Operational HWRF - Performance for 2012 and Priorities for FY2013.

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HFIP Telecon, December 12, 2012
Outline

- Performance of current operational HWRF for 2012 season
- Special Projects and Real-Time Parallel HWRF Experiments
- Priorities for FY2013 (Stream 1, Stream 1.5 and Stream 2)
- Intensity Forecast Improvement is the topmost priority!
FY2012 High-Resolution Triple-Nested HWRF

- For the first time, a high-resolution hurricane model operating at cloud-permitting 3km resolution implemented into NCEP operational system
- This upgrade is a result of multi-agency efforts supported by HFIP
  - **EMC:** Computational efficiency, nest motion algorithm, physics improvements, 3km initialization and pre-implementation T&E
  - **HRD/AOML:** nest motion algorithm, multiple moving nests, PBL upgrades, interpolation for initialization,
  - **DTC/NCAR:** code management and repository, MPI profiling
  - **ESRL:** Physics sensitivity tests and idealized capability
  - **URI:** 1D ocean coupling in East Pac
  - **GFDL:** Knowledge sharing, joint T&E
  - **NHC:** Diagnostics and evaluation of the HWRF pre-implementation tests and real-time guidance

Three telescopic domains: 27km: 75x75°; 9km ~11x10° 3km inner-most nest 6x5.5°
Highlights of 2012 HWRF implementation

1. Dynamics
   • Upgrade WRF to V3.4 and add I/O servers, new mass centroid based nest movement
   • Obtain speedup factor of 3.2 in run time from ~265 min. to ~82 min.) using 4 nodes
     (2011 HWRF used 3 nodes)
   • Reduced Time step of model integration 45, 15, 5 sec (54/18 for 2011 HWRF) and
decreased frequency of physics calls 180 sec. (36 sec. for 2011 HWRF)
   • Fix a bug in mask inside the leading edge of a nest domain

2. Initialization and GSI
   • Build the vortex initialization at 3km resolution with more accurate interpolation
     algorithms and composite storm structure consistent with 3km
   • Upgrade GSI to version 3.5 which is the latest community version.

3. Ocean
   • Add one dimensional ocean coupling in Eastern Pacific basin
   • Bug fixes in ocean initialization for Atlantic basin

4. Physics
   • GFS shallow convection scheme with slight tuning (no precip. from SC when cloud is less
     than 50mbs thick and SC top is below PBL top)
   • Modify several microphysical parameters to more realistic values (NLImax, NCW and
     snow fall speed)
   • PBL: Change critical Richardson number from 0.5 to 0.25, and vertical mixing alpha=0.5
   • Surface physics - use constant Ch profile with wind speed consistent with observations
Operational HWRF Progress and Improvement w.r.t 2011

(FY2012 Operational Goals: 10% improvement in track and intensity at all times)

**NATL track error**

- **Lead time (h):** 12, 24, 36, 48, 72, 96, 120
- **% Improvement:** 8, 10, 10, 11, 11, 27, 10

**EPAC track error**

- **Lead time (h):** 12, 24, 36, 48, 72, 96, 120
- **% Improvement:** 15, 27, 32, 33, 38, 39, 49

**NATL intensity error**

- **Lead time (h):** 12, 24, 36, 48, 72, 96, 120
- **% Improvement:** 7, -1, -4, 0, 12, 25, 13

**EPAC intensity error**

- **Lead time (h):** 12, 24, 36, 48, 72, 96, 120
- **% Improvement:** 36, 28, 32, 28, 39, 41, 48
Verification of Operational HWRF for 2012 season

HWRF FORECAST – TRACK ERROR (NM) STATISTICS
VERIFICATION FOR OPER HWRF FOR AL-basin 2012

HWRF FORECAST – INTENSITY VMAX ERROR (KT) STATISTICS
VERIFICATION FOR OPER HWRF FOR AL-basin 2012

HWRF FORECAST – TRACK ERROR (NM) STATISTICS
VERIFICATION FOR OPER HWRF FOR EP-basin 2012

HWRF FORECAST – INTENSITY VMAX ERROR (KT) STATISTICS
VERIFICATION FOR OPER HWRF FOR EP-basin 2012

ATL-track

2011 HWRF 96hr FCST.errors

2012 HWRF 96hr FCST.errors

EP-track

2011 HWRF 96hr FCST.errors

2012 HWRF 96hr FCST.errors

ATL-intensity

2011 HWRF 96hr FCST.errors

2012 HWRF 96hr FCST.errors

EP-intensity

2011 HWRF 96hr FCST.errors

2012 HWRF 96hr FCST.errors
Impressive intensity forecasts for Hurricane Gordon & Hurricane Sandy

Positive Bias for Hurricanes Leslie and Nadine influenced the seasonal intensity stats
A few outliers for TS Debby & Hurricane Sandy negatively influenced the track statistics.

Ernesto was another problematic storm due to nest movement related issues.
Verifications for two Major Land-falling events of 2012: HURRICANES ISAAC AND SANDY

For Track: Operational Models (HWRF & GFDL) performed best overall for both storms. HFIP Regional Models AHW and COAMPS-TC performed very well for Sandy but not for Isaac. GFS is the best performing Model for both storms. (GFDL Ensemble Mean a close second)

For intensity: Operational models outperformed other dynamical models. (GFDL Ensemble Mean even better).
Enhanced Water Vapor Equivalents obtained from HWRF in the Life cycle of Hurricane Isaac

- Northerly shear and dry air impedes the development of circulation
- Vortex tilt, dry air, and size of the storm
- Warmer sea surface temperatures and no shear
- Terrain interactions

1. Higher Resolution for resolving convection & terrain
2. Model Physics valid for higher resolution
3. Improved representation of initial conditions
4. Advanced understanding of the TCs (observations)
Experimental Real-Time products from HWRF

Supplemental HWRF products than simple track and intensity. Synthetic Satellite Imagery, High Frequency output and Rainfall products to aid forecast guidance.

NHC Rainfall Product (below), and verifying radar-estimated rainfall totals (right).
Synthetic Satellite Imagery (SSMI/S) from HWRF

Observed ice scattering
Use of HTCF data to describe time-history of model track, intensity and structure forecasts.
Special HFIP supported Real-Time Projects

- ECMWF driven HWRF (requested and facilitated by NHC)
- Real-time TDR DA Experiments
- Real-time HWRF for Western Pacific (in support of JTWC) and North Indian Ocean (in support of IMD)
- Alternate physics (MYJ)
- Basin-Scale (hemispheric) HWRF (with multiple moveable domains & Regional Hybrid DA)
- HWRF-HYCOM

Many of these projects are supported by HFIP and allowed us to expand the Development Phase of operational HWRF for future upgrades.

HFIP resources on Jet and NCEP resources on Zeus helped us accomplish these real-time parallel systems.

Cross-platform compliancy through strict code management protocols and subversion based repository (supported by DTC) are pivotal for these efforts.
**Average Track Errors (NM)**

Statistics Plots – All 2012 Atlantic Storms

- HWRF: GFS based
- GFDE: ECMWF based

**Atlantic Track**

- HWRF/GFDL driven by High-Res ECMWF
- 17% 11%
- 14% 11%

**E-Pac Track**

- 22% 14% 8%
- 21% 19% 22%

**Average Intensity Errors (kt)**

Statistics Plots – All 2012 Atlantic Storms

**Atlantic Intensity**

- 29% 12%

**E-Pac Intensity**

- 17% 5%

- HWRF: GFS based
- GFDE: ECMWF based

**HWRF**

**HWFE**

**GFDL**

**GFDE**

15

NCEP Hurricane Forecast Project
Inner Core P3 TDR data assimilation (includes one-way hybrid GSI for HWRF using GFS ensembles)

Impact of TDR data assimilation to hurricane intensity forecast

Cross section at initial time
Assimilation of TDR data provided significant positive impact on intensity forecasts (20-30% improvement through 72-hrs), without degrading track forecast skill.

Hybrid DA framework (currently one-way) allows for assimilation of flight level, dropsonde and all-sky satellite radiance data, and fits into operational resources.
Operational HWRF for Western-Pacific Basin

- For the first time, Real-Time forecast guidance from NCEP Operational HWRF is made available for JTWC for all Western Pacific storms starting with Sanvu (03W) from May 21, 2012.

- Operational HWRF configuration for Western Pacific includes modified vortex initialization and no ocean coupling (atmosphere only).

- All operational products, including synthetic satellite imagery, high-frequency track & intensity forecasts, and additional special graphics requested by JTWC are provided through HWRF website: http://www.emc.ncep.noaa.gov/HWRF/WestPacific/

- The model setup and real-time delivery of products are accomplished using HFIP supported resources on Jet (dedicated reservations) and sophisticated automation tools developed by the HWRF team. ~80% on-time delivery of products for use by JTWC.

  - Results have been quite encouraging: HWRF track errors better than COAMPS-TC and GFDN
  - HWRF intensity errors comparable to COAMPS-TC and GFDN
  - GFDN and COAMPS-TC use NOGAPS while HWRF uses GFS for IC & BC
HWRF for North Indian Ocean Basin

- Operational implementation of HWRF in India
- http://www.imd.gov.in/section/nhac/dynamic/cyclone_fdp/CycloneFDP.htm

- Technology transfer of HWRF to IMD in June 2011 (NOAA-MoES MoU/IA)
- 7-day workshop and tutorial on HWRF at Bhubaneshwar, India in July 2012 (sponsored by IUSSTF/MoES)
- HWRF Team provided Real-Time guidance to all tropical cyclones for 2012 season using 27/9/3 uncoupled configuration
- Products available from EMC HWRF Website at: http://www.emc.ncep.noaa.gov/gc_wmb/vxt/PARA/Zhan


- HWRF
- GFDN
- GFS
- JTWC


- 2007: Gonu (AS), Sidr (BB)
- 2008: Nargis (BB)
- 2011: Thane (BB)
Weak and sheared storms mostly contribute to HWRF intensity error.
NHC’s Wish List for 2013

- Improved regional hurricane model guidance for intensity; request continued EMC participation and support of HFIP model development activities
- Assimilation of inner-core aircraft data (Tail Doppler, flight-level, dropsonde winds) in the HWRF initialization
Priorities for Operational HWRF for 2013 hurricane season

NHC’s Wish List for 2013:

Improved regional hurricane model guidance for intensity; request continued EMC participation and support of HFIP model development activities

Assimilation of inner-core aircraft data (Tail Doppler, flight-level, dropsonde winds) in the HWRF initialization

- WCOSS Transition and Timelines
- Pre-Implementation T&E
- Operational Implementation Plans
- HFIP supported real-time efforts

Transition to WCOSS and Timelines

- Entire production suite from CCS (IBM-P6) to WCOSS is expected to be completed by August 31, 2013 – which means current CCS will continue delivering operational products during early part of the hurricane season. **No scientific changes are allowed during the transition process (including bug fixes, except for those that will break the operational system due to compiler/OS/machine differences).** Initial implementation of HWRF on WCOSS will use the same 2012 operational configuration.

- EMC HWRF Team will proceed with annual upgrade process and will work with NHC to make alternate arrangements FY2013 HWRF implementation and real-time product delivery (parallel feed from WCOSS with Jet as backup)
### 2013 HWRF pre-implementation test plan

<table>
<thead>
<tr>
<th>Description</th>
<th>Baseline (H130)</th>
<th>Physics upgrades</th>
<th>Combined (H213)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PBL2 (H131)</td>
<td>Meso-SAS (H132)</td>
<td>RRTMG (H133)</td>
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<tr>
<td>Revised init/GSI</td>
<td></td>
<td>Variable Ric</td>
<td>Radiation</td>
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<tr>
<td>New nest parent interpolations</td>
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<td>Meso SAS</td>
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<td>Radiation bug fix</td>
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<tr>
<td>Revised nest movement</td>
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<tr>
<td>Increased frequency of Physics calls</td>
<td>Variable Ric</td>
<td>Meso SAS</td>
<td>Radiation</td>
</tr>
<tr>
<td>Cases</td>
<td>Whole 2012 storms</td>
<td>Priority /All 2012 cases</td>
<td>Priority /All 2012 cases</td>
</tr>
<tr>
<td>Due date</td>
<td>Jan. 15</td>
<td>Jan. 15/ Feb. 15</td>
<td>Jan. 15/ Feb. 15</td>
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</table>

**Improved intensity forecast skill is the highest priority for 2013 implementation**

**Additional testing for Western Pacific Storms based on final H213 configuration**
New Baseline* for 2013 HWRF

- Define the baseline configuration (H130) (individual components tested for all 2012 storms):
  - Revised vortex initialization scheme
  - Infrastructure changes with new nest-parent interpolation
  - Revised nest-motion algorithm based on PDYN from d01/d02 and increased frequency of physics calls
  - Revised GSI (one-way hybrid, with TDR and flight level DA capability) with modified vortex initialization procedure
  - Performance of the baseline configuration should be equal or better than the operational HWRF

Physics Upgrades*

- Physics upgrades on top of the baseline configuration, Two-stage testing; idealized and real cases
  - Revised PBL scheme with various critical Richardson number approach H131
  - Meso SAS: H132
  - RRTMG radiation scheme: H133
  - Microphysics feedback: H134
  - Removal of flux truncation and 3-D ocean for Eastern Pacific basin: H135
  - Evaluation of results, Model diagnostics, web-based graphics and extended verification based on HFIP ADD efforts
  - Goal is to accomplish at least 20% improvement in intensity forecast skill from the combination of new baseline and physics upgrades
New Interpolation

### OLD METHOD | NEW METHOD
--- | ---
Two-step spline<br>Expensive, introduces artificial structure | Single-step linear interpolation<br>More accurate, faster.
Only supports bulk (Ferrier) microphysics<br>Zero condensate advected from boundary<br>Method too expensive to allow MP. interp. | Supports any microphysics scheme<br>Faster interp allows two-way interaction of mass and number concentration.
Extra memory usage & communication<br>Two additional 3D arrays for every interpolated variable. | Less memory and communication<br>No extra 3D arrays. Framework improvements allow less communication.
Downscale-only mass adjustments<br>Framework limitations prevent mass adjustments during upscale interp. | Mass adjustment also in upscale dir.<br>Framework improvements allow both upscale and downscale mass adjustments.
Numerous minor bugs<br>Many minor bugs in both upscale and downscale directions. | Many minor bug fixes<br>Many fixes to minor bugs in upscale and downscale interp. directions.

New Nest-Parent Interpolation method in WRF-NMM is computationally advantageous (accurate and faster) and allows us to experiment with more sophisticated microphysics schemes and 100% feedback from nest to parent.

New nest movement algorithm is designed to prevent the nest loosing the storm (especially in the presence of topography or another large-scale system) and to have the nest centered over the storm more accurately. This is a significant improvement over centroid based methods.

### New Nest Motion Algorithm
Dynamic Pressure Minimum

- Mean sea level dynamic pressure:
  - \( q = P_{MSLP} + \frac{v^2 \rho_{MSLP}}{2} \)
  - Less noisy than \( P_{MSLP} \)
- Average 27km and 9km \( q \) (even less noisy!)
- 3km domain searches for minimum value.
### New Vortex Initialization procedure (total number of domains = n)

1. **Read** HWRF 6h forecast
   (domain of 1 to n)
   *diffwrf_3dvar.exe*

2. **Read** GFS analysis
   (domain of 1 to n)
   *diffwrf_3dvar.exe*

3. **Setup** the 4x domain and **ghost domain**
   *Setup_domains.exe*

4. **Hurricane initialization**
   *Storm_init.exe*

5. **Update** domain of 1 to n
   and **ghost domain**
   *Update_domains.exe*

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### Vortex initialization modularized
- Simple structure
- Flexible about various domains
- Control with a namelist
- Variable table for GSI

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### 2. Scientific difference from the operational HWRF)

<table>
<thead>
<tr>
<th>Scientific difference</th>
<th>New TC Initialization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size correction</td>
<td>Taking the intensity into account before size calculation</td>
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<tr>
<td></td>
<td>Pressure recalculation after the wind structure correction</td>
</tr>
<tr>
<td>Intensity correction</td>
<td>Tangential wind adjustment after the geopotential correction</td>
</tr>
<tr>
<td>Moisture adjustment</td>
<td>Temperature and moisture calculation from the virtual temperature and humidity</td>
</tr>
<tr>
<td>Storm blending</td>
<td>Blending two disturbance fields (Outer area: GFS, Inner core: HWRF)</td>
</tr>
</tbody>
</table>
Disturbance - Non-Hurricane

Environment = Disturbance - Non-Hurricane + Non-Hurricane

New (vortex blending)

Blending

Initial Condition
Problem of the intensity correction on pressure coordinates

Solution: Vertical stretching

- Wind at $P_{sfc}$ is relocated to $P_{sfc}^{\text{new}}$
- When wind increases $\rightarrow$ Stretched up
- When wind decreases $\rightarrow$ Stretched down

Additional benefit of the stretching

- If the first guess intensity is weaker than the observation, during the initialization, Warm core height rises as well as wind increases: Favorable to the storm intensification
Convective Parameterization for high-resolution grids (Meso-SAS)

Operational SAS scheme is not designed for high-resolution models:

Basic assumption: updraft area is very small compared to the model grid size – which begins to break down at resolution <10 km.

At 0.5-10km model resolution, use of explicit MP scheme is still problematic (vertical motion may not be large enough) and creates grid-point storms

Hua-Lu Pan re-derived the SAS scheme by removing the assumption that the updraft area be small, and make it possible to form the meso-SAS scheme which can be used in high resolution models.
- DTC has completed the runs of control and flux experiment for entire 2012 season
- Overall the impact of the change in fluxes seem beneficial
- Will be included in 2013 GFDL upgrades as well.
HFIP Stream 1.5/ Stream 2.0 efforts

- Physics driven HWRF ensembles       Stream 1.5
- Suite of High-resolution Physics    Stream 1.5
- HWRF-MPIPOM (including 3D ocean for Eastern Pacific) Stream 1.5
- FY2013 HWRF for Western Pacific and Indian Ocean basins Stream 1.5*
- Basin-scale HWRF with regional hybrid-DA       Stream 2.0
- Basin-Scale HWRF with multiple moveable domains Stream 2.0
- Three-way coupled HWRF-POM-WWIII system Stream 2.0
- Continued evaluation of HWRF-HYCOM coupled system Stream 2.0
Ensemble Prediction System for HWRF – HFIP Stream 1.5

1. IC/BC Perturbations
   - Large scale flow based, either from GEFS/ETR or GEFS/EnKF;
   - Initialize the HWRF system from Global EPS-based fields as IC and BC;
   - Reduce uncertainties in model IC/BC in the large scale flows.

2. Model Physics Perturbations
   - Physics –based method;
   - Stochastic Perturbed Parameterization Tendencies (SPPT);
   - Perturbing the convective trigger in the current SAS scheme to generate ensembles;

3. 10-20 ensemble members will be generated by combining the above two perturbations.
20 member ensemble by perturbing convective trigger in SAS

Average Track Errors (NM) from HWRF EPS
Hurricane ISAAC, 2012

Track Continuous Ranked Probability Score
Hurricane ISAAC, 2012 (HWRF EPS)

Average Intensity Errors (Ki) from HWRF EPS
Hurricane ISAAC, 2012

Continuous Ranked Probability Score for Intensity
Hurricane ISAAC, 2012 (HWRF EPS)

Large forecast skill variations among ensemble members
Advancements to Operational HWRF – Basin Scale Configuration with multiple moveable nests (Stream 2.0)

Isaac-Ileana-Kirk real-time forecast

HWRF Basin-Scale 27 09:03km - 2012-08-27 18Z
ISAAC09L - KIRK11L - ILEAN09E
FORECAST HOUR 000 (DAY 1)
Improved track forecast skill in the Atlantic from Basin-Scale HWRF

- Regional EnKF-GSI based data assimilation system is actively being developed for the basin-scale HWRF through support from HFIP with a possible 2014 implementation (EMC/ESRL/OU/DTC collaboration)
- Computational efficiency of basin-scale HWRF with multiple moveable domains is a challenging task and is explored by EMC/AOML
## Advancing the HWRF System FY2013 & Beyond

<table>
<thead>
<tr>
<th>Resolution/Infrastructure</th>
<th>2013</th>
<th>2014*</th>
<th>2015*</th>
<th>2016*</th>
<th>2017*</th>
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</thead>
<tbody>
<tr>
<td>New Nest-Parent Interpolations; expanded domain size &amp; new nest movement algorithm</td>
<td>Increased vertical resolution with higher model top</td>
<td>community R2O efforts (HFIP), Multiple moving domains</td>
<td>Upgrades to infrastructure - NEMS/ESMF/NMM-B, Other oceanic basins, HWRF Ensembles, Global to local scale modeling for hurricanes</td>
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<thead>
<tr>
<th>Physics</th>
<th>2013</th>
<th>2014*</th>
<th>2015*</th>
<th>2016*</th>
<th>2017*</th>
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<tbody>
<tr>
<td>Meso-SAS, Modified PBL, Improved microphysics &amp; Radiation</td>
<td>Microphysics, Radiation, Surface Physics, Coupling to Waves and Land Surface, Physics for high-resolution</td>
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<tr>
<th>DA/ Vortex Initialization</th>
<th>2013</th>
<th>2014*</th>
<th>2015*</th>
<th>2016*</th>
<th>2017*</th>
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<tbody>
<tr>
<td>Modified vortex initialization and One-Way Hybrid with inner-core TDR and flight level DA</td>
<td>Inner core DA (TDR, satellite), cloudy radiance assimilation Two-Way regional Hybrid DA HWRF Ensembles</td>
<td>Hybrid-EnKF DA, advanced vortex relocation procedure, improved GSI/Hybrid techniques, DA for moving nests</td>
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<tr>
<th>Ocean</th>
<th>2013</th>
<th>2014*</th>
<th>2015*</th>
<th>2016*</th>
<th>2017*</th>
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<tr>
<td>3-D ocean for Eastern Pacific &amp; removal of flux truncation</td>
<td>Improved ocean data assimilation, physics and resolution, unified coupled system for ATL &amp; EPAC</td>
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HWRF-HYCOM for all oceanic basins (driven by Global RTOFS)

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<tr>
<th>Waves</th>
<th>2013</th>
<th>2014*</th>
<th>2015*</th>
<th>2016*</th>
<th>2017*</th>
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<tbody>
<tr>
<td>Atmosphere-Ocean-Wave Coupling</td>
<td>Multi-grid surf zone physics, effects of sea spray</td>
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<tr>
<td>HWRF Ensemble based products, Coupling to Hydrological/ Surge/ Inundation models, advanced model diagnostics based on observations, improved product development</td>
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### 2013 upgrades

### Planned/ongoing developments

*Resource permitting*
Real-time and pre-implementation T&E
HWRF products:

http://www.emc.ncep.noaa.gov/gc_wmb/vxt/index.html

Acknowledgements:
HWRF team at EMC
EMC and HFIP Management
Collaborations with NHC, DTC, HRD/AOML, PSD/ESRL, GFDL, URI, UMD, FSU, CIRA and other HFIP partners

Thanks for your attention

Questions?