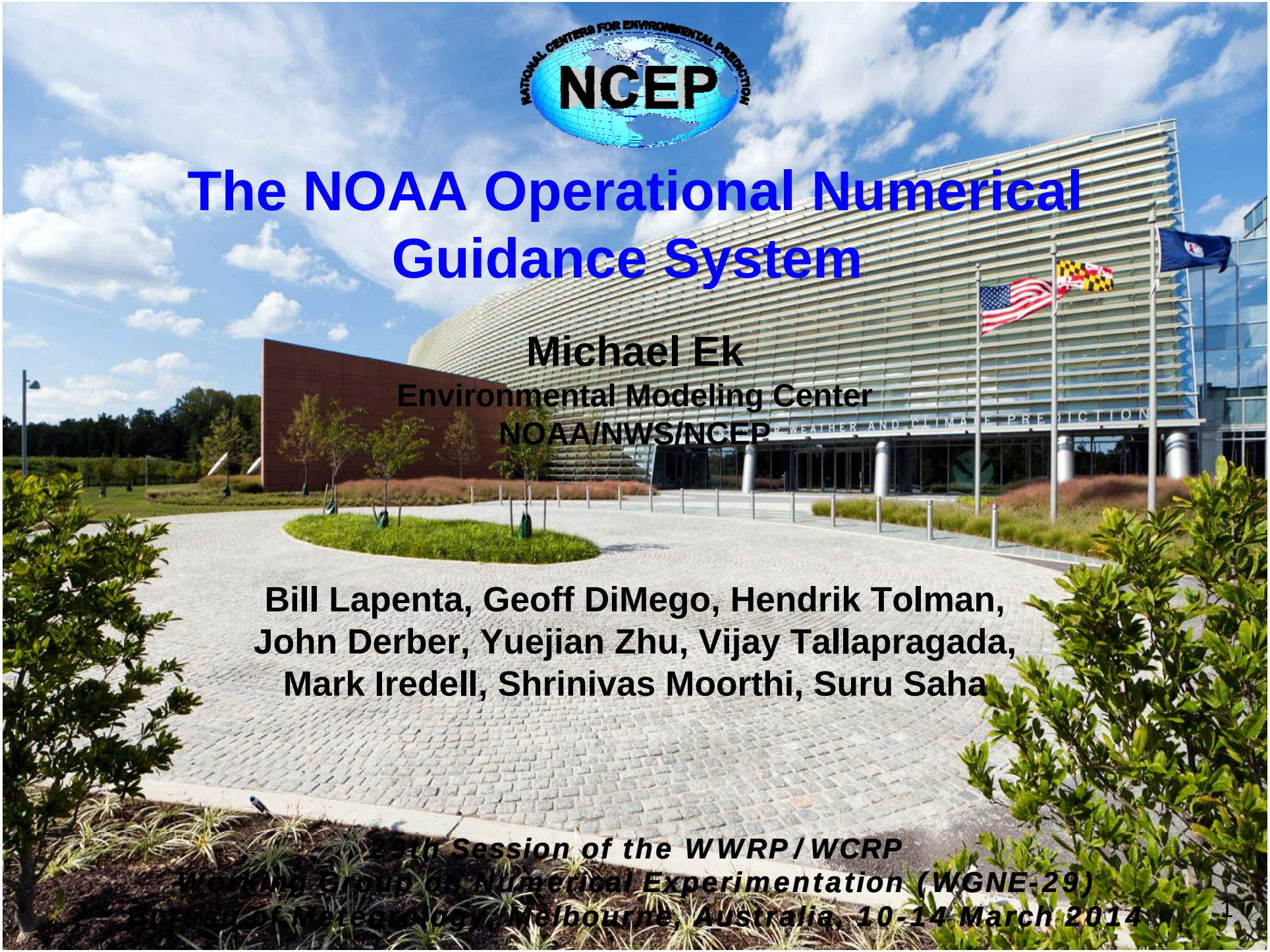


The NOAA Operational Numerical Guidance System

Michael Ek

Environmental Modeling Center

NOAA/NWS/NCEP

Bill Lapenta, Geoff DiMego, Hendrik Tolman, John Derber, Yuejian Zhu, Vijay Tallapragada, Mark Iredell, Shrinivas Moorthi, Suru Saha

29th Session of the WWRP/WCRP Working Group on Numerical Experimentation (WGNE-29)

Bureau of Meteorology, Melbourne, Australia, 10-14 March 2014

NOAA Operational Numerical Guidance Supports the Agency Mission

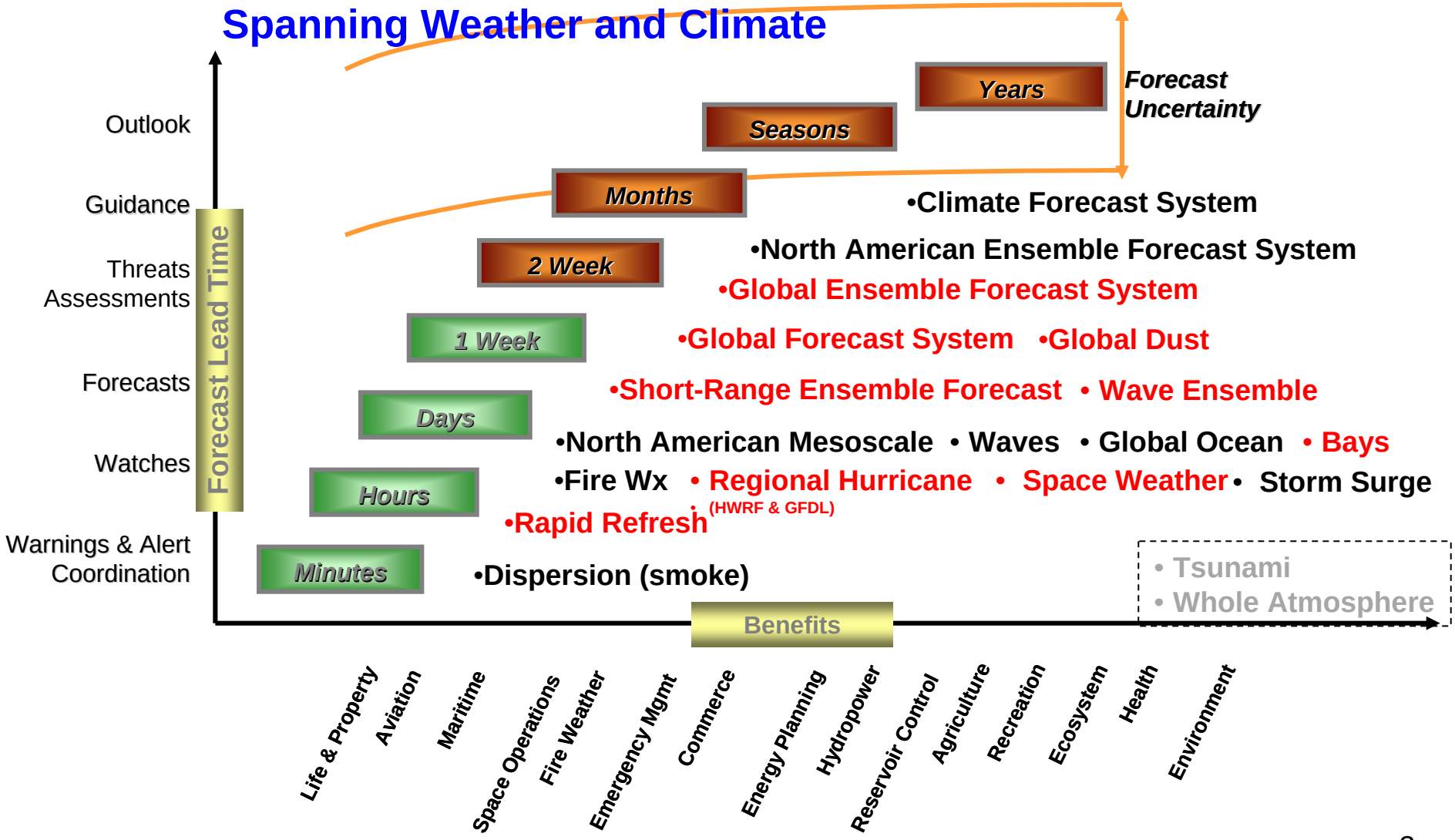
- **Numerical Weather Prediction**
  - Global Anomaly Correlation Score – "Internal" metric
  - Related to ability to meet service-based metrics (below)

- **National Weather Service GPRA* Metrics**

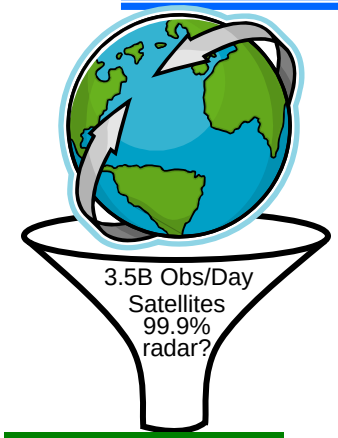
  (* Government Performance & Results Act)
  - Hurricane Track and Intensity Forecast Accuracy
  - Winter Storm Warning Lead Time and Accuracy
  - Precipitation Threat Accuracy
  - Flood Warning Lead Time and Accuracy
  - Marine Wind Speed and Wave Height Forecast Accuracy

- **Operational numerical guidance:**
  - Is a foundational tool used by the NWS to meet the above goals
  - Used by the public and private industry to improve public safety, quality of life and make business decisions that drive US economic growth

Seamless Suite of NOAA Operational Numerical Guidance Systems



NOAA's NWS Model Production Suite



Global Data Assimilation

Regional Data Assimilation

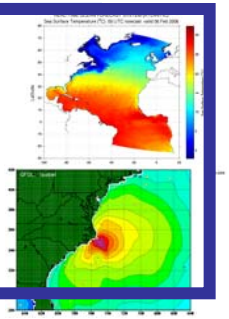
Global Forecast System

Climate CFS
MOM3

Hurricane
GFDL
HWRF

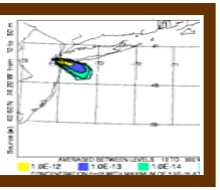
2-Way Coupled

Oceans
HYCOM
WaveWatch III

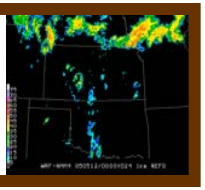


Regional NAM
WRF NMM
(including NARR)

Dispersion
ARL/HYSPLIT



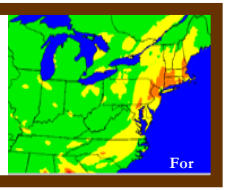
Severe Weather
WRF NMM/ARW
Workstation WRF

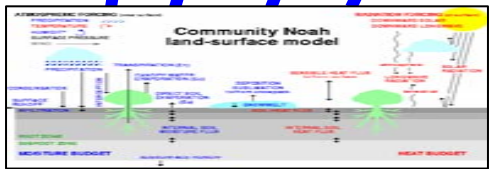


Short-Range Ensemble Forecast
WRF: ARW, NMM
ETA, RSM

North American Ensemble Forecast System
GFS, Canadian Global Model

Air Quality
NAM/CMAQ

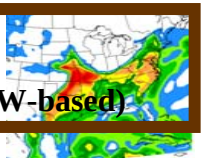




NOAH Land Surface Model

Uncoupled "NLDAS" (drought)

Rapid Update for Aviation (ARW-based)



NOAA Operational Computing: IBM iDataPlex System "WCOSS"

Location

- Primary
  - Reston, VA (IBM provided facility)
- Backup
  - Orlando, FL (IBM provided facility)

Configuration

- Identical Systems (per site)
  - IBM iDataPlex/Intel Sandy Bridge/Linux
  - 208 trillion calculations/sec
  - 10,048 processing cores
  - 2.59 petabytes of storage
- Performance Requirements
  - Minimum 99.9% Operational Use Time
  - Minimum 99.0% On-time Product Generation
  - Minimum 99.0% Development Use Time
  - Minimum 99.0% System Availability
  - Failover tested regularly

Inputs and Outputs

- Processes 3.5 billion observations/day
- Produces over 15 million products/day

Significance

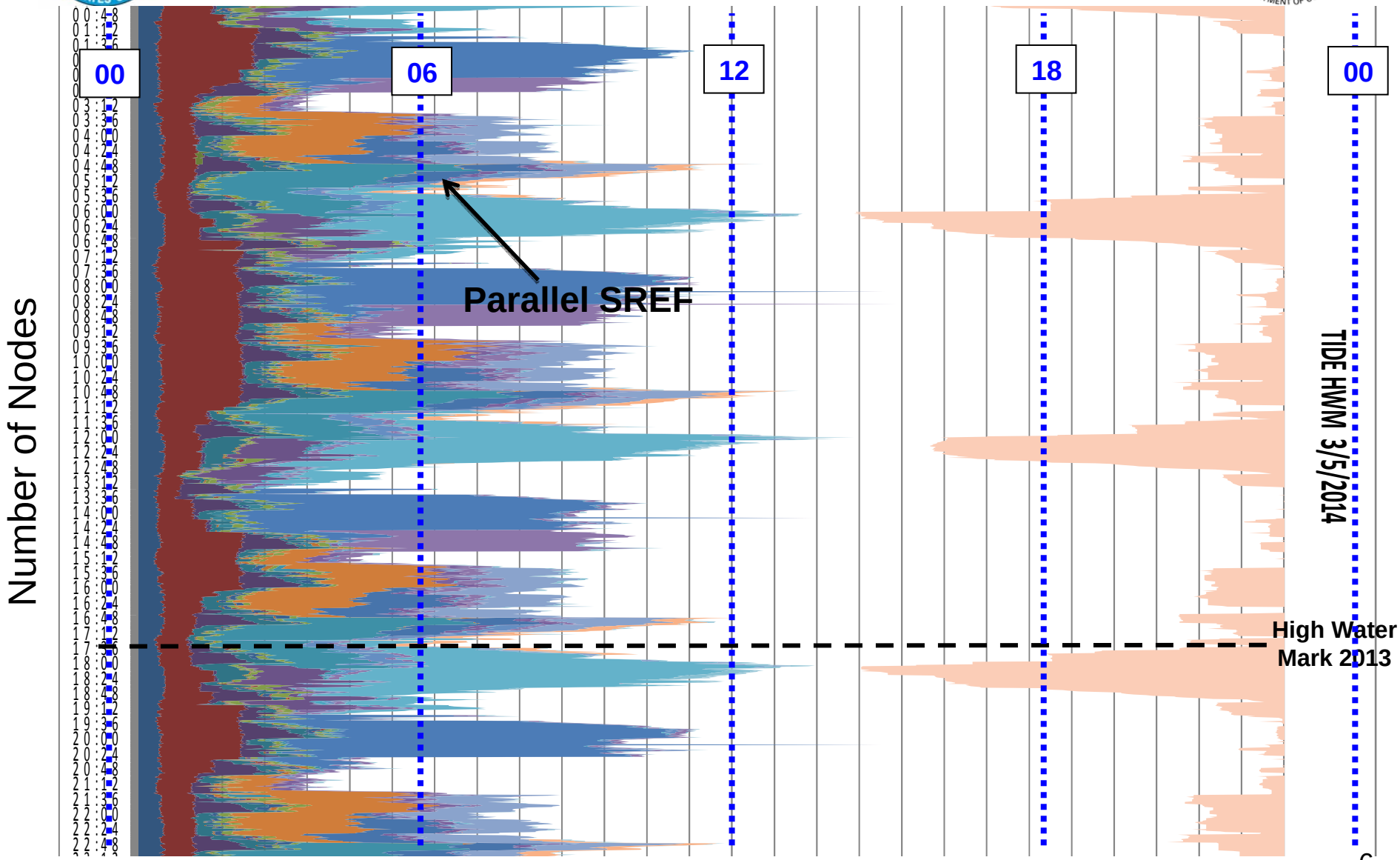
- Where United States weather forecast process starts for the protection of lives and livelihood
- Produces model guidance at global, national, and regional scales

  Examples:
  - Hurricane Forecasts
  - Aviation / Transportation
  - Air Quality
  - Fire Weather

Weather and Climate Operational Supercomputing System (WCOSS)

Production Suite on Supercomputer

August 2013



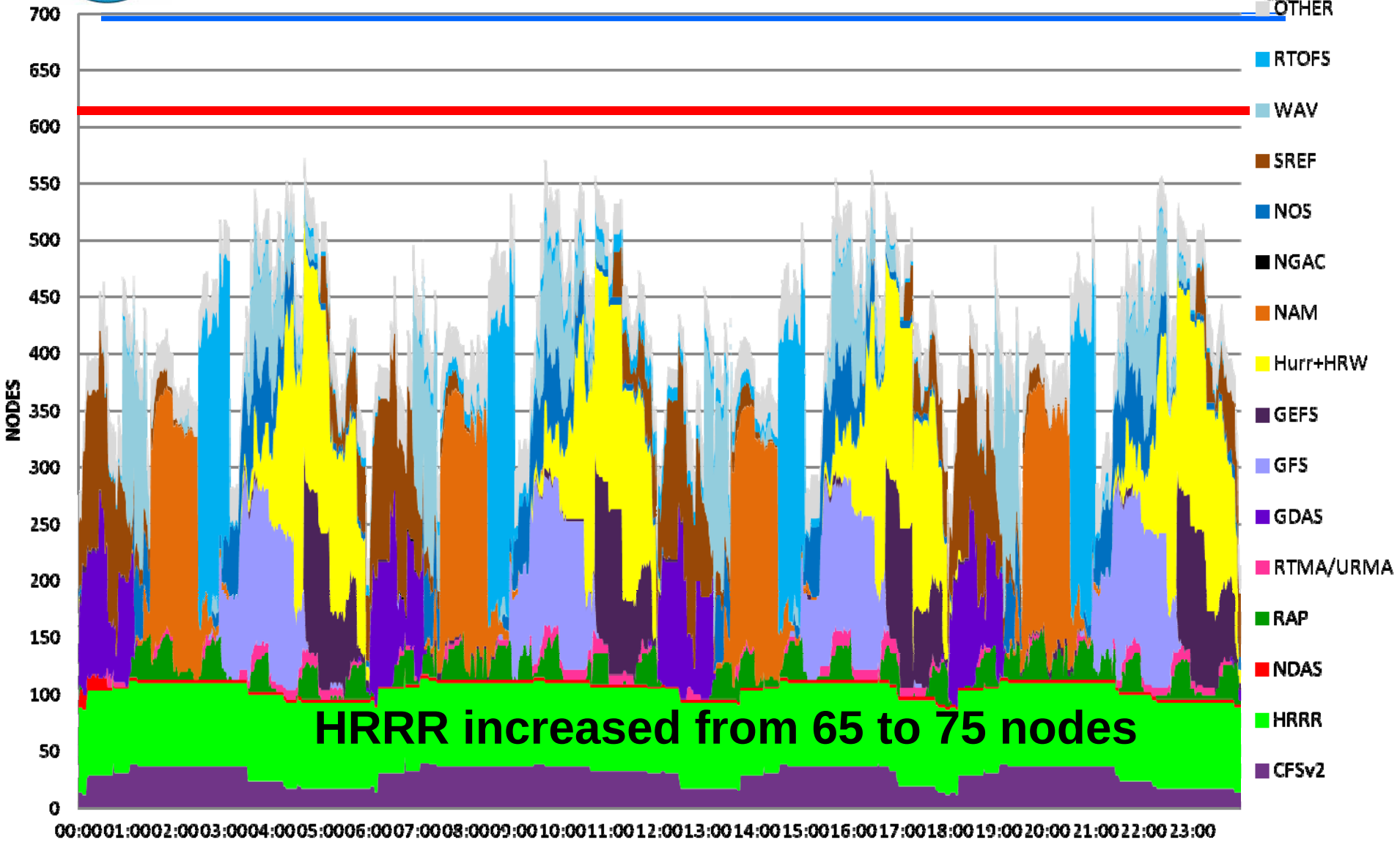
Production Suite on Supercomputer

September 2014 (projected)

- **Includes the FY2014 upgrades to:**
  - RTMA/URMA
  - RAPv2
  - SREF interim upgrade
  - HiResWindow
  - Global Wave Ensemble
  - NAEFS
  - NLDAS
  - HWRF & GFDL
  - NAM (physics & DA)
  - GFS
  - HRRR (increased from 65 to 75 nodes)
- **Also Includes:**
  - Earlier start for Multi2
  - Later start for Global Wave Ensemble
  - No preemption of HRW during HWRF & GFDL
- **Excludes the FY2015 upgrades to:**
  - GEFS
  - NAM (all nests 3km)
  - SREF (12 km)

Production Suite on Supercomputer

September 2014 (projected)



NCEP DA Plans: Next Global Implementation (~ Aug. 2014)

- Structure
  - T574 analysis (~35km at the equator)
  - T1534 forecast (~13km at the equator)
  - Code optimization
- Observations
  - GPSRO enhancements
  - Updates to radiance assimilation
    - Assimilate SSM/IS UPP LAS data
    - CRTM v2.1.3
    - New bias correction
    - Additional satwind data – hourly GOES, EUMETSAT
- EnKF modifications
  - Stochastic physics (in EnKF forecasts) to replace additive inflation
  - T574L64 EnKF-based ensembles for hybrid

NCEP DA Plans: Hybrid 4D EnVar

- Natural extension to operational 3D EnVar
  - Uses variational approach with already available 4D ensemble perturbations
- No need for development and maintenance of TLM and ADJ models
  - Makes use of 4D ensemble to perform 4D analysis
  - Modular, usable across a wide variety of models and applications
- Highly scalable
  - Aligns with technological/computing advances
- Computationally inexpensive relative to 4DVAR (with TL/AD)
  - Estimates of improved efficiency by 10x or more, e.g. at Env. Canada (6x faster than 4DVAR on half as many cpus)
- Take advantage of best aspects of (4D) variational and ensemble DA algorithms
- Expected to be implemented into global system in 2015
- Ensemble-variational Integrated Lanczos?
  - Consistent update of ensemble and deterministic components all within variational system (replacing EnKF)

Global model plans

Q4FY14 highlights

•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

Q3FY15

•NEMS

•4D-Hybrid

Q2FY16

•T1534L64 –> T1534L128

•Enhanced physics

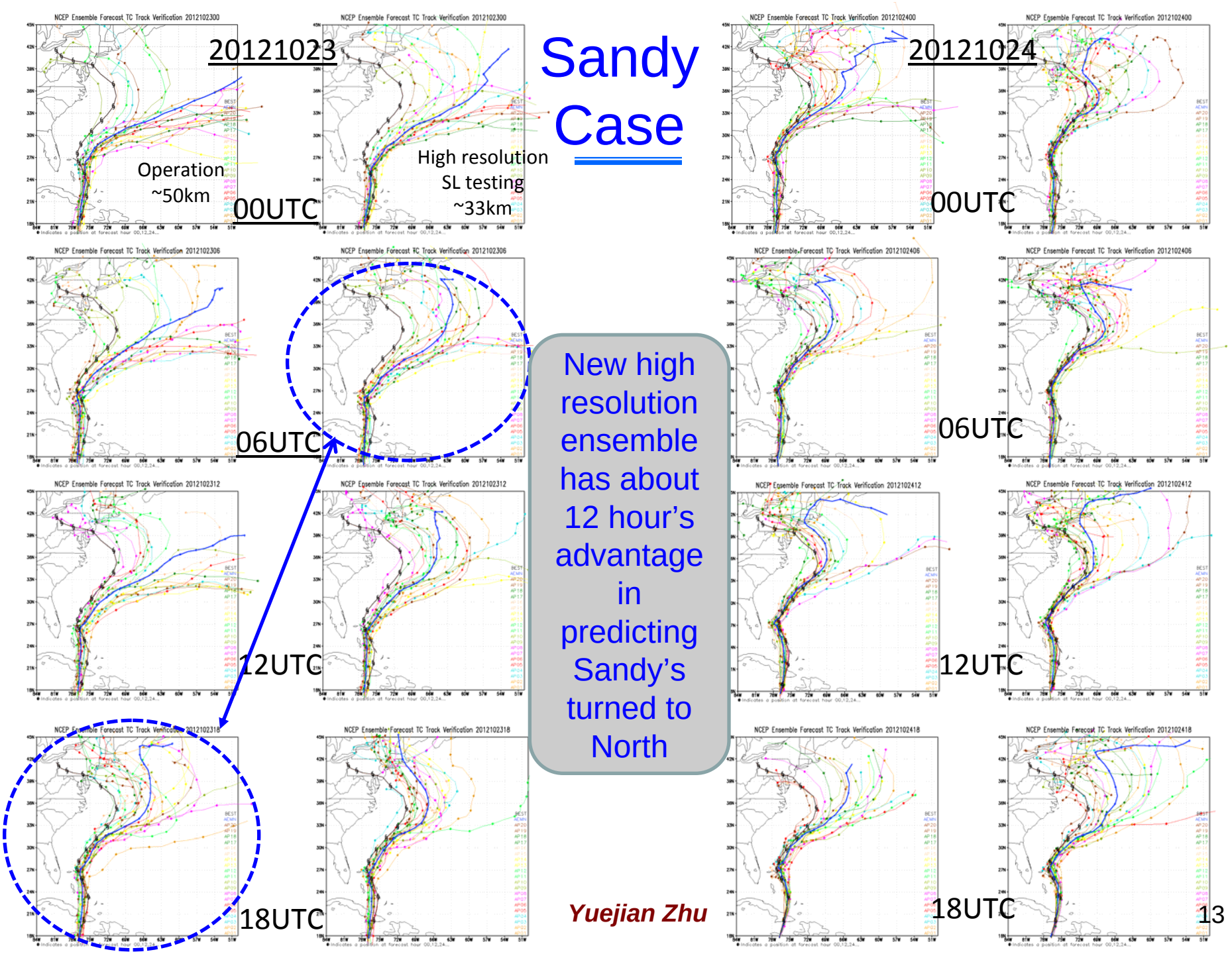
Aerosol prediction – initially lower resolution used as forcing in high res.

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

NCEP Global Ensemble Forecast System (GEFS)

- Model
  - Current: GFS Euler model
  - Plan: GFS Semi-Lagrangian model
- Horizontal resolution
  - Current: T254 (55km for 0-192 hours), T190 (73km for 192-384 hours)
  - Plan: T574 (T382 physics - 34km for 0-168 hours), T382(T254 physics – 55km for 168-384 hours)
- Vertical resolution
  - Current: L42 hybrid levels
  - Plan: L64 hybrid levels to match with GFS and DA
- Initial conditions:
  - Current: BVETR 6hr cycling + TS (tropical Storm) relocation
  - Plan: EnKF+ETR and TS relocation
- Model perturbations:
  - Current: STTP (Stochastic Total Tendency Perturbation)
  - Plan: Tuned STTP
- Output:
  - Current: every 6-hr for 1*1 degree pgrb files
  - Plan: every 3-hr for 0.5*0.5 degree pgrb files
- Implementation
  - Next upgrade is planning for Oct-Dec 2014 (Q1FY15).

Sandy Case



Yuejian Zhu

NCEP's contributions to the WGNE aerosol-NWP experiment

- **NOAA/NCEP Global Forecast System (GFS):**
  - **The cornerstone of NCEP's operational production suite, providing deterministic and probabilistic guidance out to 16 days over a global domain, four times daily at 00, 06, 12, and 18 UTC**
  - **Global spectral model with a comprehensive physics suite (http://www.emc.ncep.noaa.gov/GFS/doc.php)**
- **GFS Configuration (current operation → planned FY14 upgrade)**
  - **Eulerian dynamics → Semi-Lagrangian dynamics**
  - **T574 Eulerian (~ 27 km) out to 8 days; T190 Eulerian (~ 70 km) from 8 to 16 days → T1534 SLG (~ 13 km) out to 10 days; T574 SLG (~ 35 km) from 10 to 16 days**
  - **64 vertical levels up to 0.32 mb**
- **GFS physics relevant to this WGNE experiment**
  - **Radiation parameterizations are based on Rapid Radiative Transfer Models (RRTMG_LW v2.3 and RRTMG_SW v2.3) with NCEP's modification and optimization**
  - **A climatological aerosol distribution at 5° resolution (Hess et al., 1998) is used.**
  - **Cloud microphysics is based on Zhao and Carr (1997)**
  - **Only consider direct radiative effect**

Sarah Lu

NCEP's contributions to the WGNE aerosol-NWP experiment (cont.)

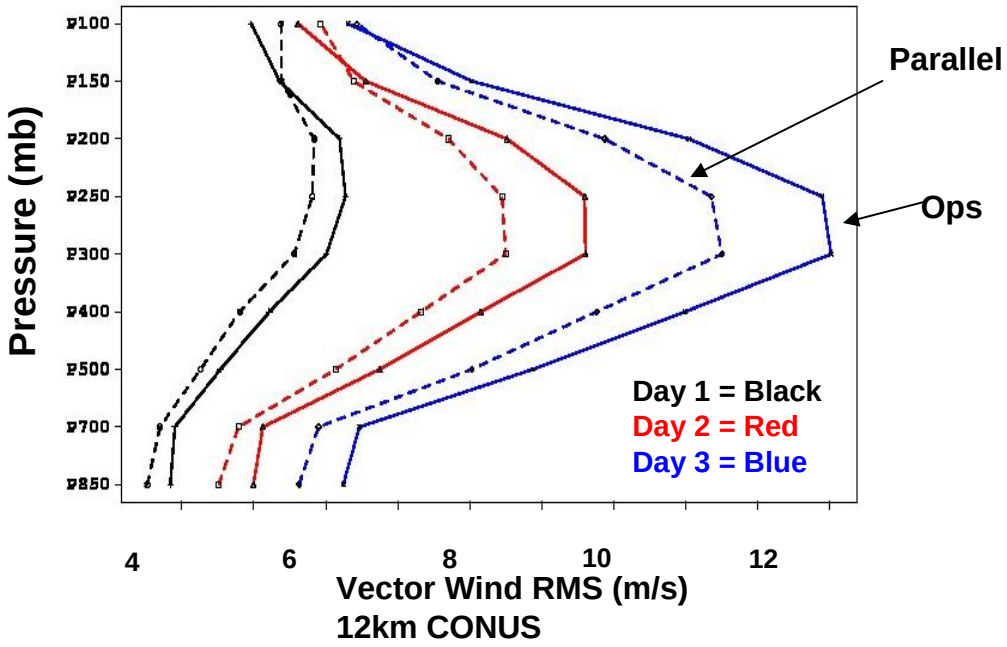
- GFS experiment setup:
  - Use the latest GFS source code (targeted for the FY14 upgrade)
  - Same configuration as the operational GFS (e.g., T574 L64, Eulerian dynamics) except for output/zero-out frequency
  - Output every 3 hour, with the same 3-hourly interval for time averaging and accumulation
  - Initialized from 00Z analysis from Global Data Assimilation System (GDAS)
- Experiments conducted at NOAA R&D supercomputer (Zeus)
  - CTRL: with radiation feedback using climatological aerosols
  - EXPT: without radiation feedback
- Three cases are completed:
  - Dust: 10-day forecast for the 2012-04-13 to 2012-04-23 period
  - Pollution: 10-day forecast for the 2013-01-07 to 2013-01-21 period
  - Smoke: 5-day forecast for the 2012-09-05 to 2012-09-15 period
- GFS output (in GRIB1 format) are mapped from Gaussian grids to 1x1 deg
- The NCEP/EMC team contributing to this experiment: Sarah Lu (the NCEP POC), Yu-Tai Hou, Shrinivas Moorthi, and Fanglin Yang

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 16 km	11 each = 22 members ~12 km	11 each = 22 members ~9 km (parent)
35 levels 6 hourly to 87 hr	40-60 levels 6 hourly to 87 hr NARRE run hourly to 18 hr	50-60 levels 6 hourly to 96 hr NARRE run hourly to 24 hr
Convection-Allowing-Scale	**Convection-Allowing-Scale**	**Convection-Allowing-Scale Ensemble (NCASE)**
Irregular suite of guidance 3-6km [HiResWindows & NAM nests] ~6 hourly to 48/60 hr for CONUS, Alaska, HI, PR	Single hourly 3 km HRRR & NAM nest run to 15 hr for CONUS Upgrade irregular suite to ~3 km 6 hourly to 48/60 hr for CONUS, Alaska, HI, PR	Ensemble HRRR (NCASE) Multiple hourly 3 km Run to 24 hr for 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] 1.33-1.5 km Run 6 hourly to 36 hr	Single placeable/movable sub-nest 1-1.5 km Run 6 hourly to 36 hr	Storm-scale ensemble (SSE) Multiple placeable/movable sub-nests: ~1 km run hourly to 18 hr and run 6 hourly to 36 hr

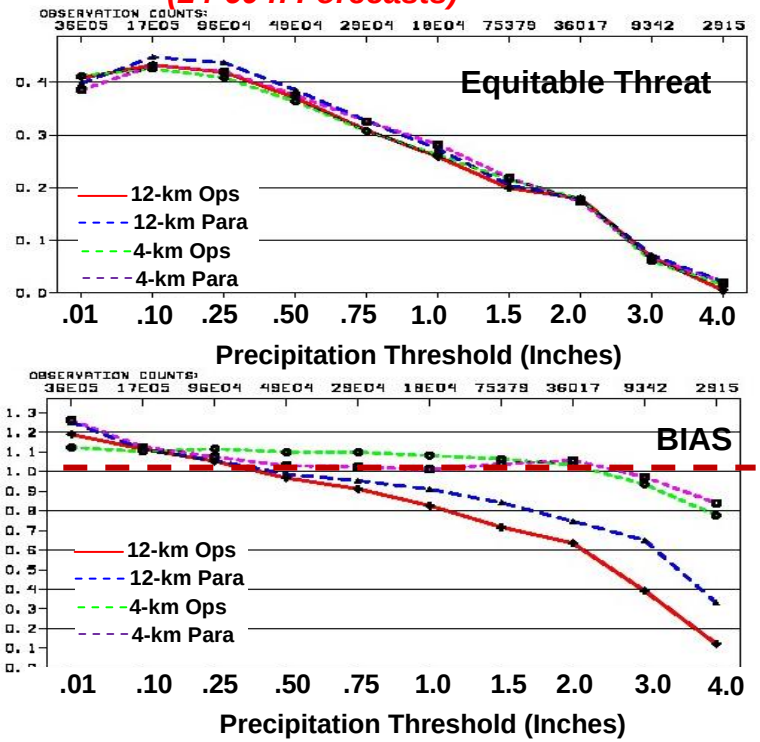
NAM test results: FY14 Upgrade Pkg

Verification from 1 October 2013 – 15 January 2014



24-h QPF scores

(24-60 h Forecasts)

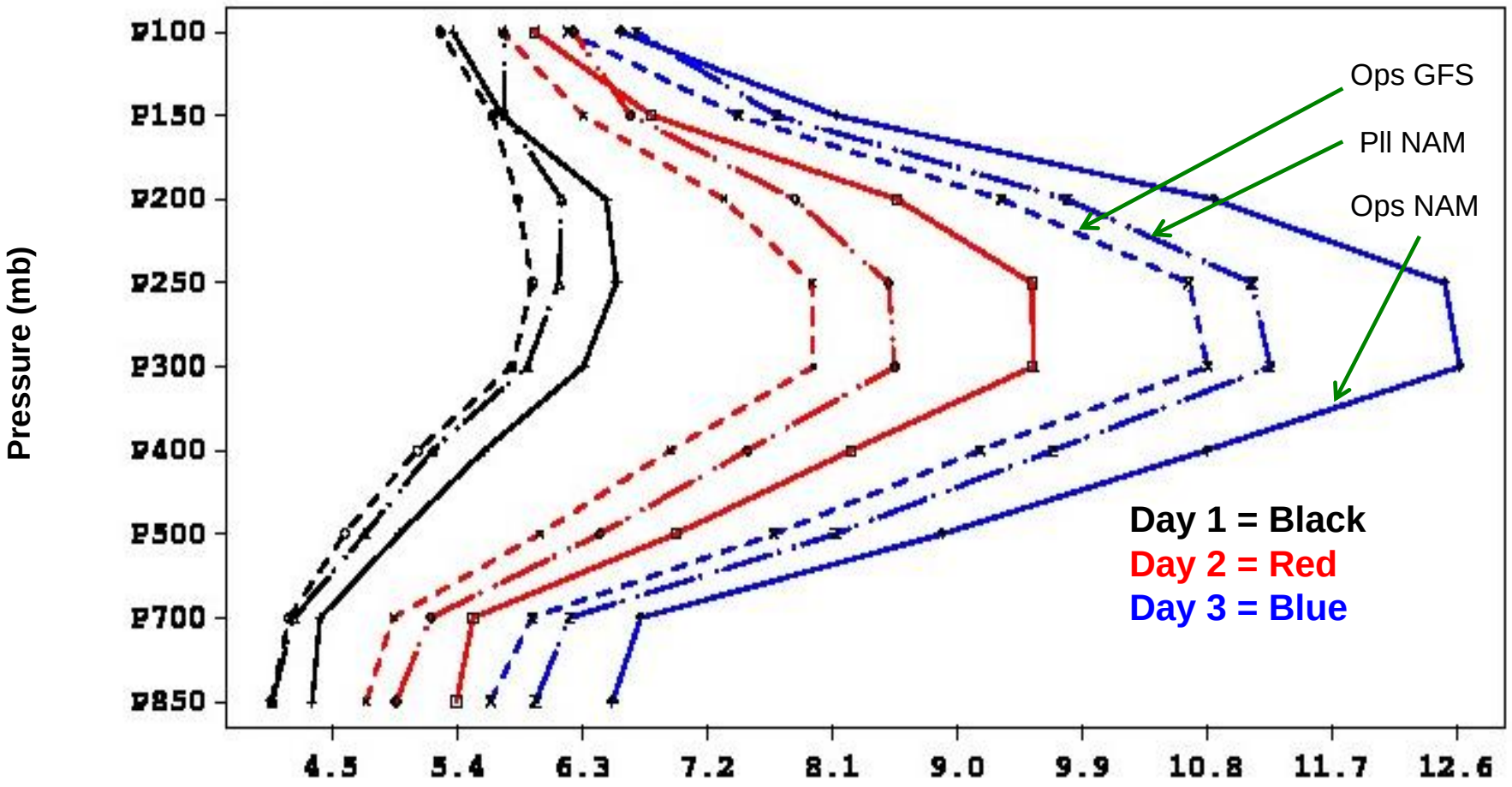


- **Physics Modifications:**
  - GWD/mountain blocking; more responsive to sub-grid scale terrain variability
  - BMJ convection : moister convective profiles, convection triggers less, increase 12 km bias
  - RRTM radiation, latest version
  - Ferrier-Aligo microphysics, tuned to improve severe storm depiction
  - Improved snow depth algorithm in LSM

- **Data Assimilation Modifications:**
  - Hybrid variational-ensemble analysis with global EnKF
  - New satellite bias correction algorithm (same as in FY14 global upgrade)
  - Cloud/radar assimilation in NDAS (planned)

NAM test results: FY14 Upgrade Pkg

Verification from 1 October 2013 – 15 January 2014

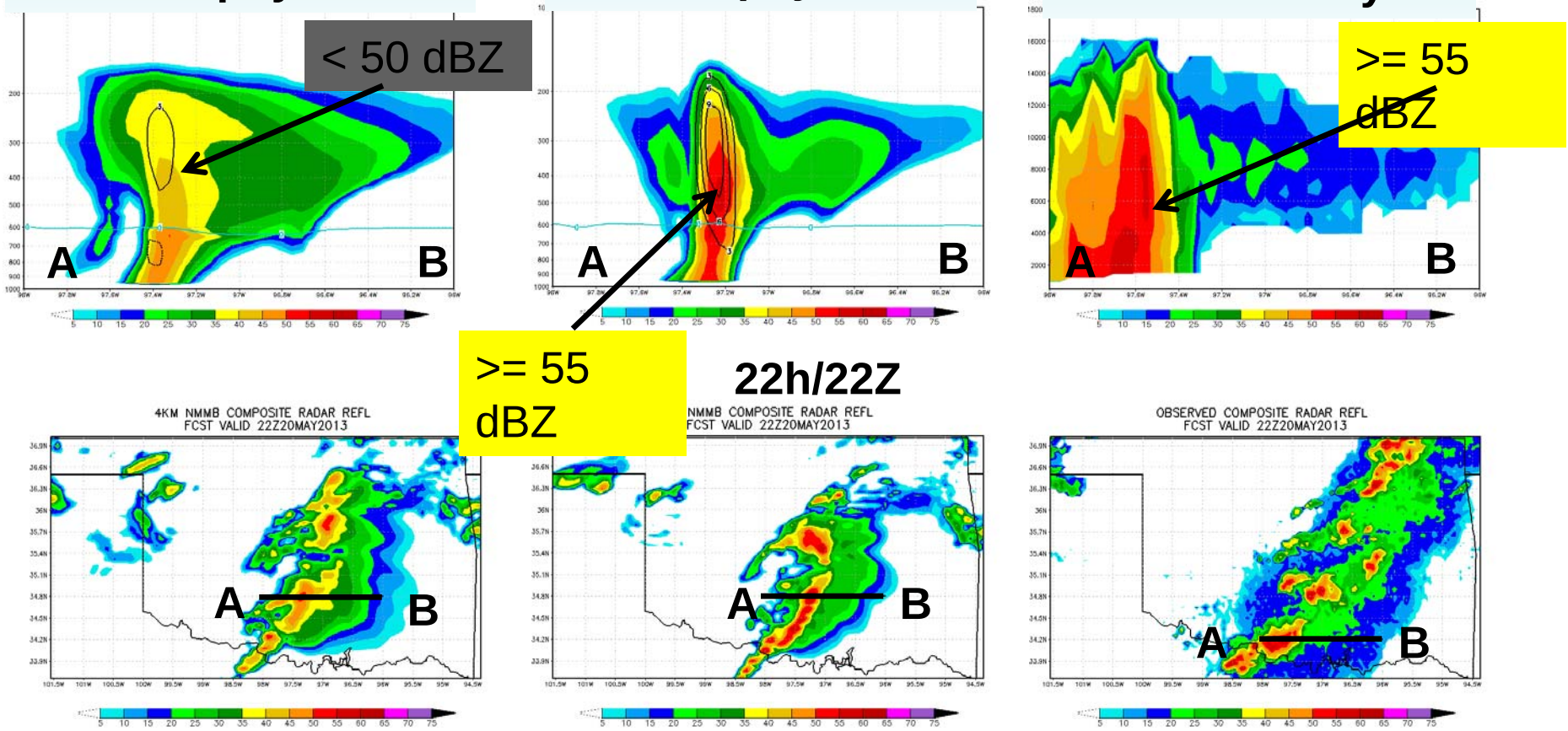


4-km North American Mesoscale (NAM) model
20-21 May 2013, Moore, OK Tornado Outbreak

Operational Microphysics

Ferrier-Aligo Microphysics

Observed Reflectivity

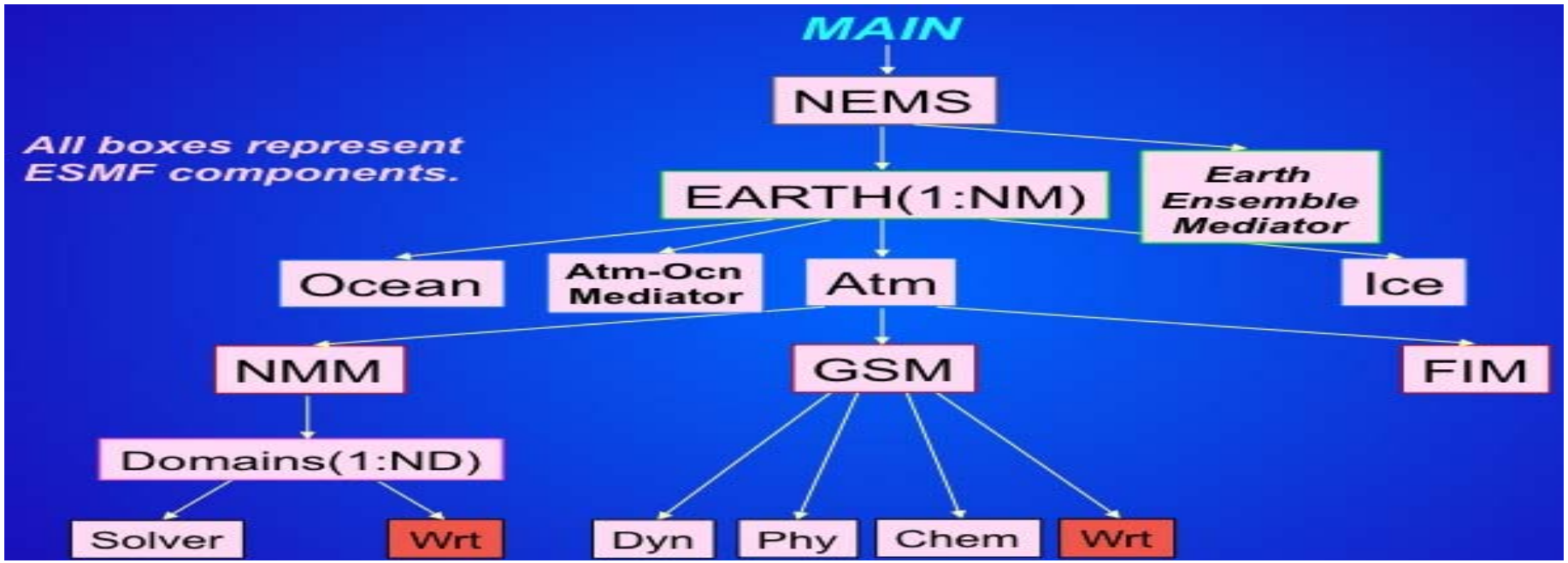


F-A microphysics: over a dozen changes, including a "hail mode", mass-weighted rime factor (variable density), increased radar return from rain + ice (post processing step)

Eric Aligo & Brad Ferrier

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)

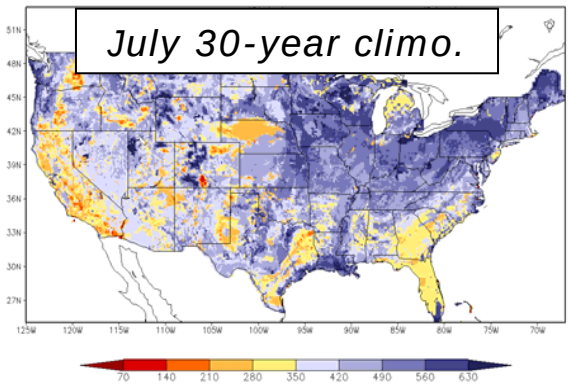


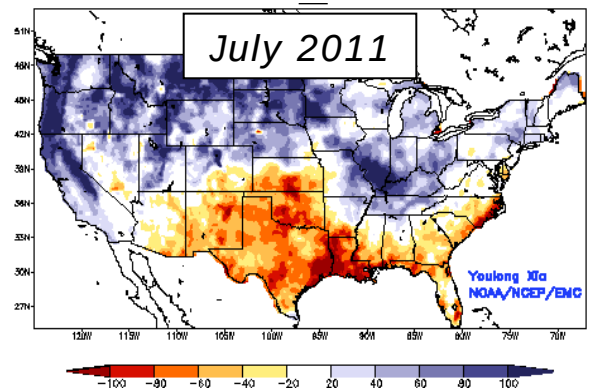
Drought: North American Land Data Assimilation System (NLDAS)

- FY2014 transition to ops: 4 land models run **uncoupled**, driven by CPC **observed precip** & **atmos** forcing from NCEP R-CDAS
- Output: 1/8-deg. **land** & **soil states**, **surface fluxes**, **runoff** and **streamflow**; anomalies compared with climatologies from 30-year land model runs
- Drought: Supports monitoring/seasonal hydrological forecasting
- Future: extend NLDAS drought concept to global domain using Opn'l CFS/Global LDAS; upgrades to NCEP Noah land model

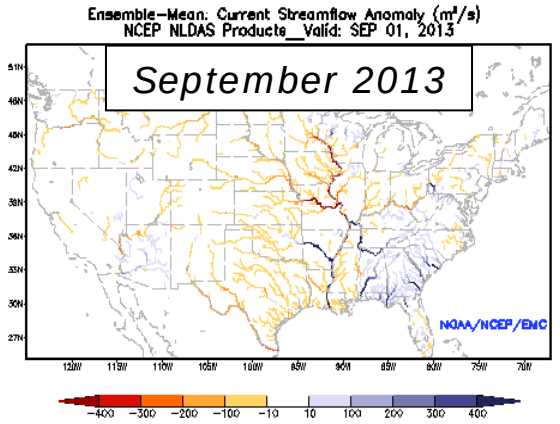
Youlong Xia

www.emc.ncep.noaa.gov/mmb/nldas





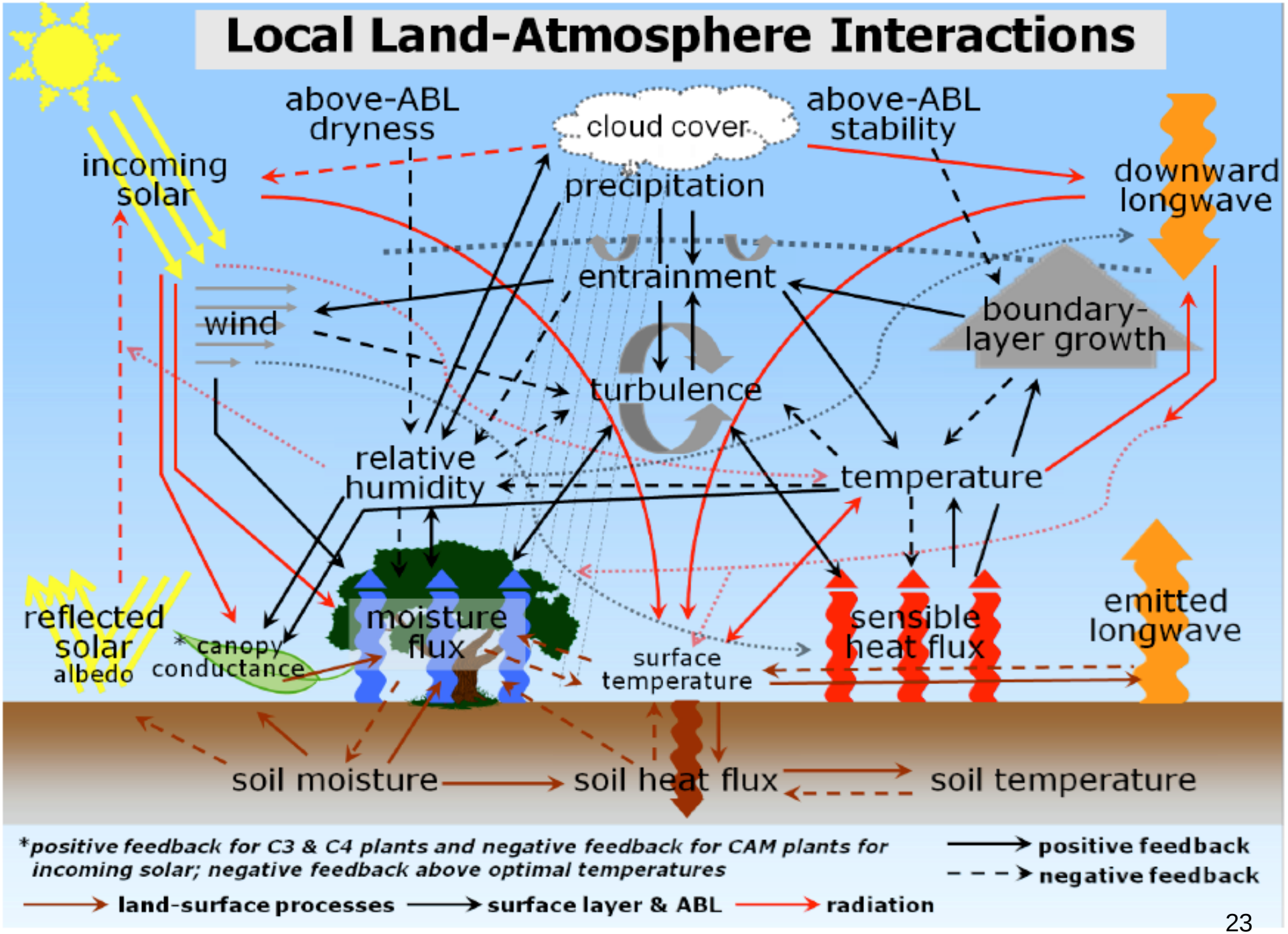
Ensemble monthly soil moisture anomaly



Daily streamflow

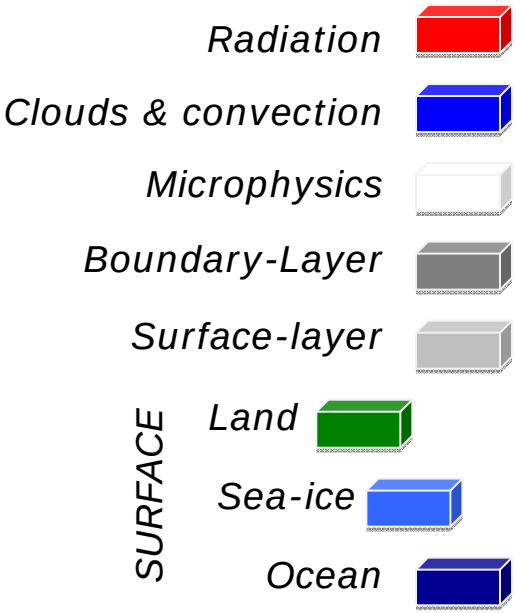
Model Evaluation Group (MEG)

- **Project designed to focus attention on product quality on a daily basis with feedback into the model development cycle**
- **Inspired by monitoring activities at ECMWF, Met Office, GMAO**
- **Evaluates daily performance of EMC forecast/analysis systems from a synoptic perspective and adds verification:**
- **Conduct weekly EMC map discussion of model performance**
- **Project benefits:**
  - **Improves situational awareness and enhances communication**
  - **Provides critical feedback to modelers and branch chiefs**
  - **Provides streamlined feedback to outside users with model concerns**
  - **Can potentially serve as a point-of-contact for all model concerns outside of EMC**


Local Land-Atmosphere Interactions
above-ABL dryness
cloud cover
above-ABL stability
incoming solar
precipitation
downward longwave
entrainment
wind
boundary-layer growth
turbulence
relative humidity
temperature
reflected solar albedo
canopy conductance
moisture flux
surface temperature
sensible heat flux
emitted longwave
soil moisture
soil heat flux
soil temperature
*positive feedback for C3 & C4 plants and negative feedback for CAM plants for incoming solar; negative feedback above optimal temperatures
positive feedback
negative feedback
land-surface processes
surface layer & ABL
radiation

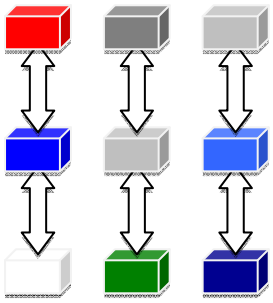
Tools for More Efficient Model Development
Example: Model Parameterization Testbed

Simulators

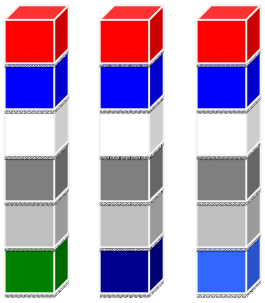


- Simulators: test submodel parameterizations at process level, e.g. rad.-only, land-only, etc.
- Testbed data sets to develop, drive & validate submodels: observations, models, idealized, with "benchmarks" before adopting changes. GEWEX/GLASS "PLUMBER" project.
- Submodel interactions, full columns ("DICE")
- Next: limited-area/3-D, & *Finally* NWP/climate
- *More efficient R2O/O2R & computer usage*

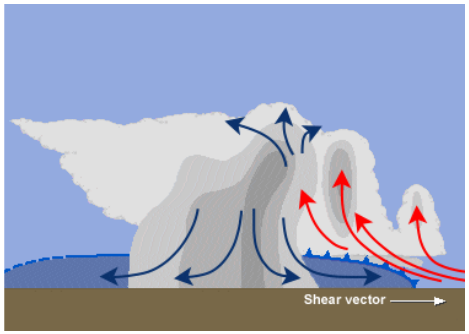
Interaction tests



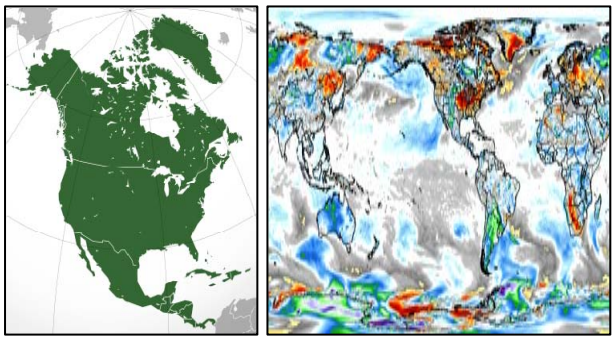
Column tests



Limited-area



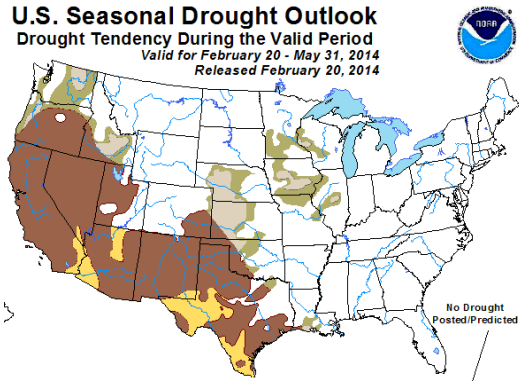
Regional & Global



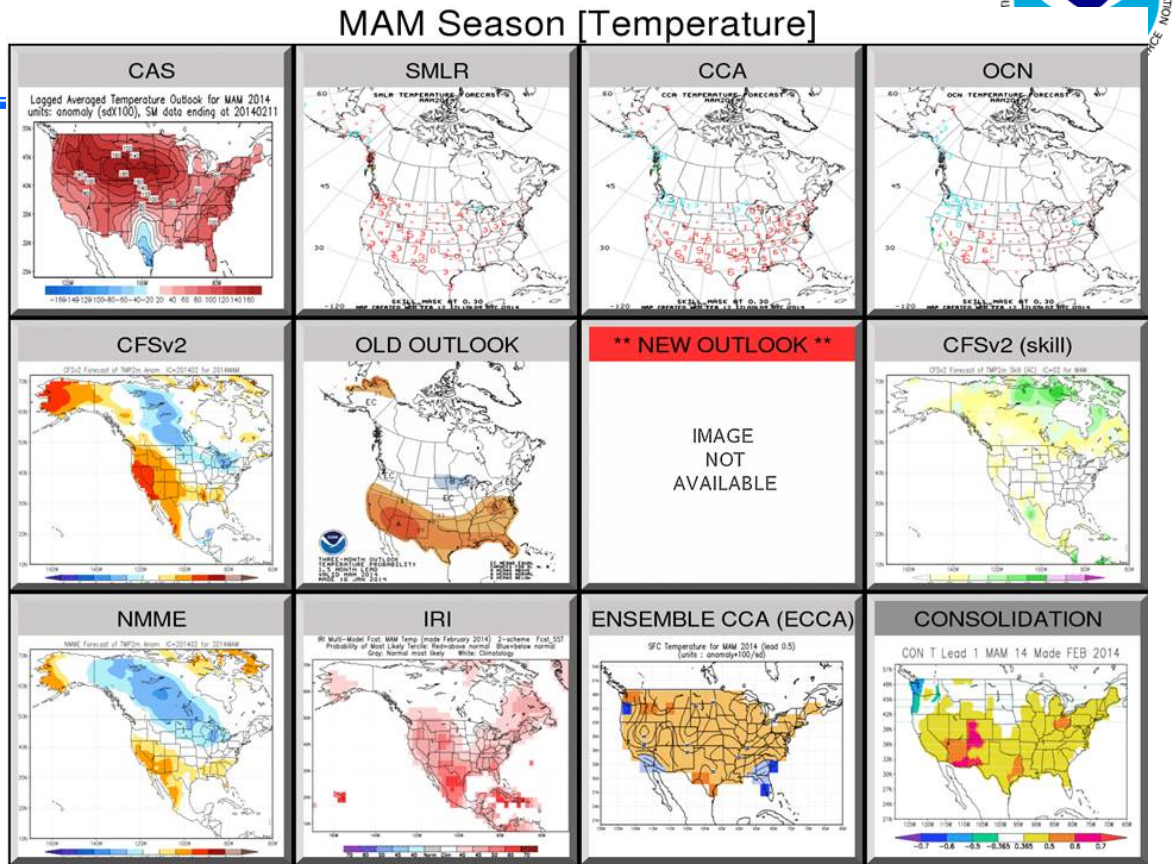
CPC Real-Time Seasonal Forecasting Tools

Used in Monthly Ocean Briefing

Used by African Desk



CPC uses NCEP/EMC land-surface products, i.e. NLDAS and CFSV2_VIC for CPC drought monitoring and forecasts.



CPC Seasonal Prognostic Map Discussion (PMD):
PROGNOSTIC TOOLS USED FOR U.S. TEMPERATURE AND PRECIPITATION

"THE TEMPERATURE AND PRECIPITATION OUTLOOKS WERE MADE CONSIDERING ENSO NEUTRAL CONDITIONS TO BE MOST LIKELY THROUGH SPRING. AN INCREASING CHANCE OF THE DEVELOPMENT OF El NINO CONDITIONS INTO SUMMER OF 2014 AND LOW PROBABILITY OF DEVELOPMENT OF LA NINA ALTERS BOTH THE FORECASTS OF DYNAMICAL MODELS, SUCH AS MODELS WITHIN THE NATIONAL MULTI-MODEL ENSEMBLE (NMME) …

Mike Halpert, Kingtse Mo

Climate Program Office (CPO)

CPO Program Areas

- Climate Observations and Monitoring
- Earth System Science
- **Modeling, Analysis, Predictions, and Projections (MAPP)**
- Climate and Societal Interactions

MAPP Task Forces

- Prediction Task Force
  Advancing ISI Climate Prediction
- Climate Reanalysis Task Force
  Research for next-generation reanalysis
- Climate Model Development Task Force
  Improved models for climate prediction
- Drought Task Force
  Advancing Drought Understanding, Monitoring, and Prediction
- **CMIP5 Task Force**
  Developing Projections for North America

MAPP Task Forces: going beyond the grant funding exercise to connect scientists in the external community with NOAA labs and operational centers.

The CMIP5 task force brings together 30+ MAPP-funded scientists working on CMIP5-related research projects.

Process-Oriented Metrics for Model Evaluation:

A CMIP5 Task Force Activity; Contact: Eric Maloney

emaloney@atmos.colostate.edu

- **A concept gaining support in the community: process- as opposed to performance-oriented evaluation of model biases**

- **External motivators:**
  - **WGNE/WGCM Climate Model Metrics Panel**
    - **"… "process-oriented" metrics might better isolate model errors and perhaps reveal more useful information as to their origins. It is hoped that ongoing research will help identify a limited set of key process-oriented metrics appropriate for this panel's use." – WGNE/WGCM Climate Model Metrics Panel Wiki**
  - **WWRP/WCRP YOTC MJO Task Force**
    - **Currently developing a set of process-oriented metrics related to the MJO**
  - **Many of the U.S. modeling centers are entering early stages of model development**

- **CMIP5 Task Force contributions**
  - **Expertise from the research community external to the modeling centers**
  - **Application of understanding gained from analysis of CMIP5 data**
  - **Understanding of both modeling center and applied user needs for process-based metrics**

- **Goals/next steps**
  - **Connect with WGNE Climate Model Metrics Panel on process-oriented metrics**
  - **Task Force already engaging with NCAR, GFDL, and NCEP**
  - **Work with user community to understand demand for process-oriented understanding of regional climate**
  - **Journal articles on individual metrics or process-oriented approach**

North American Multi-Model Ensemble (NMME)

An unprecedented MME system to improve intra-seasonal to interannual (ISI) operational predictions based on the leading US and Canada climate models.

NMME Phase-I: An experimental system initiated as a Climate Test Bed (CTB) research project supported by NOAA Climate Program Office MAPP Program in FY11.

NMME Phase-II: An **improved** experimental system as a FY12-FY13 MAPP/CTB research project with additional support from NSF, DOE and NASA.

Current Models In NMME:

- NCEP-CFSv2
- GFDL-CM2.1
- CMC1-CanCM3
- CMC2-CanCM4
- NCAR-CCSM3.0
- NASA-GEOS5

- Real-time seasonal forecast since August 2011 following CPC operational schedules - hindcast and forecasts readily available to the community
- All participating models strictly follow the same protocol and re-run hindcasts after each model upgrade
- NMME is being widely used for research and applications

NMME-II upgrades:

Models

- NCAR-CCSM4: May 2014
- GFDL-FLOR: March 2014
- NCAR-CESM1: April 2014

Output

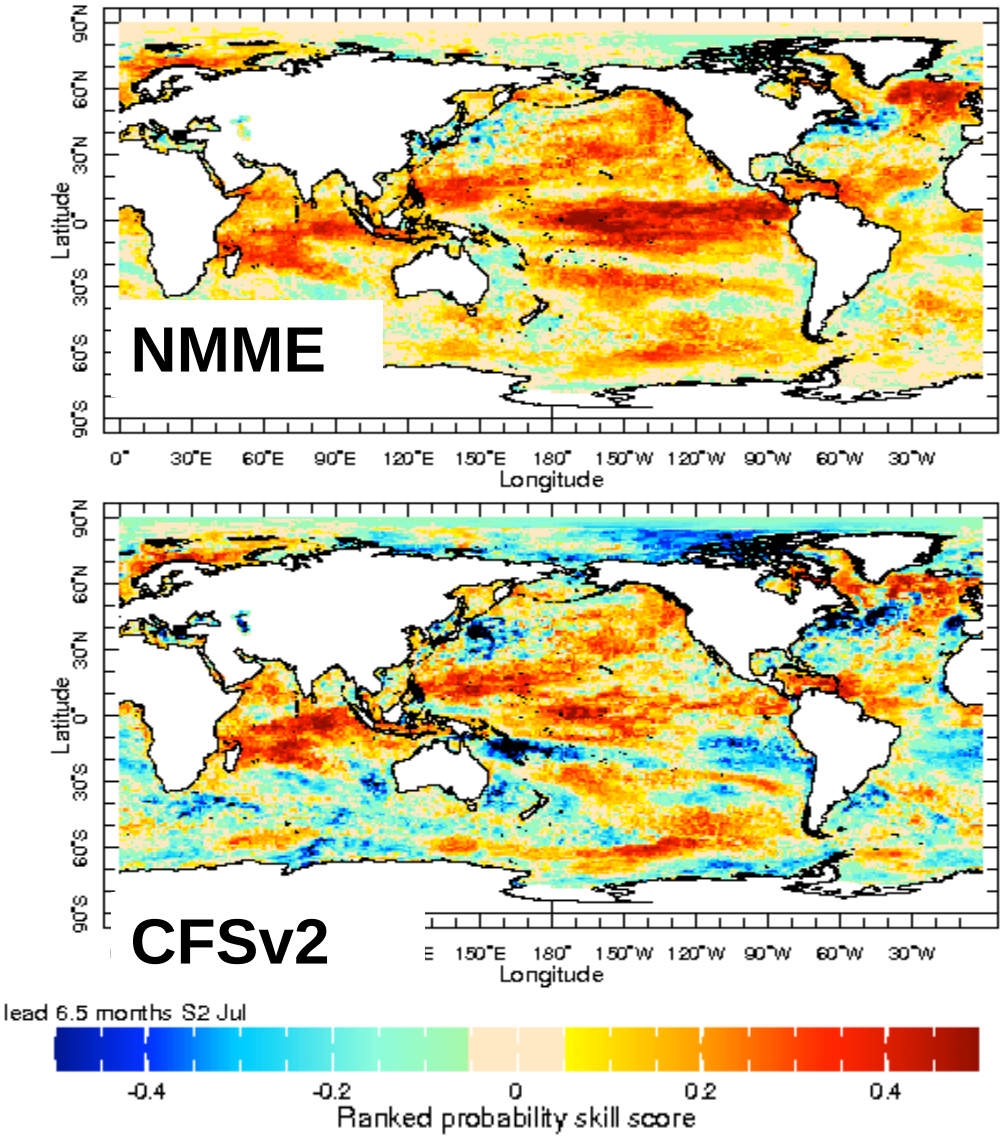
Daily data for an expanded suite of variables

Rick Rosen, Annarita Mariotti, Dan Barrie, Jin Huang

Comparison of CFSv2 skill vs NMME

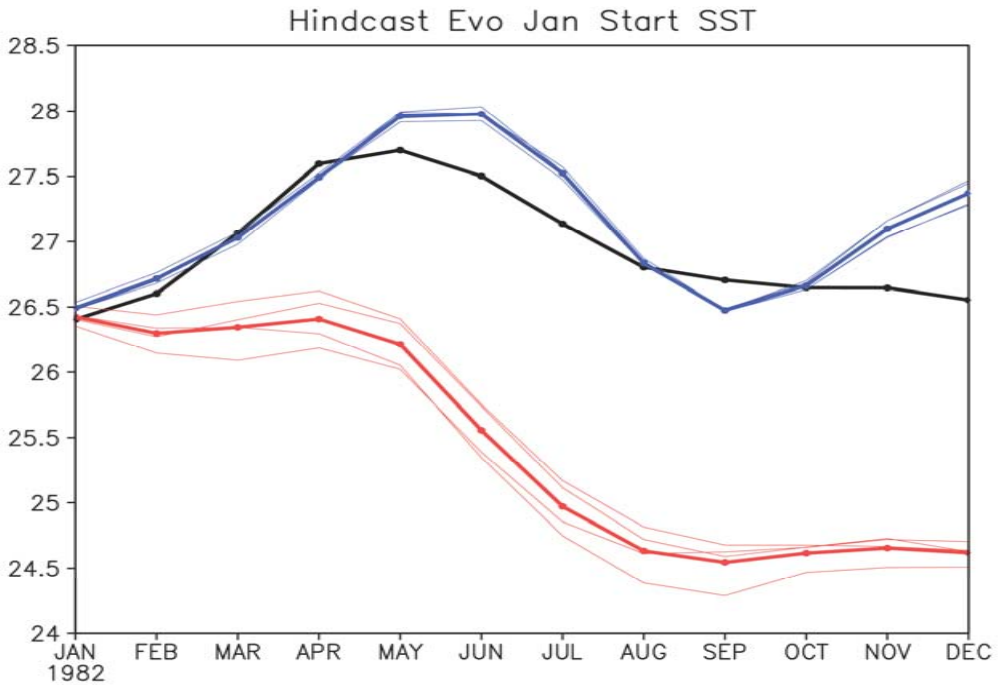
July 1 start
DJF SST forecast
Ranked
Probability Skill
Score based on
30-year NMME
hindcast data

(B. Kirtman et al.)



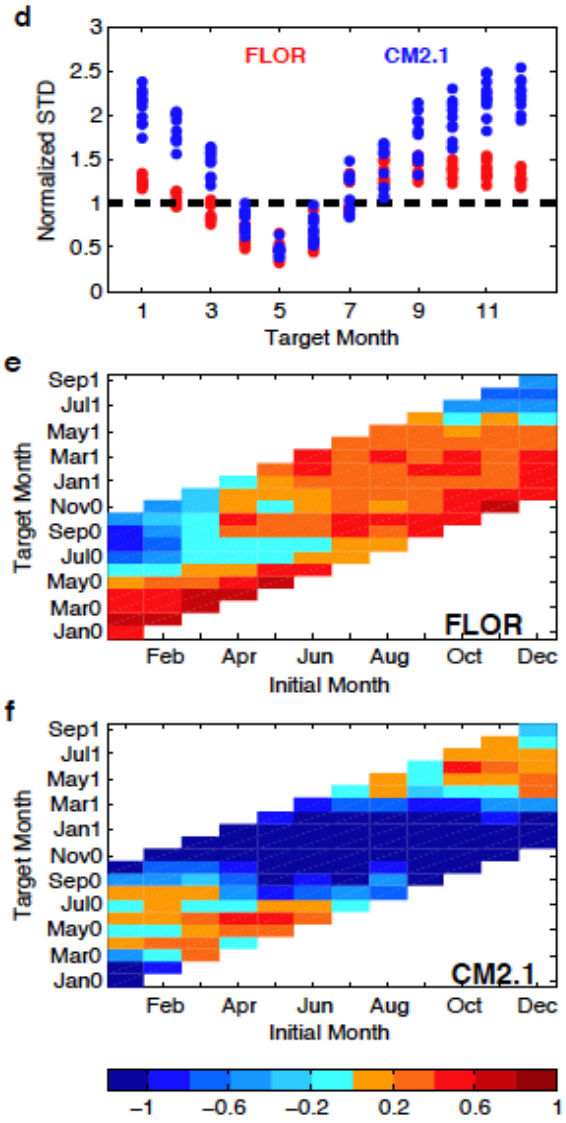
NMME Phase-II Model Upgrades

NCAR/CCSM4
(scheduled for CPC operation in May 2014)



Hindcast Evolution of NINO3.4 in CCSM3 and CCSM4 based on 30-year (1981-2010) hindcasts

Rick Rosen, Annarita Mariotti, Dan Barrie, Jin Huang



GFDL FLOR
for CPC operation in March 2014

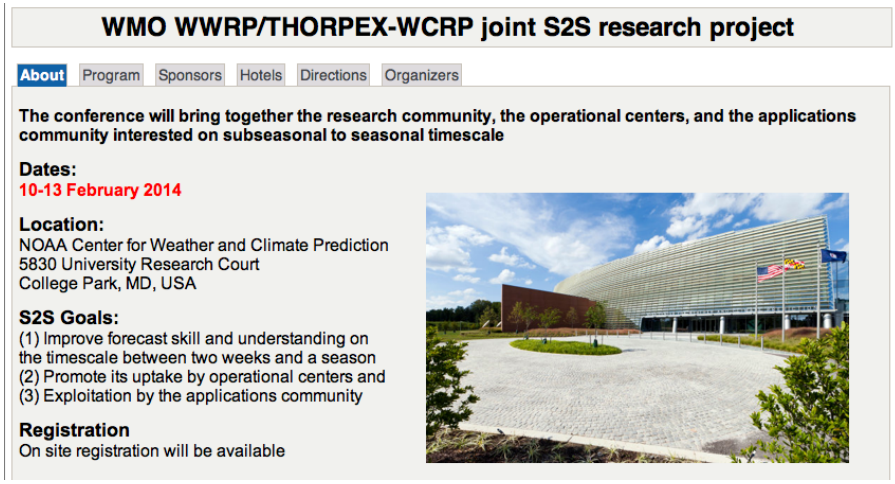
Joint GODAE Oceanview (GOV)/WGNE Workshop, 19-21 March 2013

- *Organisers – Bill Lapenta, Glenn White, Gary Brassington*
- *Modelling – Eric Chassignet and Paul Sandery*
- *Observations – Chris Fairall and Jim Cummings*
- *DA – Craig Bishop and Matt Martin*
- *Parameterisation – Baylor Fox-Kemper*
- *Whitepapers in progress*

CONCLUSIONS

- **Evidence now compelling for coupled modelling (short- to medium-range).**
- **Coupled framework will put spotlight on the problem of air-sea interaction.**
- **Communication/dialogue amongst more diverse set of groups a challenge.**
- **Coupled modeling introduces add'l requirements on obs system, both for air-sea parameterisation & systematic bias. Dialogue to specify requirements.**
- **Parameterisations exists that should translate to coupled high -es modelling.**
- **May or may not be advantageous to conserve interfacial fluxes in a coupled model. The coupled framework provides greater control and discipline over the decision of what to exchange.**
- **The latency and coverage for observations of the coupled boundary layers will limit progress. Requirements for observing the coupled boundary layer unique and might need different designs. Present autonomous engineering community with requirements to determine if a cost effective solution can be achieved.**

International Conference on Subseasonal to Seasonal Prediction, 10-13 February 2014



- More than 130 abstracts and more than 60 presentations. Presentations are posted at ftp://ftp.emc.ncep.noaa.gov/exper/nova/workshop/
- Served as a venue for the S2S SG to discuss current status and to design a project's work agenda. A meeting summary paper will be submitted to BAMS

- Organized by NCEP, IAO-NWS and the S2S Steering Group
- Brought together more than 150 participants from operational centers, the research and the applications communities.
- Program included 5 general themes:

a. Relevant phenomenon for S2S prediction and predictability: MJO, stratospheric variability, land-atmosphere feedbacks, etc.
b. Prediction of extremes: Blockings, short-lived extremes, tropical cyclones, heat waves, etc.
c. Initialization and ensemble perturbation methods: Coupled breeding, ocean, land, snow initialization, etc.
d. Design of Forecast Systems: Multi-model ensembles, monthly forecasting systems, etc.
e. Approaches to Integrate S2S forecasts

http://www.emc.ncep.noaa.gov/gmb/ens/s2s/