HFIP ENSEMBLE TEAM REPORT

ESRL:T. Hamill, J. Whitaker, M. Fiorino
NCEP: Y. Zhu, G. Vandenberghe, M. Wei, J. Du, W. Lapenta, S. Lord, Z. Toth
CIRA/CSU: M. Zupanski
AOML: S. Aberson, F. Marks (w/ F. Zhang)
NRL: C. Reynolds, J. Goerss, J. McLay, E. Serra

GOALS

- Develop more reliable and useful automated probabilistic numerical guidance for hurricane track, intensity, and associated weather elements based on ensemble forecast systems.
- Work closely with DA group on development of ensemble DA/Forecast system.

FY09 Accomplishments: Overview

- ESRL: EnKF-FIM ensembles (20-member 30km, on TACC) outperformed NCEP and UK operational ensemble for limited 2009 case set.
- NCEP: GFS T574 (23km) 5-member ensembles run on TACC. Promising results for new GEFS.
- CIRA/EMC: MLEF-HWRF is interfaced with the HWRF system and with the GSI observation operator
- NRL: NOGAP resolution experiments for 2008 almost complete. T239 (55km) ensembles for 2008-2009 underway.
- AOML: Work on evaluation of Global model impact on regional model ensemble spread, development of algorithms for ensemble evaluation.

FIM Ensemble Statistics for Tropical Cyclones

Tom Hamill, Jeff Whitaker, & Mike Fiorino

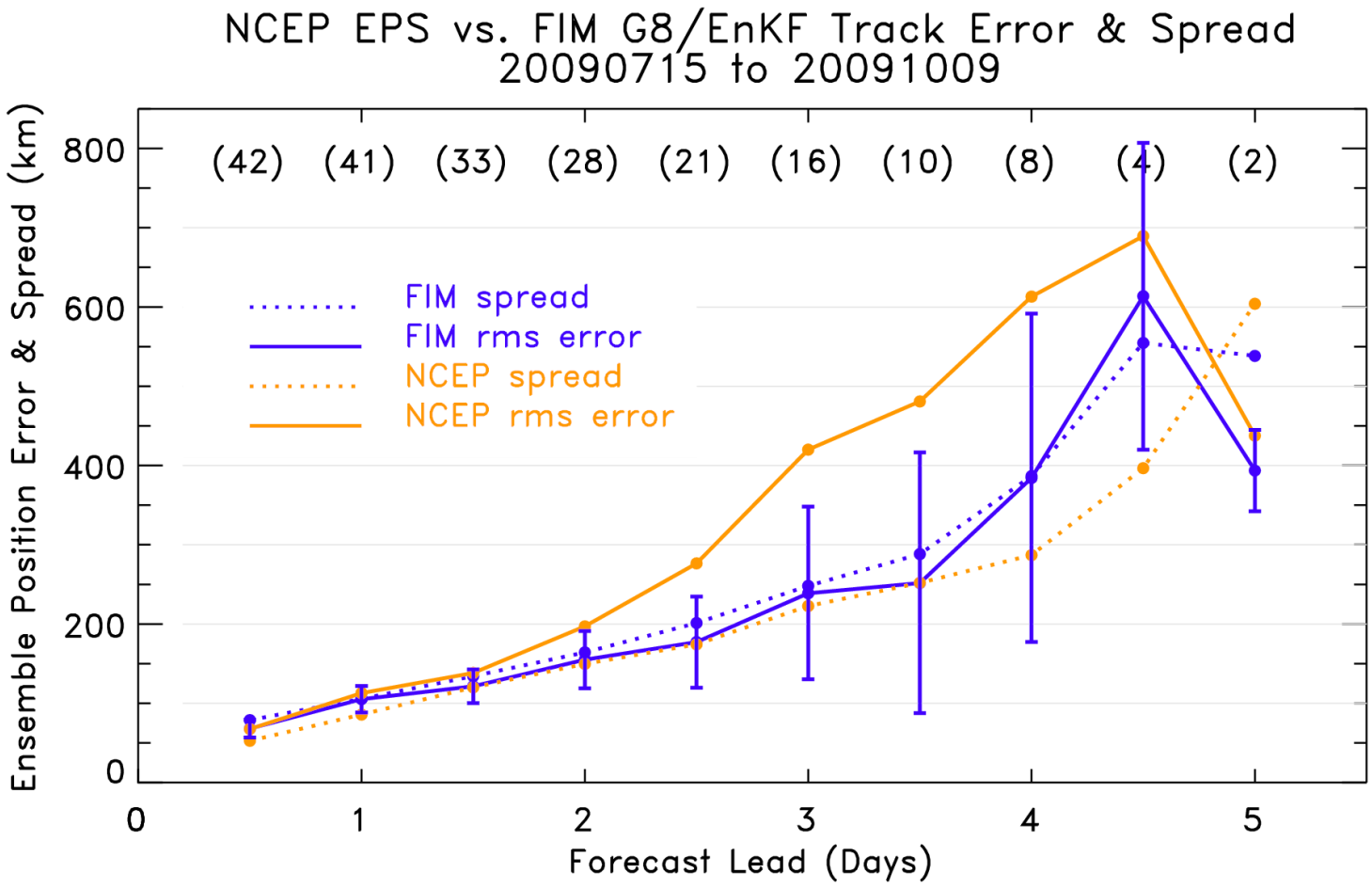
NOAA ESRL

22 October 2009

20-member 30-km FIM/EnKF Ensemble: Comparison Procedure

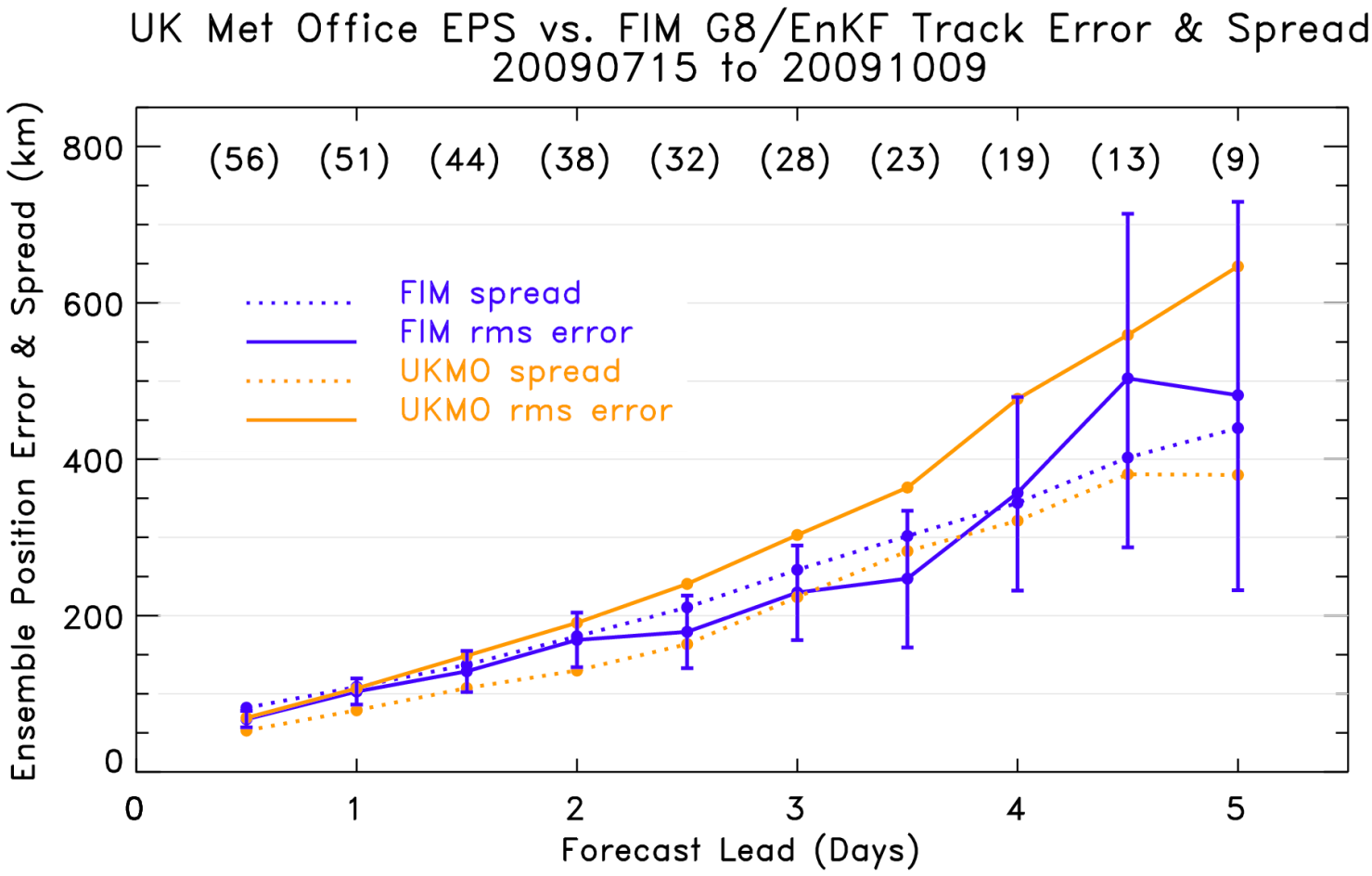
- Consider only the forecast cyclones that have a TD or stronger at the time the forecast was initialized and at the particular forecast lead we're considering.
- In comparing FIM ensemble forecast vs. another model, include datum for a particular storm only if there is at least one member tracking the storm in both models.
- Error is defined as the ensemble-mean error among all members that track the storm.
- Spread is the standard deviation of ensemble members about the mean for all members tracking the storm.
- Still trying to figure out bugs with CMC data.

FIM G8/EnKF vs NCEP GEFS/ET



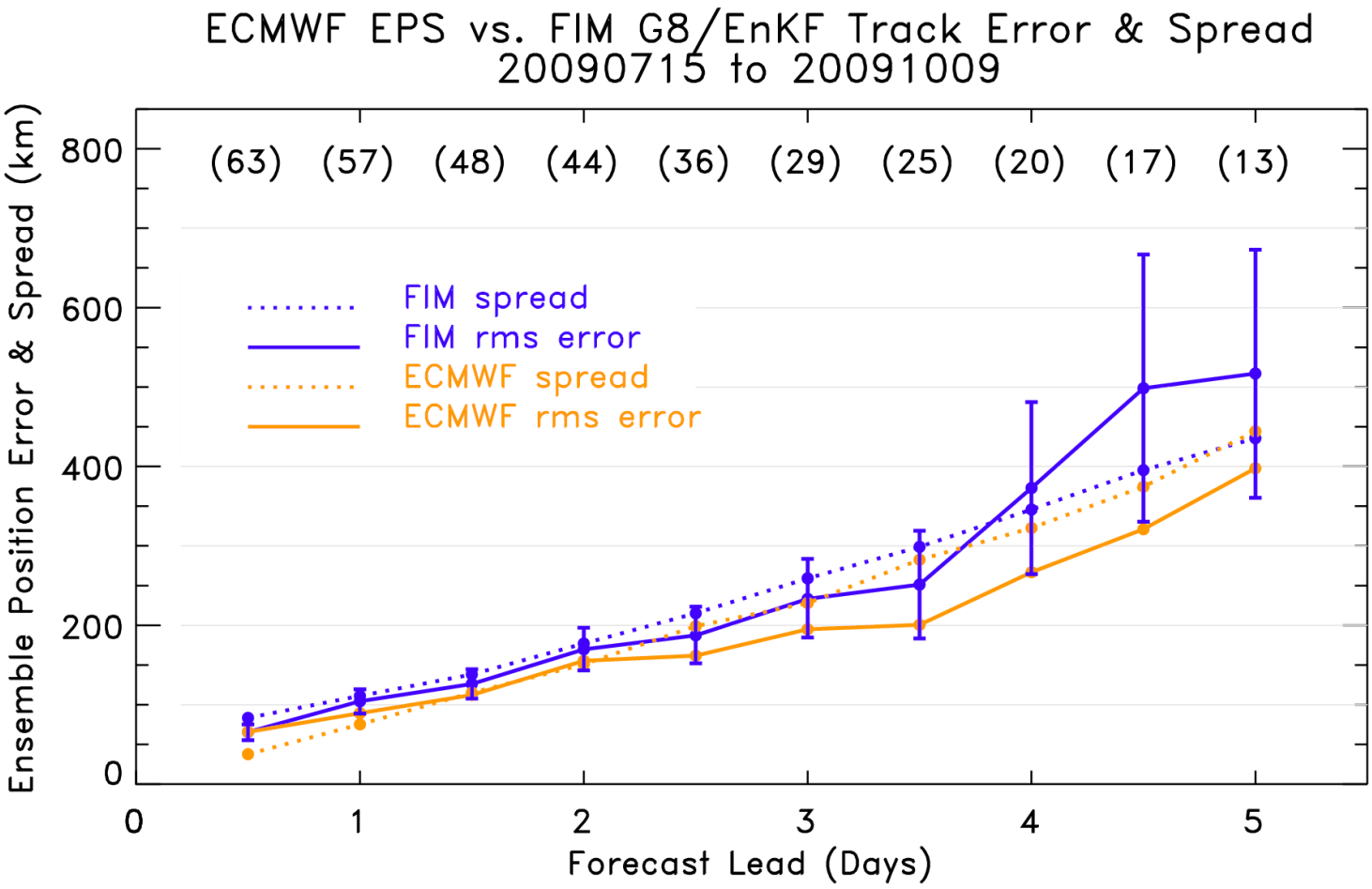
Error bars are 5th and 95th percentiles from paired block bootstrap.
Numbers in parentheses are the sample size at this lead.

FIM G8/EnKF vs UK Met Office



Error bars are 5th and 95th percentiles from paired block bootstrap.
Numbers in parentheses are the sample size at this lead.

FIM G8/EnKF vs ECMWF



Summary and Next Steps

- EnKF-FIM ensemble outperformed NCEP and UK ensemble for limited 2009 case set
  - EnKF is a viable method for producing initial conditions for global ensemble hurricane forecasts.
  - Further testing and diagnosis required for general global weather applications
  - Ensemble generation is an important part of future advanced data assimilation system
- Over next 1-3 years ESRL will:
  - Work with NCEP to develop, test and implement a hybrid Var-EnKF data assimilation system that will
    - Generate ensemble perturbations for data assimilation and free forecasts
    - Outperform current 3d-var GSI and operational global ensemble
  - Work with NCEP to accelerate development and testing of improved global operational ensemble
    - Developed within NOAA Environmental Modeling System (NEMS)
      - Multi-model composition with separate dynamics and physics components
        - » GFS
        - » FIM
        - » GFDL
    - Further testing of improved ensemble perturbation generation for global weather application
  - Continue research to
    - Develop improved methods for representing model error in the ensemble.
    - Improve the “sustainability” of the EnKF initialized vortex (to avoid unrealistic initial decay as much as possible).
    - Develop methods for optimal sub-sampling of the EnKF ensemble to initialize longer-range ensembles (which typically use a smaller ensemble size than the EnKF)

EMC Progress Report and Plans

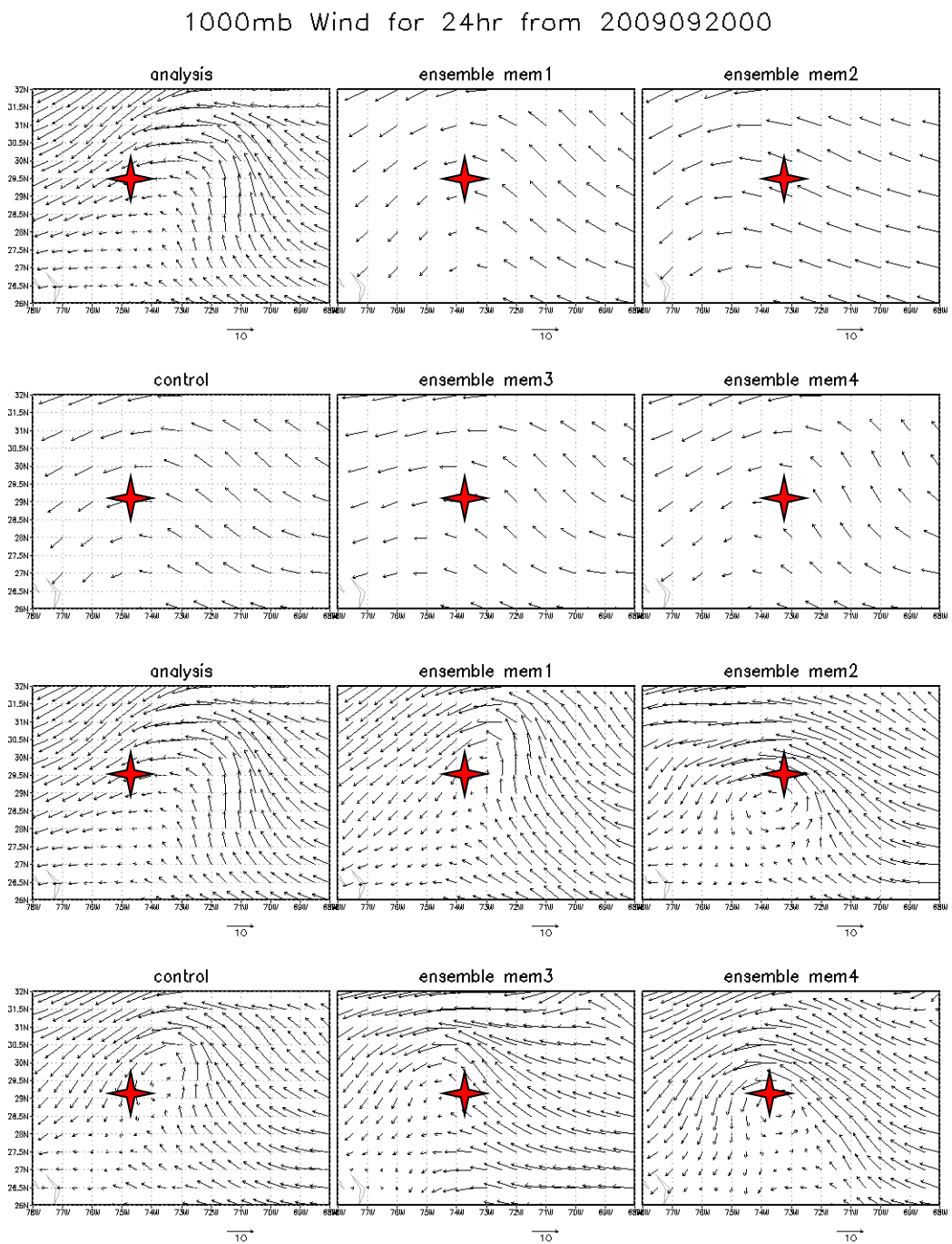
Yuejian Zhu
EMC ensemble team
October 2009

Acknowledgement to:
George Vandenberghe, Mozheng Wei, and Jun Du
Bill Lapenta and Stephen Lord

Initial Experiment Setup

(completed, 20 cases has been run during September)

- High resolution global ensembles (NCEP/GEFS)
  - T574L64 (~23km horizontal resolution)
  - Initial analysis
    - GSI T382L64 analysis
    - ETR (ensemble transform with rescaling)
      - Every 24 hours
      - Cycling at T382L64 resolution
      - NCEP/CCS
    - Upgrade to T574L64
  - Integrations
    - At Texas Advanced Computing Center (TACC)
    - Use GFS model at T574L64 resolution
    - 5 members (include control)
    - Out to 168 hours
  - Experiments
    - Once per day during the period of September 1st – 20th 2009
  - Output
    - Tracks for each members, ensemble mean (and medium) and spread



Hurricane Fred (07L)

Fred (07L) was reduced to Tropical depression after 2009092100

24-hr 1000hPa winds forecast from 2009092000

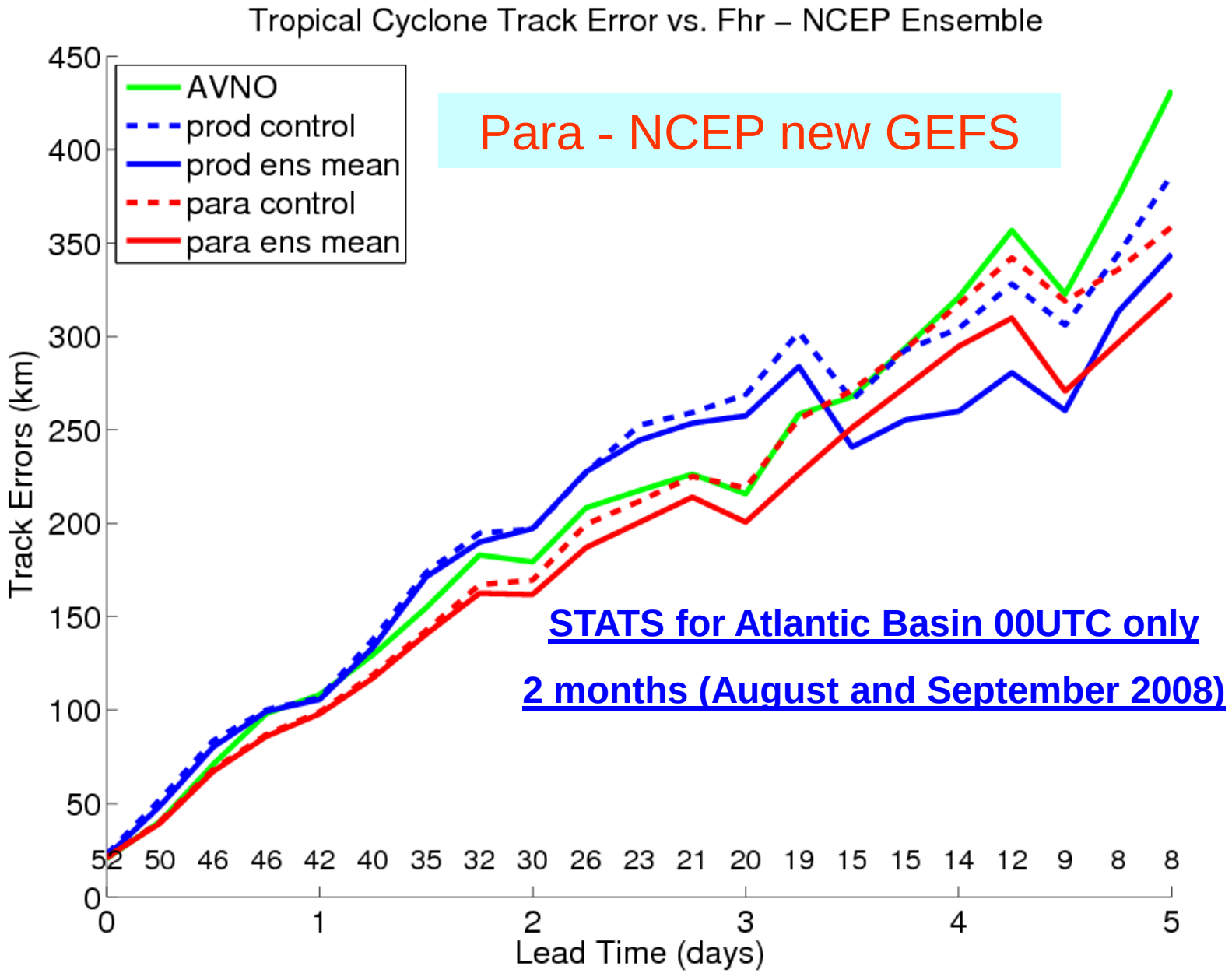
Top 6 panels (left):
GSI verify analysis with operational GEFS (T126 -90km), 4+1 members

Bottom 6 panels (left):
GSI verify analysis with high resolution GEFS (T574 – 23km)

Results:
High resolution ensemble with high resolution initial perturbations recycling (at T382) could catch storm development very well

Plots from Jessie Ma

High Expectations for new GEFS implementation



Summary and Plans at EMC/NCEP

- Global ensembles (partly set up and run experiments):
  - High resolution ensembles at TACC machine
    - T574 (23km), 10menbers (5 for gfs, 5 for fim)
  - Improved ET initial perturbations (FY10)
  - Improved stochastic perturbations in physics (FY10)
- Meso-scale ensemble (under NEMS with various physics):
  - 20km resolution, 21 members
  - ET initial perturbations (consistent with GEFS)
  - Stochastic physics for convection
  - possibly land surface perturbations (soil moisture, soil temperature etc.)
  - 5-day integrations for case studies and possible experimental extension of operational SREF to 5-days for FY10 demo
- Storm following high-resolution ensemble:
  - nested within SREF (perturbed LBCs and ICs, two-way or one-way);
  - 5km; membership (7-10?);
  - ET initial perturbations (consistent with SREF);
  - use various models available in NEMS and leverage WRF community research (Krishnamurti's work)
- Post-processing for storm related forecasts:
  - Decompose gridded forecast errors into phase and amplitude component;
  - Evaluate, then correct bias for phase before amplitude corrections

Ensemble Data Assimilation Research for Hurricane Forecasting (*with EMC/NCEP*)

Prepared by Milija Zupanski, CIRA/Colorado State University

- ***Goal***: Use ensemble data assimilation (Maximum Likelihood Ensemble Filter - MLEF) with HWRF as guidance for situation-dependent error covariance modeling in GSI (*Collaborative work with EMC/NCEP*)

- ***Status***: MLEF-HWRF system installed on NCEP computer (Vapor) and currently being evaluated (hurricane Gustav (2008), 20 km/ 6.6 km resolution)

- ***Accomplishments***: MLEF-HWRF is interfaced with the HWRF system and with the GSI observation operator. This is accomplished by utilizing components of the HWRF and GSI codes and scripts.

- ***Future plans*** (1-3 years):

  - Use ensemble forecast perturbations (and their spatial gradients) from ensemble data assimilation to estimate parameters in anisotropic error covariance

  - Use perturbations from several hurricane cases (begin with 2008)

  - Extend to error covariance modeling of cloud variables

  - Include assimilation of cloudy radiances

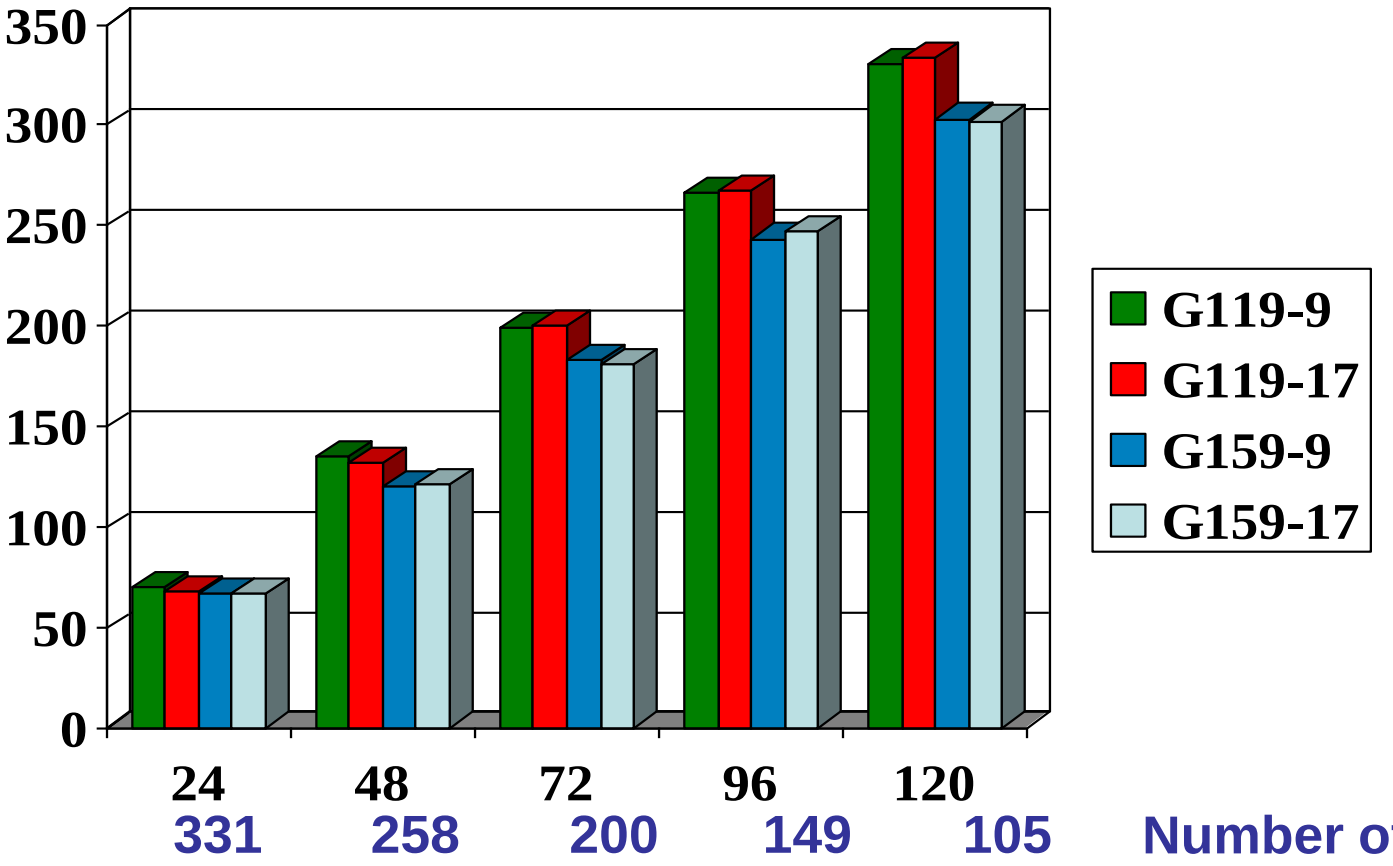
NRL Accomplishments in FY09

- Global Ensembles:
  - NOGAPS ensembles will be run to examine member vs. resolution question for 2008 season
    - T119L30 32 member
    - T159L30 16 member
    - T239L30 8 member
    - Tested with and without model uncertainty (stochastic convection)
    - Tested various initial perturbation methods
  - Examine value of different forecast combinations for mean track errors
  - NOGAPS quasi-real-time T239L30 8 member ensemble for 2009.

- Mesoscale Model:
  - COAMPS-TC, run down to 5km, part of the multi-model mesoscale ensemble

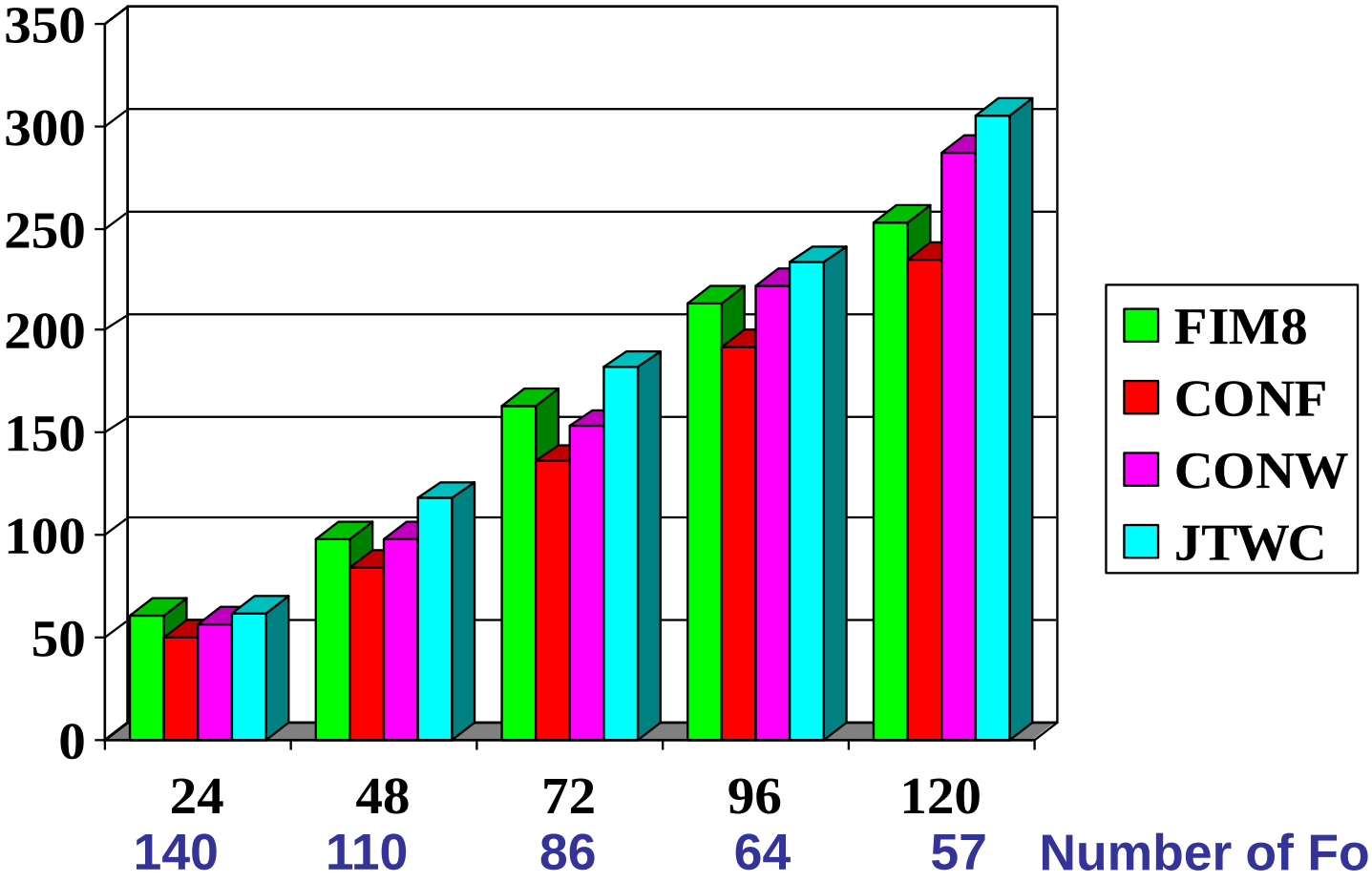
NOGAPS 2008 Northern Hemisphere Homogeneous TC Forecast Error (nm)

Comparison of global ensemble transform at T119 and T159. T159 superior. Preliminary results do not show much advantage to T239 over T159 (not shown).

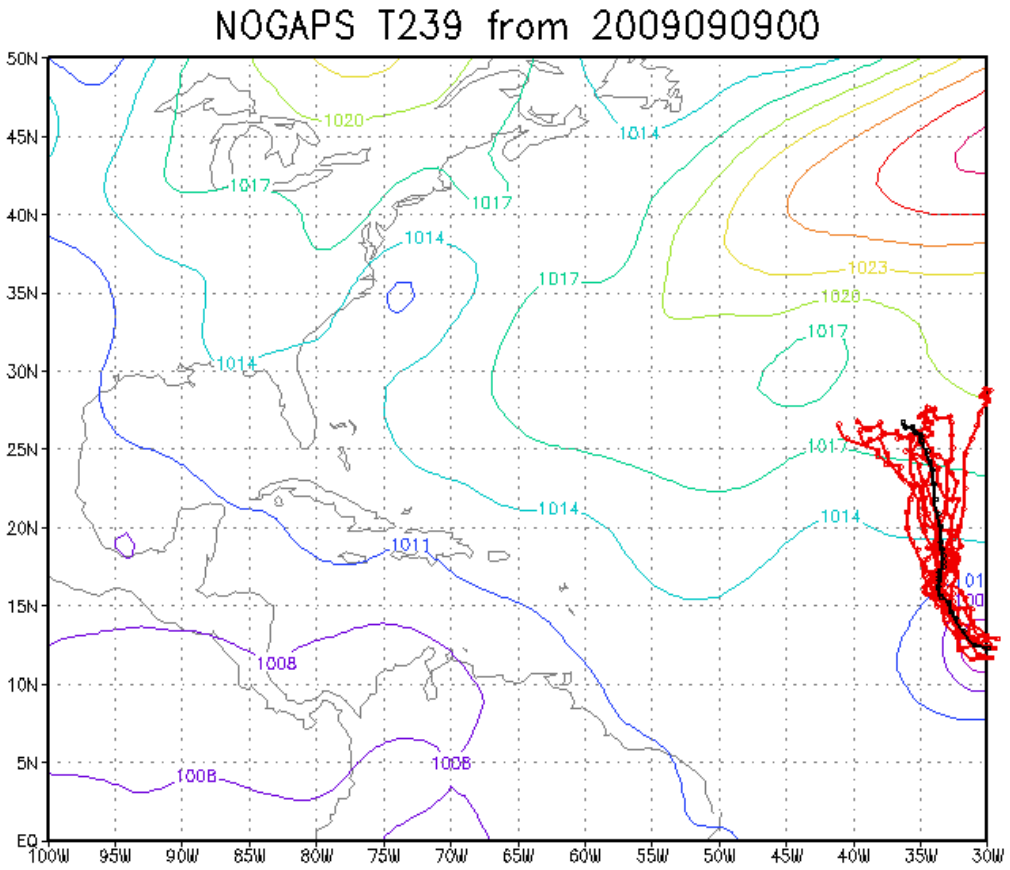


2009 Western North Pacific (08W-23W) Homogeneous TC Forecast Error (nm)

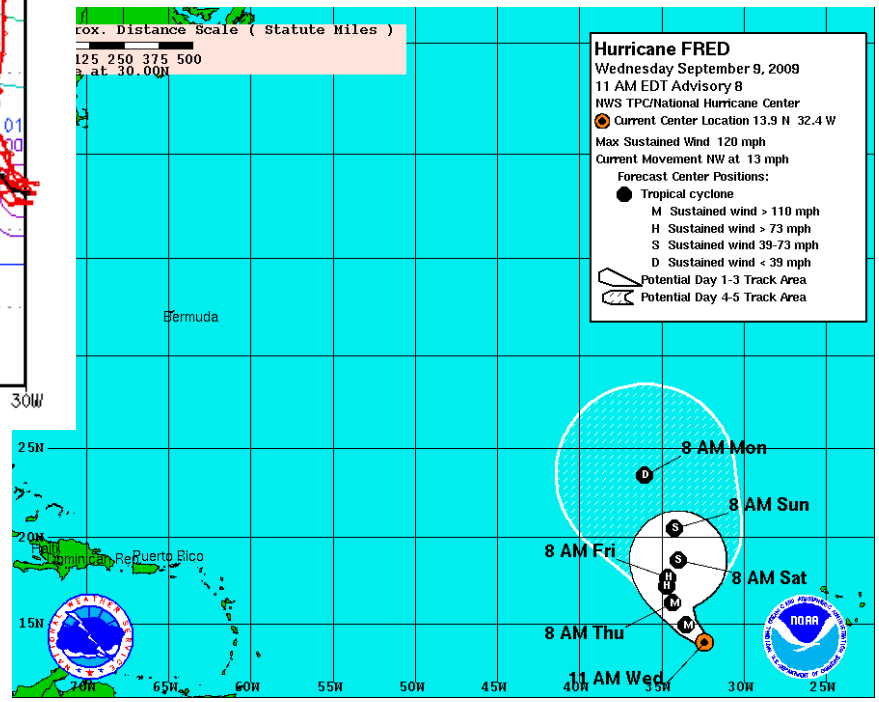
Adding FIM8 (green) to the multi-model consensus (red) improves current consensus (pink)



NOGAPS T239L30 9-member Ensemble

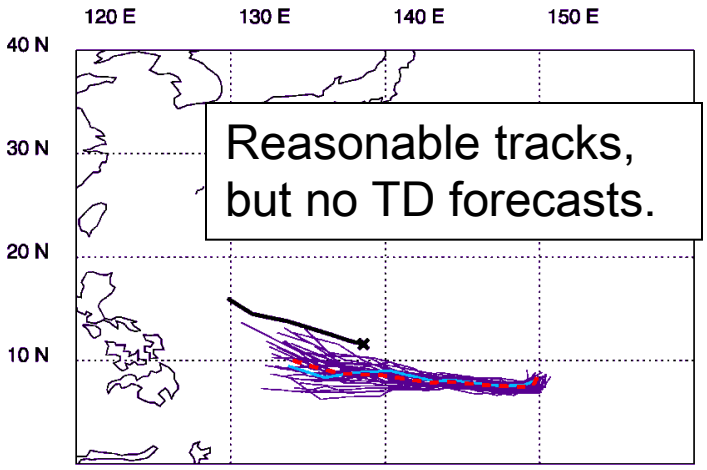


- Quasi-real time at DoD HPCs.
- Statistics not yet completed.
- ATCF files sent to HFIP site.
- Preliminary results indicate ensemble mean similar in skill to control member.
- Issues with current tracker.

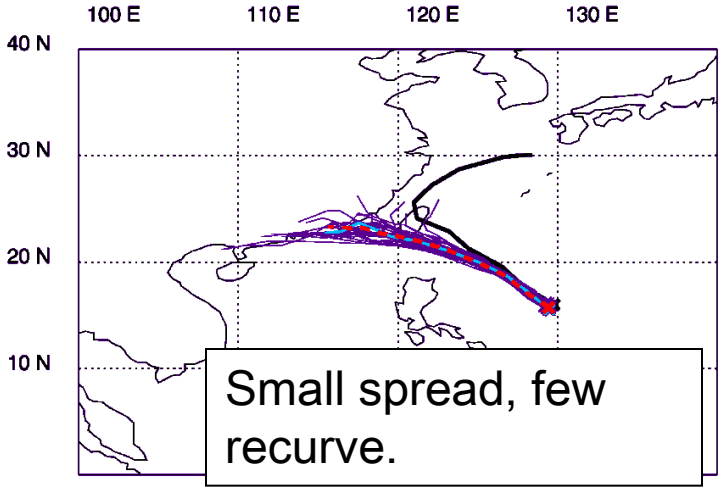


Jangmi

CTRL

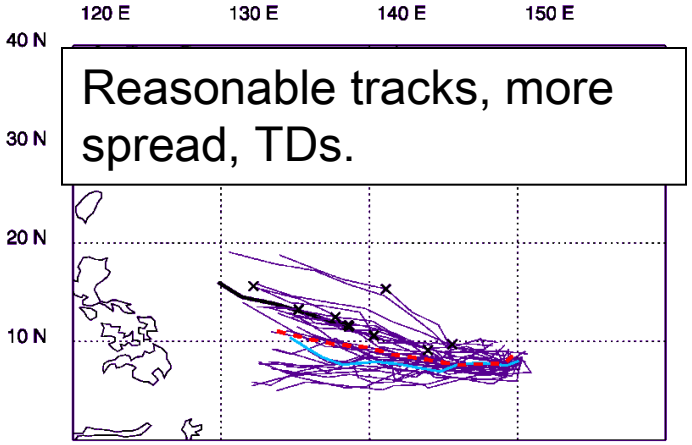


Reasonable tracks, but no TD forecasts.



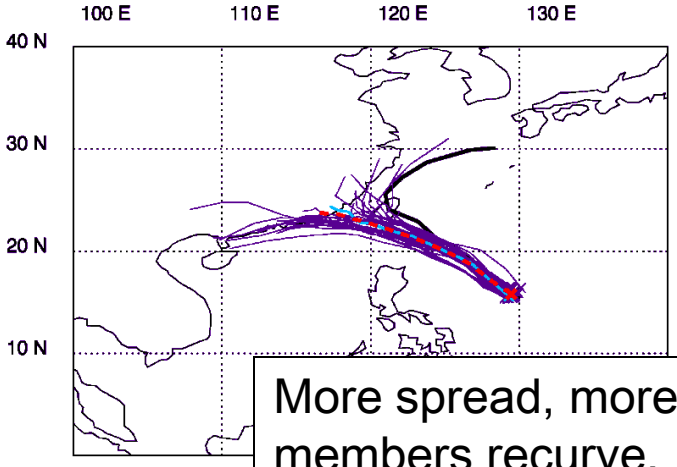
Small spread, few recurve.

STO



Reasonable tracks, more spread, TDs.

21 Sept. 00UTC
(66h before TD)



More spread, more members recurve.

26 Sept. 00UTC
(54h after TD)

NRL HFIP Ensemble Plans

- FY10:
  - Finish comparison of single and multi-model ensembles
    - Look at benefit to adding single-model ensemble mean track to multi-model consensus
    - Examine results for T239 8-member ensembles for 2008 and 2009
    - Examine results for inclusion of model uncertainty (stochastic, lower boundary)
  - Begin testing of high-resolution NOGAPS Semi-Lagrangian. First in deterministic mode, to 20 km, then in ensemble mode.
  - COAMPS Deterministic model reruns for 2008, 2009 with improved model formulation
- FY11-12:
  - Continue testing global ensembles (SL) at high resolution with incorporation of model uncertainty.
  - Development of simple coupled atmo-ocean model
  - COAMPS coupled forecasts and ensembles.
  - Examine impact of hybrid DA on TC performance (out years).

AOML Ensemble Research

S. Aberson and F. Marks

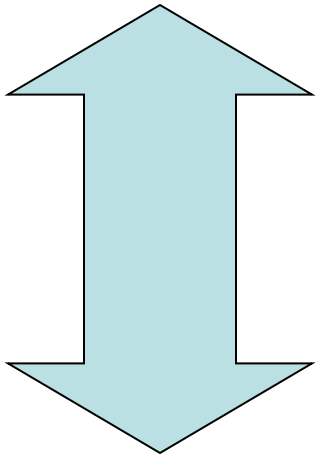
- Working with F. Zhang (PSU) to evaluate impact of global model on regional model ensemble spread (currently using GFS EnKF DA from ESRL to initialize WRF-ARW).

- Developing algorithms for ensemble evaluation as part of WRF-ARW and HWRFx ENFK and FSU multi-model regional ensembles (ensemble spread, spread in center location, ensemble model covariances. Use to evaluate appropriateness of ensemble spread for EnKF.

- Regional multi-model and single model ensemble spread being compared to global model ensemble spread. Work continues into FY10 on verification alogrithms.

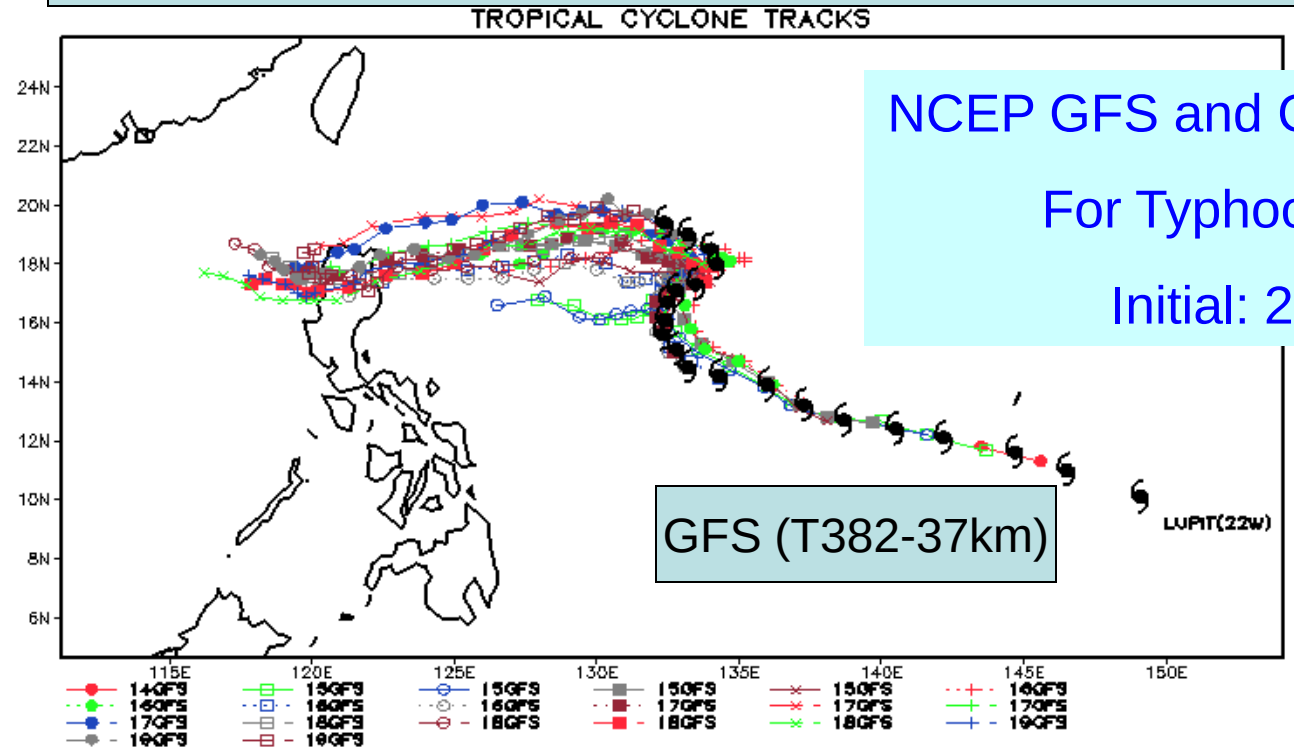
Future Plans and Issues: Overview

- Continue research on improving ensemble formulation
  - Higher resolution
  - Better accounting for model uncertainty and lower boundary uncertainty
  - Better initial perturbations/representation of storm
  - Managed ensembles (single model ensembles + multi-model ensembles + deterministic)
  - Work on mesoscale ensembles will continue
- Integration with DA group: Work on hybrid methods from ESRL/NCEP and CIRA/NCEP (and at NRL in out-years)
- <u>Integration with Diagnostics, Verification, PPAD on probabilistic product development and verification</u>



Extra Slides: NCEP

Contrast of deterministic high resolution model to low resolution ensemble

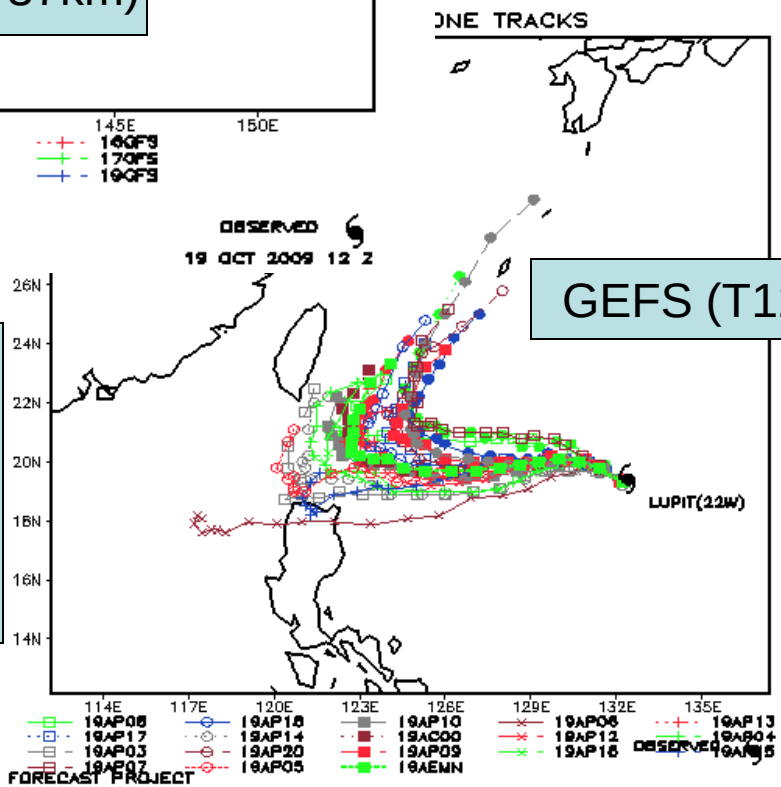


NCEP GFS and GEFS tracks forecast

For Typhoon Lupit (22W)

Initial: 2009101912

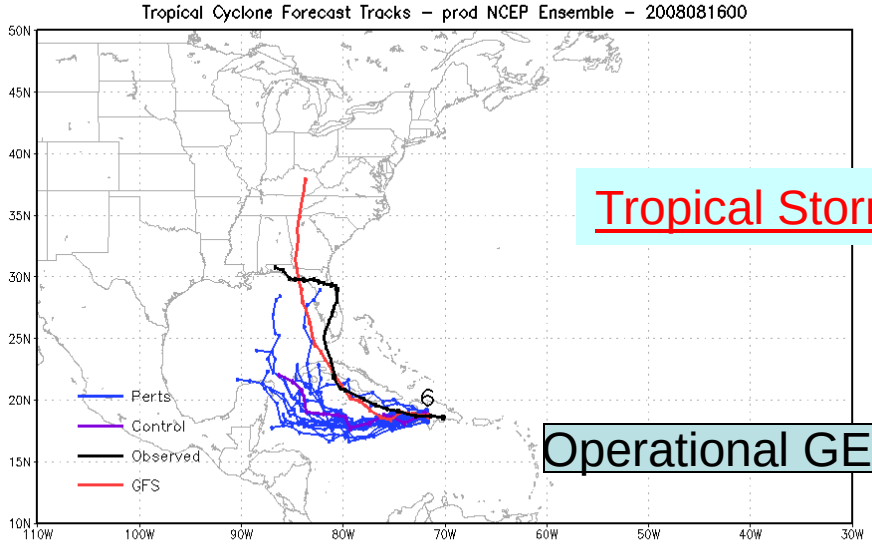
GFS (T382-37km)



GEFS (T126-90km)

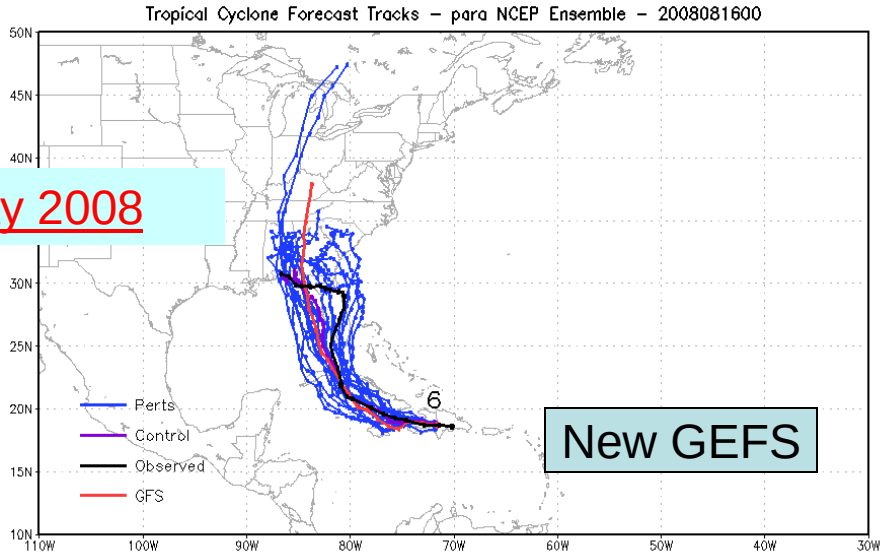
Ensemble has ability to predict Lupit turned into Northeast of Pacific in 4-day advance, but deterministic forecast not

[Track plots from Hua-Lu Pan]

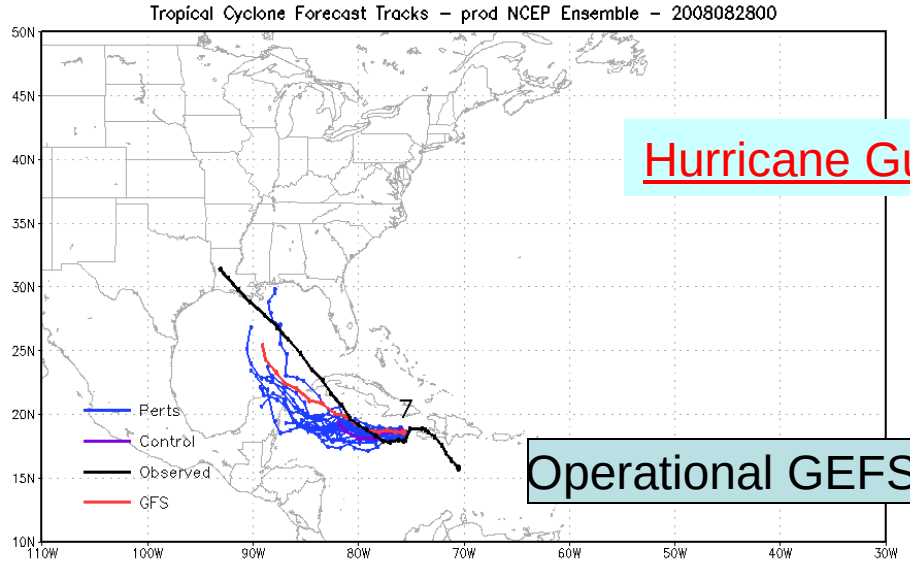


Tropical Storm Fay 2008

Operational GEFS

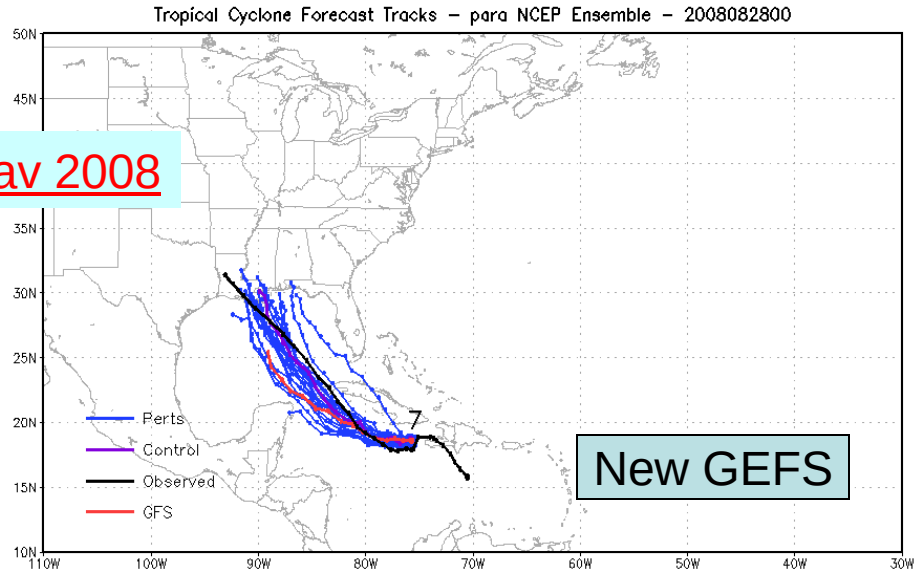


New GEFS

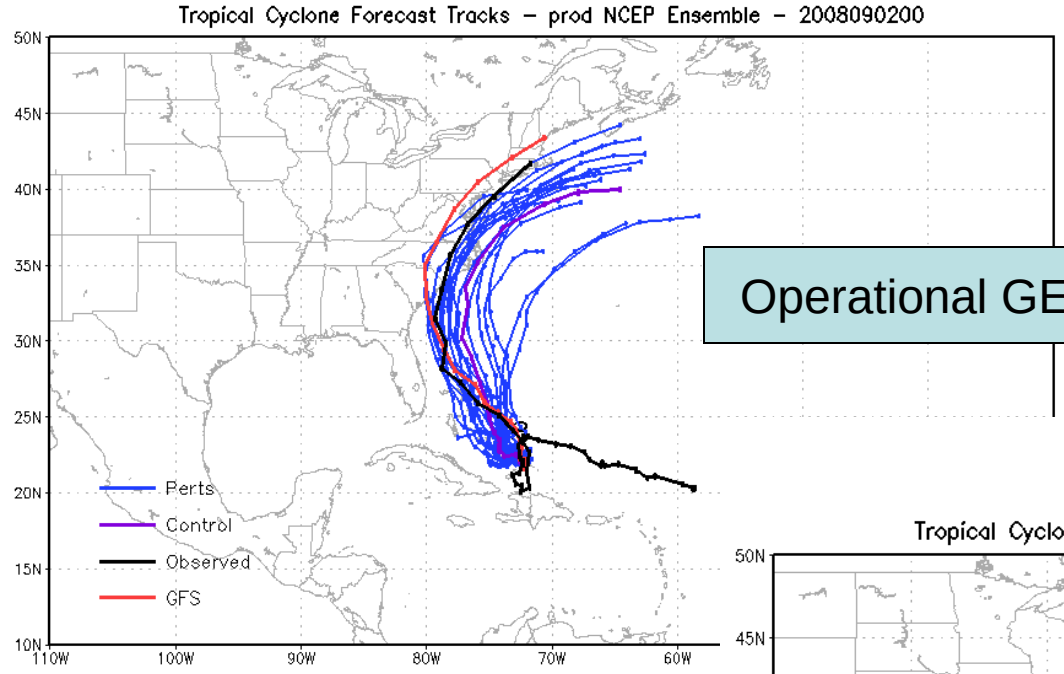


Hurricane Gustav 2008

Operational GEFS

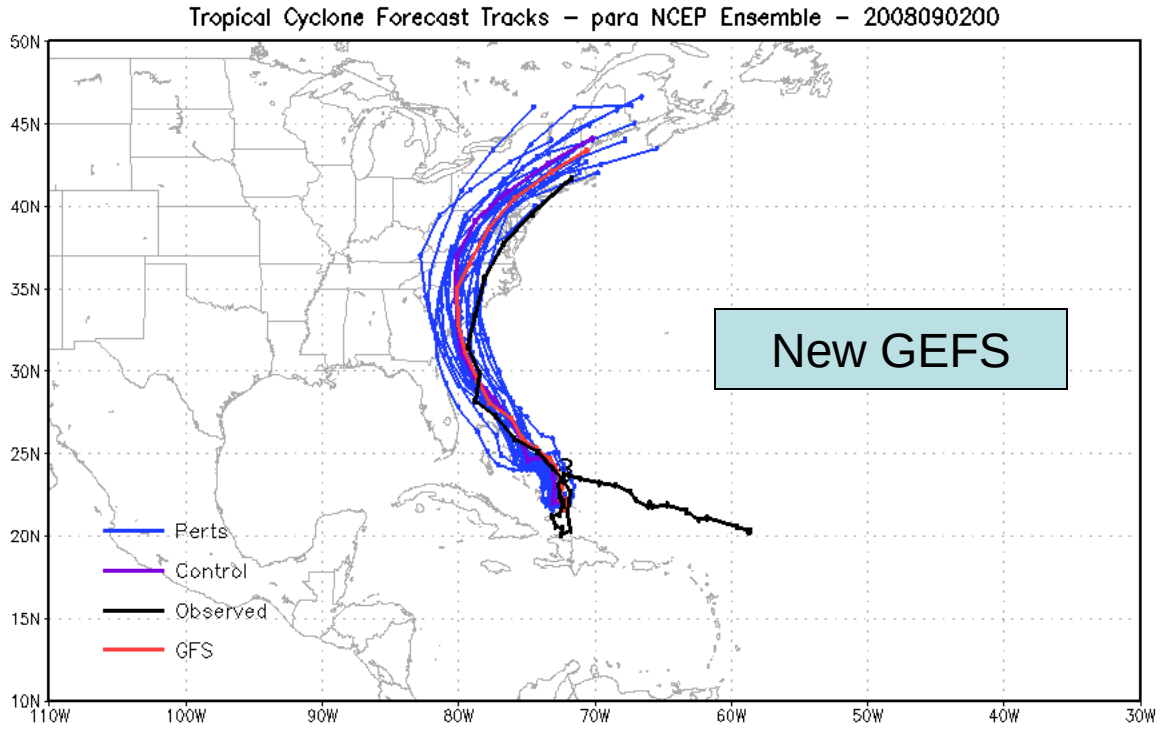


New GEFS



Operational GEFS

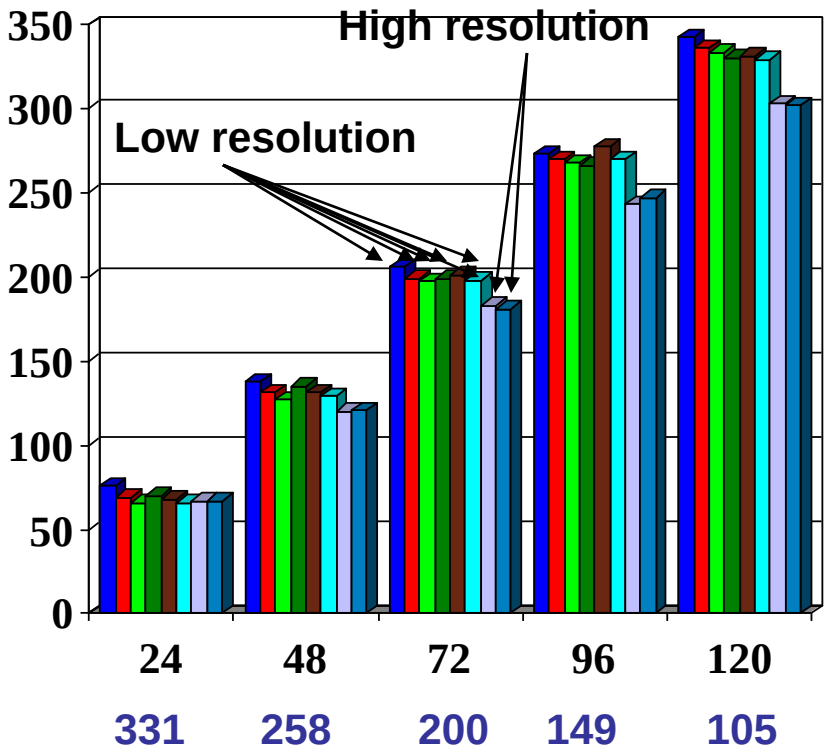
Hurricane Hanna 2008



New GEFS

Extra Slides: NRL

Average NOGAPS forecast error (nm) for 2008 TCs, All Basins



Testing many configurations to study impact on TC track forecasts.

- B119-9
- B119-17
- B119-33

Banded ET at T119 resolution, 9, 17 and 33 members.

- G119-9

Global ET at T119, 9 members.

- M119-9
- M119-17

Modified Banded ET at T119 resolution, 9 and 17 members.

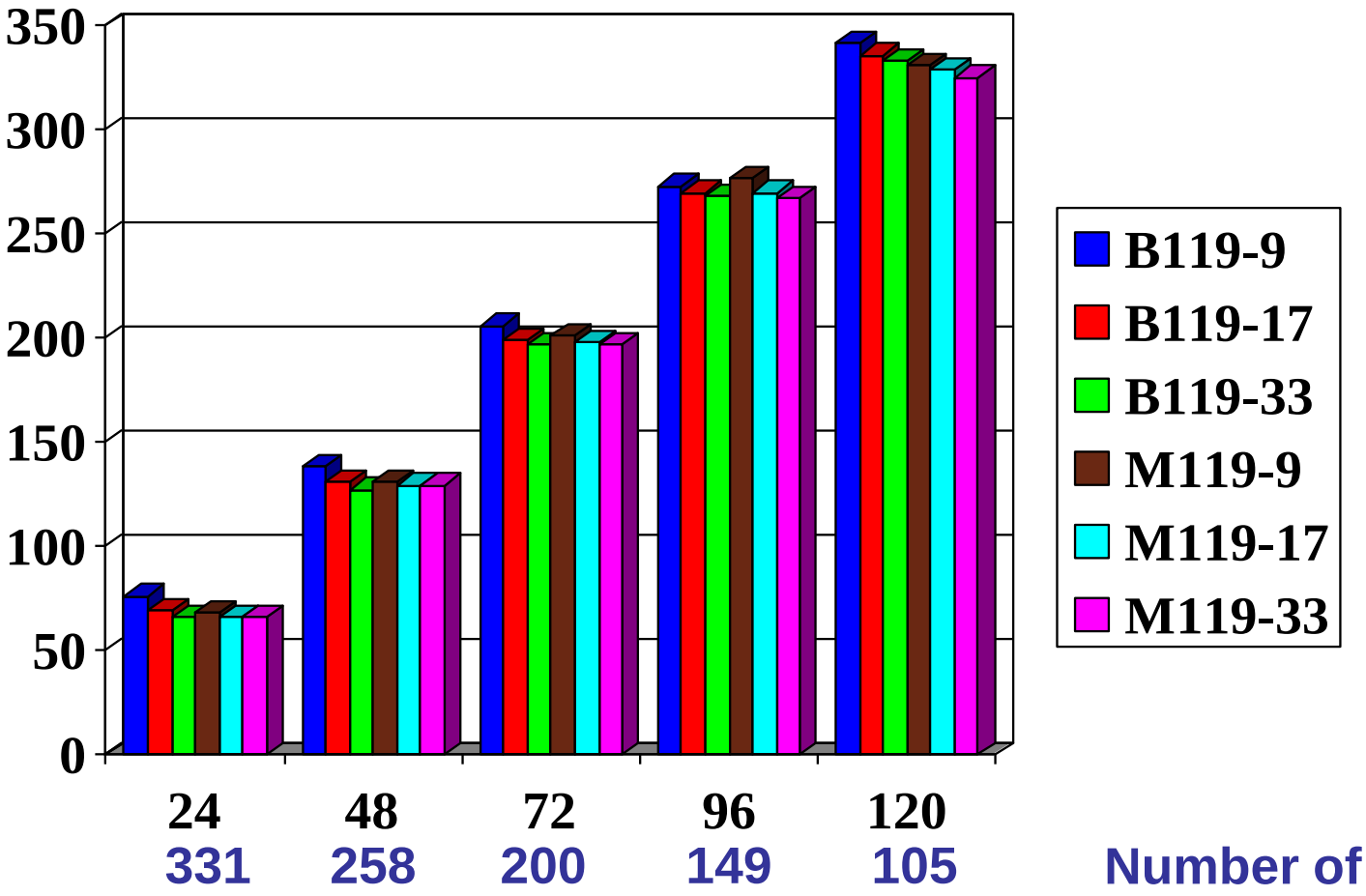
- G159-9
- G159-17

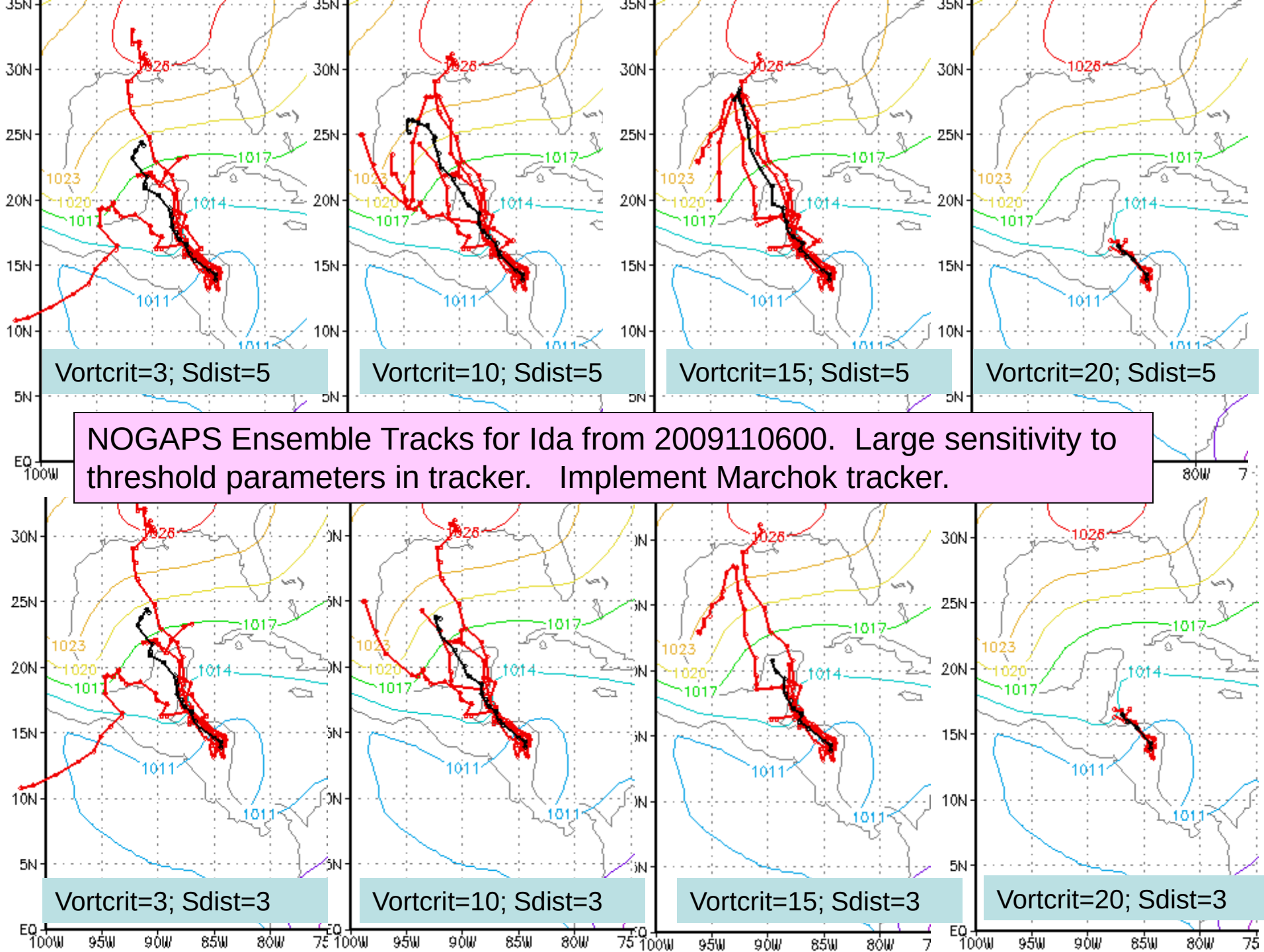
Global ET at T159 resolution, 9 and 17 members.

Running a 9-member high resolution (T159, or 83 km) ensemble outperforms a 33-member low resolution (T119 or 110 km) at less computational cost. Experiments continue with even higher resolution and stochastic convection.

NOGAPS 2008 Northern Hemisphere Homogeneous TC Forecast Error (nm)

Comparison of Banded “B” and Modified Banded “M” Ensemble Transform initial perturbations. Slight advantage to modified banded initial perturbations.




Vortcrit=3; Sdist=5
Vortcrit=10; Sdist=5
Vortcrit=15; Sdist=5
Vortcrit=20; Sdist=5
NOGAPS Ensemble Tracks for Ida from 2009110600. Large sensitivity to threshold parameters in tracker. Implement Marchok tracker.
Vortcrit=3; Sdist=3
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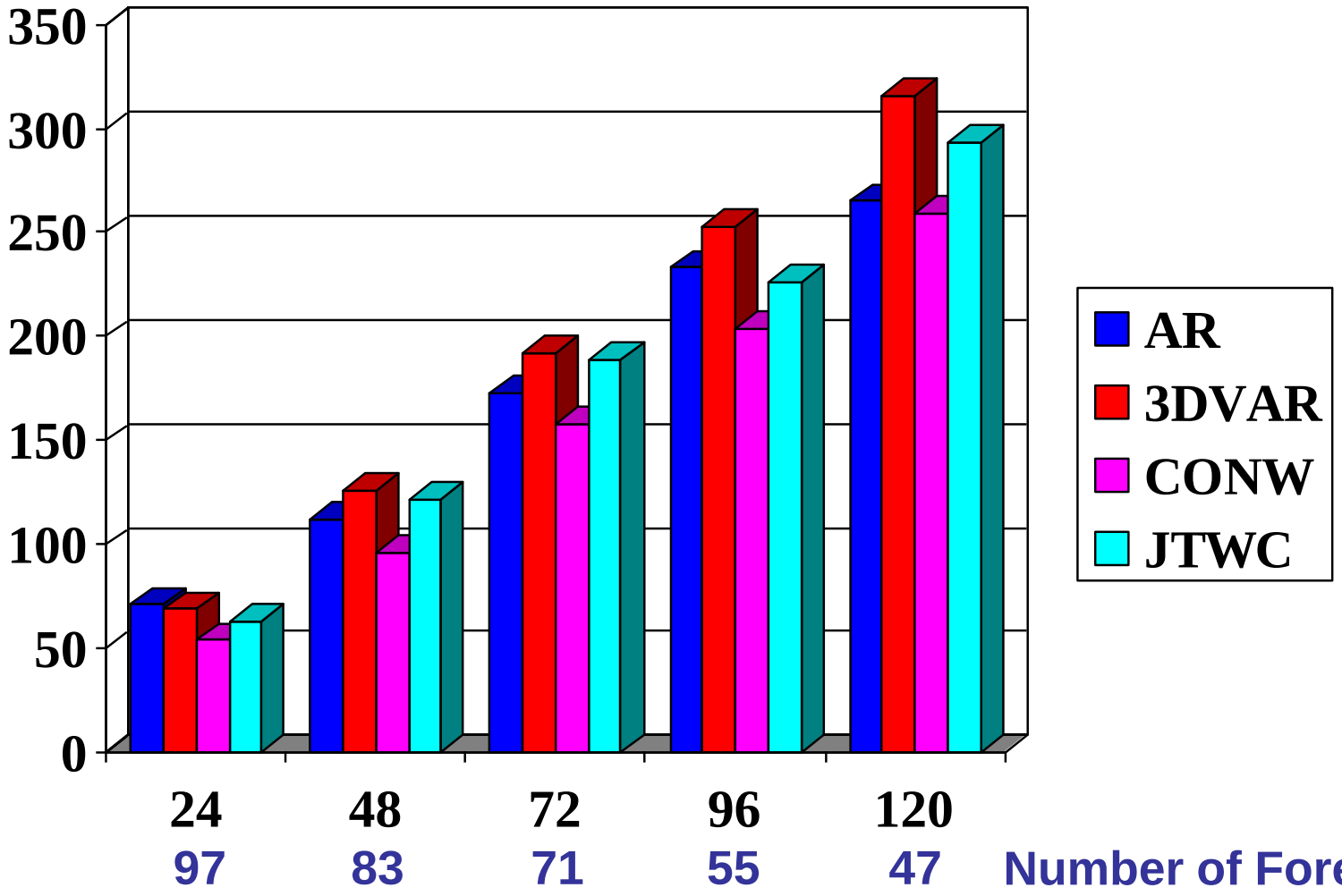
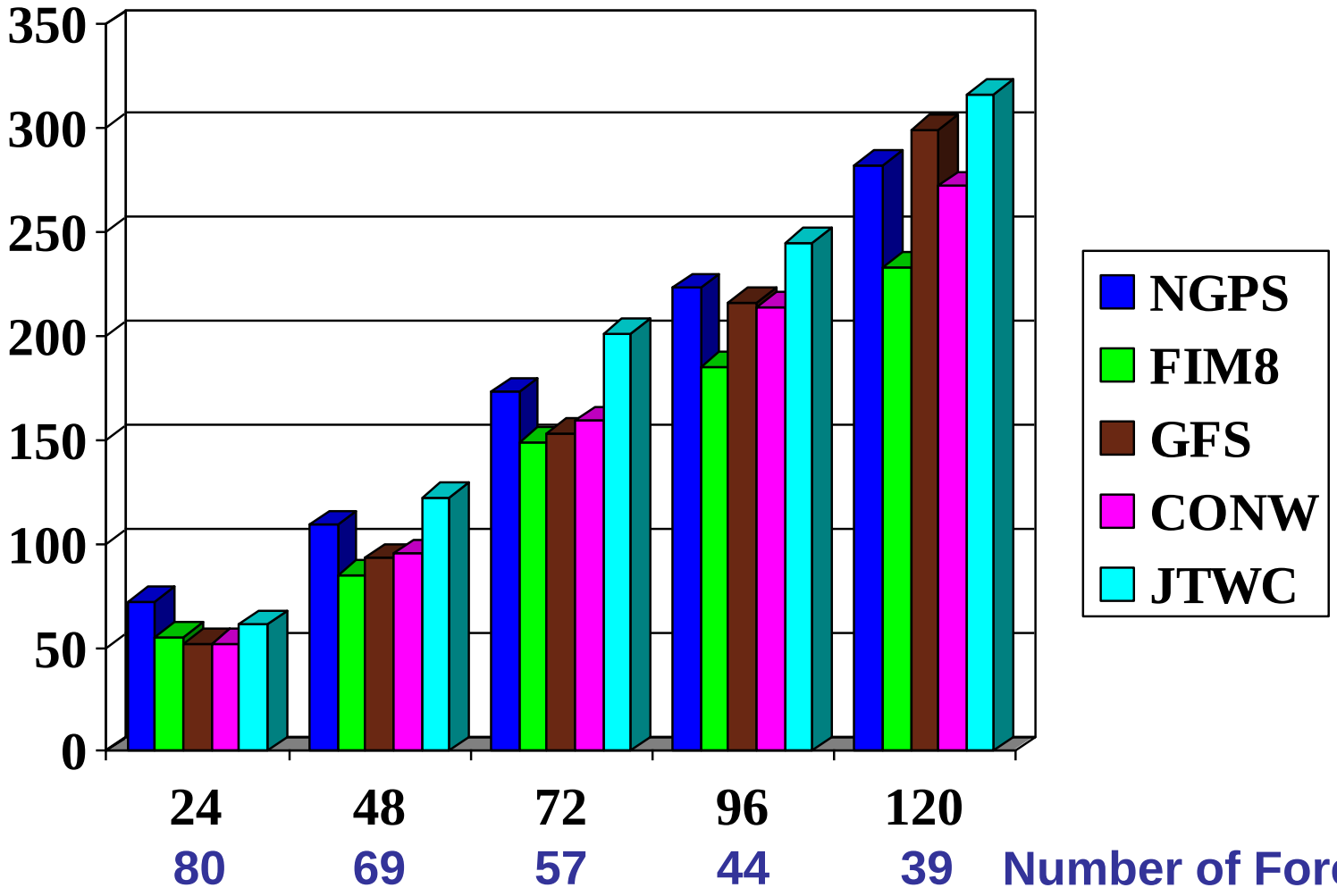
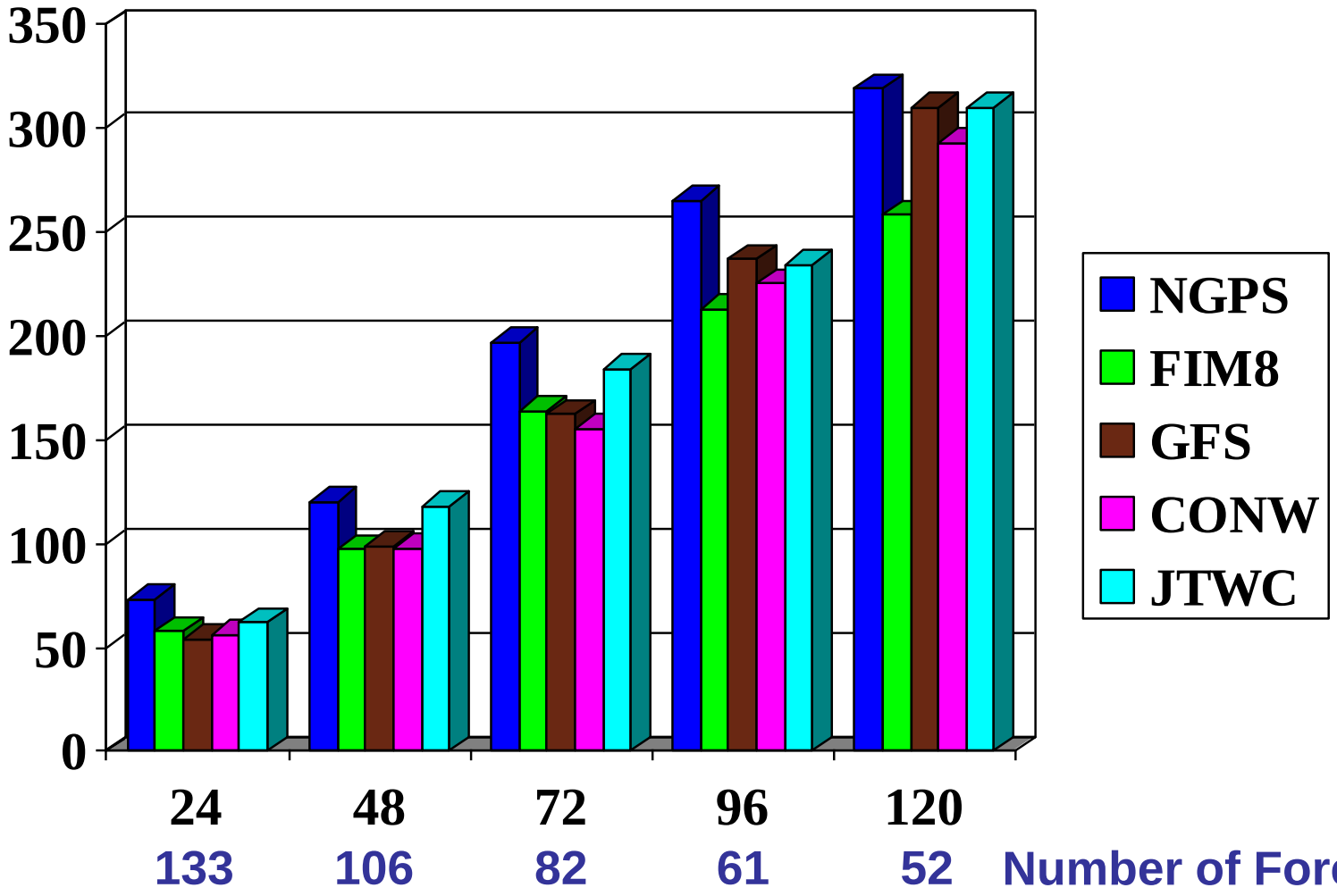
2009 Western North Pacific (17W-23W)
Homogeneous TC Forecast Error (nm)



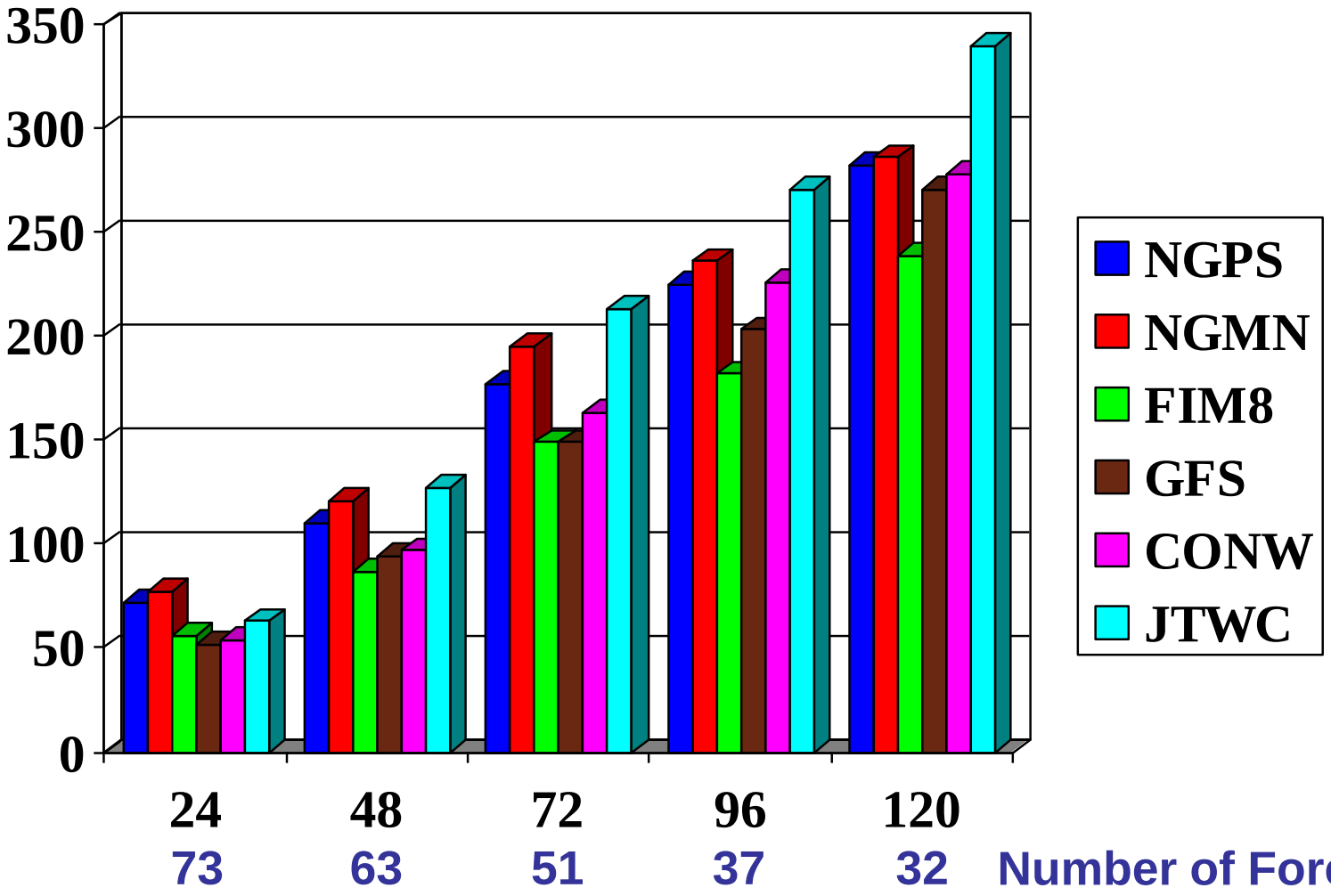
2009 Western North Pacific (17W-23W)
Homogeneous TC Forecast Error (nm)



2009 Western North Pacific (08W-23W)
Homogeneous TC Forecast Error (nm)



2009 Western North Pacific (17W-23W)
Homogeneous TC Forecast Error (nm)



2009 Western North Pacific (08W-23W)
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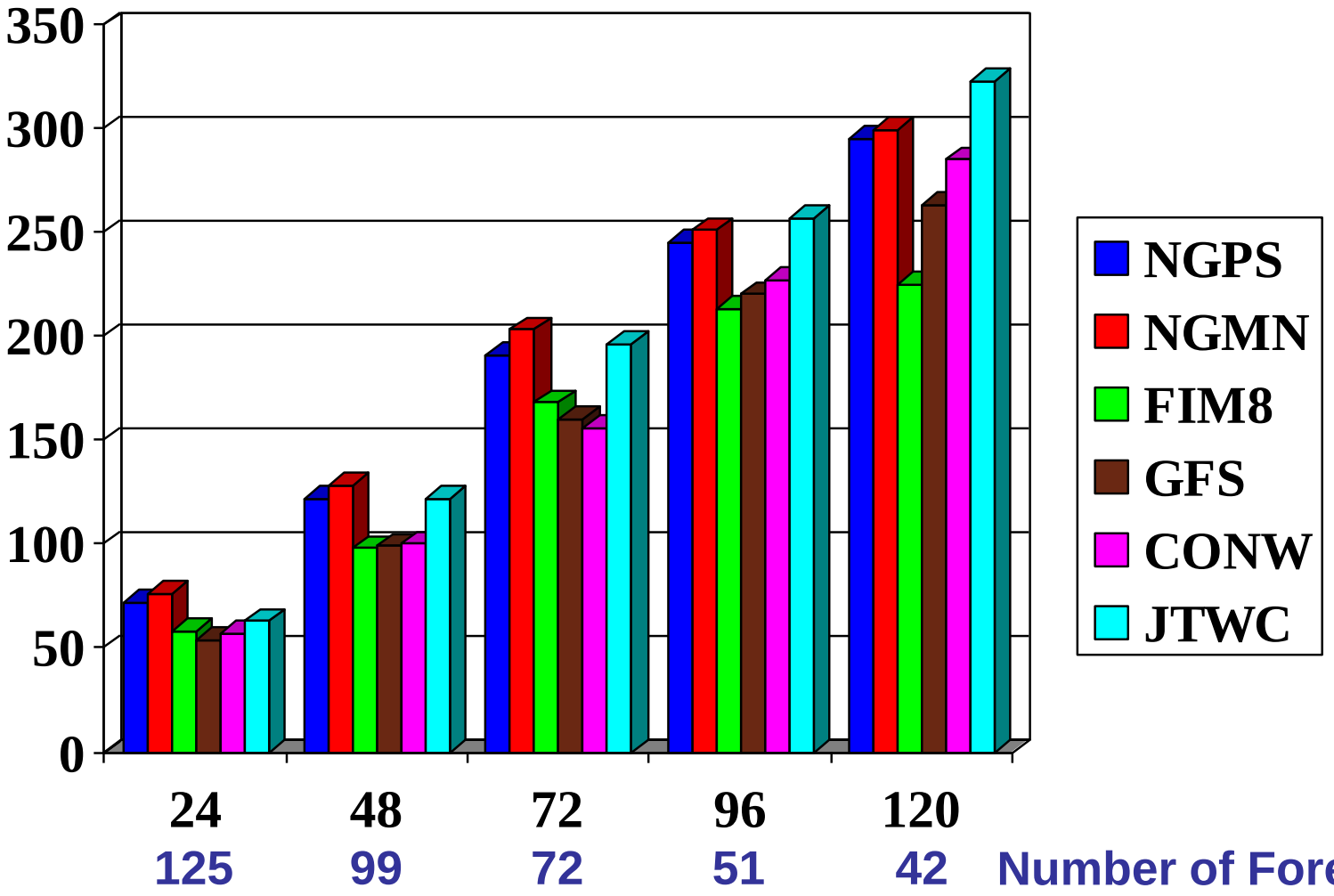

HFIP ENSEMBLE PLAN

Technical Approach:

- **Design and use probabilistic measures of hurricane forecasts to evaluate value added in probabilistic HFIP R&D**
- **Improve initial and model uncertainties in NOAA and Navy global ensemble forecast systems for improved track forecasts and LBCs for finer scale ensembles**
- **Evaluate potential of mesoscale ensemble forecasting using the NCEP SREF system for improved track, intensity, and structure forecasts**
- **Develop a fine-scale relocatable (storm-following) hurricane ensemble system to be used as an inner mesh within a mesoscale ensemble to represent initial state and model related forecast uncertainties**
- **Interface with verification and diagnostics groups to ensure probabilistic measures are incorporated into standard diagnostic and verification packages**
- **Interface with DA team in ensemble-based DA efforts**
- **Interface with Numerical Modeling Team in exploring the use of various models for global ensemble TC forecasting**
- **Interface with post-processing/applications team in designing probabilistic forecast products for hurricane track, intensity and associated weather elements**