Operational Modeling at EMC: Path Forward

Vijay Tallapragada

The Environmental Modeling Center
NOAA / NWS / NCEP

Focus areas: Global Modeling & NGGPS

With inputs from: Hendrik Tolman, Senior Advisor for Advanced Modeling Systems, NWS/STI

Outline

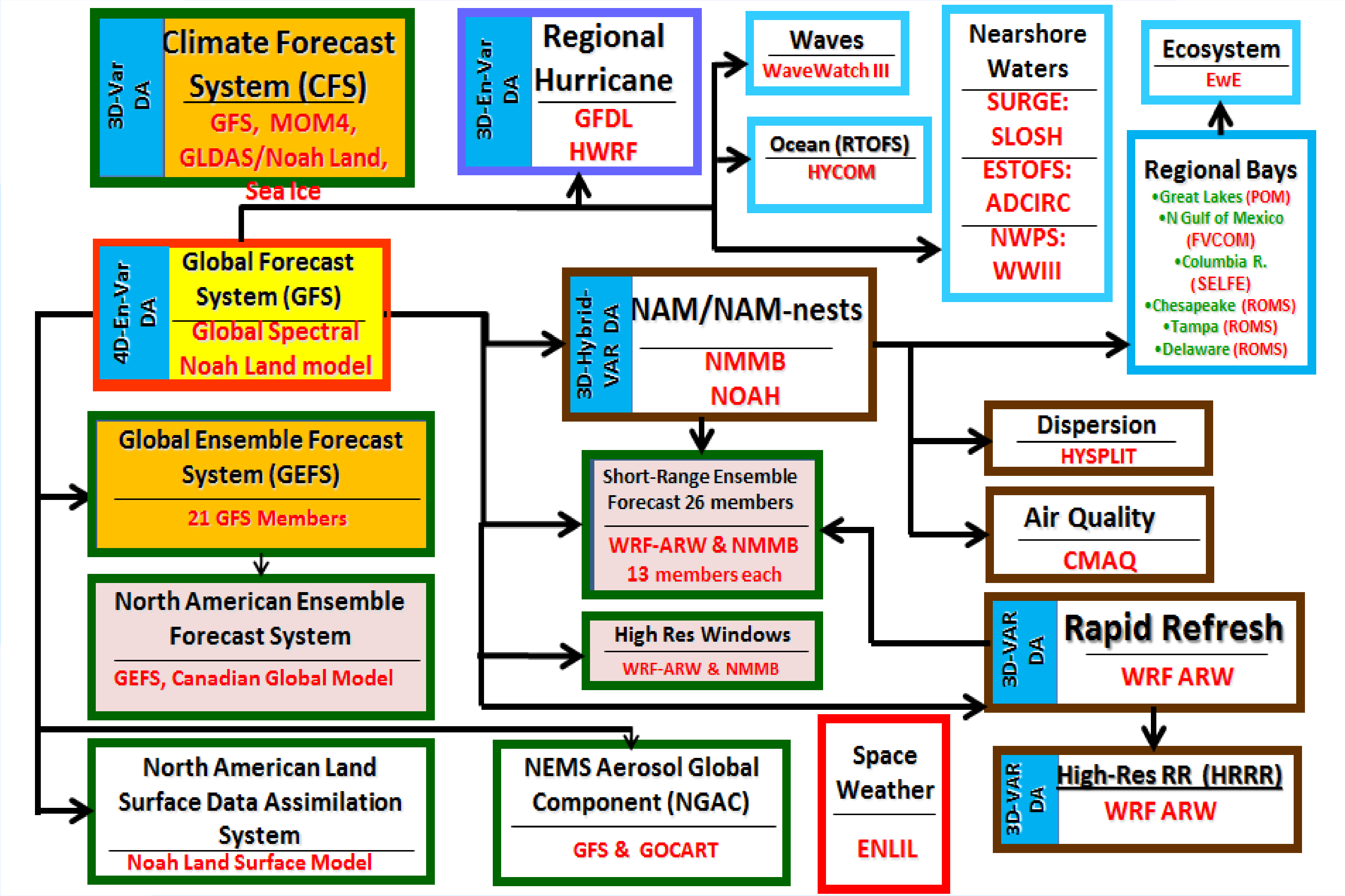
The present production suite

- Too complicated
- Too much
- More is requested!

Basic issues, UMAC findings and interpretation

Basic approach: Unified Modeling Efforts Supported by NGGPS

- Atmosphere
- Coupling
- Data Assimilation



Production suite ca. March 2016

Emerging requirements

- Weather Ready Nation.
  - Products.
  - Social science.
- High impact events.
- Weather to climate—seamless suite of guidance and products.
  - Week 3-4.
  - Systematic reforecast need.
    - Forecast uncertainty.
    - Calibration of outlook products.
- Range of products beyond weather:
  - Land, ice, ocean, waves, aerosols, (ecosystems, space weather).
  - Water cycle, National Water Center (NWC).

UMAC main recommendations

- Reduce the complexity of the NCEP Production Suite.
- The NOAA environmental modeling community requires a rational, evidence-driven approach towards decision-making and modeling system development.
- A unified, collaborative strategy for model development across NOAA is needed.
- Essential to effective planning and execution is the creation of a Chief Scientist position for Numerical Environmental and Weather Prediction (NEWP). NOAA needs to better leverage the capabilities of the external community
- NOAA must continue to enhance High Performance Computing (HPC) capabilities
- NOAA must develop a comprehensive and detailed vision document and strategic plan that maps out future development of national environmental prediction capabilities.
- Execute strategic and implementation plans based on stakeholder requirements.

https://www.earthsystemcog.org/projects/umac_model_advisory

Basic issues / UMAC

Moving away from implementing solutions:

- Need better NWS requirements process
- Map requirements to products (not models)
- Target model development to better serve requirements
  - Community involvement from start
- Business case is integral part of decisions:
  - Unified model with concentrated effort, versus
  - models tailored to selected requirements

Additional considerations

- Coupled modeling needs to be considered in this context
- Focus on predictability and outlook products requires systematic ensemble / reanalysis (retrospective) / reforecast approach
- Data assimilation

Basic approach : atmosphere

Start with weather side:

- We are NWS !

Starting with products:

- What forecast time ranges
- which reasonably imply
  - Run cadences
  - Update cycle.
- Not so clear:
  - Resolutions
  - Data Assimilation
  - Reforecast / reanalysis / retrospectives
- Need to map requirements to forecast ranges

Possible Approach			
Range	Target	Cadence	Means
year	Seasonal	?	9-15mo
month	S2S	6-24h	35-45d
week	Actionable weather	6h	3-16d
day	Convection resolving	1h	18-36h
hour	Warn On Forecast *	5-15 ‘	3-6h
now	Analyses **	?	now

* FACETs
** Separating from DA for models

Tentatively vetted at the Dec. 2015 NCEP Production Suite Review

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 products
- Produce “too much” compared to tailored products (forecast range)

Basic approach : coupling

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

- Where no products exists, 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)

Subsystem	Year	Month	Week	Day	Hour
Land / hydro	Y	Y	Y	S	?
Ocean / coast	Y	Y	Y	S/R	?
Ice	Y	Y	S	?	?
Waves	S	Y	Y	Y	?
Aerosols	S	S	Y	Y	?
Space weather	?	?	Y	?	?

Y: present product
S: science benefit
R: unmet requirement
?: TBD

Basic approach : DA

Unifying on GSI based hybrid 4D-EnVAR.

Global focus:

- Is a single DA system for all global model applications feasible?
  - Freeze or update DA for ensembles and climate applications
- Where do we go with coupled DA?
- Issues:
  - Scaling of GSI
  - Resolution of underlying ensemble

JEDI:

- Unifying infrastructure for all DA applications
- Community engagement & support

Modeling systems

Again starting with atmosphere

- Mapping existing elements of NPS to forecast ranges

Address coupling

- For each additional model suite element map present products to the six forecast ranges
  - Including space weather
  - Excluding marine ecosystems for now

Data assimilation

- Table with DA for forecast ranges and components

Models: atmosphere

Range	Year	Month	Week	Day	Hour	Now
Target	Seasonal outlook	S2S outlook	Actionable weather	Convection resolving	Warn On Forecast	Analyses / nowcast
Present models	CFS	CFS (GEFS extension)	GFS, GEFS, NAM, SREF, RAP, hurricane	HRRR, NAM nest, HiresW		RTMA, URMA, blend
Cadence	? (is 6h)	24h (is 6h)	6h	1h	5-15'	?
Range	9-15mo global	35-45d global	3-16d global (?)	18-36h regional (?)	3-6h ? regional	0 regional (?)
Updates	4y	2y	1y	1y	1y	6 mo
Reanal.	1979-now	20-25y	3y	?	?	
Where	?	WCOSS	WCOSS	WCOSS	?	WCOSS

- Ensemble based DA for all ranges (day and hour TBD), except possibly for the now range
- All global applications from single unified modeling system.
- Global / regional unification ?

- Present NPS elements not fitting in this layout:
  - Space weather (WAM-IPE / Geospace).
  - Hurricane models (GFDL / HWRF).

Models: ocean

black: existing
red: studies suggest benefit

<table>
<tr><th colspan="2">Range</th><th>Year</th><th>Month</th><th>Week</th><th>Day</th><th>Hour</th><th>Now</th></tr>
<tr><td colspan="2">Present models</td><td>CFS</td><td></td><td>RTOFS, ESTOFS, PSURGE, ….</td><td></td><td></td><td>RTGSST, +4</td></tr>
<tr><td colspan="2">Unmet req.</td><td></td><td>MOM/HYCOM</td><td></td><td colspan="2">TBD</td><td></td></tr>
<tr><td rowspan="7">coupling input for</td><td rowspan="2">Atmos.</td><td rowspan="2">dynamic</td><td colspan="4">fixed SST fields</td><td rowspan="2"></td></tr>
<tr><td colspan="3">dynamic coupling (SST, inundation)</td><td>TBD</td></tr>
<tr><td>Land / H.</td><td colspan="4">inundation (fresh-salt coupling)</td><td></td><td></td></tr>
<tr><td>Ice</td><td>dynamic</td><td colspan="2">dynamic</td><td colspan="2">TBD</td><td></td></tr>
<tr><td>Waves</td><td colspan="5">momentum exchange, water level (depth), inundation</td><td></td></tr>
<tr><td>Aerosols</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Space W.</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

- DA: unify GODAS, NCODA, GSI?
- Coastal processes:
  - 2D for inundation focus
  - 3D for water quality focus

- Present models not fitting in ranges:
  - Tsunami
  - Other regional subdivision than CONUS
  - Mix of 2D and 3D approaches at same ranges

Models: ice

black: existing
red: studies suggest benefit

Range		Year	Month	Week	Day	Hour	Now
Present models		CFS	GEFS, ice drift	RTOFS-G			ice conc.
Unmet req.					TBD		new pars.
coupling input for	Atmos.						
	Land / H.						
	Ocean						
	Waves						
	Aerosols						
	Space W.						

- Ice is static input in waves, …..

- Present models not fitting in ranges:
  - none

Models: waves

black: existing
red: in prep / suggested benefits

Range		Year	Month	Week	Day	Hour	Now
Present models			GWES	multi_1, multi_2, GLW			RTMA
Unmet req.		TBD		(rip current)	TBD (rip current)	TBD	new pars
coupling input for	Land / H.	coastal inundation					
	Ocean	surface fluxes, momentum exchange, Stokes drift, Langmuir mixing, bottom friction, turbidity (sediment agitation)					
	Ice	compacting, ice break up					
	Aerosols	sea spray					
	Space W.	no direct linkage					

- DA: presently not used, moving to ensemble based GSI
- Wave models generally have a shorter forecast horizon than the atmospheric models driving them (coupling will result in longer runs)

- Present models not fitting in ranges:
  - Multi_2 (HWRF driven).
  - NDFD driven GLWN.
  - NWPS (on demand).

Data Assimilation

black: existing
red: studies suggest benefit

component	Year	Month	Week	Day	Hour	Now
Atmos.	GSI	GSI	Hybrid GSI	Hybrid GSI	Hybrid GSI	GSI
Land / H.						
Ocean	GODAS	GODAS	NCODA			
Ice						
Waves			GSI	GSI		
Aerosols						
Space W.						

Where to go from here

v1.0

A look forward and compute resources estimates are discussed in a separate whitepaper, starting from the table with forecast ranges in Part I. Guiding principles (repeat):

- Five key forecast ranges
- All probabilistic,
  - Away from high resolution deterministic supported by low resolution ensemble,
  - **but that still may be needed in transition ….**
- Coupled.

For each NPS element, the next slides consider

a. Tentative layout
b. Present status
c. Key science questions
d. Implementation issues

v1.0

Year:

Tentative layout:

- 50km resolution, 9-15 month forecasts, full ensemble, updating weekly. Assuming DA mostly from hourly range, coupled

Present status:

- Corresponds to present CFS, but will only include longest runs

Key science questions

- Predictability; what to focus on for products
- Advanced coupling
- Physics suitable for severe weather outlook

Implementation issues:

- Dropping 45 day runs of present CFS requires “month” solution to be in place, otherwise “trivial”.

Month:

v1.0

Tentative layout:

- Extend present weather scale ensembles out to week 3-4.
- 35km resolution (constant for forecast), coupling (ocean, ice, ?), increased ensemble size, DA from week range ?

Present status:

- Extend range of GEFS without stepping down resolution
- Could be uncoupled baseline IOC, but coupling preferred

Key science questions:

- Predictability, target products
- Need / payback for coupling
- Physics improvements (severe weather outlook)

Implementation issues:

- Slot can be filled by natural extension of GEFS v1.0

Week:

Tentative layout:

- *High-Resolution Global Deterministic Medium Range Forecast system (10-day forecast with hourly output & 6h cadence)*
- Focal point for global DA.
- At least 1-way coupling for other component products
- Global 10-13km resolution full ensemble (21-26 members?), 5-7 day forecast at 6h cadence.

Present status:

- GFS, GEFS, NAM, SREF, RAP, hurricane all have element to be merged in this (single) product
- Wave, ocean, ice, aerosol all have “downstream” products in this range

Week (cont'ed):

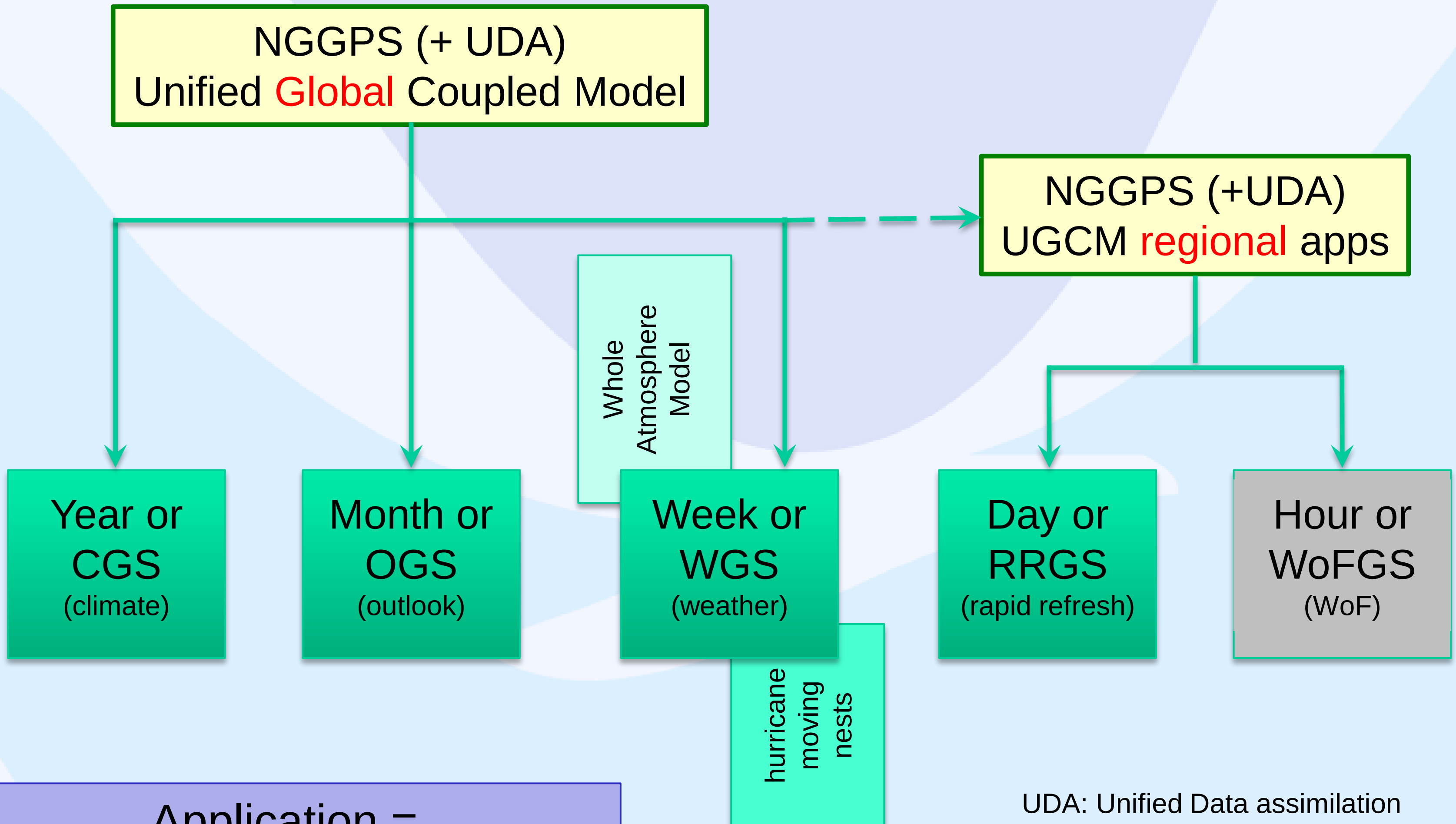
Key science questions:

- Develop suitable single-core ensembles at this scale
- Develop scale aware and stochastic "unified" physics
- DA development, in general,
  - higher cadence for DA to support full suite?
- How and where to merge space weather and hurricanes
- Move this eventually into "grey zone" resolutions?

Implementation issues:

- Consolidating of models in a single set of products will be tricky
  - Products for users (availability, quality)
  - Transition downstream dependencies (regional models)
  - Develop incremental plan
- Larger relative resources needed compared to longer forecast ranges (due to regional → global ensembles)

Unified design (high level goal)



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

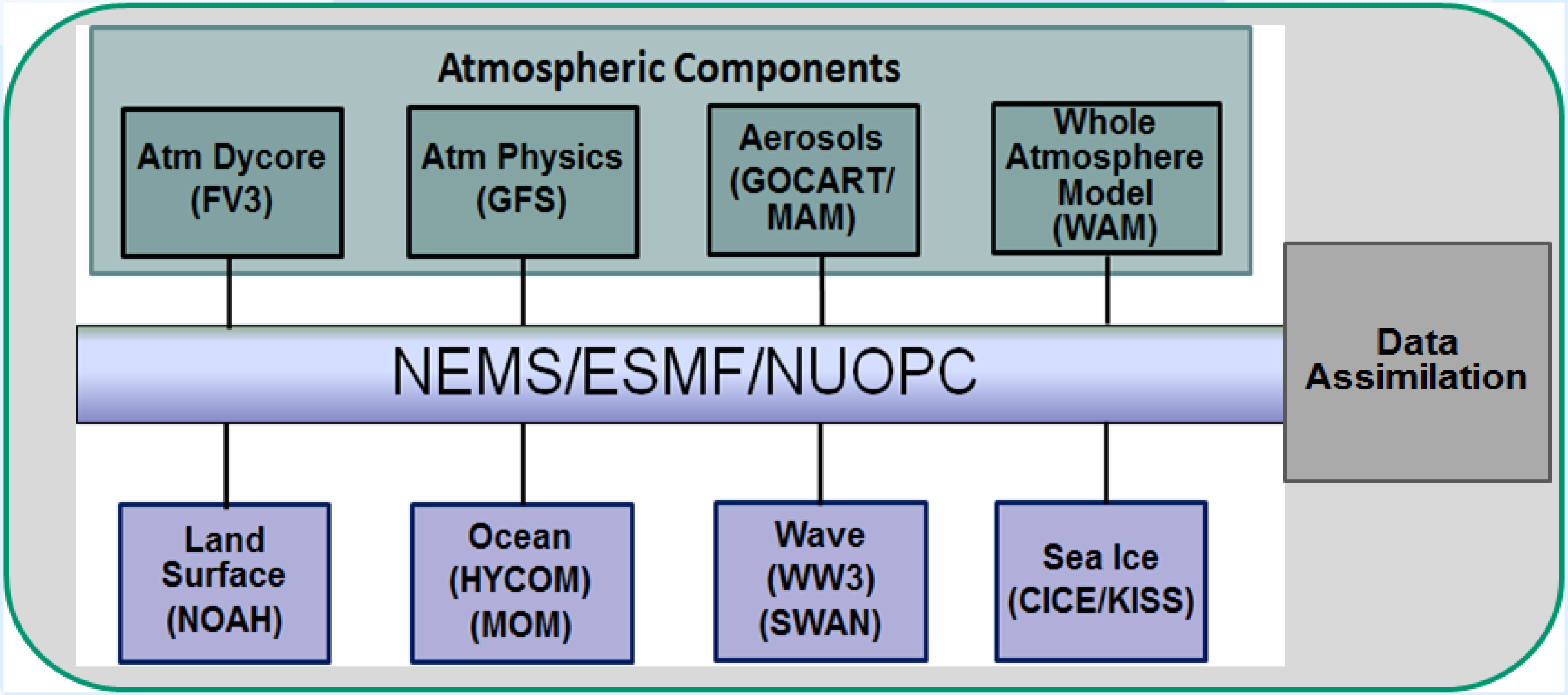
(Next Generation Global Prediction System)

NWS R2O funding and NGGPS projects.

- NWS as a funding agency.
  - Fund gaps in operations.
  - Project based funding for strategic development.
    - Within US government.
    - Academia, with NWS partners / champions.
  - Test beds for R2O.

- Key element: Next Generation Global Prediction System.
  - GFDL FV3 as the Next generation Dycore.
  - Unified physics interface, focus on physics.
  - 11 more NGGPS teams ….
  - Model Coupling
    - Started with Climate Forecast System

Unified System using NEMS/ESMF



Modular modeling, using ESMF to modularize elements
in fully coupled unified global model
(+ *NWM, ionosphere , ecosystems , ……*)

NGGPS physics

Scale aware
Stochastic
"Unified"

Atmosphere Model including Dynamics

Dynamical equations, advection, horizontal mixing, diffusion.

standard interface for model physics

Δt, u, v, w, T, θ, p, z, q_x, c_x, a_x destaggered

Tendencies and Updates

Atmospheric Physics Driver

(init, run, finalize modes)

Modified Kalnay Rules Layer

- Radiation
- Deep and Shallow Cumulus
- Surface Layer
- PBL and Vertical Mixing
- Micro-physics

Initialize Physics Tables and Databases

Init Mode

Finalize Mode.

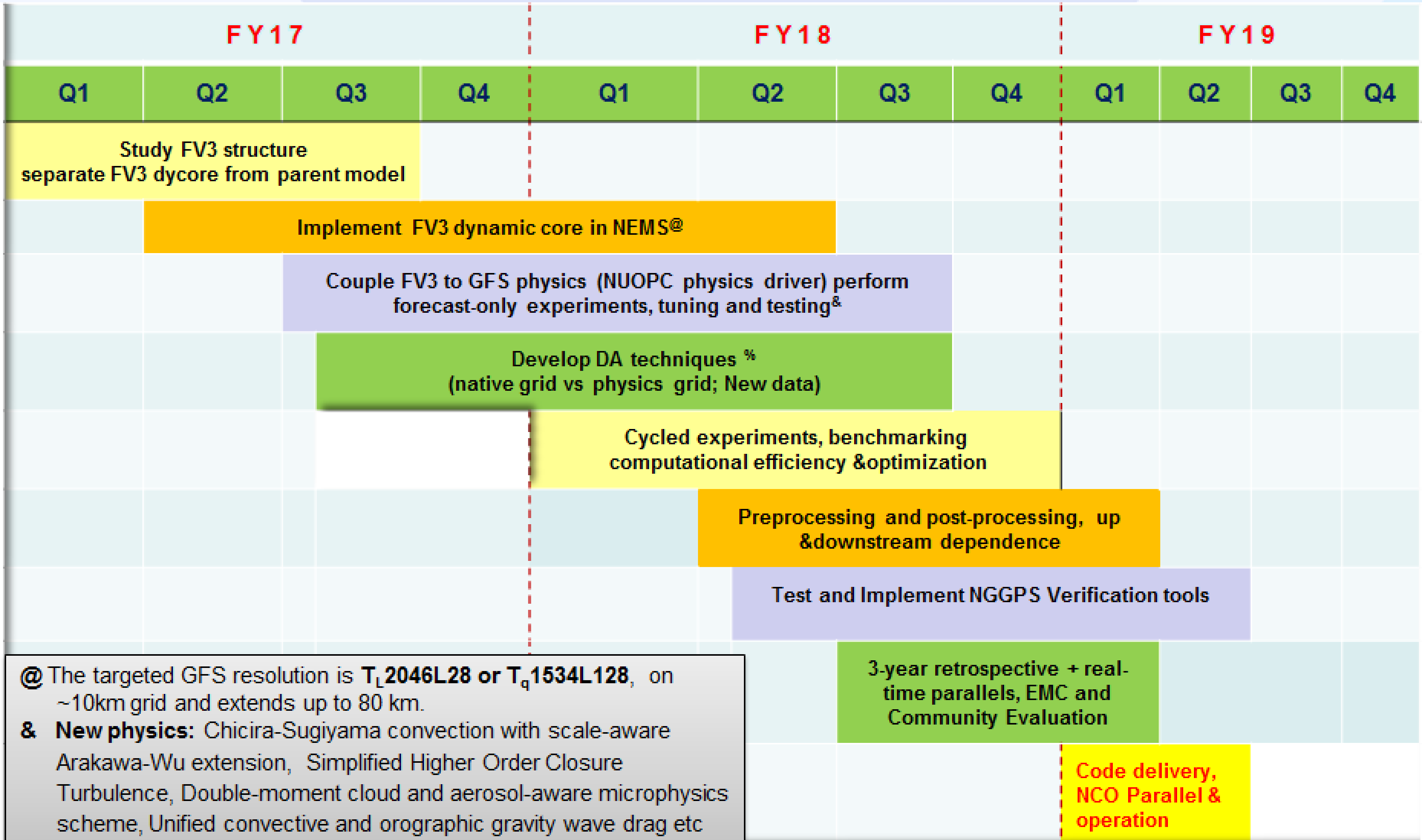
Output Diagnostics
- fields
- rates
- budgets
- others

NUOPC Physics Driver Schematic

Extend to coupling!

DTC/GMTB support as CCPP

Implementation Plan of FV3 in NEMS GFS



@ The targeted GFS resolution is **T_L2046L28 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

Next Steps

- Integrate Aerosol and Atmospheric Composition Module (NGAC) for FV3 based GFS in NEMS
  - Aerosol DA requirements
- Implement FV3 dynamic core for GEFS in NEMS
  - Reanalysis/Reforecast requirements
  - Coupled System
  - Coupled DA
- Implement FV3 dynamic core for CFS in NEMS
  - Fully coupled system with strongly coupled DA
  - Reanalysis/Reforecast requirements
- Design and development of high-resolution generalized nesting capabilities in NEMS
  - Movable, two-way interactive
  - Subsume hurricane models
- Global-Meso Unification

Guiding Principles (following UMAC recommendations)

- Reduce the complexity of the NCEP Production Suite
- Rational evidence-driven approach towards decision-making and end-to-end modeling system development
- A unified, collaborative strategy for model development across NOAA
- Better leverage the capabilities of the external community
- Develop a comprehensive and detailed vision document and strategic plan that maps out future development of national environmental prediction capabilities
- Execute strategic and implementation plans based on stakeholder requirements
- Community Modeling and support (internal and external)
- Governance (internal and external)
- Project Management approach (planning for success)

Questions?