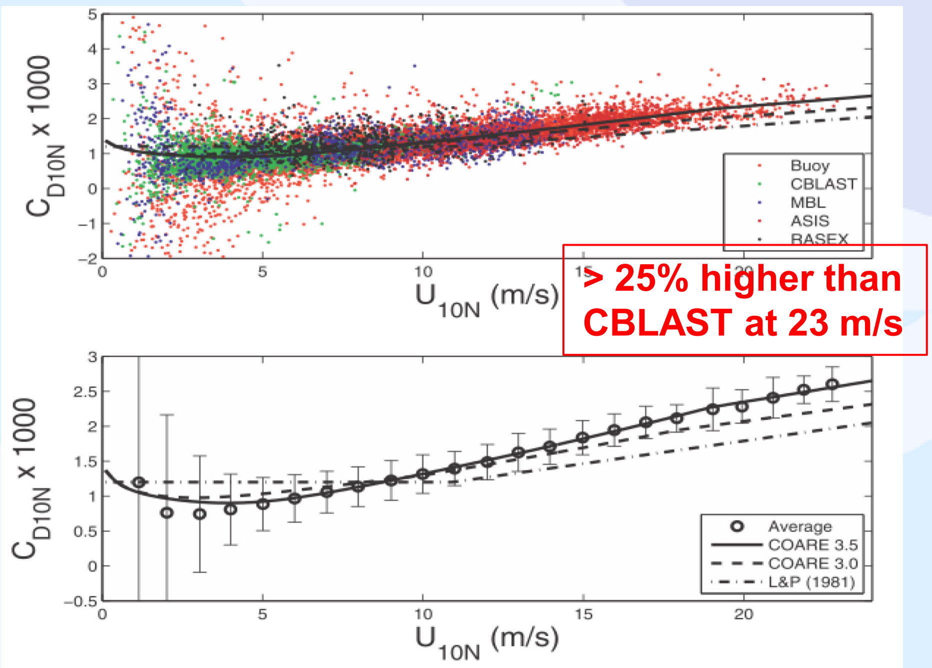




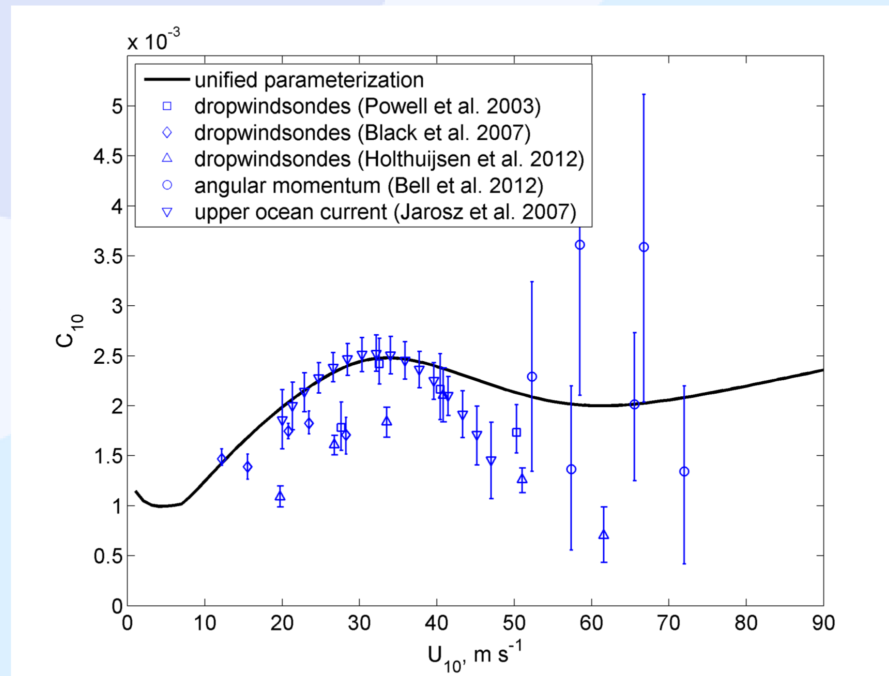
Physics Improvements: Air-Sea Interface

Revisiting C_d formulation based on recent observational and theoretical studies

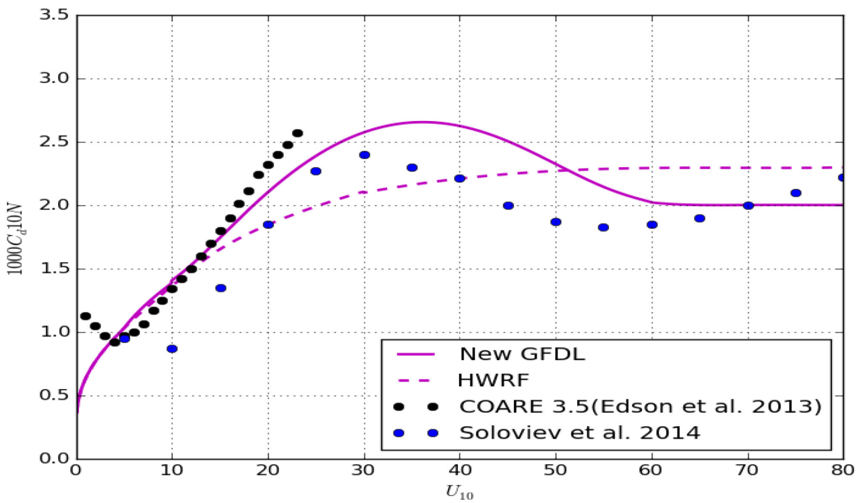
Edson et al, 2013

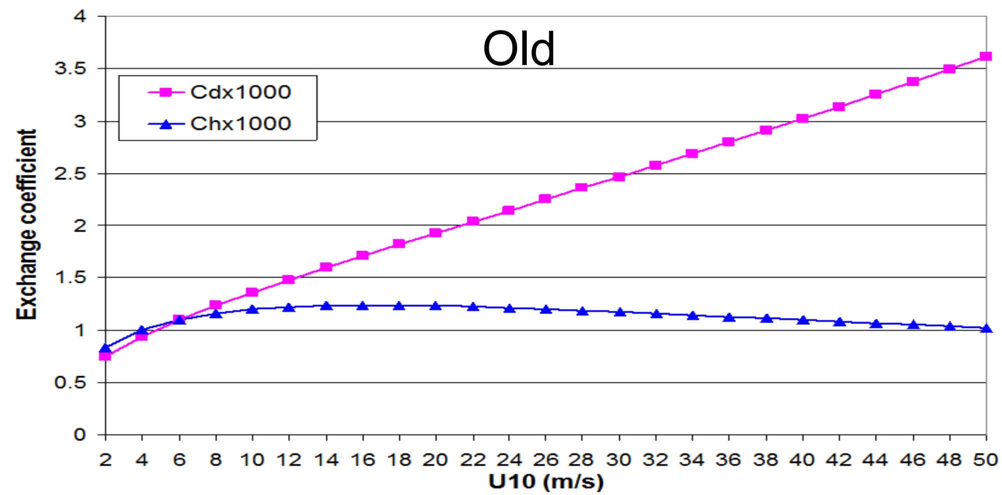


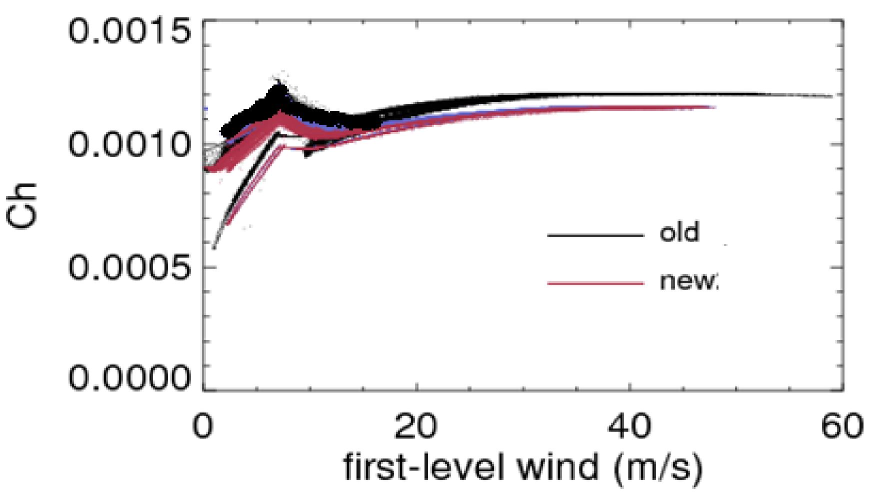
Soloviev et al, 2014

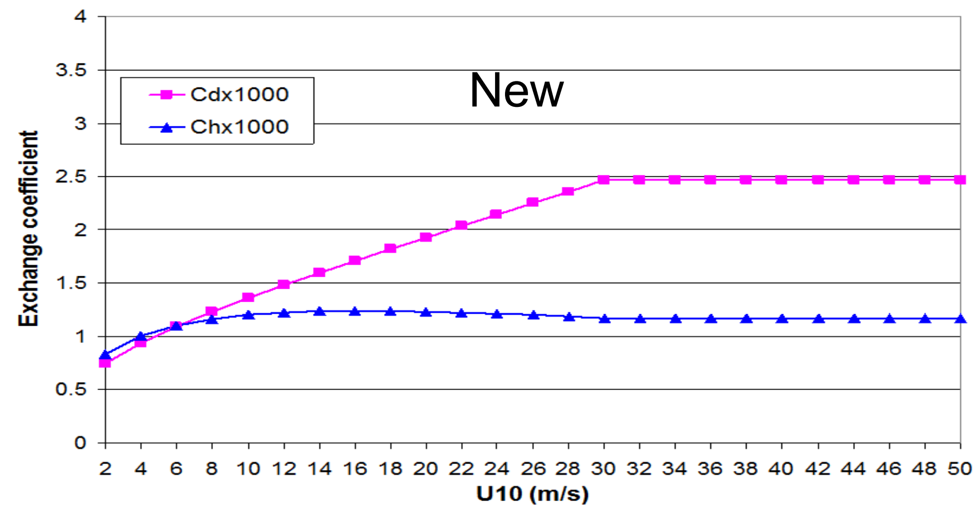


Drag coefficients for exchange of momentum and heat









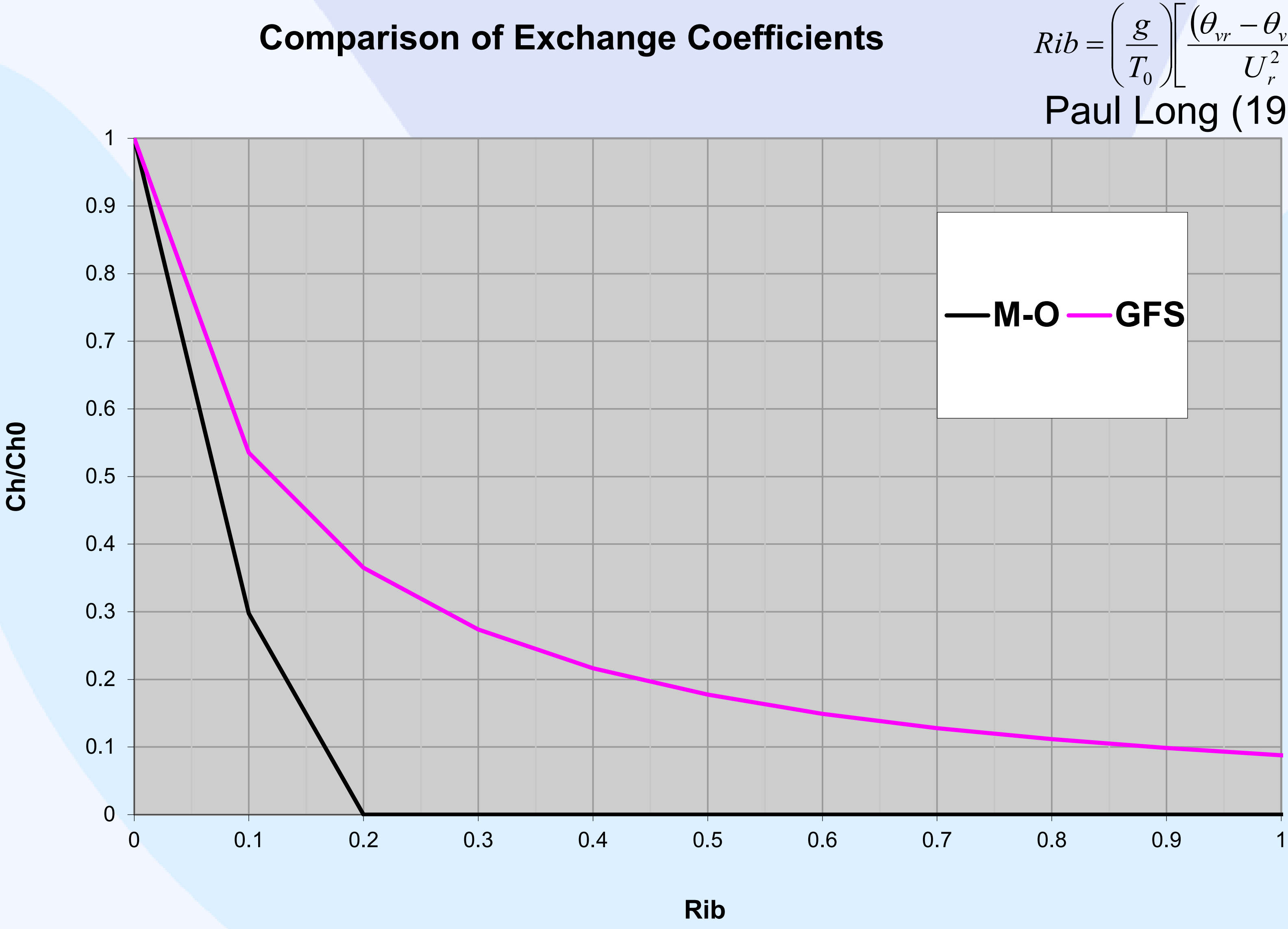
New Bulk C_d/C_h Parameterization for hurricane models

Bulk C_d/C_h Parameterization in GFS

Ch in Stable Conditions

$$Rib = \left(\frac{g}{T_0}\right)\left[\frac{(\theta_{vr} - \theta_{v0})z_r}{U_r^2}\right]$$

Paul Long (1986)



Sea state dependent C_d in Atmospheric Model

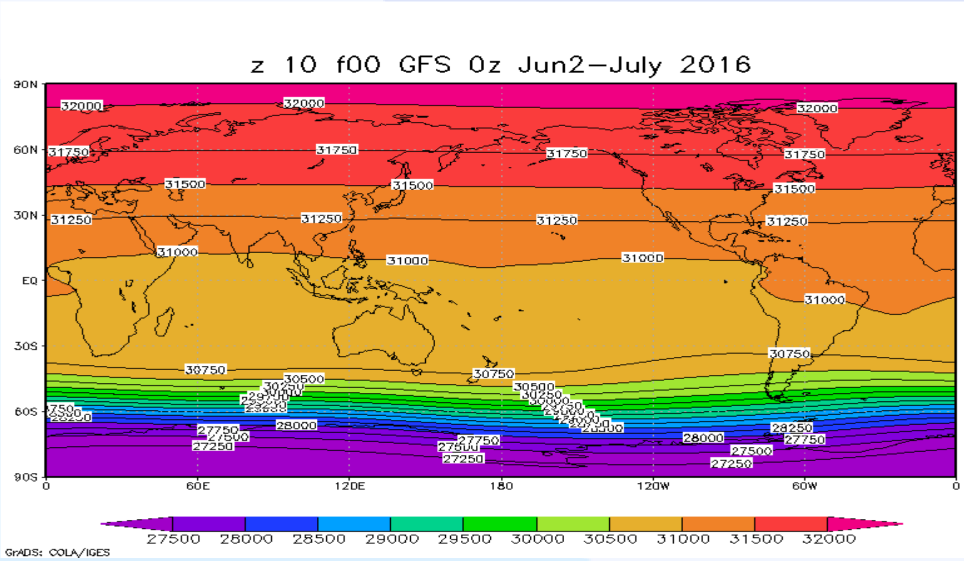
- Obtained by integrating the wave spectrum times the growth rate over all wavenumber/directions
- Methods:

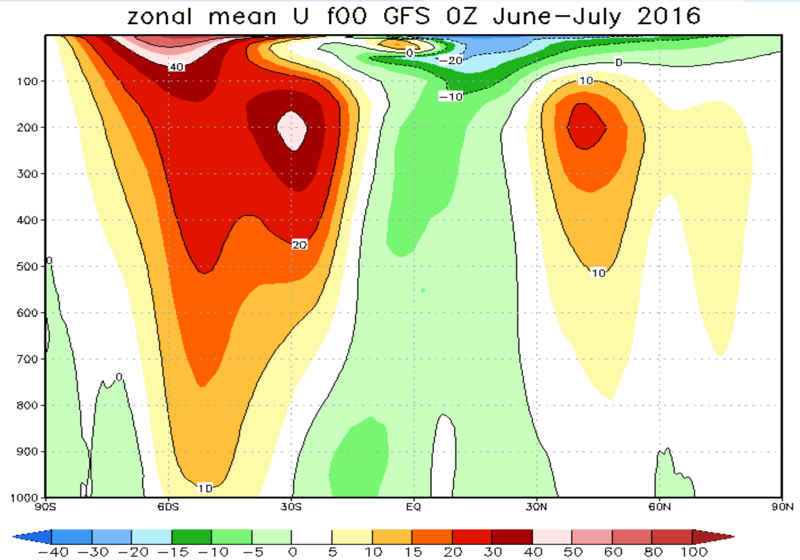
[1] Moon et al., 2004 [2] Reichl et al., 2014 [3] Donelan et al., 2012

	URI[1,2]	DCCM[3]
Determine growth rate from:	stress	wind
Growth-rate of waves that oppose the wind:	weak or strong	strong
Calculate the Wind profile:	Energy conserving	simple logarithmic

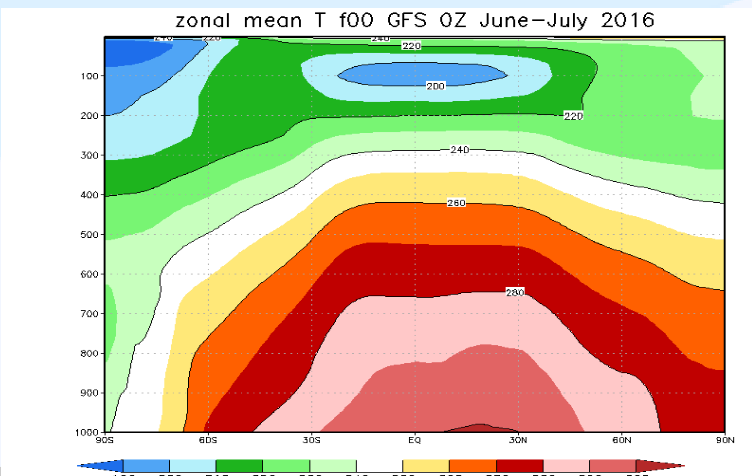
- HWRF is the first wave coupled system in operations at NCEP
- GFS will be coupled to WaveWatch-III (one-way) by 2018 (two-way feedback experiments in progress)

Non-Orographic Gravity Wave Physics





GFS T1534 initial conditions averaged over 2 months (JJ2016), (left) 10 mb Height [m], (right) Zonal mean wind [m/s], and (lower) T (Plots from GW)



The middle atmosphere is dominated by a westerly jet in the winter hemisphere, an easterly jet in the summer hemisphere, and a meridional circulation comprised of upwelling in the tropics and downwelling over the winter pole, referred to as the Brewer–Dobson circulation (Brewer 1949)

Non-orographic gravity waves (nGWD) in the GFS

- Wave drag arising from the deposition of momentum from the breaking of small-scale non-orographic gravity waves and large-scale planetary waves.

- In the GFS the effect of the nGWD is approximated by Rayleigh friction on the zonal flow.

- Underestimation of the poleward circulation between the summer and winter hemispheres and downwelling over the winter pole show that forcing of the mean flow is unrealistically weak if nGWD is neglected.

- Weak downwelling is associated with excessively cold winter polar stratospheric temperatures.

GFS Orographic and Convective Gravity Wave Drag

- Orographic gravity wave drag in its simplest form is for inviscid, linearized, non-rotating flow with the Boussinesq and hydrostatic approximations.

- Additional physical processes include the effect of orography anisotropy, vertical wind shear, trapped lee waves, rotation and nonlinearity, frictional and boundary layer effects.

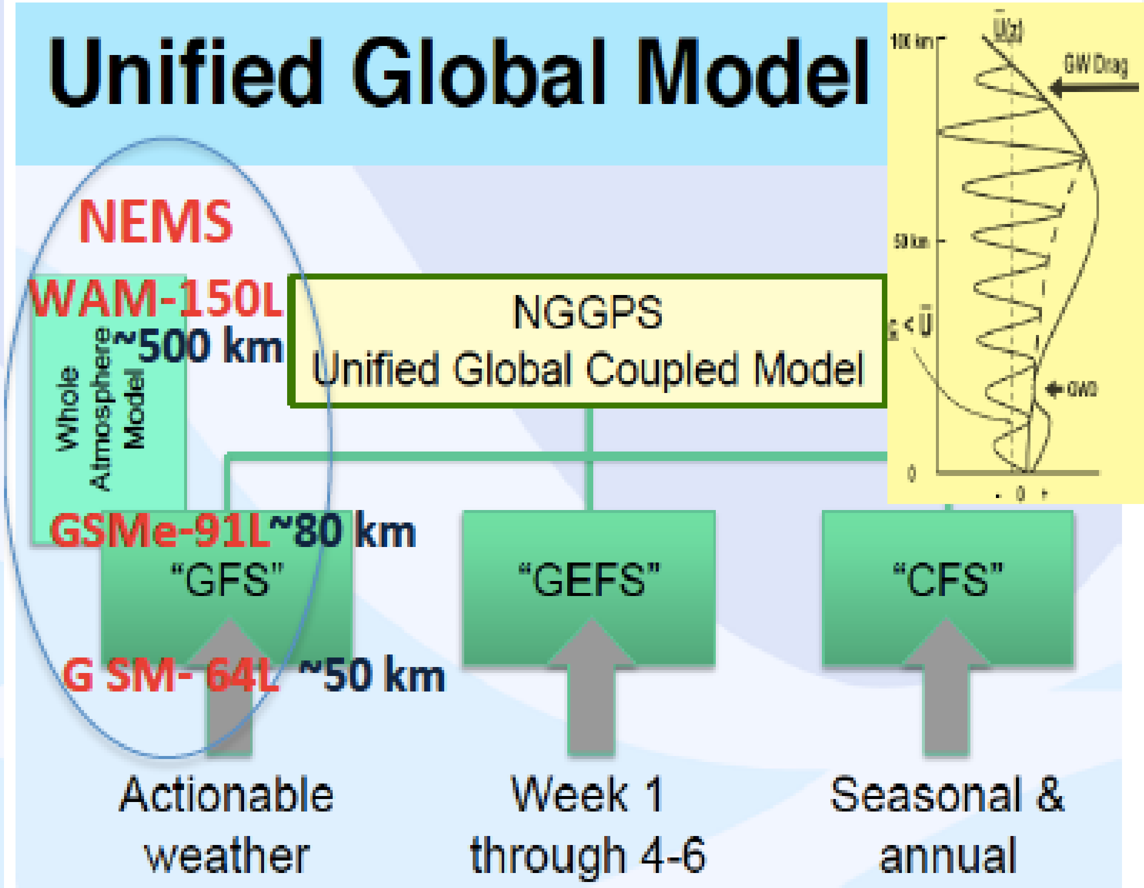
- GFS also has a convective GWD based on the work of Chun and Baik 1998, JAS, and Johannson (2008).

The Vertically Extended Global Atmosphere Models of NOAA Environmental Modeling System (NEMS)

The first vert. extended GFS (from the current 64L to 91L) promises to improve the stratospheric forecasts and the trop-stratosphere coupling.

For *vertically extended* models, we are unifying the **GFS-91L** (lid ~80km) and the 150L **Whole Atmosphere Model (WAM-150L,** ~500 km).

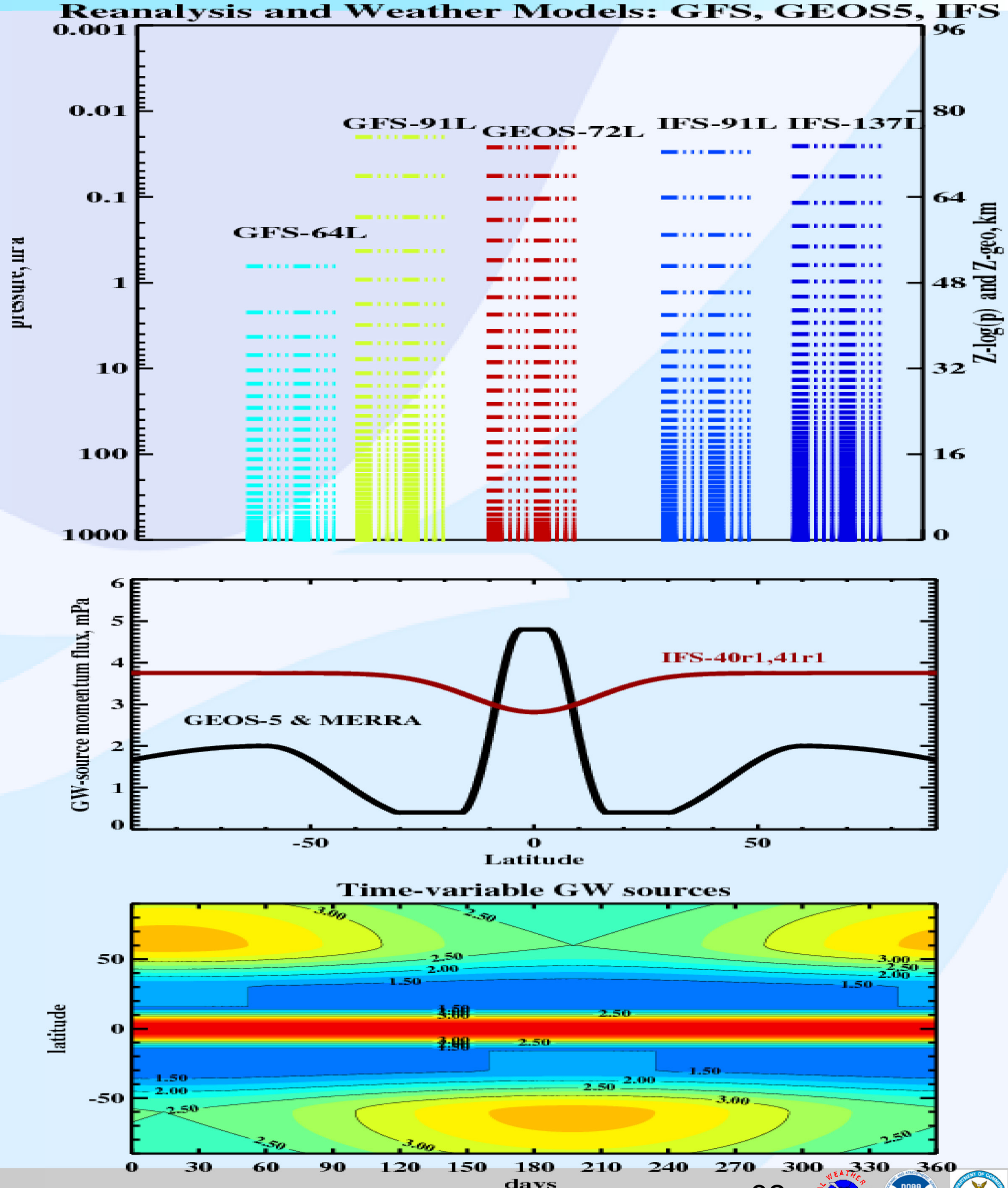
Unification and upgrades of GFS and WAM physics will streamline the interaction of analysis and forecast for terrestrial and space weather and climate predictions under NEMS/NGGPS framework



Dynamics and physics of resolved and sub-grid quasi-stationary *Orographic GWs* (OGWs) and *Non-stationary GWs* (NGWs) represent the major uncertainties for extended models

Extending GFS-64L to GFS-91L & First Steps towards "GW-Unified"

- **Vertical levels and top lid of GFS-91L** follow IFS-91L of ECMWF and resemble GEOS5-72L of GMAO;
- **Decreased** (3-times, 1/15 days) **Rayleigh damping above ~70 km.**
- **Previous** (IFS, NOGAPS, NCAR) **choices for GW intensity at ~ 700 hPa** (or at ~500 hPa) *to replicate latitudinal and seasonal variations of GW activity in the stratosphere;*
- **GW solvers: (a) Linear saturation of modified Lindzen-81**; (b) Hines'-97 with dissipation and nonlinear saturation;
- **GW physics acts every time-step**: 4 azimuths; 10-25 modes in each azimuth

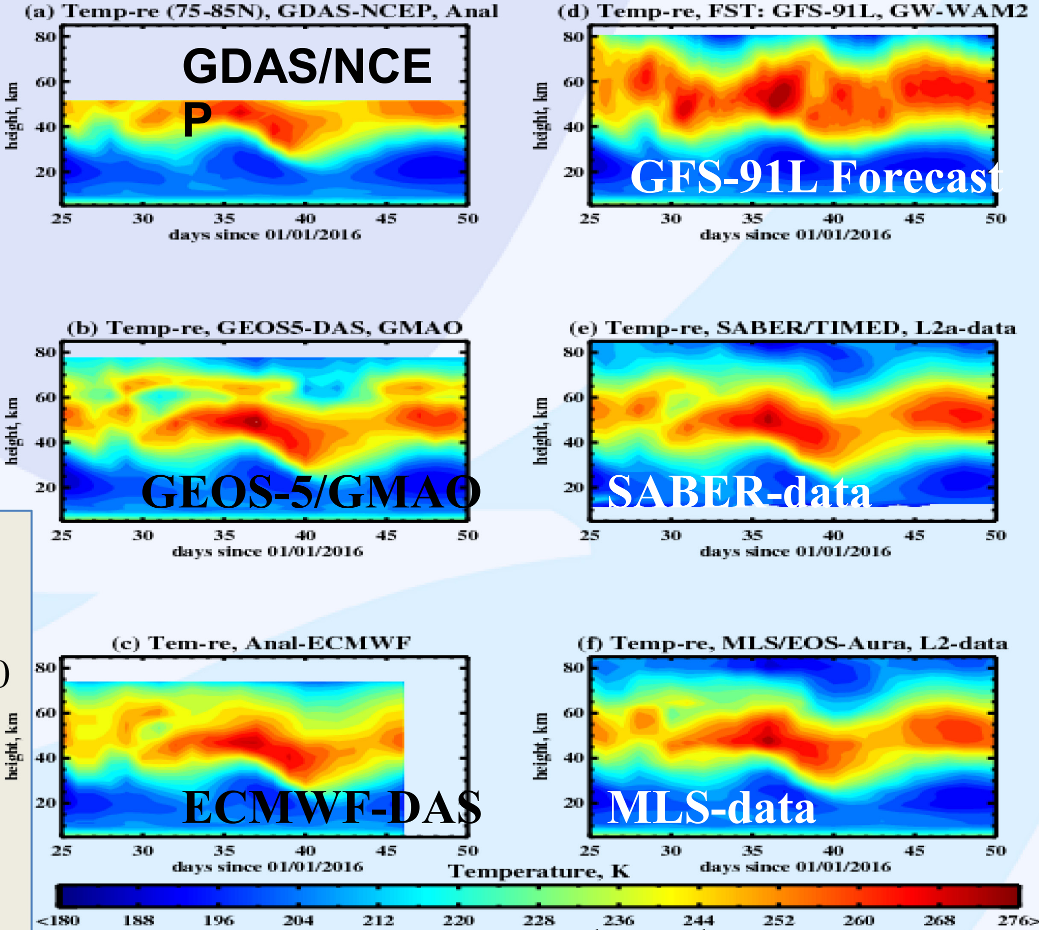


Integrating Unified Gravity Wave Physics into the Next Generation Global Prediction System

- ***Summary of the 1-year results***

GW physics in NEMS-WAM improved zonal mean flows, planetary waves and tides.

GW physics in GFS-91L brought a realism in the stratospheric dynamics during winters and winter-to-spring transitions comparing to the Rayleigh Friction simulations.



Jan-Feb 2016: GFS-91L 25-day polar temperature forecasts (d), SABER (e) & MLS (f) data (left), and NWP analyses (right column) : GDAS-NCEP (a), GEOS5-GMAO (b) and IFS-ECMWF(c).

Transition to NOAA operations, climate tests, and future plans

a) ***Analysis-Forecast Cycling with GFS-90L*** (~80 km top) with "parallel" operational scripts; tests during SSW events (2009, 2013, & 2016).

b) ***NEMS-WAM multi-year climate runs*** for self-generated equatorial oscillations (QBO and SAO).

c) ***New related projects: Assimilation of middle atmosphere O_3, H_2O and T profiles*** (MLS & SABER) to properly initialize NGGPS forecasts.

Summary

- Aggressive implementation strategy for NGGPS (GFDL FV3) based GFS for weather applications
- Emphasis on improved representation of physical processes at all spatial and temporal scales
- Unified global-to-local scale modeling and coupled earth system modeling to transform NWP at NCEP

Thanks for your attention

Questions?