Long Range Plans for Numerical Guidance from NCEP: NGGPS/FV3 based Unified Coupled Modeling System Development at NCEP

Transforming Operational Models for seamless prediction of Weather, Hurricanes, Sub-Seasonal and Seasonal Climate

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*HFIP Annual Meeting @NHC, Miami, FL*
January 11, 2017

Outline

- Further improvements to the Global Spectral Model
  - ◆ Q2FY17 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 and DA improvements key for making forecast improvements
- Community modeling approach: opportunities to make US NWP second to none: HFIP/HWRF development as a great example

What we have …..
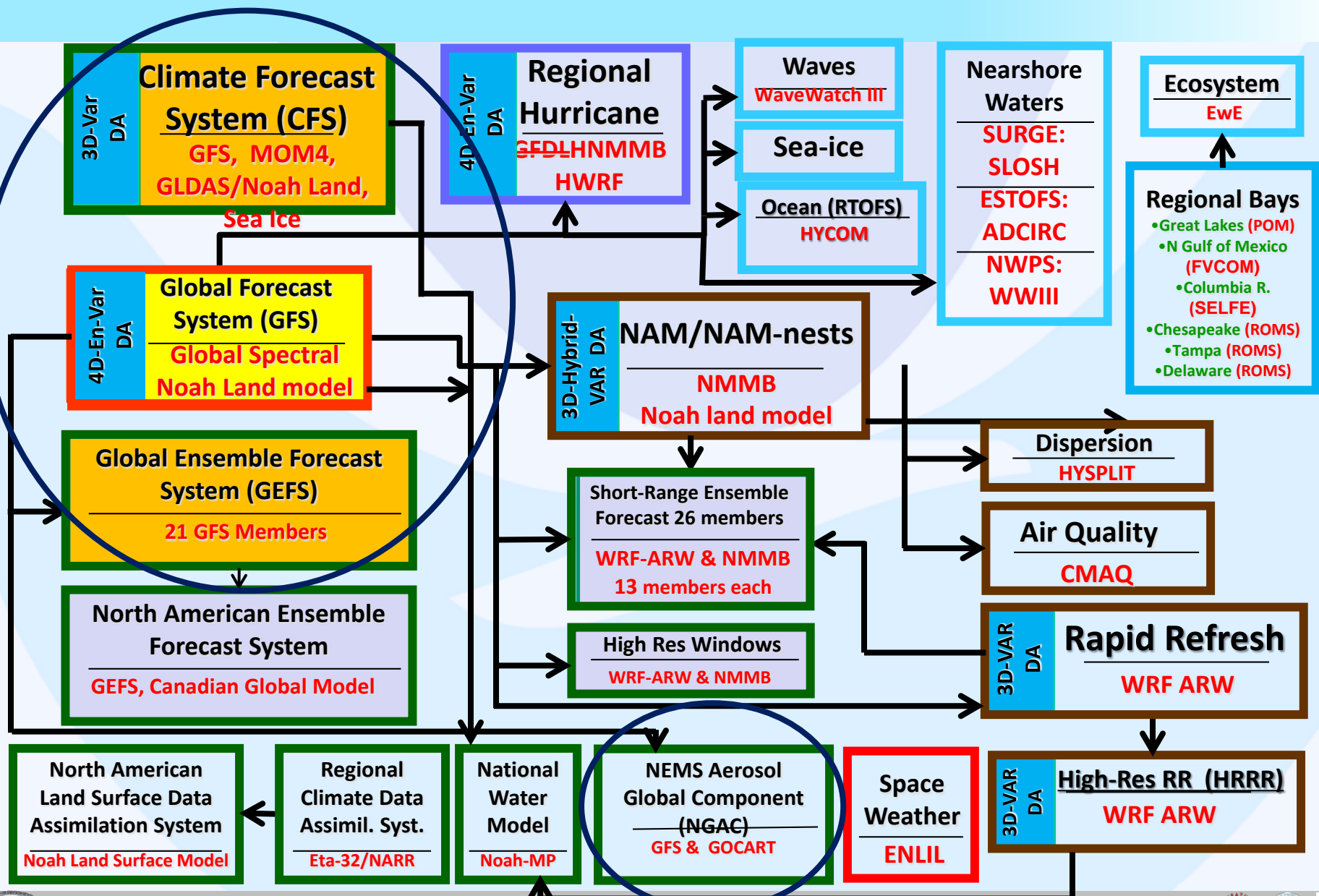
What we want ….
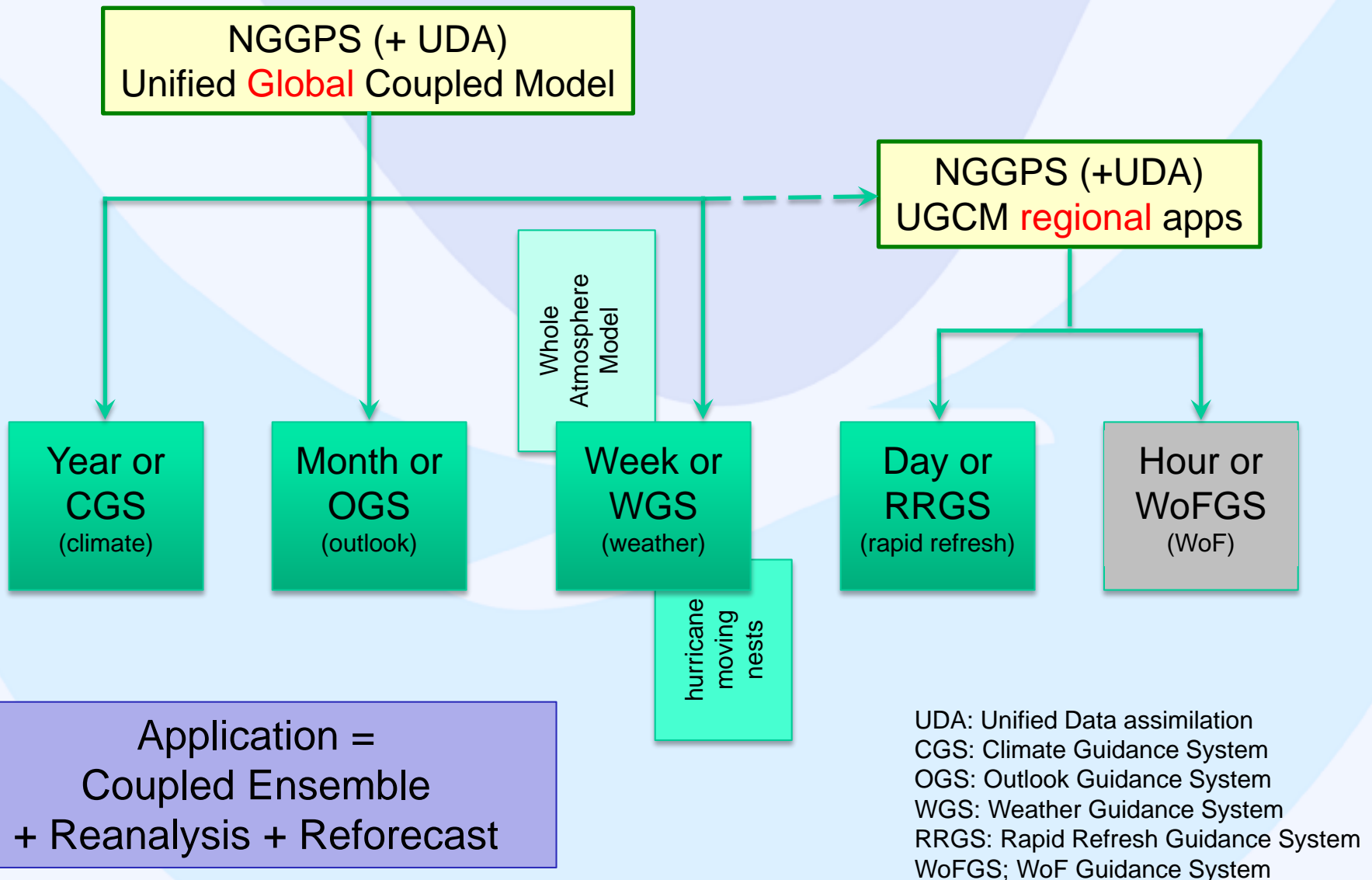
Scientific Changes Implemented/Planned for NCEP GFS (FY15-20)
(Blue represents significant upgrade)

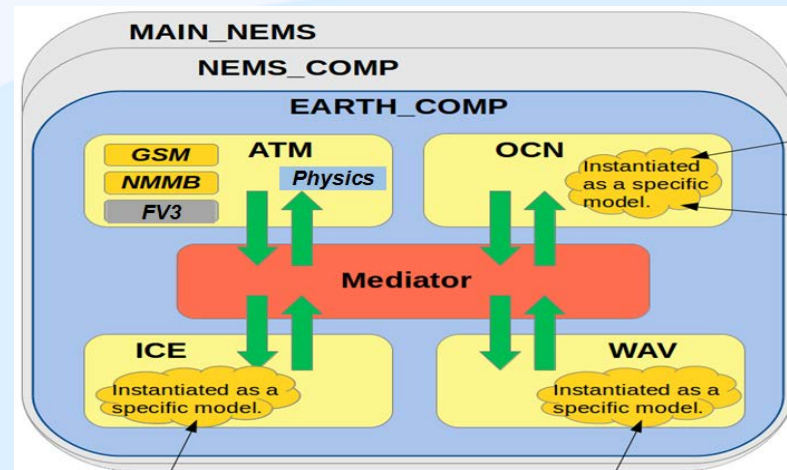| GFS Implementation	Q3FY16 GFS V13.0	Q3FY17 GFS V14.0	FY18 GOES-R/ JPSS DA ONLY	Q3FY18 GFS V15x (beta)	Q3FY19 GFS V15.0	Q3FY20 GFS V16.0
Resolution	T1534 (13 km) L64	T1534 (13 km) L64	T1534 (13 km) L64	C768 (13 km) L64	C1152 (9 km) L128	C1152 (9 km) L128
Physics	Noah LSM Upgrades	NSST Noah LSM upgrades Scale-aware SAS & EDMF PBL		NUOPC Physics Driver	Advanced Physics TBD	Advanced Physics (TBD)
Dynamics	None	None		FV3		
DA	- All-sky radiances - 4D Hybrid	JPSS, CrIS and GOES-R Ready SEVIRI IR; VIIRS GOES WV Winds GPSRO RARS & DBNET	- GOES-R & JPSS data assimilated	GSI for FV3	- JEDI/Unified forward operator L128 mod	DA on FV3 grid
Products	- Hourly output - Five more levels	1/8 degree products		TBD	TBD	TBD
Significant Component	4D EnVAR LSM upgrades	NEMS/ESMF LSM upgrades	GOES-R/JPSS Data	GFS/FV3 (prototype experimental parallel)	Operational GFS/FV3	- Advanced Physics/ CCPP - DA on FV3 grid
	May 11, 2016 Done	**May 10, 2017 Planned**	**Planned**	**Planned**	**Planned**	**Planned**

Today

NGGPS Era

Q3FY17 GFS V14.0 Implementation Plan
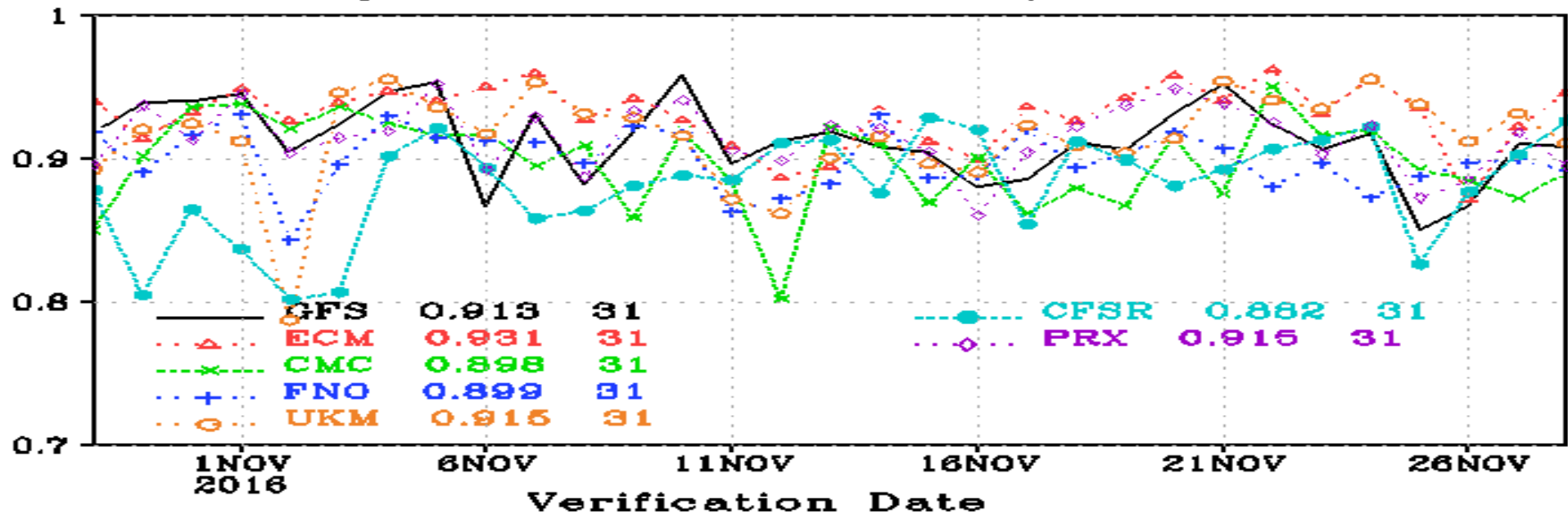
Objectives:

1. Physics and LSM improvements
   - *Convection and PBL schemes*
   - *High resolution LSM and Terrain Data*
   - *address the rapid temperature drop during sunset and wet bias during sunrise*

2. Data Assimilation improvements
   - *Near Surface Sea Temperature (NSST)*
   - *SEVIRI IR; VIIRS; GOES clear air water vapor winds; additional GPSRO data; RARS and DBNET data*
   - *Readiness for CrIS; JPSS and GOES-R*

3. Modern infrastructure
   - *GSM in NEMS (ESMF & NUOPC)*
   - *Support integrating NGGPS FV3 dynamic core coupled to GFS Physics*
   - *Support developing unified coupled modeling system*

Testing and implementation Plan:

- May 2014 through May 2017

  - *Three summers and two winters*
  - *Comprehensive evaluation including case studies from field*
  - *real-time data feed through mageval and para-NOMADS*

Anomaly Correl: HGT P500 G2/NHX 00Z, fh120

GFS	0.913	31
ECM	0.931	31
CMC	0.898	31
FNO	0.899	31
UKM	0.915	31
CFSR	0.882	31
PRX	0.915	31

Verification Date

Anomaly Correl: HGT P500 G2/SHX 00Z, fh120

GFS	0.904	31
ECM	0.934	31
CMC	0.904	31
FNO	0.866	31
UKM	0.907	31
CFSR	0.841	31
PRX	0.909	31

Verification Date

CONUS Precip Skill Scores, f36-f60, 10may2015-01sep2015 00Z Cycle

Summer 2015

36-60h
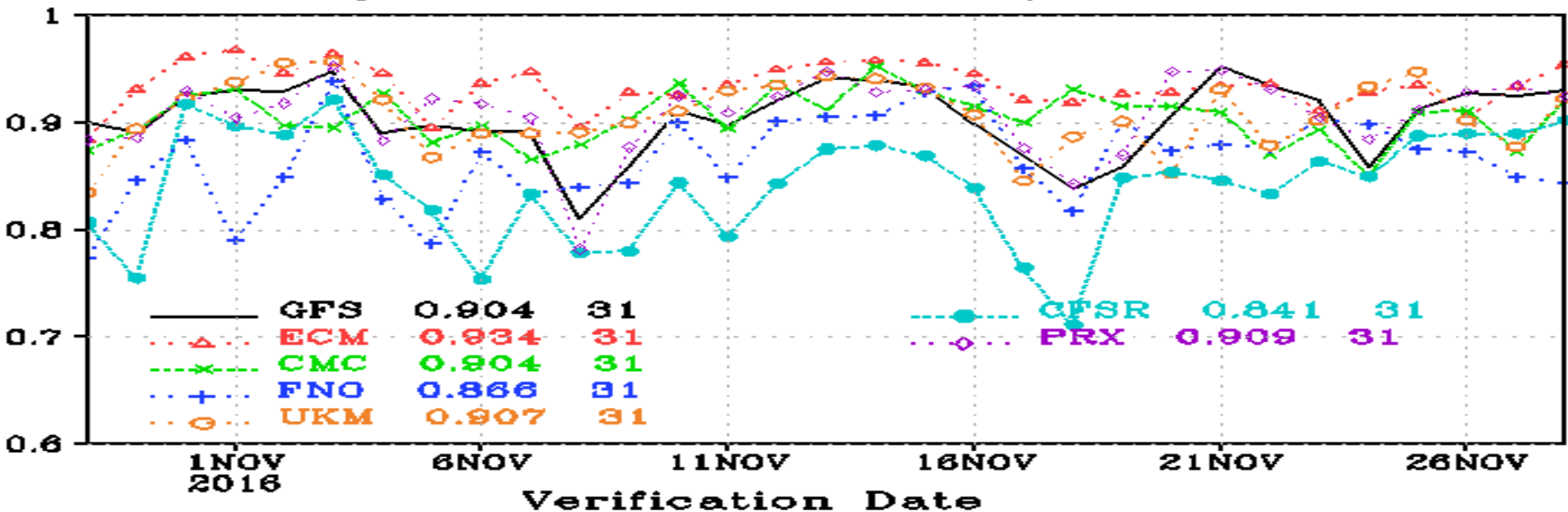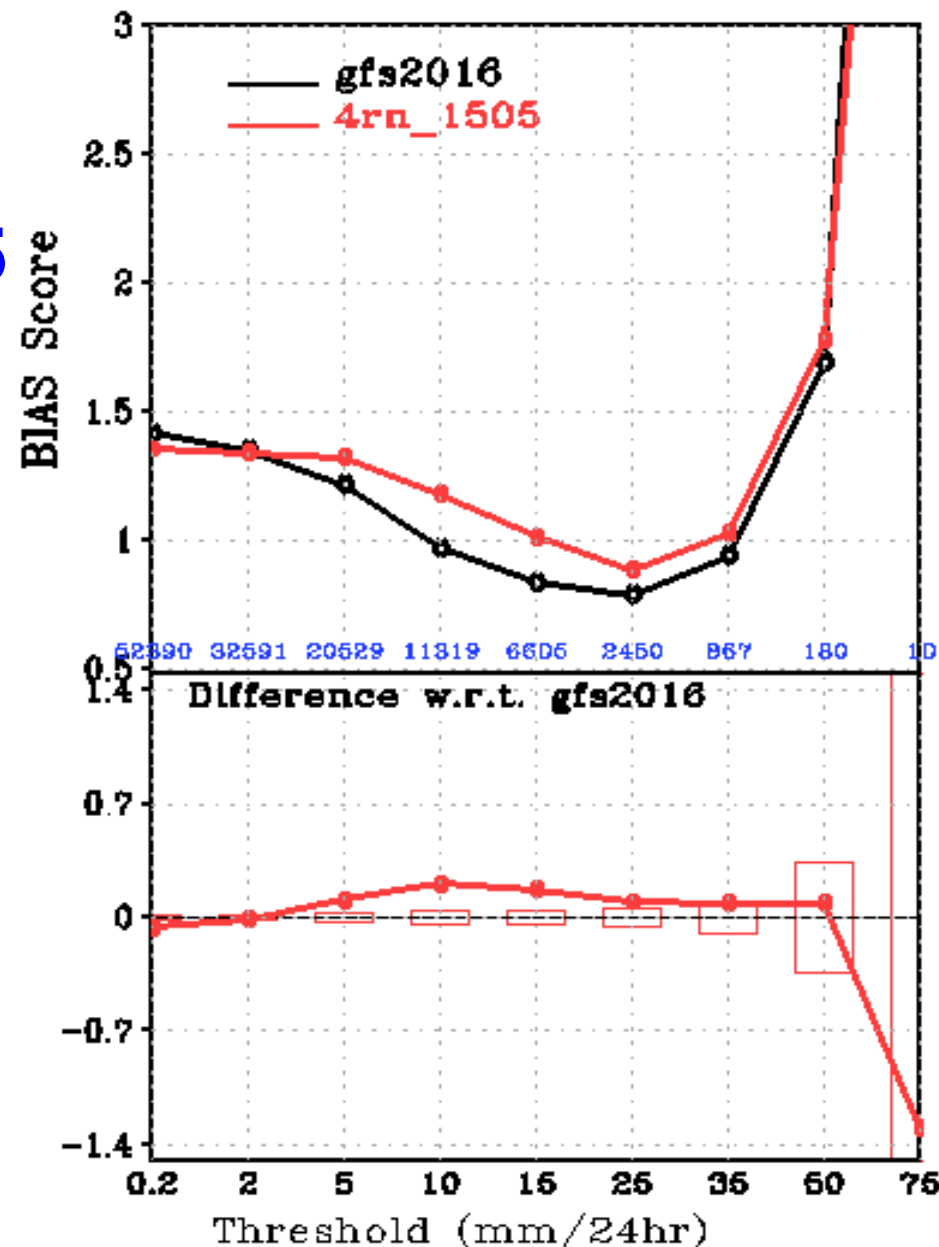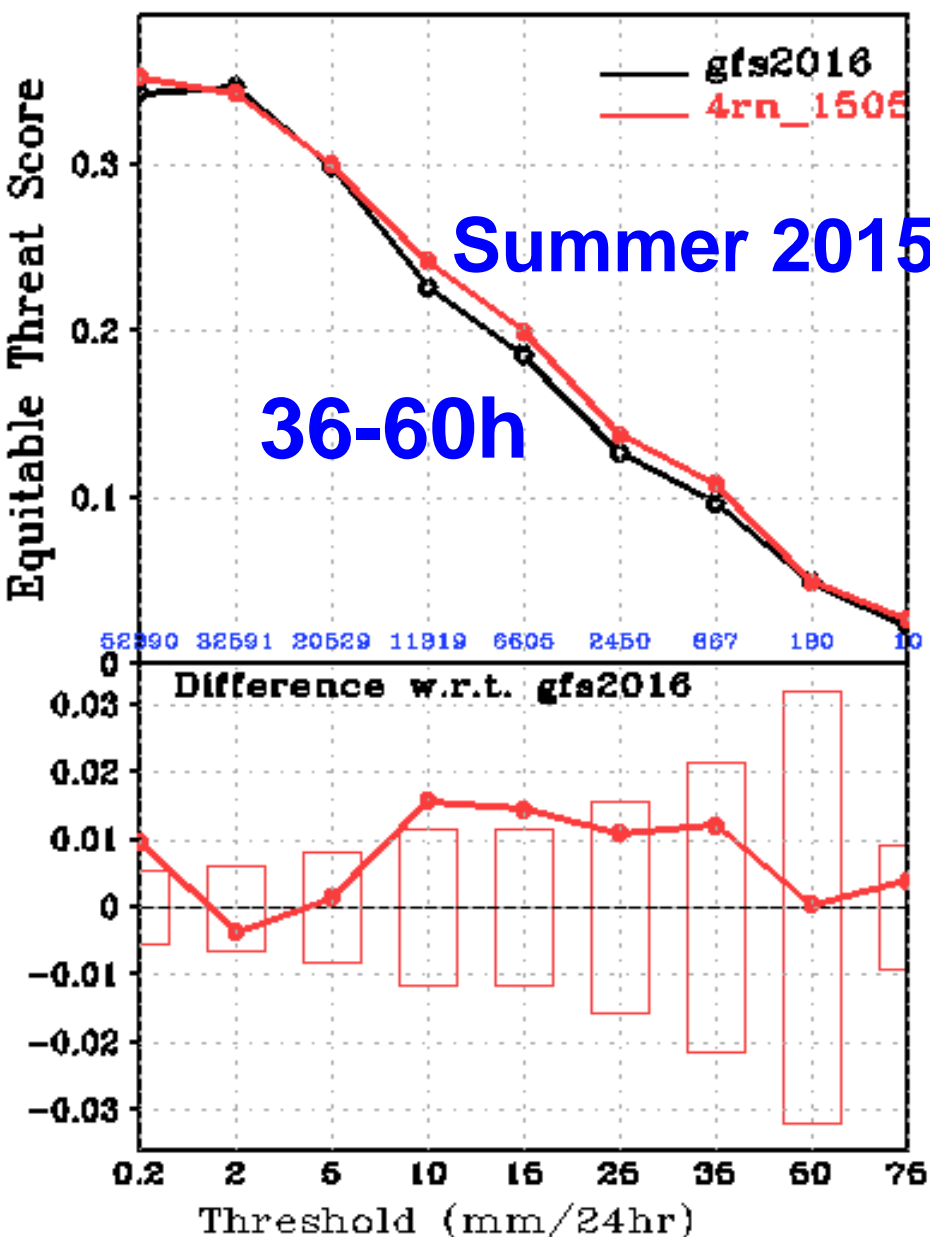
Differences outside of the hollow bars are 95% significant based on 10000 Monte Carlo Tests

CONUS Precip Skill Scores, f24-f48, 25dec2015-03mar2016 12Z Cycle

Hurricane Track Errors — Atlantic 20142016
20140501__20161231__4cyc
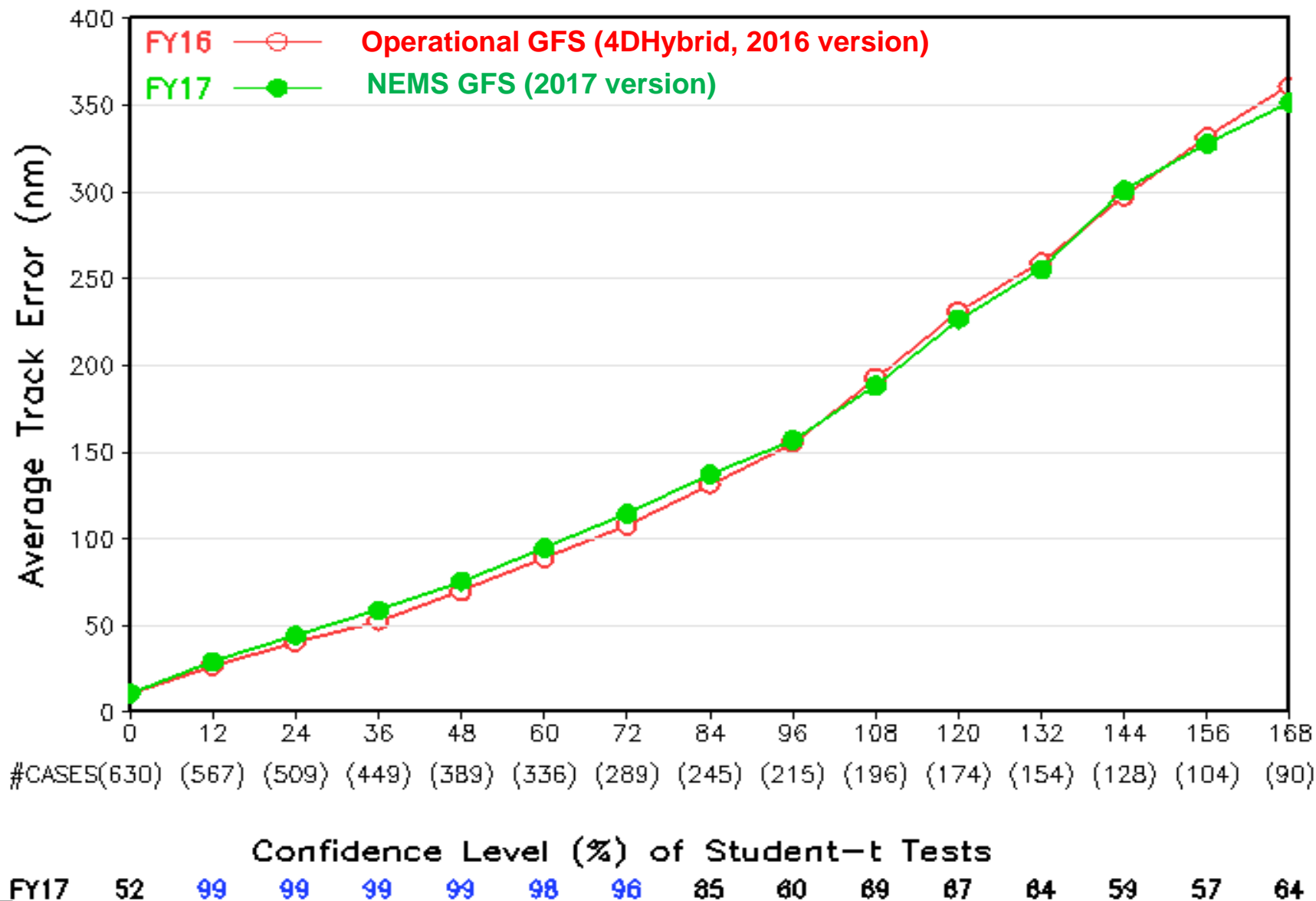
Hurricane Track Errors — East-Pacific 20142016
20140501__20161231__4cyc

FY16 ——○—— Operational GFS (4DHybrid, 2016 version)

FY17 ——●—— NEMS GFS (2017 version)

#CASES (1156)(1050) (950) (857) (772) (688) (612) (544) (478) (417) (360) (310) (261) (222) (185)

Confidence Level (%) of Student-t Tests

FY16_FY17   64   94   87   98   98   98   97   92   97   94   98   98   93   63   52
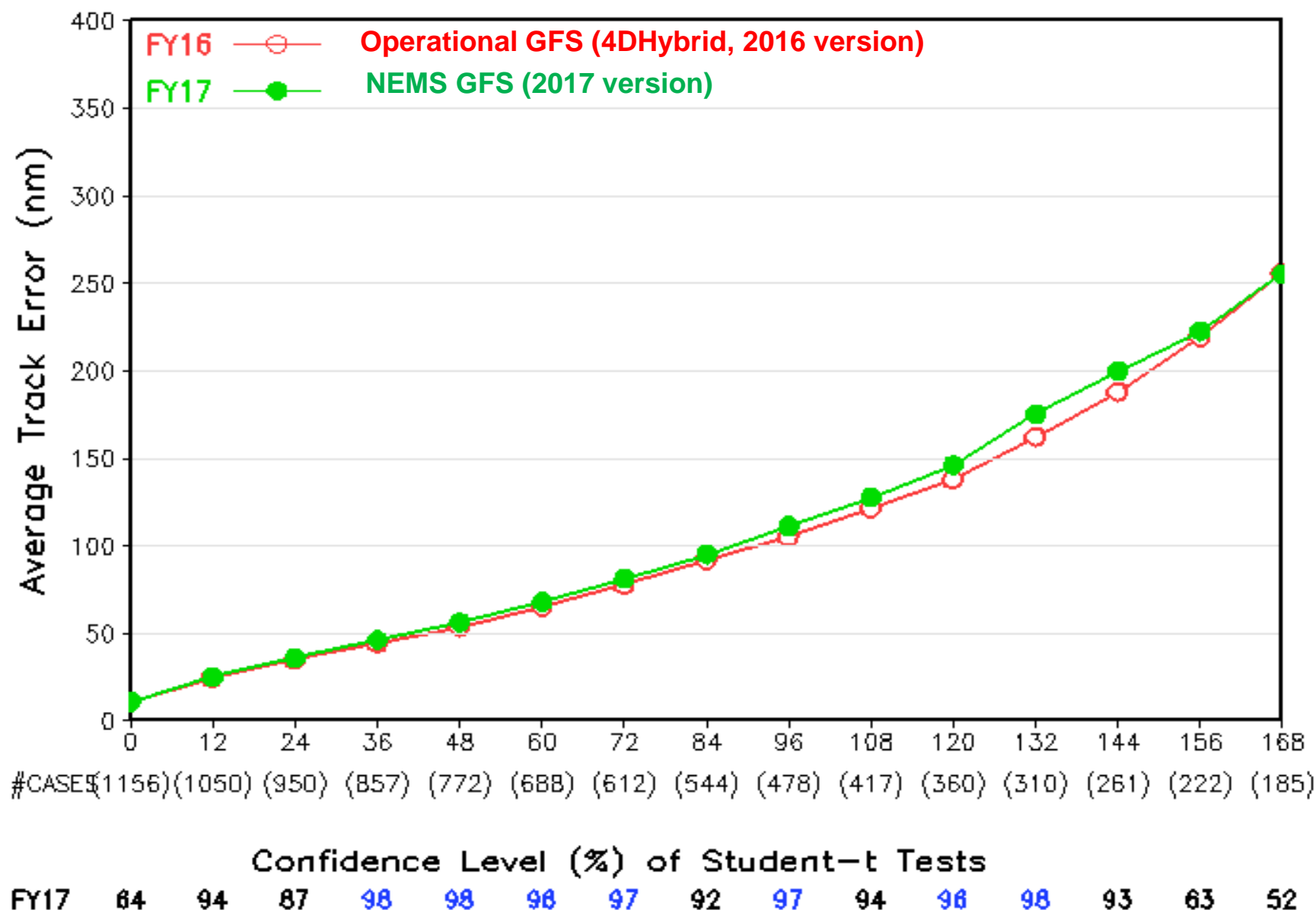
Hurricane Track Errors — West-Pacific 20142016
20140501__20161231__4cyc
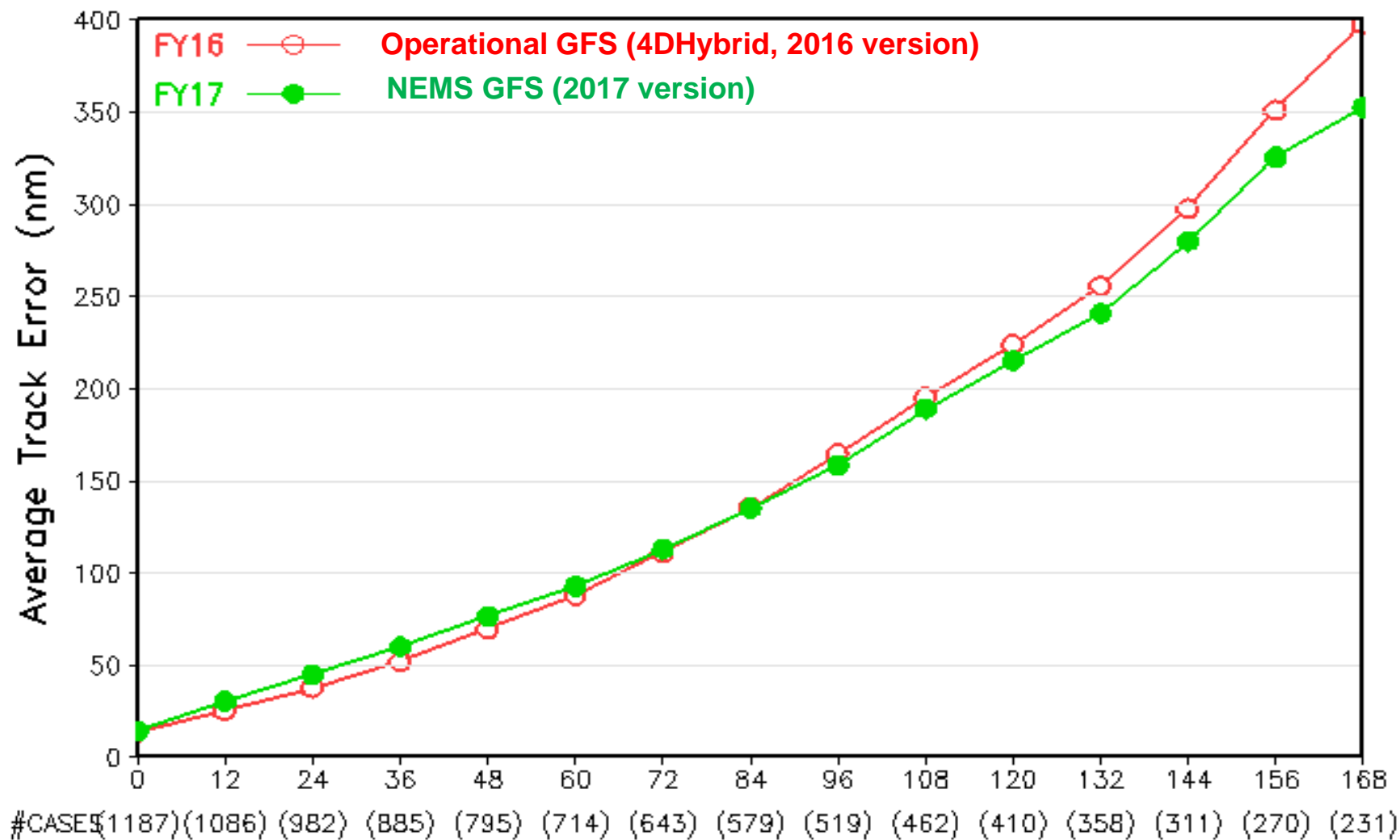
NGGPS: The future of advanced global weather prediction at NCEP

- 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

NEMS Component Schematic for GFS and GEFS and CFS
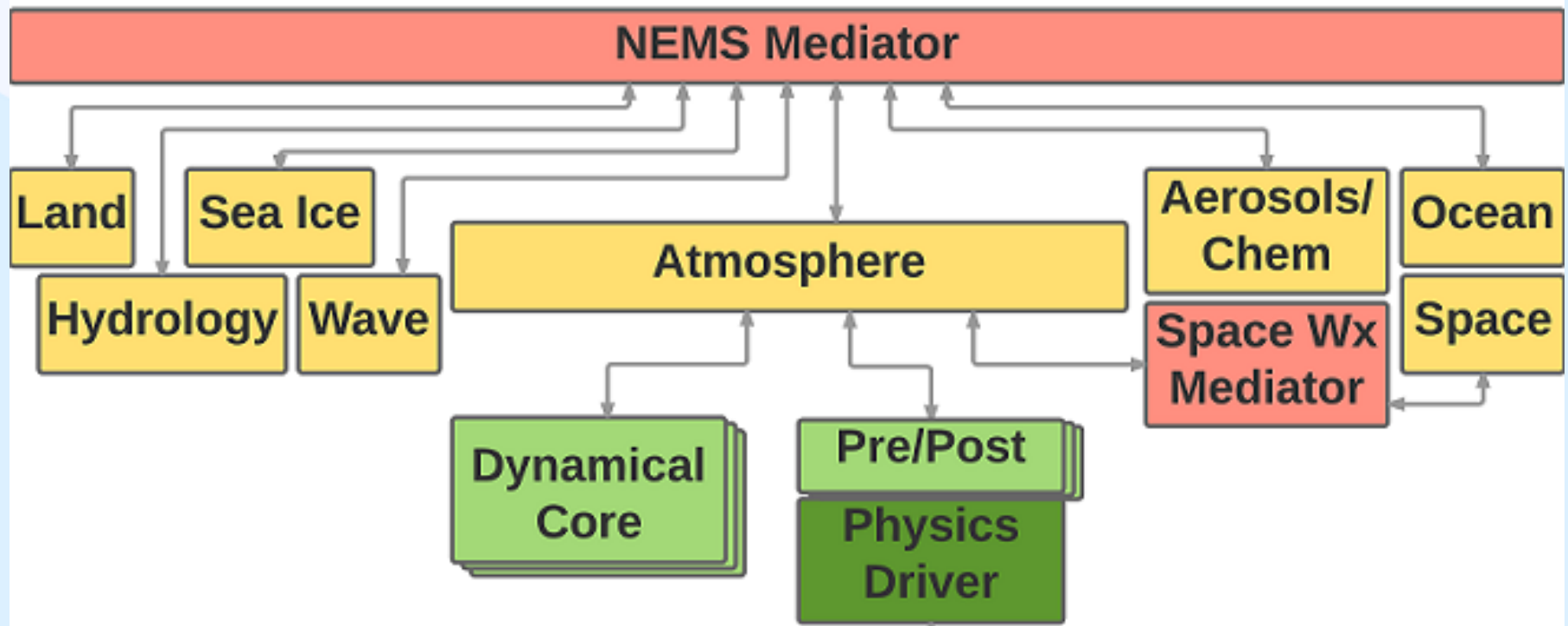
- **FV3 dynamic core included in NEMS (November 2016)**

- **NUOPC Physics Driver is coupled to FV3 dynamic core (Ongoing)**

- **NEMS/FV3GFS Forecast only experiments with NEMS/GSM IC (Ongoing)**

- **GEFS V12 configuration developed with stochastic physics (Ongoing)**

- **Planning for CFSV3 (Ongoing)**

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

Process

1. Individual Parameterizations

2. Single Column Model

3. Limited-Area Domains

4. Global (Cold-Started w/o DA)

5. Global (Cycled w/ DA)

System

Science Working Group — Advises on direction for physics development

NGGPS PIs & collaborators — Diagnostics and physics Improvement

Physics development team — Physics implementation and transition

EMC — Pre-implementation testing

NCO — Operational testing and production

GMTB role

Code management to foster community involvement

Support to user and developers

Diagnostic tools, initial test

Community liaison

Comprehensive testing

NCEP

Implementation Plan of FV3GFS
(FY17-FY19)

	FY17				FY18				FY19			
Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4

Evaluate FV3 structure and document FV3 modeling system

Implement FV3 dycore in NEMS[@]

Couple FV3 to GFS physics (NUOPC physics driver) perform forecast-only experiments, tuning and testing[&]

Develop DA techniques [%] (native grid vs physics grid; New data)

Cycled experiments, New physics options, benchmarking, computational efficiency & optimization

Preprocessing and post-processing, up & downstream dependencies

Test and Implement NGGPS Verification tools

3-year retrospective + real-time parallels, EMC and Community Evaluation

Q3FY19 FV3GFS Configuration

[@] The targeted FV3GFS resolution is ~10km L128 with model top ~80 km.
[&] New physics: Scale-aware convection and PBL, Double-moment cloud and aerosol-aware microphysics, Unified convective and orographic gravity wave drag etc
[%] ~25km L128 4D-EnVAR data assimilation

Early experimental implementation of FV3GFS (~13km L64) w/cycled DA

Code delivery, NCO Parallel & operations

NEMS/ FV3GFS in operations

FV3GFS Development/Implementation Plan

- **After Q3FY17 NEMS/GSM implementation (last spectral model upgrade), <u>all resources are diverted to FV3 implementation task</u>**

- **Benchmark FV3GFS with fully cycled DA to <u>match or exceed the skill</u> of operational GFS**

- **Experimental <u>early (parallel) implementation</u> of FV3GFS in Q2FY18**

- **Simultaneous development and testing of <u>advanced physics and higher resolution</u> for FV3GFS**

- **<u>First official implementation of FV3GFS in Q2FY19</u>**

Physics: Two-Stream Strategy
NUOPC Physics Driver in NEMS using Community Common Physics Package

Physical Processes	Operational Physics	Advanced Physics* (CCPP – ongoing activities)
Radiation	RRTMG	RRTMGP (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

FV3 GFS Data Assimilation Plan (30 Nov 2016)

GFS Upgrade Timeline

FY18	FY19	FY20
GFS V15x	**GFS V15**	**GFS V16**
Early experimental implementation of FV3GFS	FV3GFS Operational	Advanced DA on FV3 Grid (JEDI/UFO)

Adapt GSI to FV3

GOES-R and JPSS DA

Incorporate JEDI/ UFO infrastructure

L128 modification

DA on FV3 Grid

1 Jan 2017   1 Jul 2017   1 Jan 2018   1 Jul 2018   1 Jan 2019   1 Jul 2019   1 Jan 2020   1 Jul 2020   1 Jan 2021
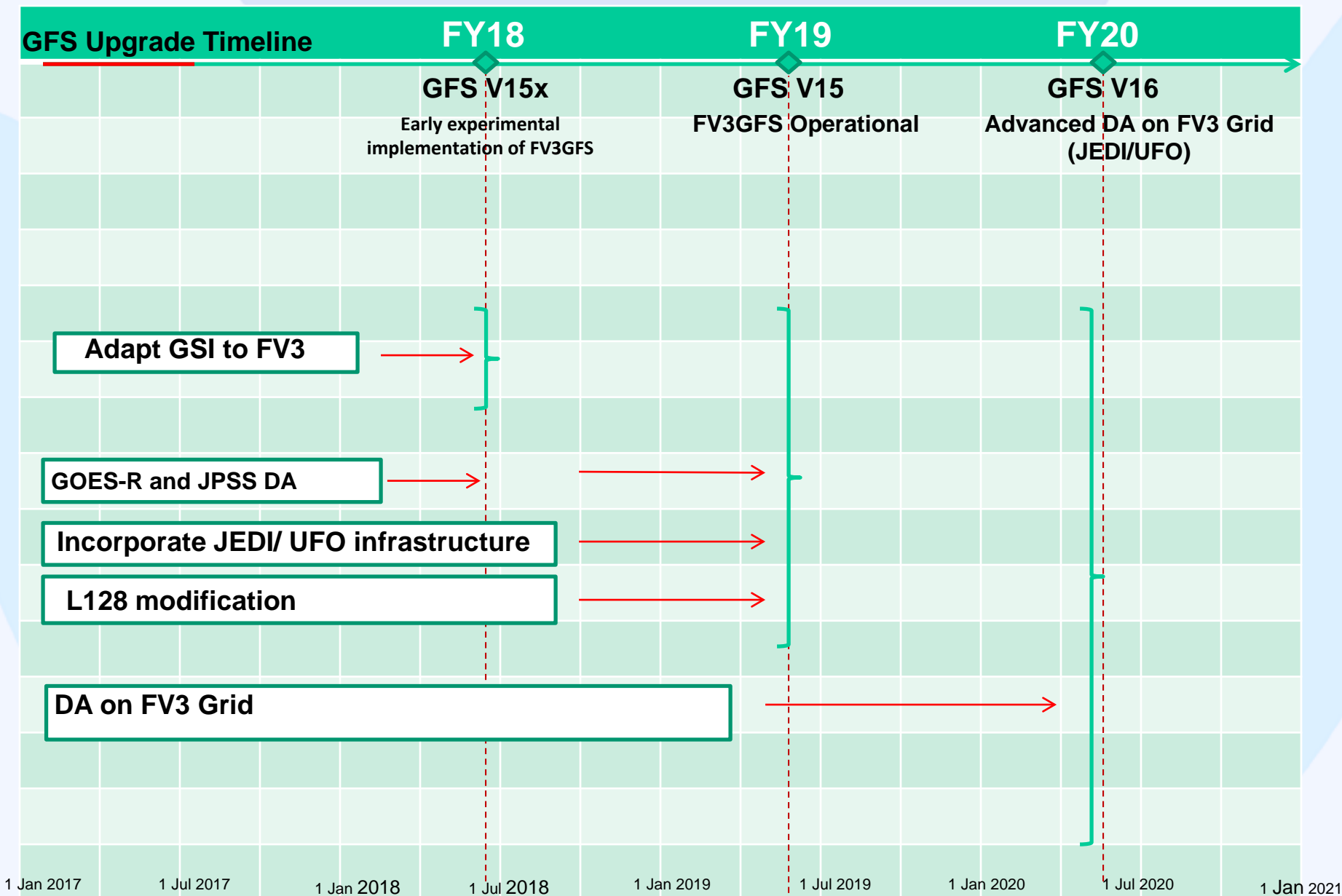
FV3 based GEFS v12 plan (proposed) with reanalysis and reforecast

GEFSv12 →   Development testing   Integration testing   Implementation testing

FY2017   FY2018   FY2019

Help develop and test the FV3 configuration used in reanalysis and real-time DA (ESRL)

NEMS/GFS (Final GSM) Implementation

Receive FV3 GFS codes and configure it for GEFS application (EMC)

NEMS/FV3GFS Available for reforecasts

Reanalysis production using FV3GFS (ESRL)

NEMS/FV3GEFSv12 reforecasts (EMC)

NEMS/FV3GFS in Operations

NEMS/FV3GEFS v12 Implementation

| 01/2017 | 07/2017 | 01/2018 | 07/2018 | 01/2019 | 07/2019 |

Proposed changes: 1) Start producing FV3-based reanalysis for GEFS v12 in ~Q1 FY18, using the configuration of FV3GFS. 2) Reforecasts will commence soon after starting the reanalysis, uncoupled*, with 2-tier SST approach, and will include extension to 35 days

Under-Dispersiveness of GEFS – A scientific challenge

GEFS-T254 vs. GEFS-T574 spread-error relationship 2016 TC track AL/CP/EP/WP

T574 ---- GEFS production-error
T254 ---- GEFS Legacy-error
S574 ---- GEFS production-spread
S254 ---- GEFS Legacy-spread

ETR vs. EnKF

Please note that, the model versions are different, model resolutions are different in additional to initial perturbations.

Opr – EnKF from 4DEnVar
Legacy – ETR cycling

CASES   307   285   254   230   199   157   118   91
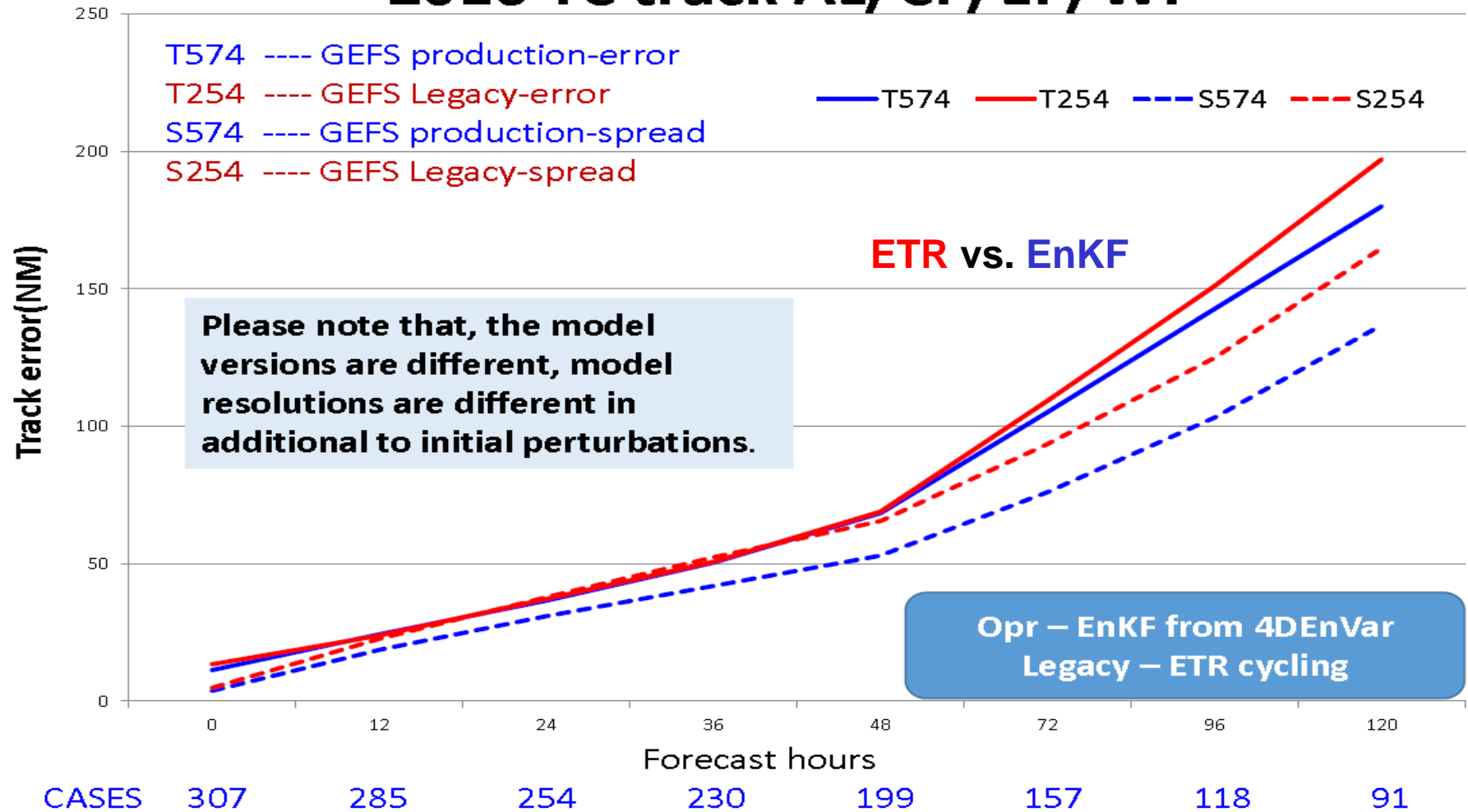
Need to move to advanced physically based stochastic parameterizations

GEFS-T254 vs. GEFS-T574 spread-error relationship
MATTHEW (AL14, 2016)

AEMN ---- GEFS production-error
LEGA ---- GEFS Legacy-error
S574 ---- GEFS production-spread
S254 ---- GEFS Legacy-spread
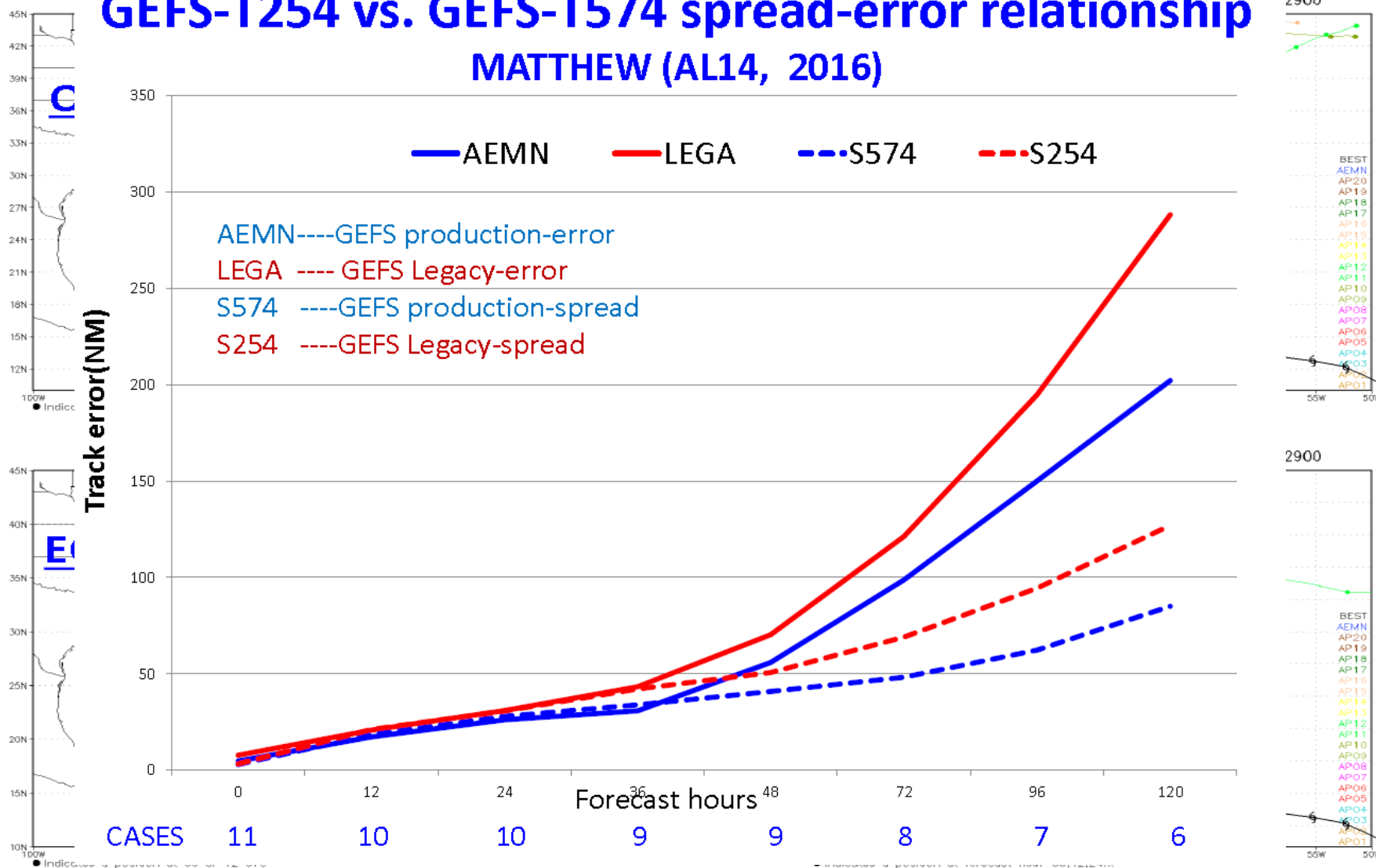
Coupling with Ocean and Sea-ice

Coupling with ocean and sea-ice model will add <u>significant risk</u> for reforecasts and GEFS v12 implementation

- UGCS Seasonal is ***NOT READY*** for testing extended range predictions for weather
- Will continue investigating the impact of coupling on GEFS forecast skill

- **For GEFSv12, use 2-Tier SST (e.g., bias corrected CFS predicted SST)**

Ongoing developments:
- Functions of ensemble capabilities in NEMS
- Finalize ocean (MOM6?) and sea-ice (SIS2 or CICE)
- Coupled DA development and scientific evaluation (JEDI)
- Retune the physics to address degradation and bias from coupling
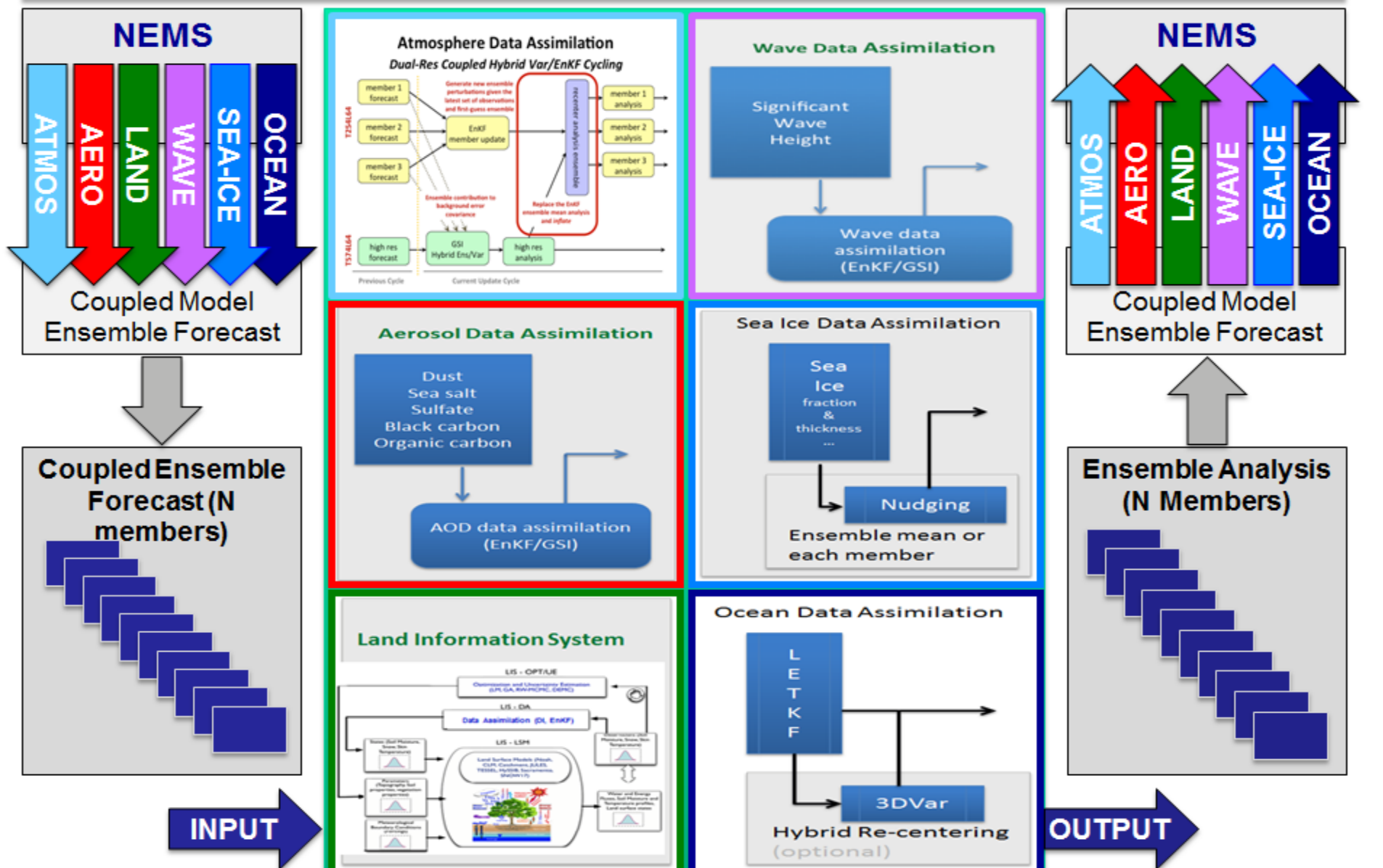- Strategies aligned with UGCS for all time scales

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

   o Parallel efforts to develop Unified Global Coupled System

   o 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)

COUPLED DA PROOF OF CONCEPT

- Atmosphere: Hybrid 4D-EnVAR approach using a 80-member coupled forecast and analysis ensemble and 128 levels in the vertical hybrid sigma/pressure coordinates.

- Ocean/Sea ice: GFDL MOM5.1/MOM6-SIS and/or HYCOM-CICE for the ocean and sea-ice coupling, using the NEMS coupler.

- Aerosols: Inline GOCART for aerosol coupling.

- Waves: Inline WAVEWATCH III for wave coupling.

- Land: Inline Noah Land Model for land coupling.

# NCEP Coupled Hybrid Data Assimilation and Forecast System

NEMS
ATMOS · AERO · LAND · WAVE · SEA-ICE · OCEAN

Coupled Model Ensemble Forecast

Coupled Ensemble Forecast (N members)

Atmosphere Data Assimilation
Dual-Res Coupled Hybrid Var/EnKF Cycling

member 1 forecast → member 1 analysis
member 2 forecast → member 2 analysis
member 3 forecast → member 3 analysis

EnKF member update

Generate new ensemble perturbations given the latest set of observations and first-guess ensemble

recenter analysis ensemble

Replace the EnKF ensemble mean analysis and inflate

Ensemble contribution to background error covariance

high res forecast → GSI Hybrid Ens/Var → high res analysis

Previous Cycle · Current Update Cycle

Wave Data Assimilation

Significant Wave Height

Wave data assimilation (EnKF/GSI)

Aerosol Data Assimilation

Dust
Sea salt
Sulfate
Black carbon
Organic carbon

AOD data assimilation (EnKF/GSI)

Sea Ice Data Assimilation

Sea Ice fraction & thickness ...

Nudging

Ensemble mean or each member

Land Information System

LIS - OPT/UE
Optimization and Uncertainty Estimation

LIS - DA
Data Assimilation (DI, EnKF)

LIS - LSM
Land Surface Models

Ocean Data Assimilation

LETKF

3DVar

Hybrid Re-centering (optional)

NEMS
ATMOS · AERO · LAND · WAVE · SEA-ICE · OCEAN

Coupled Model Ensemble Forecast

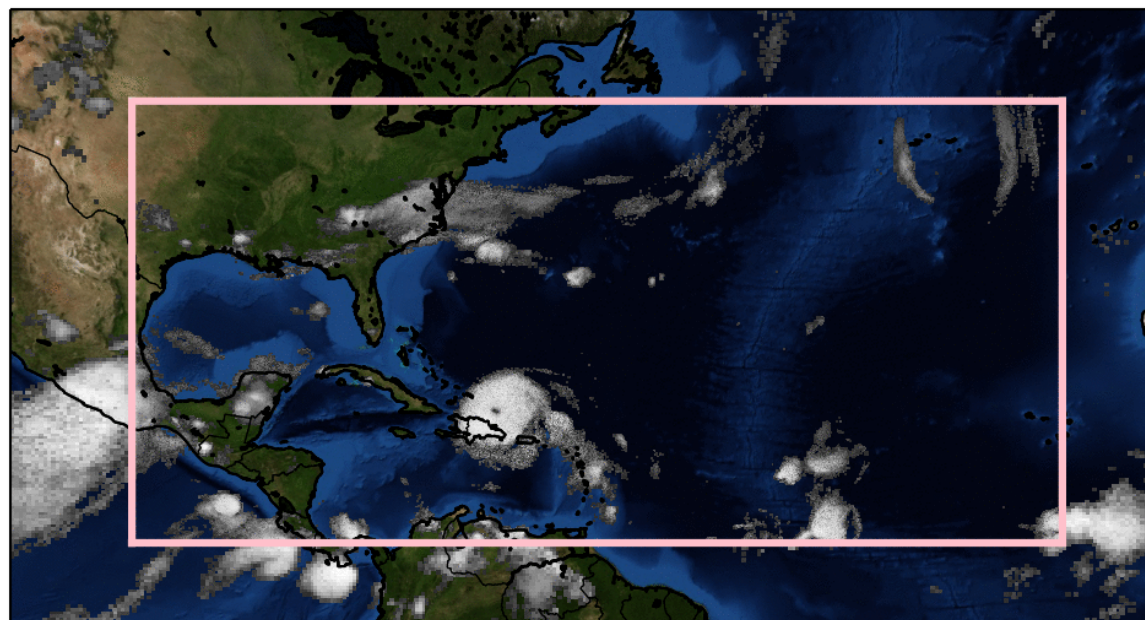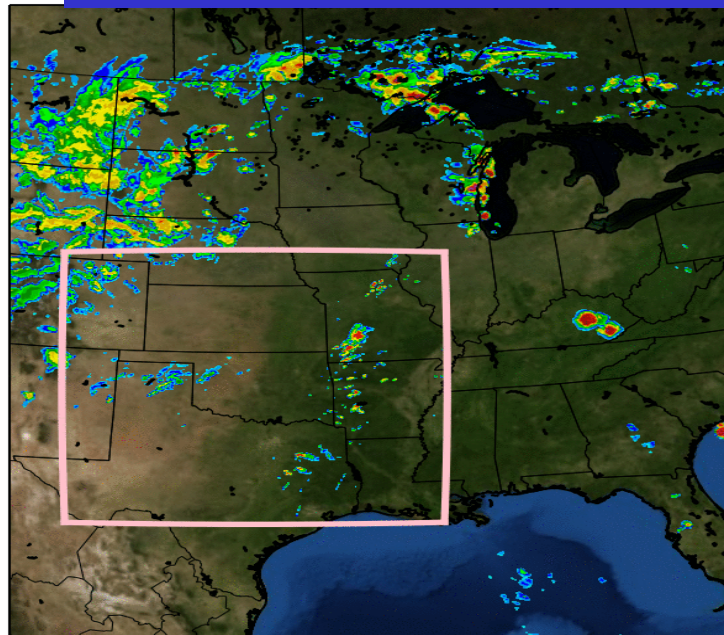Ensemble Analysis (N Members)

INPUT

OUTPUT

Adapted from Saha

FV3/NEMS based Global-Meso Unification including hurricanes (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
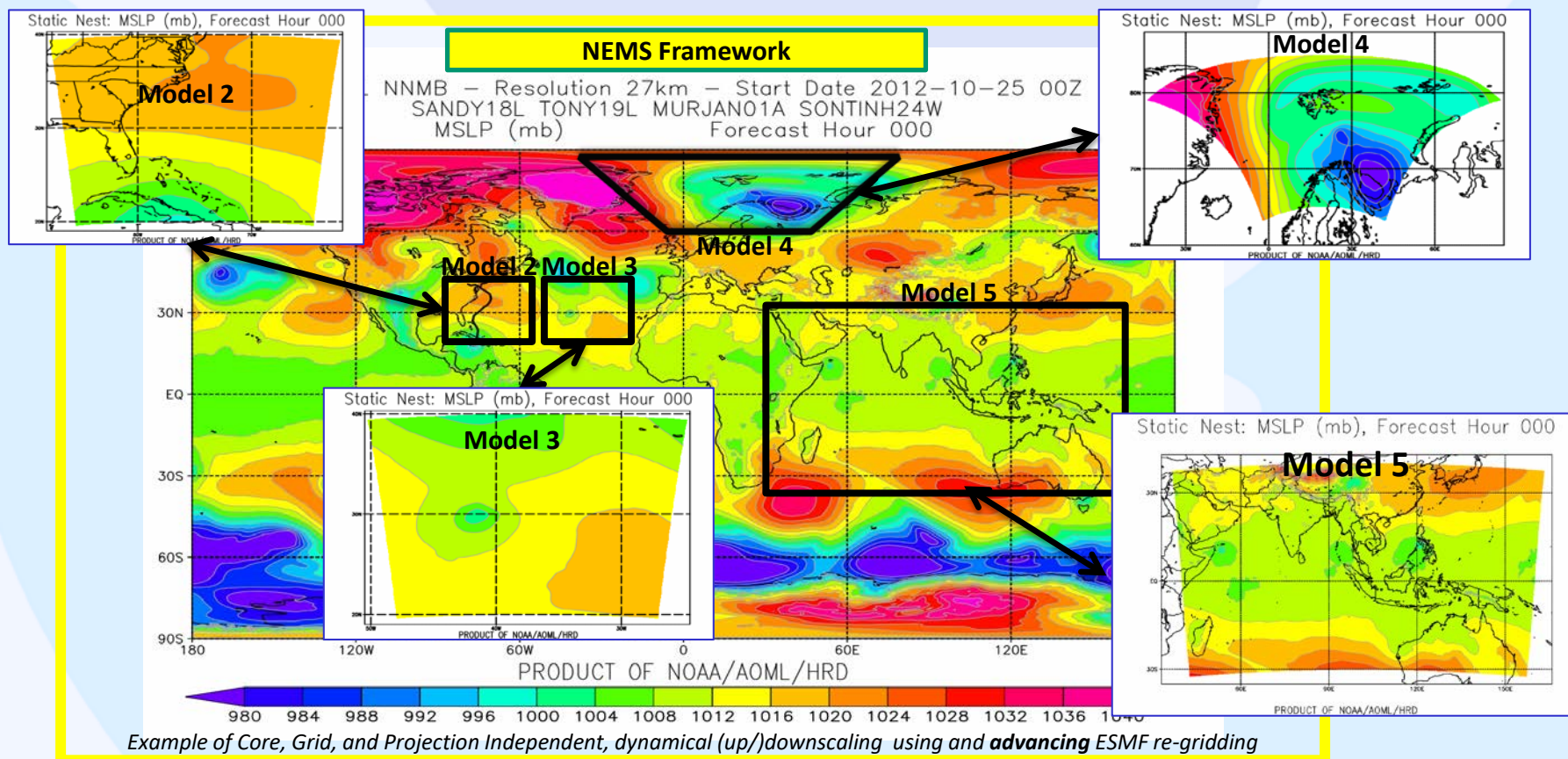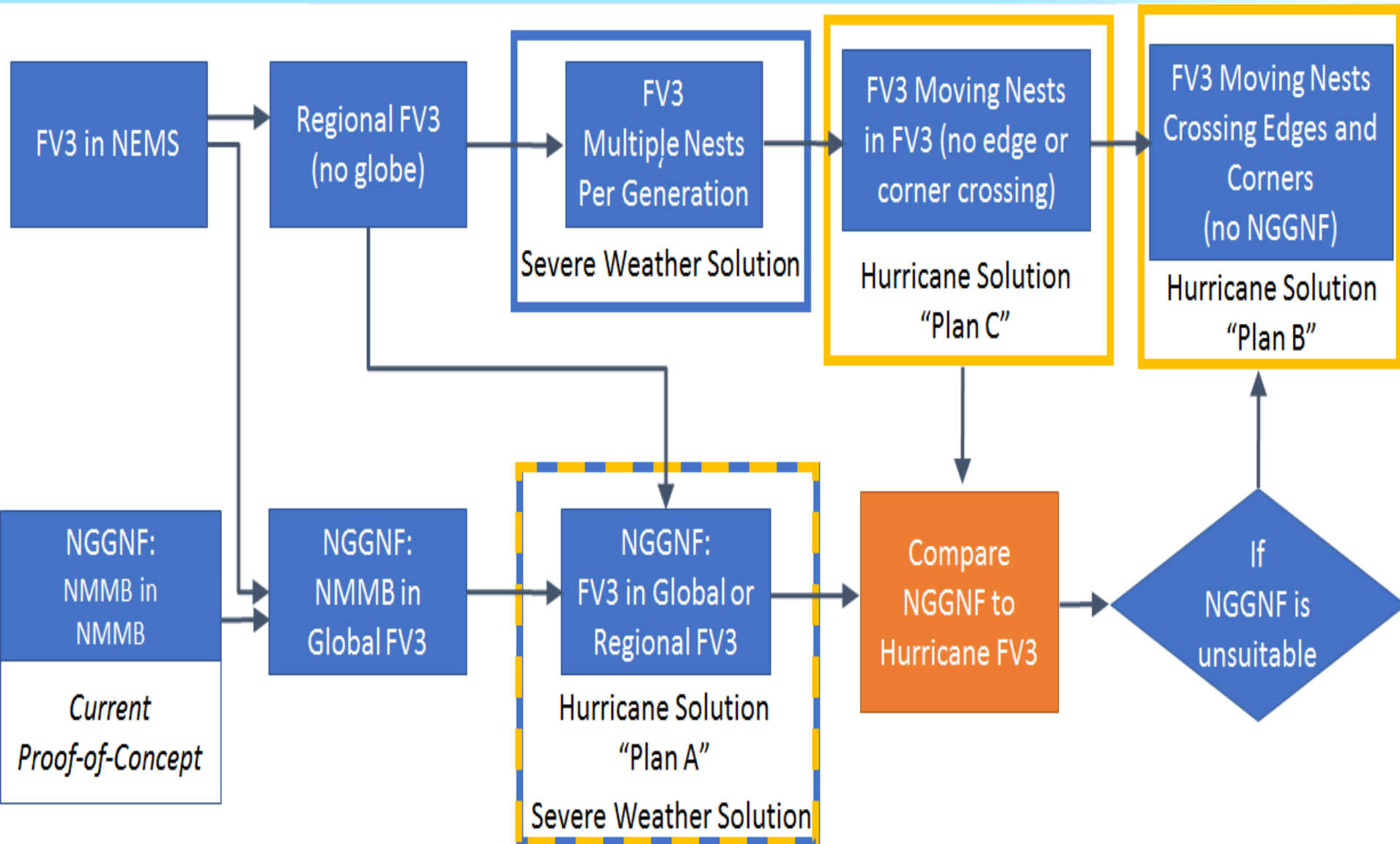
20-May-2013
20:20:00
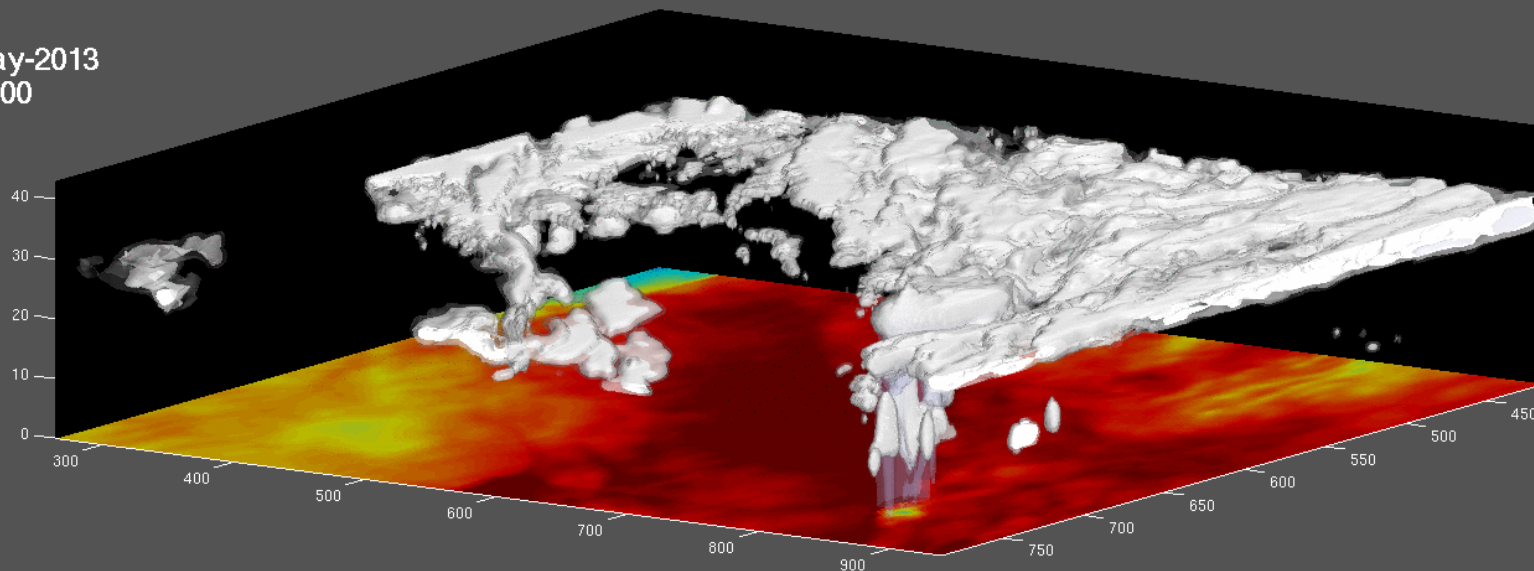
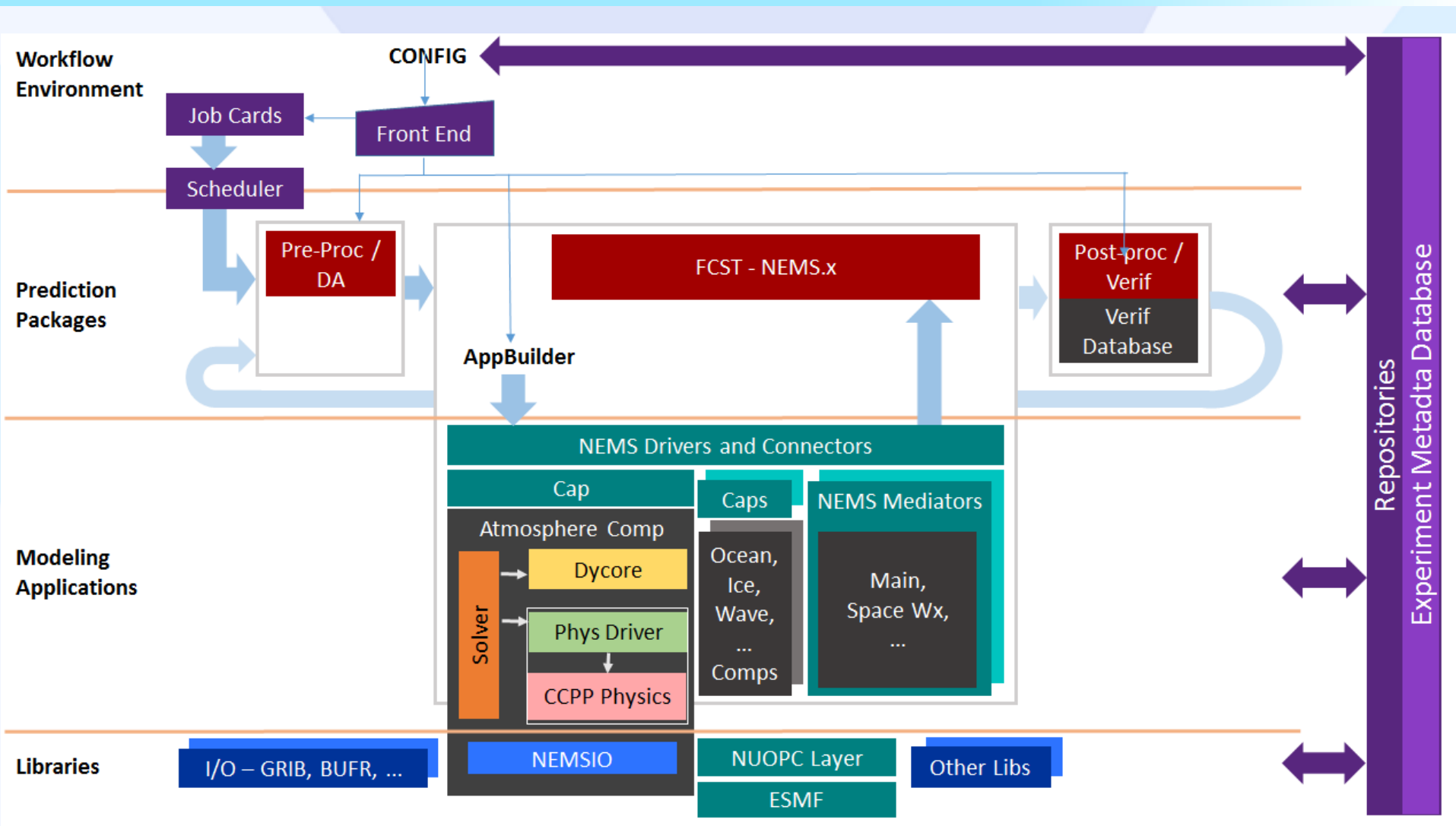FV3 for convective scale forecasts – path forward for global-meso unification??

Example: Generalized Nesting By Coupling

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

Schematic of Global-to-local scale modeling for severe weather and hurricanes

Unified Modeling System Architecture

Summary

➢ Aggressive implementation strategy for NGGPS (GFDL FV3) for weather, sub-seasonal and seasonal prediction 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

➢ Continued improvement of hurricane track and intensity forecast skill remains one of the major objective of NGGPS and NCEP