The NOAA Operational Numerical Guidance System: EMC overview

Hendrik Tolman, Michael Ek et al
Environmental Modeling Center (EMC)
NOAA/NWS/NCEP

CICS/CPC and EMC mini-workshop at ESSIC
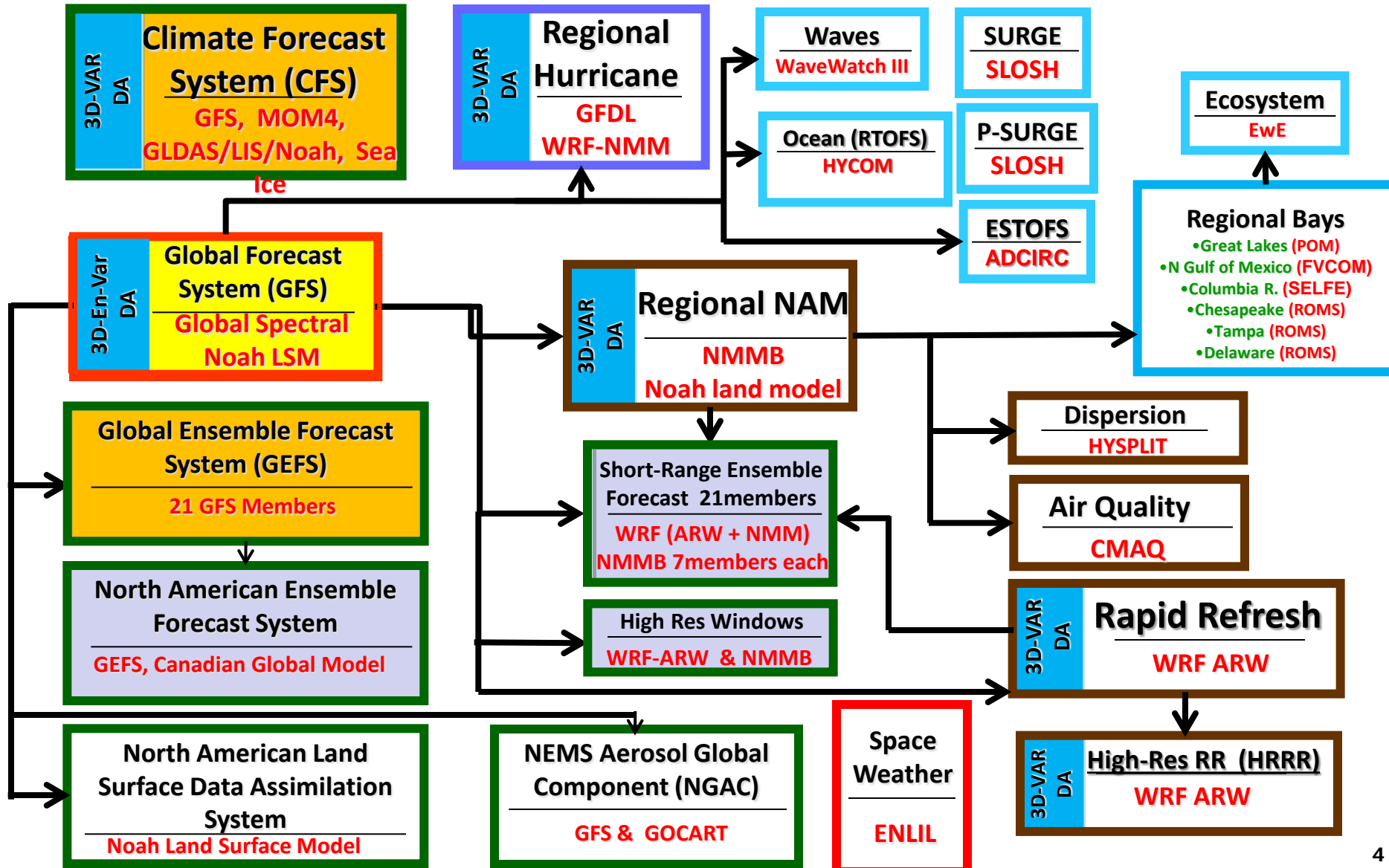**College Park, Maryland, USA, 6 May 2015**

Outline

- **NCEP and EMC**

- **Production Suite**

- **Components:**
  - **Data Assimilation**
  - **Global Forecast System (GFS), Global Ensemble (GEFS)**
  - **Unified Global Coupled System (medium-range to seasonal)**
  - **North American Multi Model Ensemble (Seasonal)**
  - **North America Mesoscale (NAM) model, Hurricane (HWRF), Short-range Ensemble Forecast (SREF)**
  - **Hurricane, Land-Hydrology, Ocean, Sea-ice**
  - **NOAA Environmental Modeling System (NEMS)**

- **NCEP/EMC Model Evaluation Group (MEG)**

National Centers for Environmental Prediction Specialized Services – Common Mission

Environmental Modeling Center

Numerical Forecast Systems

RAP | GFS | WAVEWATCH III®
SREF | CFS | RTOFS
ARL / HYSPLIT | NAQFC | SEA ICE
NOAH LAND-SURFACE | GEFS | SST
NAM | HWRF | NEMS
| GFDL |

EMC: Enhancement, transition, and maintenance of numerical mo[...] that provide operational guidance.

CICS/CPC and EMC mini-workshop, ESSIC, College Park, Maryland, USA, 6 May 2015

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NOAA's Operational Numerical Guidance Suite (Feb 2015)

Climate Forecast System (CFS)
3D-VAR DA
GFS, MOM4, GLDAS/LIS/Noah, Sea Ice

Regional Hurricane
3D-VAR DA
GFDL
WRF-NMM

Waves
WaveWatch III

SURGE
SLOSH

Ocean (RTOFS)
HYCOM

P-SURGE
SLOSH

ESTOFS
ADCIRC

Ecosystem
EwE

Global Forecast System (GFS)
3D-En-Var DA
Global Spectral
Noah LSM

Regional NAM
3D-VAR DA
NMMB
Noah land model

Regional Bays
•Great Lakes (POM)
•N Gulf of Mexico (FVCOM)
•Columbia R. (SELFE)
•Chesapeake (ROMS)
•Tampa (ROMS)
•Delaware (ROMS)

Global Ensemble Forecast System (GEFS)
21 GFS Members

North American Ensemble Forecast System
GEFS, Canadian Global Model

Short-Range Ensemble Forecast 21members
WRF (ARW + NMM)
NMMB 7members each

High Res Windows
WRF-ARW & NMMB

Dispersion
HYSPLIT

Air Quality
CMAQ

Rapid Refresh
3D-VAR DA
WRF ARW

North American Land Surface Data Assimilation System
Noah Land Surface Model

NEMS Aerosol Global Component (NGAC)
GFS & GOCART

Space Weather
ENLIL

High-Res RR (HRRR)
3D-VAR DA
WRF ARW

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Data Assimil. Plans: Next Global Implementation (~Dec. 2015)

- Hybrid 4D EnVar:
    - Hourly time bins (7 time levels per analysis).
    - 80 ensemble members.
    - T1534L64 deterministic with T574L64 ensembles used for T574 analysis increments
    - Modified thinning of data in time.
- Observation changes:
    - Cloudy Microwave Radiances: Cloud analysis impacted by covariances from Hybrid and cloud impacted microwave radiances.
    - Upgraded CRTM2.2.
    - Additional aircraft and AMV data.
    - Bias correction of aircraft temperature observations.
- NSST:
    - Variation in Near Sea-Surface Temperature of ocean included in both forecast model and analysis.
    - Directly uses radiances and accounts for depth of observations in NSST analysis.
    - Diurnal cycle of Ocean and observations accounted for much better.

Global Model Plans

Q2FY15 implementation (January 14, 2015)
- T1534 Semi-Lagrangian (~13km)
- Use of high resolution daily SST and sea ice analysis
- High resolution until 10 days
- Physics:
  - Radiation modifications
  - Reduced drag coefficient at high wind speeds
  - Stationary convective gravity wave drag
  - Soil Moisture climatology from CFSv2
  - Changes to roughness length calculations

FY16
- NEMS
- 4D-Hybrid EnVAR
- Convective upgrade
- Land and surface layer upgrade

FY17
- T1534L64 –> T1534L128
- Enhanced physics

Aerosol prediction – initially lower resolution used as forcing in high res.

WAM – Whole Atmosphere Model – initially lower resolution up to 600km

Mark Iredell

Global Ensemble Plans

	Current	Next GEFS Configuration (v11.0.0)
Model	GFS Euler model (V9.0.1)	GFS Semi-Lagrangian model (V10.0.0)
Horizontal res.	T254 (~52km) for 0-192 hours, T190 (~70km) for 192-384 hrs	TL574 (~34km) for 0-192 hours, TL382(~52km) for 192-384 hr
Vertical res.	L42 hybrid levels	L64 hybrid levels to match GFS and DA
Compute	84 nodes (+ post process) for 55 minutes	300 nodes (first 35 minutes), 250 nodes (2nd 30 minutes)
Output	every 6-hr for 1*1 degree pgrb files	every 3-hr for 0.5*0.5 degree pgrb files
Schedule	Feb. 2015 – deliver codes/scripts to NCO	Apr. 2015 – implementation (WCOSS-phase II)

- **Increase model resolution and membership.**
- **Introduce other stochastic schemes:**
  - Stochastic Kinetic Energy Backscatter (SKEB) represents processes absent from model.
  - Stochastic Perturbed Physics Tendencies (SPPT) designed to represent the structural uncertainty (or random errors) of parameterized physics. Biggest impact for tropics.
  - Stochastically-perturbed boundary layer HUMidity (SHUM) designed to represent influence of sub-grid scale humidity variability on the the triggering of convection.
  - Stochastic perturbed land-surface.
- **Extend GEFS to 35 days: Coupling with ocean/ice model, or alternate method.**

Yuejian Zhu

NCEP Unified Global Coupled Hybrid Data Assimil. and Forecasting Suite: *Atmosphere, Land, Ocean, Sea-ice, Wave, Chemistry, Ionosphere*
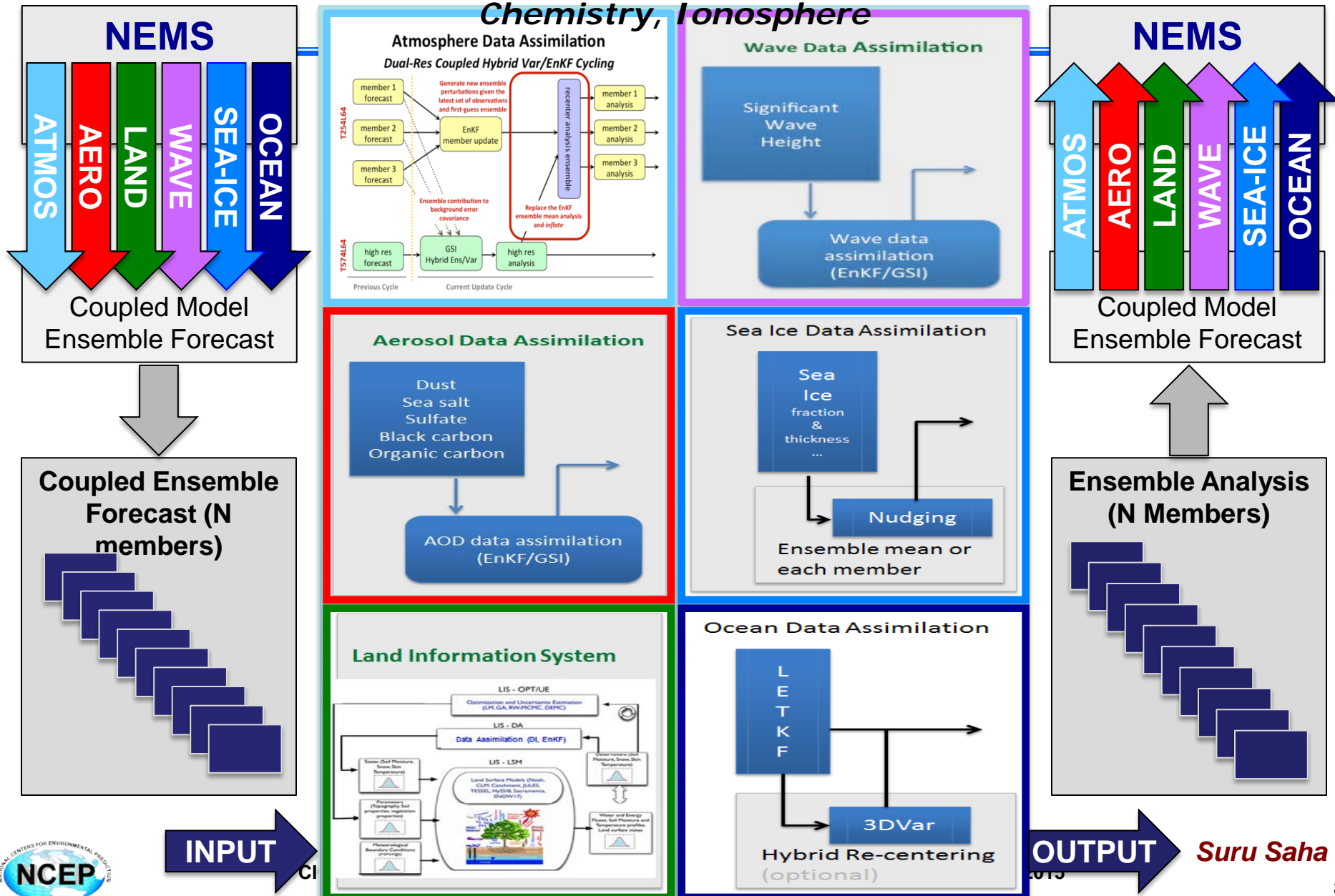
NMME = National (or North American) Multi-Model Ensemble for Seasonal Prediction

- **Real-Time definition: Each month a global NMME seasonal forecast of SST, precip and T2m on a global 1X1 grid in support of CPC operations. (This is "phase I")**

- **In early 2014, the SIX real time participants were CFSv2, NCAR-UoFlorida-CCSM3, NASA-GEOSS, GFDL-CM2, Canadian CMC3 and CMC4. (Retired participants include CFSv1, IRI-f and IRI-a)**

- **During 2014, two models were added: NCAR-UoFlorida-CCSM4, and GFDL-Flor-a/b. A third model NCAR-CESM1 is in the pipeline (hindcasts 1982-present to be finished). CCSM3 has been retired by late 2014. Currently SEVEN models, soon EIGHT. Close to 100 ensemble members in hindcasts. More members in real time.**

- **A review of NMME took place Sept 2014 and NMME as a CPU-distributed system will be continued for seasonal prediction and is considered 'operational' .**

- **The phase II R&D effort (_daily_ data to study intra-seasonal) has yielded a big archive managed at NCAR.**

- **The IMME carries on each month. IMME at NCEP ~ Eurosip (at ECMWF).**

http://www.cpc.ncep.noaa.gov/products/NMME

Huug van den Dool, CPC

Recent and planned upgrades to North American Mesoscale (NAM) system
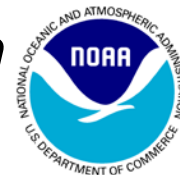
NAM 2014Q4 upgrade

- NAM forecast configuration:
  - 12km parent to 84-hr.
  - 4 fixed nests: 4km CONUS, 6km Alaska, 3km HI/PR to 60-hr.
  - 1.33km relocatable storm scale nest to 36-hr.
- Hybrid variational ensemble analysis; new satellite bias correction algorthim.
- RRTM radiation scheme.
- Ferrier-Aligo microphysics; tuned to improve severe storm structure.
- Convection: Modified BMJ (moister profiles) to improve 12km parent bias; explicit in nests except AK.

NAM 2016Q1 upgrade

- CONUS/Alaska nest to 3km, explict convection in AK nest.
- New shallow convection scheme in 12km parent NAM; improves cold season QPF bias.
- More frequent calls to radiation/physics.
- Digital filter with radar-derived temperature tendencies.
- 4-d EnKF.
- Rapidly updated hourly assimilation system (NAMRR).
- Others T.B.D.

June 29-30, 2012 "DC Derecho" - 27hr fcst NAMRR Test with 3km CONUSnest

Significant improvement at longer lead times with 3km NAMRR relative to Operations (at the time)

CONUSNEST Column Max Reflectivity
20120629 00Z cycle Fhr 27 Valid 20120630 0300Z

CONUSNEST Column Max Reflectivity
20120629 00Z cycle Fhr 27 Valid 20120630 0300Z

Obs Column Max Reflectivity
20120630 0300Z
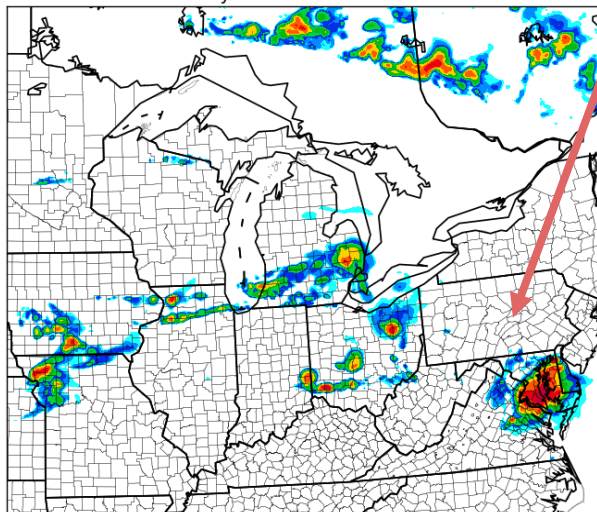
4 km Ops NAM CONUSnest
Fhr=27
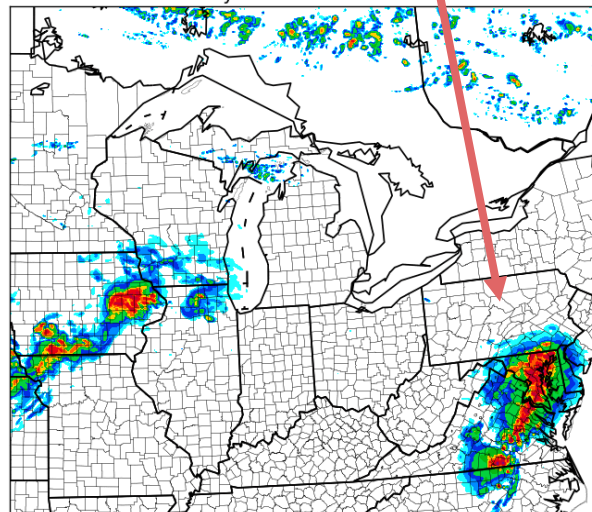
3 km NAMRR CONUSnest
Fhr=27
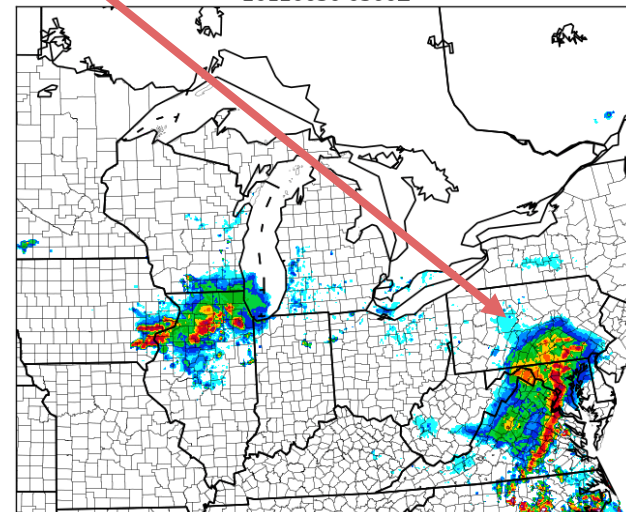
Observations

Eric Rogers

Moore OK Severe Weather Event 20 May 2013

Fhr = 03 Valid 21Z

Fhr = 16 Valid 22Z

Ops 4km

NAMRR 3km

Obs

CONUSNEST227 Column Max Reflectivity
20130520 1800Z cycle Fhr 03 Valid 20130520 2100Z

CONUSNEST187 Column Max Reflectivity
20130520 1800Z cycle Fhr 03 Valid 20130520 2100Z

Obs Column Max Reflectivity
20130520 2100Z

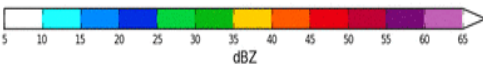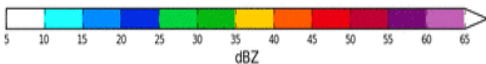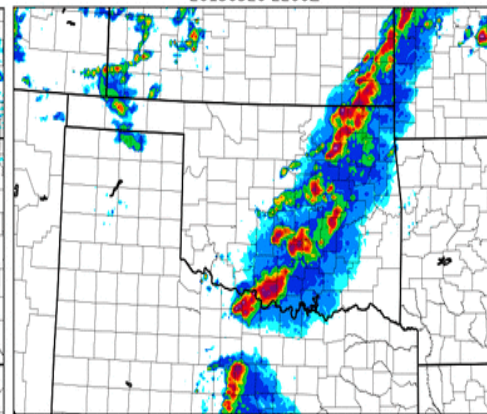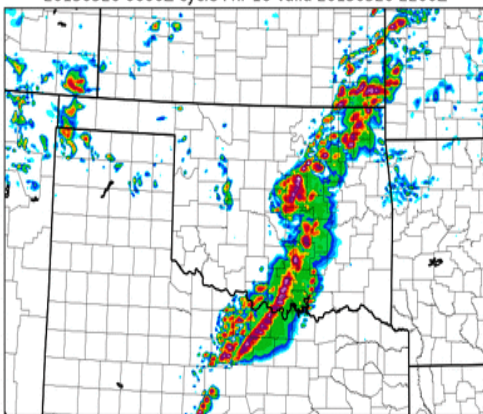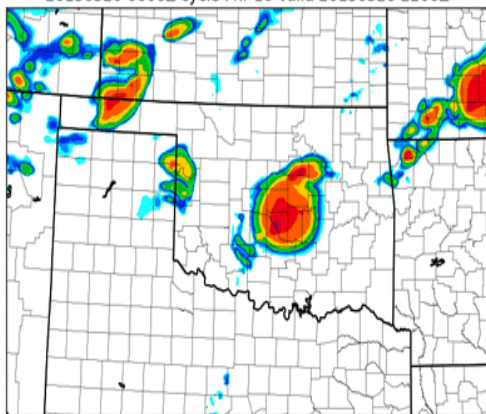CONUSNEST227 Column Max Reflectivity
20130520 0600Z cycle Fhr 16 Valid 20130520 2200Z

CONUSNEST187 Column Max Reflectivity
20130520 0600Z cycle Fhr 16 Valid 20130520 2200Z

Obs Column Max Reflectivity
20130520 2200Z

Rapid Refresh and HRRR
NOAA hourly updated models
(situational awareness for energy, aviation, severe weather, etc.)
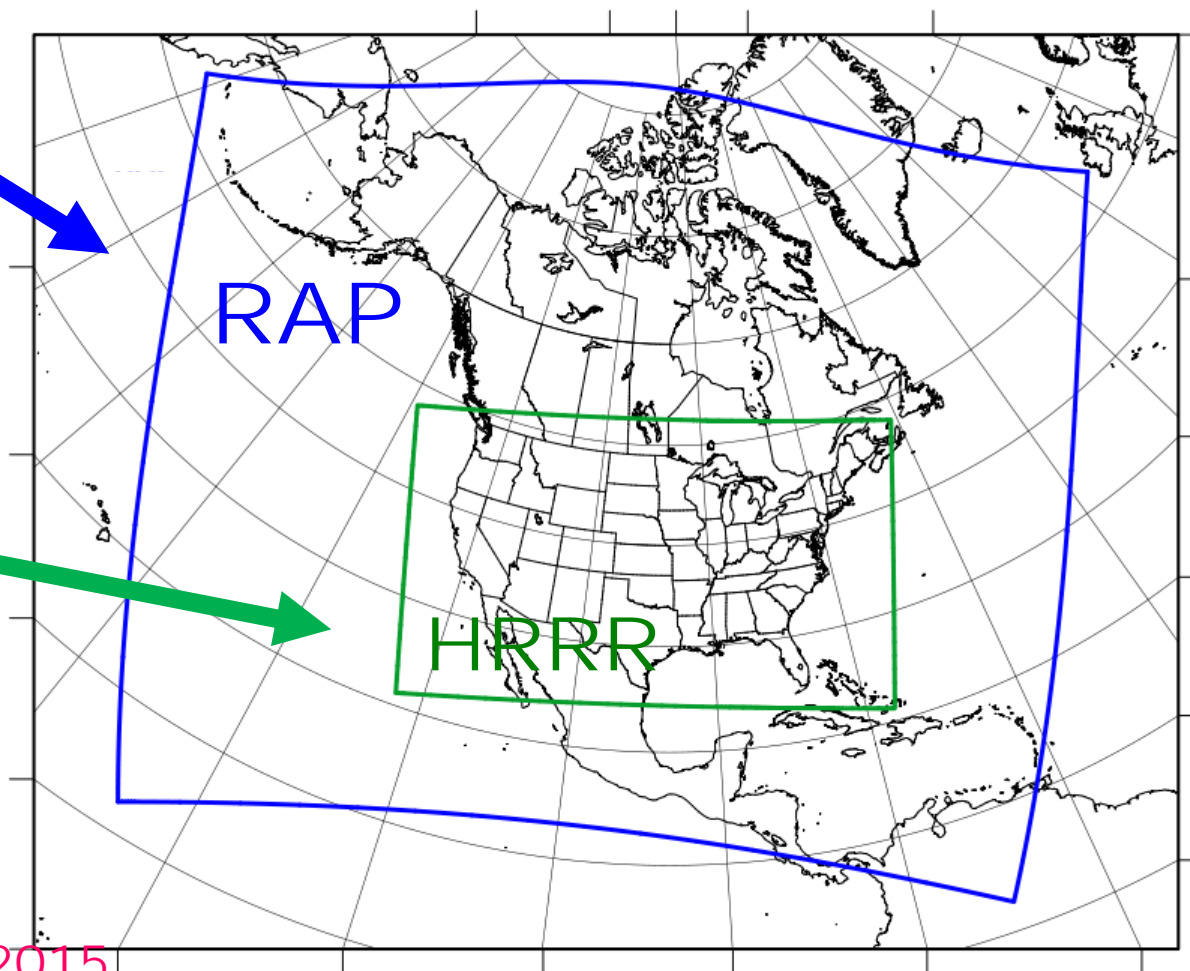
13km Rapid Refresh (RAP) (mesoscale)

Version 2 -- NCEP implement 25 Feb 2014

Version 3 – GSD Planned NCEP –summer 2015

3km High Resolution Rapid Refresh (HRRR) (storm-scale)

Initial -- NCEP implement 30 Sept 2014
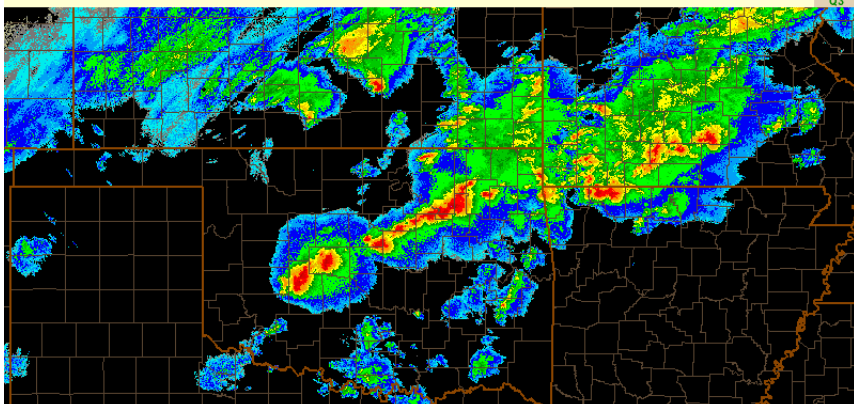
Version 2 – GSD Planned NCEP –summer 2015

RAP

HRRR

NCEP

NCEP RAPv3 and HRRRv2

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	758 x 567	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly - RAP (no-cycle)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.6+	GSI Hybrid 3D-VAR/Ensemble	13-km DFI	RRTMG/RRTMG	Thompson – aerosol v3.6.1	GF v3.6+	MYNN v3.6+	RUC v3.6+
HRRR	WRF-ARW v3.6+	GSI Hybrid 3D-VAR/Ensemble	3-km 15-min LH	RRTMG/RRTMG	Thompson – aerosol v3.6.1	GF shallow	MYNN v3.6+	RUC v3.6+

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5th/5th	Positive-Definite	w-Rayleigh 0.2	Yes 0.12	20 min	MODIS Fractional	0.01 K/s	60 s
HRRR	5th/5th	Positive-Definite	w-Rayleigh 0.2	Yes 0.25 (flat terr)	15 min with SW-dt (Ruiz-Arias)	MODIS Fractional	0.07 K/s	20 s

CICS/CPC and EMC mini-workshop, ESSIC, College Park, Maryland, USA, 6 May 2015

Composite Reflectivity
Derived From Mosaic3D
Valid: 03/25/2015 23:00:00 UTC

SPC Storm Reports for 03/25/15
Map updated at 0255Z on 03/26/15

TORNADO REPORTS.. (8)
WIND REPORTS/HI...... (20/1)
HAIL REPORTS/LG...... (108/10)
TOTAL REPORTS....... (136)

National Weather Service
Storm Prediction Center   Norman, Oklahoma
PRELIMINARY DATA ONLY

■ High Wind Report (65KT +)
▲ Large Hail Report (2" dia. +)

HRRRv2

12z 25 Mar 2015
11h fcst
Valid 23z
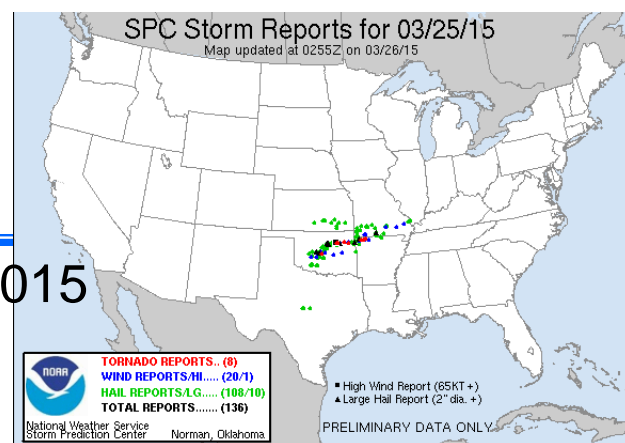
HRRRX 03/25/2015 (12:00) 11h fcst - Experimental   Valid 03/25/2015 23:00 UTC
Composite Reflectivity (dBZ)
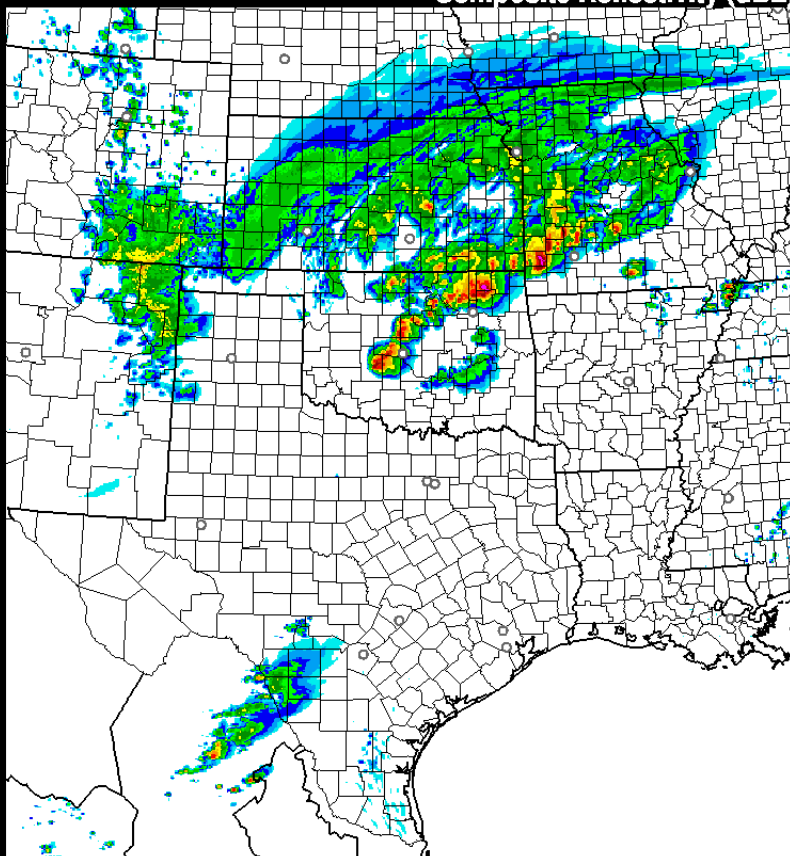
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75

HRRRX 03/25/2015 (12:00) 11h fcst - Experimental   Valid 03/25/2015 23:00 UTC
Max Updraft Helicity (over prev hour) (m²/s²), 0-1 km shear (kt)
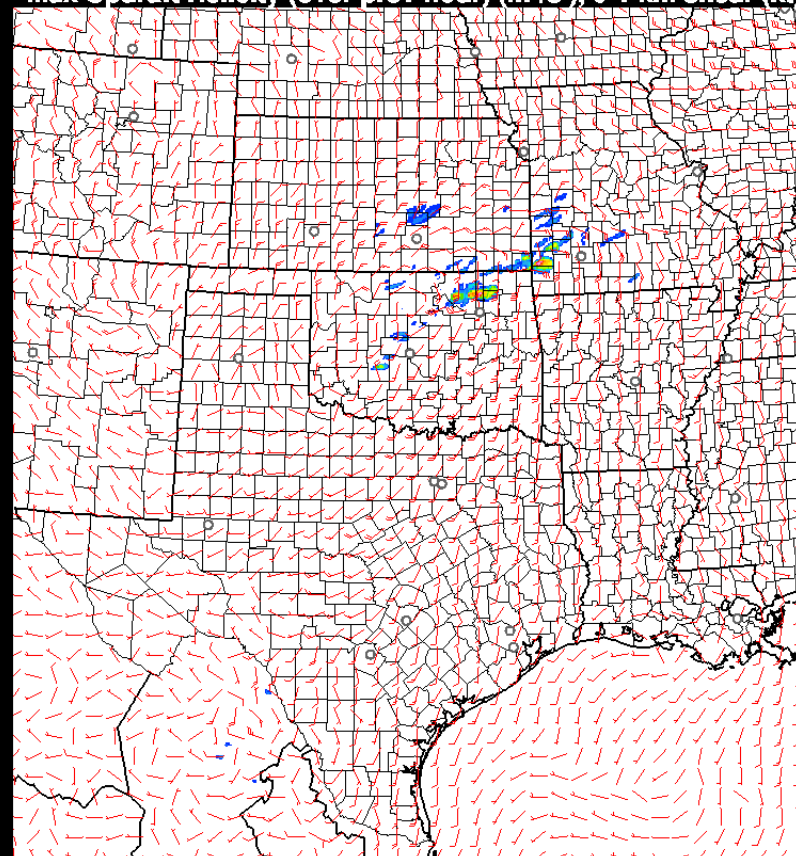
25 50 75 100 125 150 175 200 225 250 275 300

NCEP Mesoscale Ensembles Replace Regional Deterministic Guidance: Current and Future

| Current	~2015	~2018
SREF continental scale	**SREF continental scale**	**SREF continental scale**
WRF-ARW, -NMM, NMMB	WRF-ARW & NMMB	WRF-ARW & NMMB
7 each = 21 members 16km	13 each = 26 members ~16km	13 each = 26 members ~9km (parent)
35 levels 6 hourly to 87 hr	40 levels 6 hourly to 87 hr NARRE-TL run hourly to 18 hr	50-60 levels 6 hourly to 96 hr. SREF_RR run hourly to 24 hr
Convection-Allowing-Scale	**Convection-Allowing-Scale**	**Convection-Allowing-Scale Ensemble**
hrly 3km HRRR & NAM nest run to 15 h for CONUS Irregular suite of guidance 3-6km, ~6 hourly to 48/60 hr for CONUS, Alaska, HI, PR	Upgrade irregular suite (HiResW) to ~3km, 6 hourly to 48/60 hr for CONUS, Alaska, HI, PR	HREF_RR (high-res ensemble fcst): Multiple hourly 3km run to 24 hr; HREF: run 6 hourly extended to 60 hr for CONUS, Alaska, Hi, PR
Storm Scale	**Storm Scale**	**Storm Scale Ensemble**
Single placeable sub-nest [fire weather run] 1.33-1.5km Run 6 hourly to 36 hr	Single placeable/movable sub-nest 1-1.5km Run 6 hourly to 36 hr	Storm-scale ensemble (SSE) Multiple placeable/movable sub-nests: ~1km run hourly to 18 hr and run 6 hourly to 36 hr

Jun Du[16]
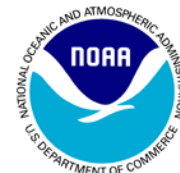
HWRF Model Configuration:

- **Three telescopic domains with high resolution storm following nests: 27km/9km/3km; 61L *going to 18km/6km/2km in 2015.***
- **Coupled to MPI POM Ocean Model worldwide using NCEP Coupler.**
- **Sophisticated vortex initialization.**
- **EnKF/GSI hybrid regional DA system with real-time inner core aircraft data assimilation.**
- **Advanced physics tailored for hurricane conditions based on observations.**
- ***Coupled Noah LSM in 2015***
- ***Expanding the scope of operational HWRF for all global tropical cyclones in 2015.***

Accurate and reliable Track, Intensity & Structure Forecasts

HWRF forecast for Arthur (01L) at 2014070...
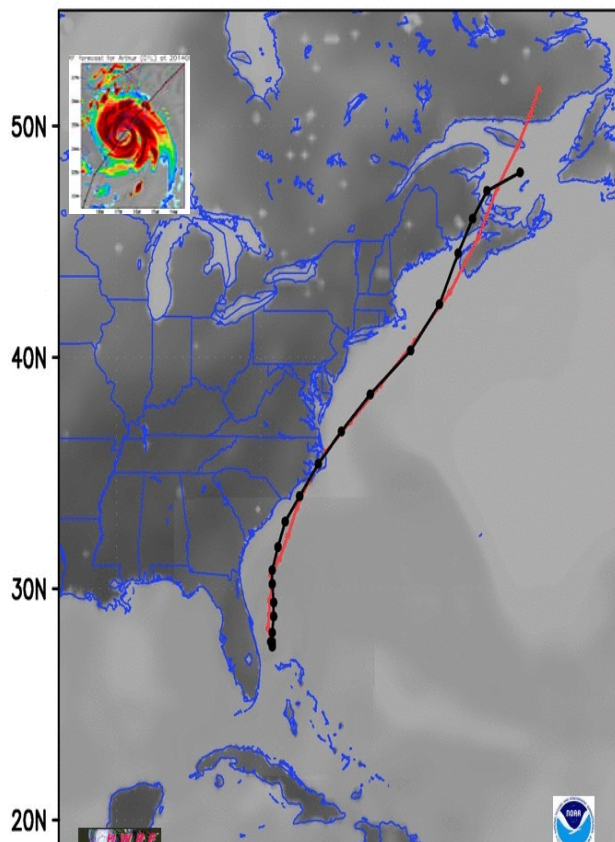
**Significant Improvements in the past 5 years, meeting HFIP Goals**
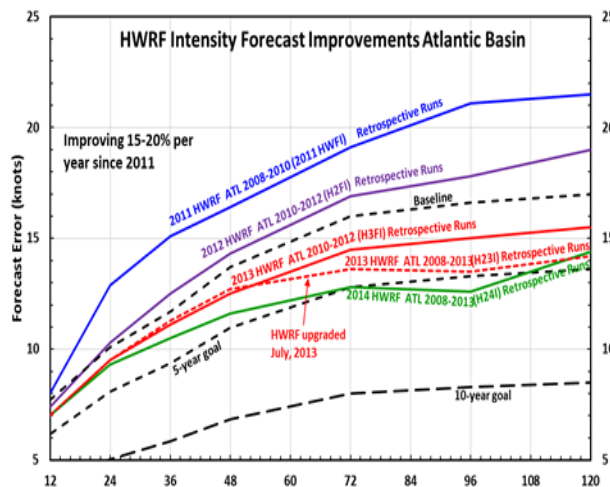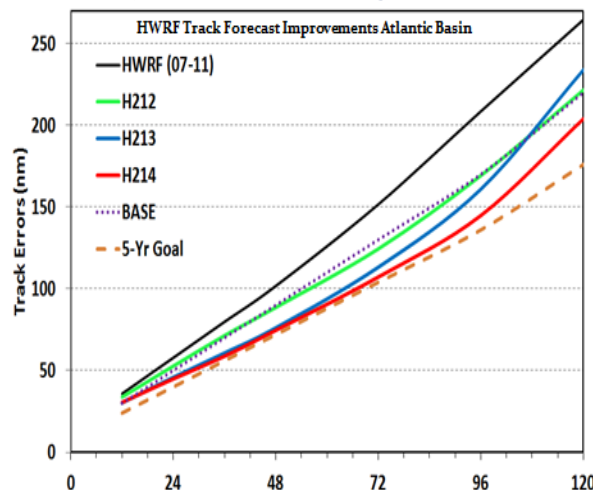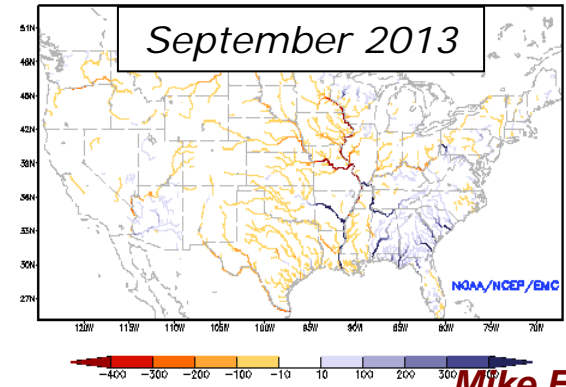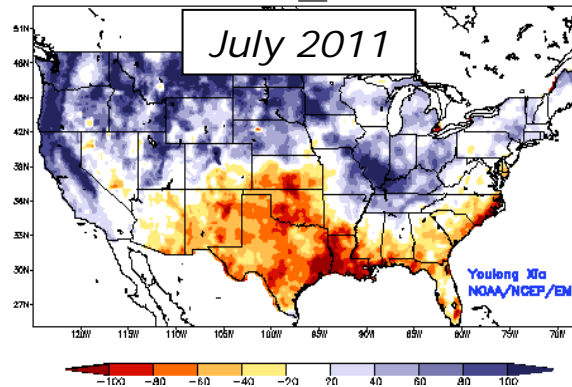
Land Data Assimilation System (LDAS)
www.emc.ncep.noaa.gov/mmb/nldas

- 5 Aug 2014: North American LDAS (NLDAS) operational.

- NLDAS: 4 land models run uncoupled, driven by CPC observed precipitation & NCEP R-CDAS atmospheric forcing.

- Output: 1/8-deg. **land** & **soil states**, **surface fluxes**, **runoff** & **streamflow**; anomalies from 30-yr climatology for drought.

- Future: higher res. (~3-4km), extend to N.A./global domains, improved land data sets/data assimil. (soil moisture, snow), land model physics upgrades inc. hydro., initial land states for weather & seasonal climate models; global drought information.

July 30-year climo.

July 2011

September 2013
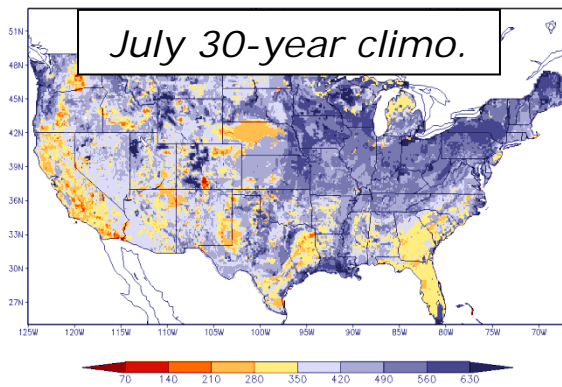
Ensemble monthly soil moisture anomaly   *Daily streamflow*

Mike Ek

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Global and Basin Scale Ocean Forecast Systems

RTOFS Global
Sea Surface Temperature

Surface Height

Surface Temperature

Surface Salinity

Surface Currents
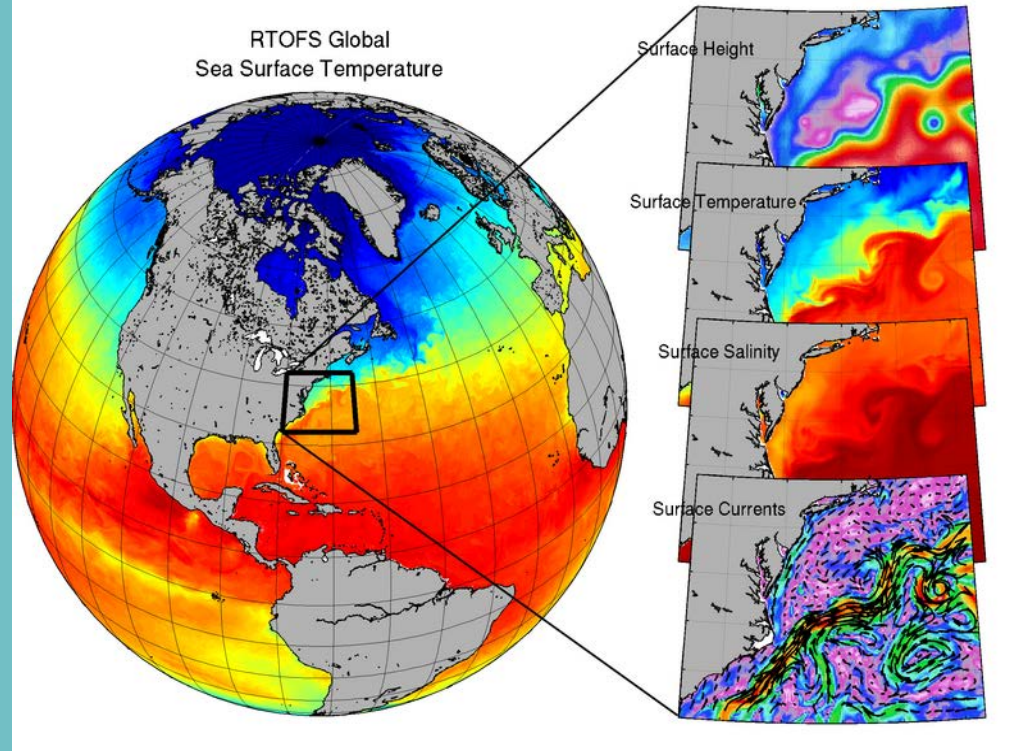
- ➤ Eddy Resolving Ocean Modeling and Initialization
- ➤ Coupled Modeling for Hurricanes (Air-Sea-Wave flux interaction, mixing)
- ➤ Coupled Modeling for short-term, medium-term and seasonal scales (Air-Sea-Ice-Wave flux interactions, ensembles)
- ➤ Coupled Ecosystem Forecasting (Biogeochemical, NPZD, tracers)
- ➤ All Ocean Forecast Systems presently based on HYCOM, RTOFS (Real Time Ocean Forecast Systems) represents line of products

Primary Users:
**NOAA:** NWS, NOS, IOOS, OAR, JCSDA
External: DHS, Academia, Japan (JAEA), India (INCOIS)

Strong collaboration with US Navy, leveraging core HYCOM and data assimilation developments at NRL.

Avichal Mehra

WAVEWATCH III and Wave Coupling

- **GFS model** air-sea fluxes depend on **sea state** (roughness -> Charnock).
- **WAVEWATCH III model** forced by **wind** from GFS and currents from Ocean.
- **Ocean model** forced by **heat flux**, sea state dependent **wind stress** modified by **growing or decaying wave fields and Coriolis-Stokes effect.**
- **Current Status:**
  - Wave model driven in uncoupled mode with GFS 10m winds for global forecasts (4 cycles a day out to 180 h of forecast).
  - Hurricane wave model uses blend of GFS and HWRF winds for forecasts (4 cycles a day out to 126 h of forecast).
  - Use first guess model results from previous cycle as final wave analysis.
- **Planned Upgrades:**
  - Drive the wave model in a coupled mode with atmospheric winds (for wave dependent boundary conditions in atmospheric models).
  - Include wave-ocean coupling (currents from ocean model to wave model, and wave induced langmuir mixing & stokes drift from wave model to ocean).
  - Data assimilation of significant wave heights to develop a wave analysis: GSI and LETKF approaches.
 - Planned sources of data: Spectral data from ocean buoys; Satellite data from altimeters.
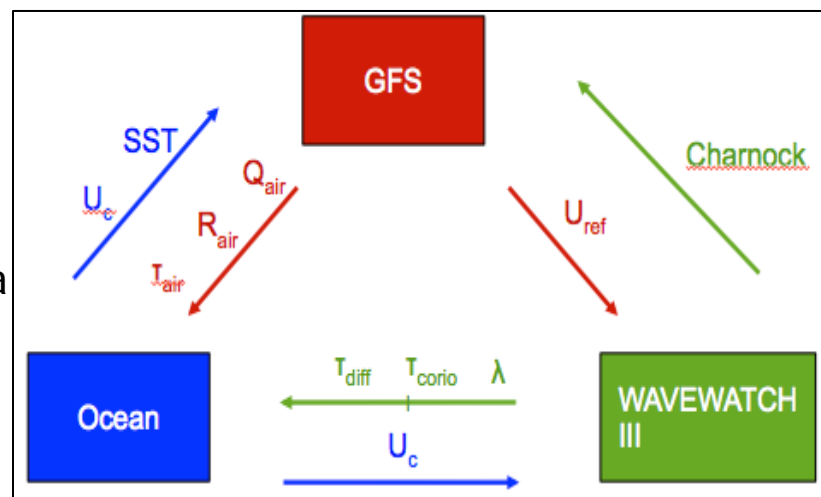
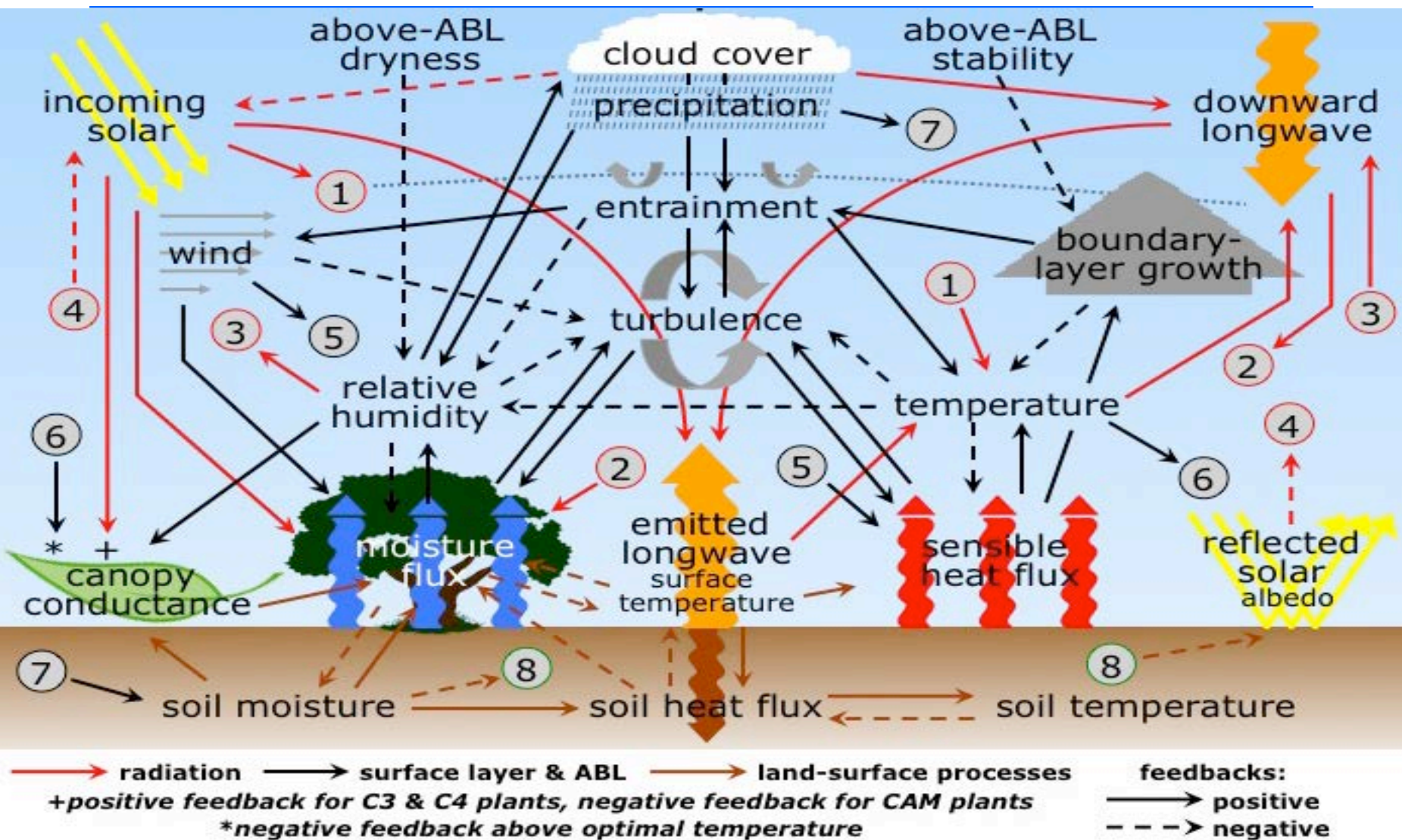*Arun Chawla, Henrique Alves, Hendrik Tolman*

NOAA Environmental Modeling System (NEMS)

- Unify NCEP operational systems under a single framework.
- More easily share common structures/components.
- Expedite interoperability.
- First two systems under NEMS implemented in NCEP ops: NAM, and NEMS Global Aerosol Component (NGAC).

Mark Iredell
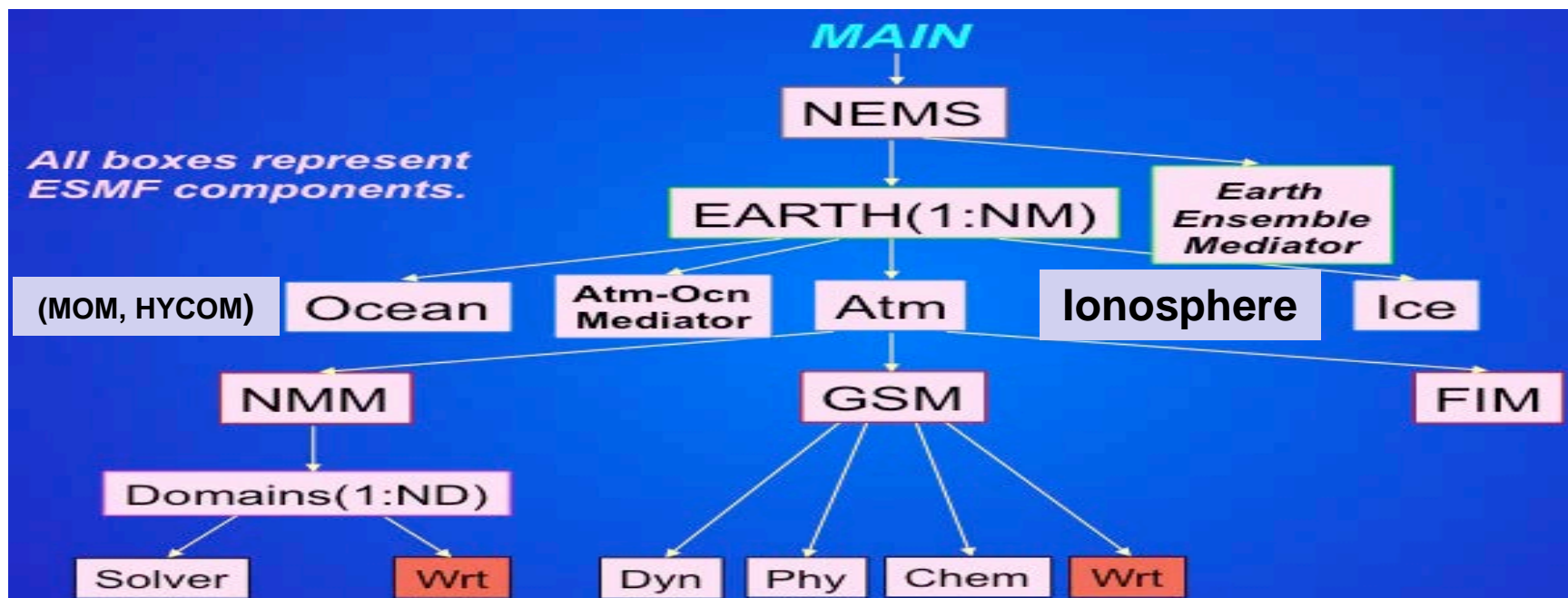
Model Evaluation Group (MEG)

- **Verifies and evaluates daily performance of EMC forecast/analysis systems from a synoptic and mesoscale perspective to complement the statistical perspective.**

- **Conducts weekly EMC map discussion of model performance**
  - **Audience recently expanded to involve more NWS regional and local forecasters.**

- **Project benefits:**
  - **Provides critical feedback to modelers and branch chiefs.**
  - **Provides streamlined feedback to outside users with model concerns.**
  - **In first 3 years, several model problems noted, brought to attention of EMC modeling team, and corrected or at least mitigated in operations.**

- **MEG also to work closely with forecasters to understand and evaluate proposed model upgrades prior to the short formal evaluation period.**

- **How can MEG best include experience and knowledge of model users?**

Glenn White, Geoff Manikin, Corey Guastini

Thank you!