HFIP Data Assimilation Activities

W. Lapenta (EMC)

Contributions by

J. Whitaker (ESRL)
J. Ward, F. Yang & R. Treadon (EMC)
F. Zhang (PSU)
M. Tong (EMC)
M. Zupanski (CIRA)
J. Doyle (NRL)
A. Aksoy (AOML)
Y. Xie (ESRL)
H.-S. Kim (EMC)

Overview

- **Global data assimilation**
  - EnKF Research (ESRL)
  - Operational implementation (EMC)
- **Regional research**
  - MLEF (CIRA)
  - Hi-res EnKF
    - AOML
    - PSU
  - Variational 3d-var
    - Doppler radar (EMC, ESRL)
    - COAMPS (NRL)
- **Ocean**
  - Buoys (EMC)

Global Research (EnKF)

- **Why EnKF?**
  - EnKF provides
    - Ensemble of initial conditions (unifies the ensemble forecast and data assimilation steps).
    - Flow-dependent background-error covariances crucial for hurricanes
    - Estimate of analysis error
  - EnKF
    - Is relatively simple to code, portable from one model to another
    - Lacks tangent linear, adjoint models
    - Scales well on large numbers of processors
  - EnKF
    - Does not control global scale dynamic balances
    - May suffer from undersampling in ensemble space
- **EnKF configurations**
  - **60 member EnKF ensemble to generate initial conditions (using T382 GFS in DA cycle)**
  - **20 member 30 km FIM ensemble out to 7 days once per day initialized from EnKF ensemble**
  - **15 and 10 km deterministic FIM runs (15 km run initialized from both EnKF mean and operational GSI analysis)**

Global EnKF Results

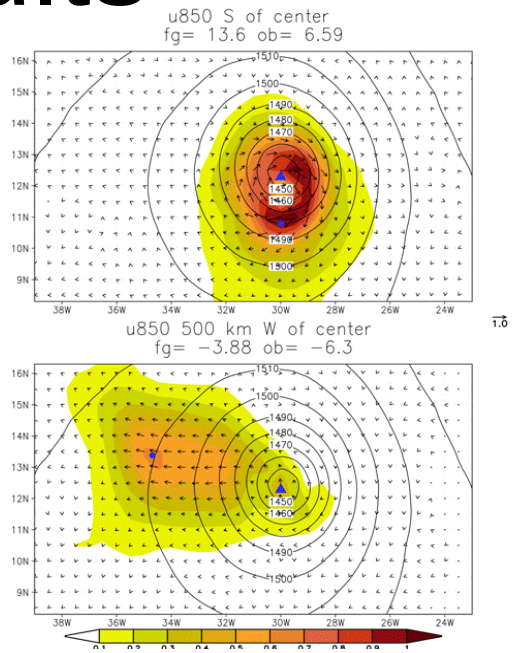
- Single observation results give flow-dependent background error covariances
- TC track forecast errors reduced
- Tropical wind error statistics improved with EnKF

Hurricane Fred 00Z 9 Sep

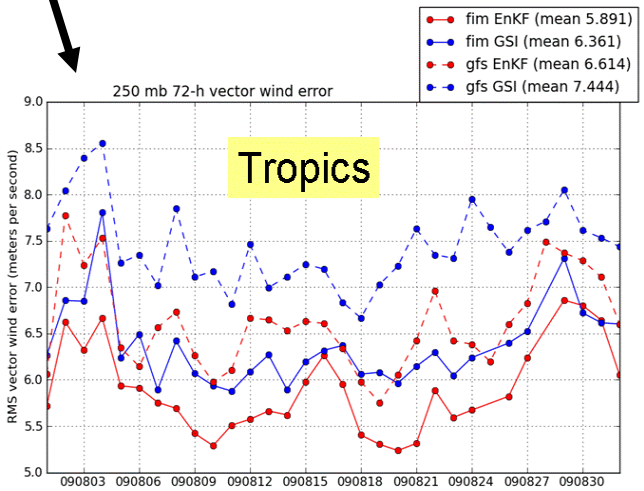
Single ob increments for 850 hPa u ob 1 m/s different than background.

- *Increments highly flow dependent.*
- *Analysis "knows" there is a hurricane.*

***Solid contours**: 850 hPa background geopotential height.*
***Colors**: wind speed increment*
***Arrows**: vector wind increment*
***Blue triangle**: hurrican center.*
***Blue circle**: location of ob.*



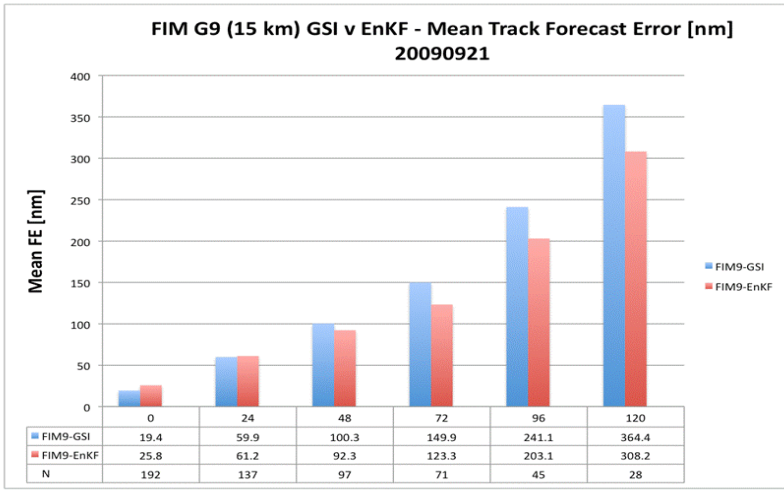
72h **250hPa** Wind RMS vector error (vs. analyses) **smaller is better**



FIM – _____
GFS ----------
GSI init conds
EnKF init conds

FIM better than GFS, EnKF better than GSI.

Tropical Cyclone Track Forecasts



	0	24	48	72	96	120
FIM9-GSI	19.4	59.9	100.3	149.9	241.1	364.4
FIM9-EnKF	25.8	61.2	92.3	123.3	203.1	308.2
N	192	137	97	71	45	28

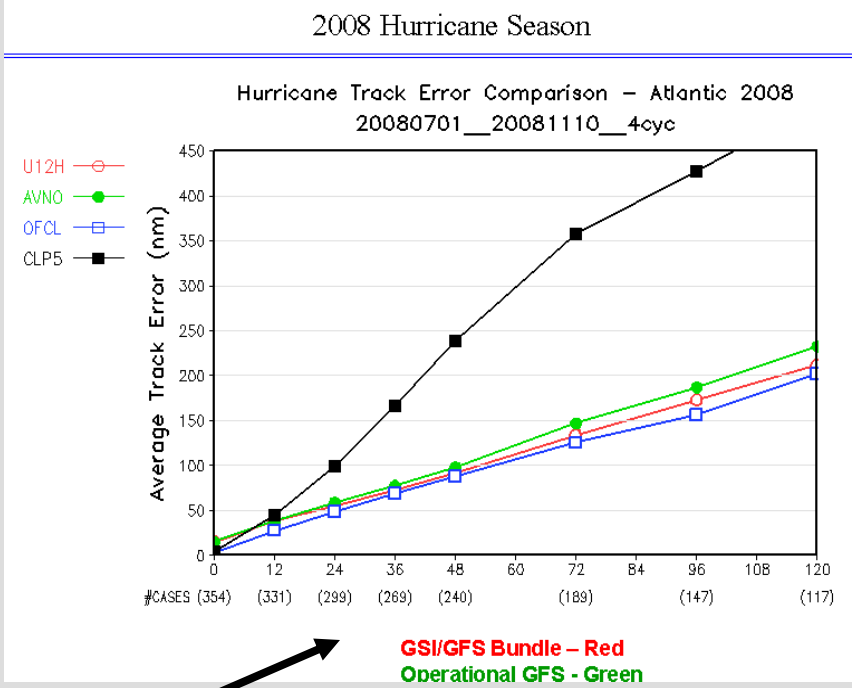
Whitaker - ESRL

Operational Implementation NCEP for GFS/GSI Dec 2009 – May 2010

- GSI/GFS December 15, 2009
  - Ingest new data types
  - GSI Code changes
  - GFS code restructuring
  - Benefits
    - Better tropical cyclone definition
    - Improvement in track forecast skill (117 cases)
- GFS Shallow Convection – March 2010
  - Shallow convection, Deep Convection, PBL
  - Benefits
    - Significant reduction in gridpoint storms
    - Small improvement in global forecast skill
- GFS Resolution Increase – May 2010
  - T574L64
  - Benefits
    - Overall improvement in forecast skill

Operational Implementation NCEP - 2

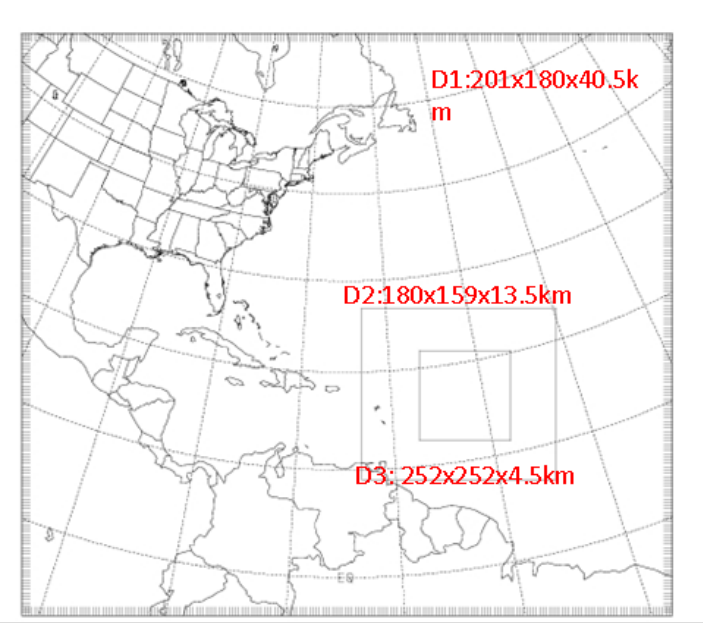
- **December 2009 upgrade**
- **Adding new observation data sources**.
  - **Tropical storm pseudo sea-level pressure obs**
  - NOAA19 hirs/4,AMSU-A, & MHS brightness temp obs
  - NOAA18 sbuv/2. Monitor N19 GOME, and OMI ozone (no assimilation)
  - RARS (currently only EARS) 1B data
  - EUMETSAT-9 atm motion vectors
- **Implementing improved techniques in GSI analysis**.
  - Use uniform thinning mesh for brightness temp data
  - Improvements to assimilation of GPS RO data (QC, retune ob errors, improved forward operator)
  - Add dry mass pressure constraint
  - Merge GMAO & EMC codes for 4d-var capability
  - Update background error covariance
  - Proper use of different spectral truncation between background and analysis
- **Benefits**
  - **Improved GFS tropical storm track & intensity forecasts**
  - Small improvement in global forecast accuracy

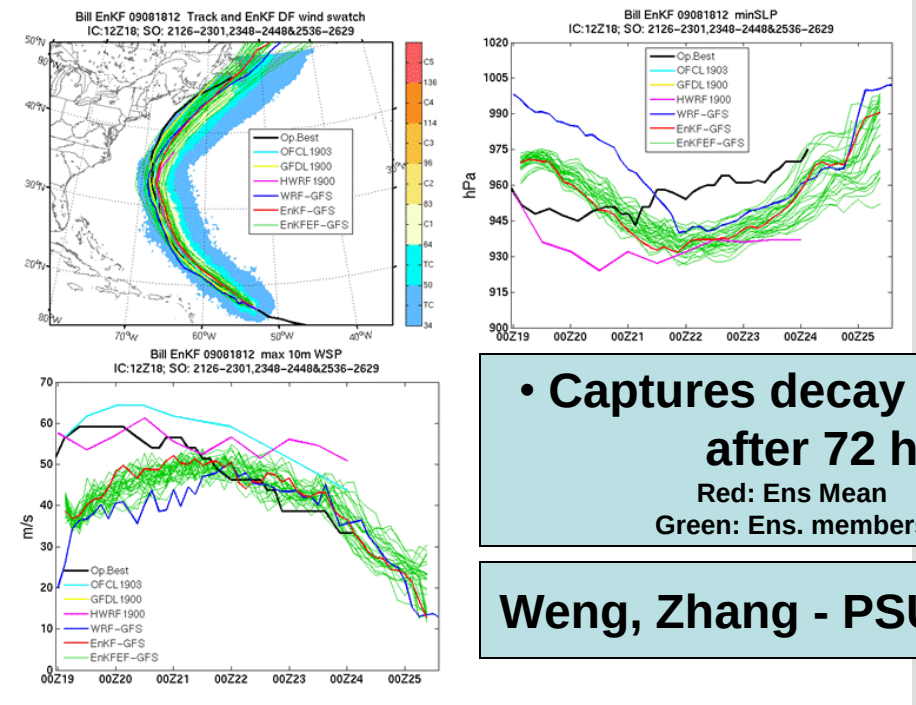


NCEP

Regional Research - HiRes EnKF - 1

- Real-time EnKF Assimilation of Airborne Doppler Velocity for the 2009 Season
  - Yonghui Weng and Fuqing Zhang (PSU)
  - ARW-EnKF of airborne Vr for all 10 P3 2009 missions
  - WRF ARW V3.1; 35 vertical levels; 2-way nest; D2-3 movable; ICs and BCs from GFS; 30 member EnKF





• Captures decay of Bill after 72 h

Red: Ens Mean
Green: Ens. members

Weng, Zhang - PSU

Regional Research - HiRes EnKF - 2

- **Development of Vortex-Scale Ensemble Kalman Filter for HWRFx**
  - **Altug Aksoy, AOML/HRD**
  - A square-root EnKF has been developed for HWRFx
  - Initial ensemble perturbations obtained from the GFS ensemble members
  - Forward operators completed to assimilate flight level, dropsonde, and Doppler wind observations
  - Some delays occurred due to issues with WRF-NMM restart capability ➔ This is still under development and testing by EMC and HRD
  - System currently tested with simulated observations
  - 27-km resolution on HRD's computer
  - Will port the system to NOAA's Njet computer in Boulder

Aksoy - AOML

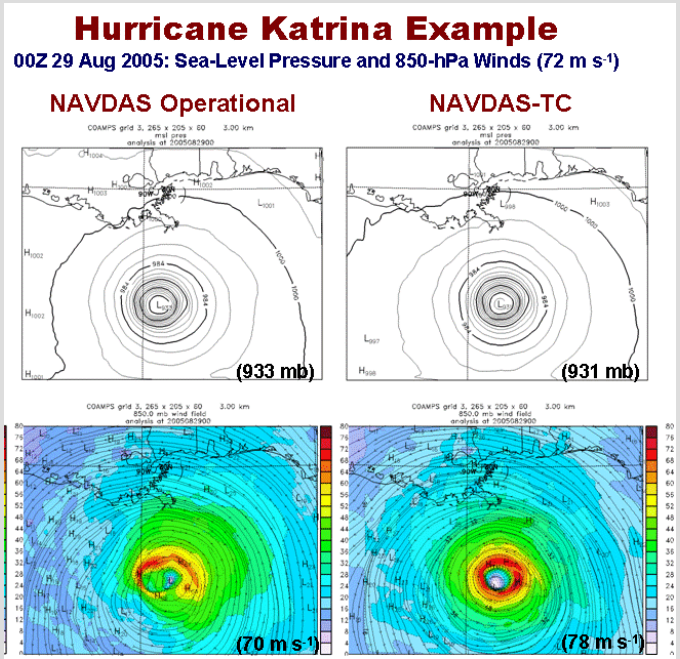
Regional Research - HiRes EnKF - 3

- **Ensemble Data Assimilation Research for Hurricane Forecasting**
  - Milija Zupanski, CIRA/Colorado State University
  - Use HWRF ensemble data assimilation (Maximum Likelihood Ensemble Filter - MLEF) with as guidance for situation-dependent error covariance modeling in GSI (*Collaborative work with EMC/NCEP*)
  - MLEF-HWRF system installed on NCEP computer (Vapor) and now being evaluated (Hurricane Gustav, 2008), **20 km/ 6.6 km resolution**)
    - (1) Interfacing MLEF with HWRF (completed)
      - Included parts of the HWRF system infrastructure to set-up hurricane case, initiate all models, access GFS and observation files, and execute the forecast
    - (2) Interfacing MLEF with the GSI observation operator (completed)
      - Use forward component of the GSI to access observations in ensemble DA system
      - Observation error characteristics and quality control from GSI
    - (3) Evaluation of the MLEF-HWRF system (in progress)
      - Forecast error covariances evaluated before further processing in GSI

Zupanski - CIRA

Regional Research - 3d-var - 1

- COAMPS-TC Data Assimilation
  - J. Doyle (NRL)
  - Improvements to NAVDAS for TC analysis
    - Correlation length scale dynamic balance
    - Added more observations and included impact of boundary layer friction
    - Relocation now includes microphysical parameters
    - Verified and analyzed results for 2008 season in the Atlantic basin
    - Shared real-time results with HFIP community in real time (web, DTC, FSU etc.)
    - Identified systematic problems with the analysis and initialization



- Improvement over operational analysis for Katrina example

Doyle - NRL

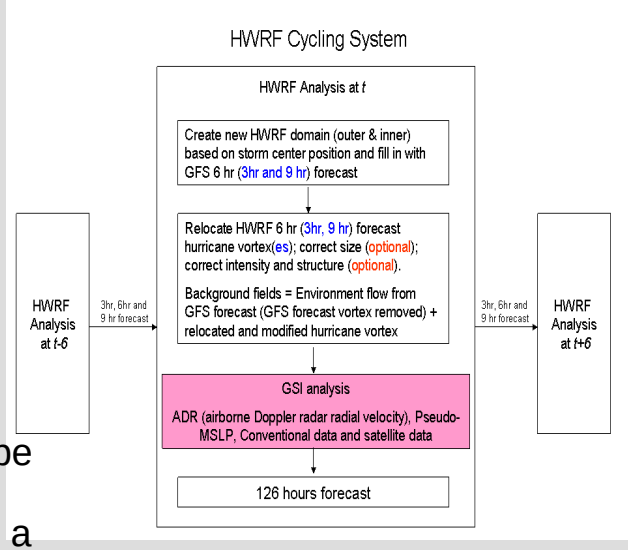
Regional Research - 3d-var - 2

- Assimilation of Airborne Doppler Velocity with a Multi-scale Analysis
  - Yuanfu Xie (ESRL)
  - Develop a multiscale EnKF-variational scheme for assimilation of airborne radar data
  - Use the variational scheme as a forward operator to reduce noise produced by an EnKF
  - Airborne radar data ingest into our local analysis system is completed
  - Currently testing and debugging local radar data assimilation operator using a retrieval method instead of a statistical method
  - An improvement to lower boundary analysis constraint is close to completion

Xie - ESRL

Regional Research - 3d-var - 3

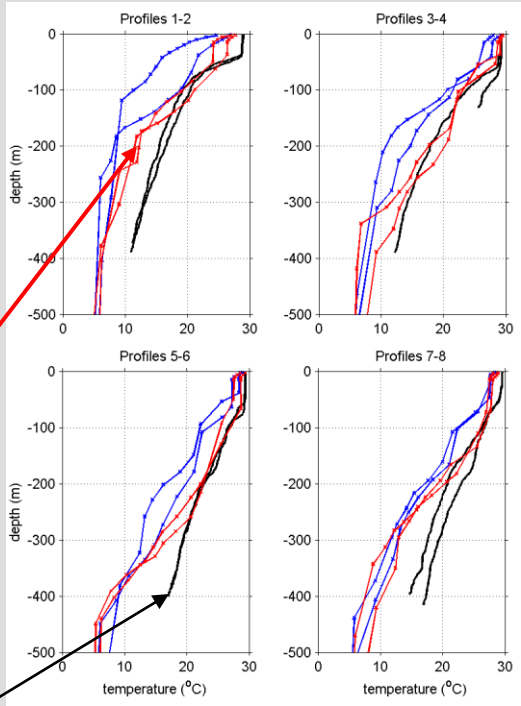
- Assimilation of Airborne Doppler Velocity for the 2009 Season
  - Mingjing Tong (EMC)
  - Airborne Doppler Radar (ADR) for sample cases (2008, 2009)
  - GSI-HWRF with anisotropic background error covariance
  - ADR data are thinned with 9km resolution (HWRF inner domain resolution)
  - 2009 progress
    - Modified HWRF cycling system to make each component (relocation, size correction, intensity and structure correction) optional
    - Modified and tested HWRF code and scripts so that W can be included as an additional control variable in GSI analysis
    - Modified and tested GSI code so that pseudo-MSLP data can be assimilated into regional models
    - Finished ingest for airborne radar BUFR data and tested it with a sample data
    - Tested
      - Ability of radar data in moving hurricane vortex to the right location and correcting vortex size, structure and intensity
      - Case tested Dropsonde, pseudo-MSLP, satwind obs
  - Major issues
    - Dynamic and thermodynamic balance in analysis increments
    - Operational ADR data flow to NCO is not complete in 2009



Tong - EMC

Ocean Data Assimilation (ODA) - 1

- Improving ODA for hurricanes
  - Hyun-Sook Kim
  - Synthetic T-S profiles to RTOFS for hurricane forecast
    - T & S profiles constructed with combination of SSHA, SST and historical profiles by AOML
    - Data assimilation into RTOFS for periods during Emily (2005), Rita (2005) and Wilma (2005)
    - Results
      - Improvement in the upper layer
      - Minor impact on hurricane Intensity forecasts



Example: Synthetic data assimilation significantly brings the estimates of water temperature and mixed-layer depths closer to the AXBT observation

Red: HyHWRF simulation w/ synthetic data
Blue: HyHWRF simulation w/o synthetic data
Black: AXBT data

H.-S. Kim - EMC

Ocean Data Assimilation (ODA) - 2

- Improving ODA for hurricanes (cont)
  - Assimilate AXBT in real time RTOFS to improve ocean estimates for hurricane forecasting
    - Participated in planning strategies for aircraft flights tracks for AXBT drops. (There is a need to form a NOAA wide standing planning group.)
    - Pipeline for real-time data transmittal is now in place in NCO and has been tested.
    - Initial tuning of assimilation parameters and experiments has been carried out using bogus data.
    - Initial results show small improvements
    - Current work
      - Adapting 3D VAR data assimilation to regional hurricane domain
      - Tuning of assimilation parameters for further improvement on the simulation

H.-S. Kim - EMC

Summary and Conclusions - 1

- Multiple organization effort
  - ESRL
  - NCEP/EMC
  - AOML
  - CIRA
  - PSU
  - NRL
- Demonstration of potential improvements due to global EnKF
- NCEP operational implementation (December) reduces GFS track errors
- Research in progress for regional assimilation
  - Much less mature than global effort
  - Doppler radar operational data flow not ready
- Ocean DA progress
  - Small but positive impact
  - Real-time data flow required

2010 Plans

- Copied verbatim from material provided by all participants
- Unedited and unreviewed
- Coordination and consolidation of effort to improve FY10 productivity may be desirable

Global EnKF

ESRL proposes:

- Continue to develop the EnKF
  - Emphasis on improving the treatment of sampling and model error.
- NCEP, ESRL will evaluate EnKF initialized 1-15 day ensemble forecasts relative to operational ET system.
- ESRL, OU and NCEP will develop hybrid Var-EnKF system
  - “The best of both Var and EnKF techniques”
  - Anticipated series of implementations 2011-2013
- EnKF and Var-EnKF hybrid systems will be tested on both NCEP and ESRL computer systems, using a single source code base

NCEP - ESRL

Regional Research - 1

NRL (Doyle) proposes:

- Continue to develop 3D-Var (NAVDAS) for COAMPS-TC
  - Improved synthetic obs. including options for weak storms
  - Improved analysis correlations within 3D-Var
  - Test AMSU radiance assimilation and impact on track
  - Filtering of global bogus for cold starts

- Initialization improvements
  - Development and testing of a diabatic digital filter
  - Test a nonlinear balance initialization
  - Test a nudging initialization method

- Demonstration of the Navy Coupled Ocean Data Assimilation (NCODA) system for the two-way (air-sea) COAMPS-TC

Doyle - NRL

Regional Research - 2

PSU proposes to:

- Evaluate the 2009 realtime or near-realtime regional EnKF performance, both deterministically and probabilistically
- Examine predictability limits for 2009 storms (e.g., Ana, Bill, Danny, Erika and Fred)
- Take advantage of the global GFS-EnKF analysis for regional-scale EnKF or ensemble forecast initialization
- Continue the realtime demo experiments in 2010 by assimilating airborne Doppler observations in realtime if continued funding/computing allowed

Weng, Zhang - PSU

Regional Research - 3

AOML (Aksoy) proposes:

- Testing for real observations to start by December 2009
- Cycling of observations will be possible when restart capability is implemented
- System tests on Njet computer expected to start by mid November 2009
- Results from OSSE experiments will be presented at the AMS Annual Meeting in January 2010
- Results from real data tests will be presented at the EnKF Workshop in April 2010 and Hurricane Conference in May 2010
- Plans to explore obtaining initial ensemble perturbations from the FIM ensemble
- Planned system characteristics:
  - Forward model at 9/3-km resolution
  - Perform DA at 3-km resolution
  - Assimilate flight-level data, dropsonde, and Doppler wind data

Aksoy - AOML

Regional Research - 4

ESRL (Yuanfu Xie) proposes:

- Compare GSI and ESRL performance of forward model for airborne radar data
- Compare GSI background error vs ESRL system
- Investigate non-gaussian, non-linear DA methods for hurricane core

Xie - ESRL

Regional Research - 5

CIRA (Zupanski) proposes:

Continuation of Ensemble Data Assimilation (EnsDA) Research for Hurricane Forecasting (*Collaboration with EMC/NCEP*)

- ***Milestones for 2010:***

  - Conduct extensive historical hurricane data assimilation experiments on the NOAA R&D computer using HWRF-EnsDA system. Use results to further improve GSI-SDBE covariance modeling .

  - In synergy with the JCSDA/EMC development of forward operators for cloudy radiances, begin work on utilizing and evaluating cloudy radiances in hurricane situations with EnsDA.

  - Conduct preliminary HWRF-EnsDA experiments with cloud microphysics control variables in selected hurricane cases. Evaluate the applicability of ensemble error covariances for developing cloud microphysical SDBEs covariances in GSI. ☐

Expected accomplishments:

- Provide large data base with hurricane ensemble data assimilation results. Evaluate the benefit of ensemble-based error covariances for SDBE covariance modeling.

- Complete development and testing of HWRF-EnsDA system with cloud microphysics control variables. Perform preliminary evaluation of cloud microphysical SDBEs in GSI.

- Conduct first HWRF-EnsDA experiments with hurricane assimilation of clou

Regional Research - 6

NCEP/EMC (Tong) proposes continued work on Doppler radar data assimilation

- Further improve analysis and intensity forecast by tuning the assimilation system and modifying experiment configurations
- Address balance issues using results from CIRA/Zupanski work
- Run real-time parallel with radar data for summer 2010
- Investigate the possibility of assimilating tcvital data in correcting storm size and structure

Tong - EMC

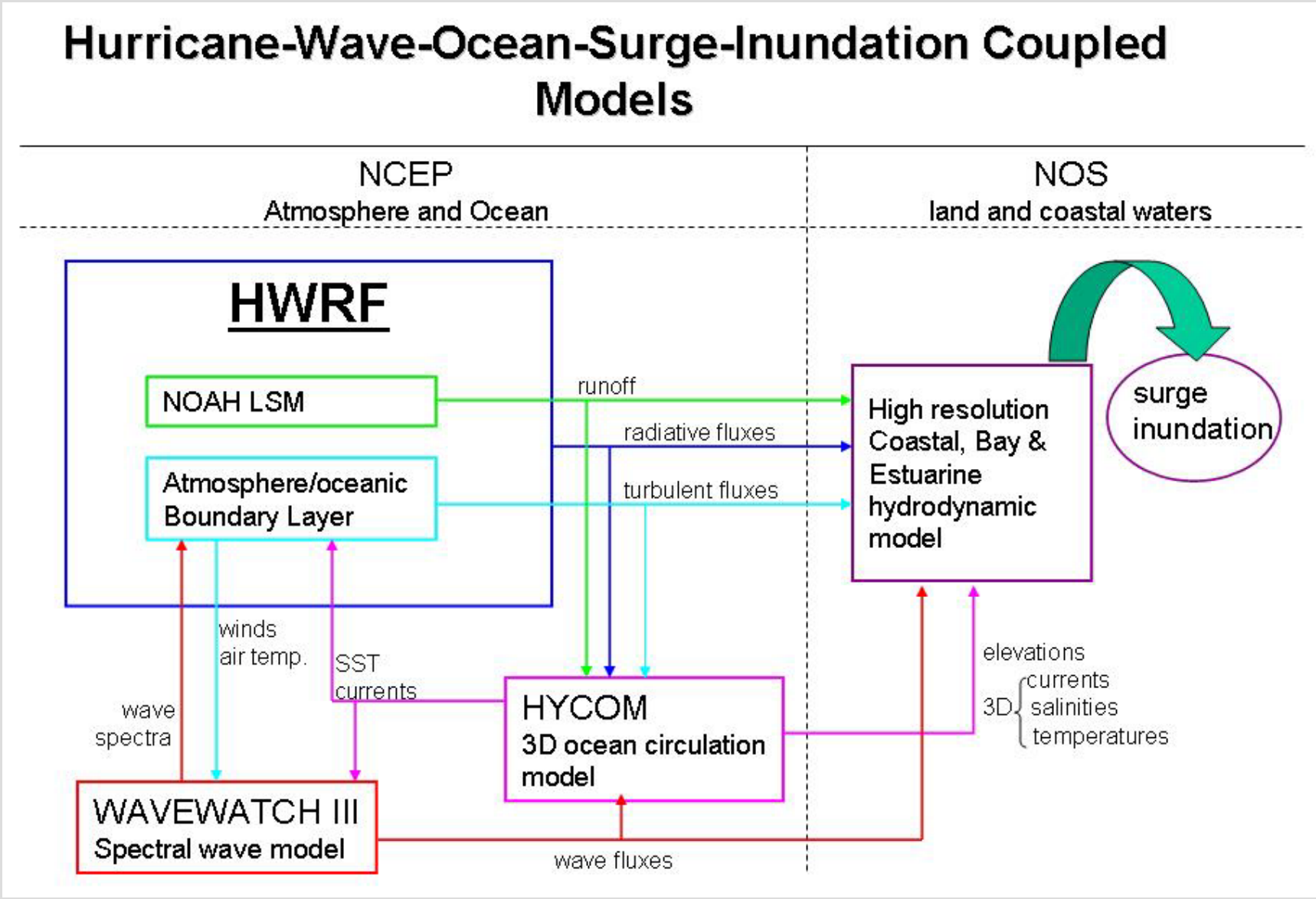
Ocean Data Assimilation

NCEP/EMC (H-S Kim) proposes

- Implement WRF-HYCOM system (replace POM) for Atlantic basin (Q3)
- Add JASON-2 altimeter data to HYCOM assimilation (Q2)
- Implement global 1/12 degree HYCOM for uniform atmosphere-ocean system globally (Q4)
- Work with AOML to evaluate ocean-hurricane interaction
- Improve data assimilation (tuning)
- Ingest and evaluate buoy data in real time for 2010 season
- With URI (Ginis), test and evaluate coupling with Wavewatch III
- Improve representation of atmosphere-ocean fluxes

H.-S. Kim - EMC

NCEP Hurricane Forecast System—Regional Component



Improving Operational HRS at NOAA/NCEP to Better Serve our Customers

FY07 FY08 FY09 FY10 FY11 FY12 FY13 FY14

Initialization/DA
Resolution 9km to 4km to 1km?
Coupling—atm/ocean/waves/surge
Physics—ocean, PBL, precipitation, clouds, radiation
Ensembles—global, regional, moving nests?

EMC HRS Staff ~ 10 (includes ocean, GFS and HWRF)
HPC availability (what lies beyond P6?)
Technological advances in the above
Maintenance of HRS—must leverage off production suite

Key questions to be addressed by the HFIP for success in HFS/GFS improvements:

- **At 1-km or less grid resolution which physical processes are crucial to the intensity change problem and are they predictable on the time scales needed? What is the necessary vertical resolution vs. horizontal?**

- **What is the appropriate physics package and what complexity is essential to address the intensity change problem (e.g. atmosphere-ocean boundary layer, microphysics, radiation)**

- **What is the best way to determine predictability with reference to the forecast metrics? Can ensembles be used to increase the predictability and at what scales?**

- **What is the best way to develop ensembles for the intensity change problem, i.e., multi-models, different physics packages, different initial conditions?**

Steps required to address the HFS/GFS modeling systems to accurately represent the physical processes responsible for rapid intensity change:

Develop, test, and implement:

- **Near (~5 years) and long term (~10-15 years) high resolution (1 km), non-hydrostatic HFS and establish baseline performance for track, intensity, and rapid intensity change**
  - **Next-generation high-resolution GFS (10 km) to improve track guidance,**
  - **HFS, GFS, and multi-model ensembles to quantify and bound uncertainty, and**
- **Next-generation storm surge modeling system**

Research & Development Strategies for HFS/GFS:

- Research to insure the physical processes are represented accurately, and assess how these processes influence the predictability of track and intensity changes, particularly rapid intensity change,
- Research and development to enhance modeling techniques (e.g., high-resolution, data assimilation, ensembles, on-demand computing), and
- Develop and implement High Performance Computing strategy for HFS/GFS

- **Regional Model Initialization**
  - **Factors for change**
    - **Global Models increasing resolution**
    - **Need to improve 3D vortex dynamic/thermodynamic structure**
    - **Need for cycling in DA system**
    - **Observations in vicinity of and surrounding vortex**
    - **Adopting coupled atm/ocean systems**
  - **Requirements**
    - **Advanced DA methodology that is computationally affordable and can be applied at high resolution**
    - **Coupled atm/ocean DA**
    - **Must not forget about model physics**

  - **Higher Resolution:**
    - **Currently at 9km**
    - **Testing at 4km in 2009 not very encouraging**
    - **Where to place emphasis for future HWRF upgrades next 5 years?**