Use of a high resolution multi-model ensemble track, and intensity - a demo project in the `09 hurricane season using the HWRF, GFDL, AHW and COAMPS

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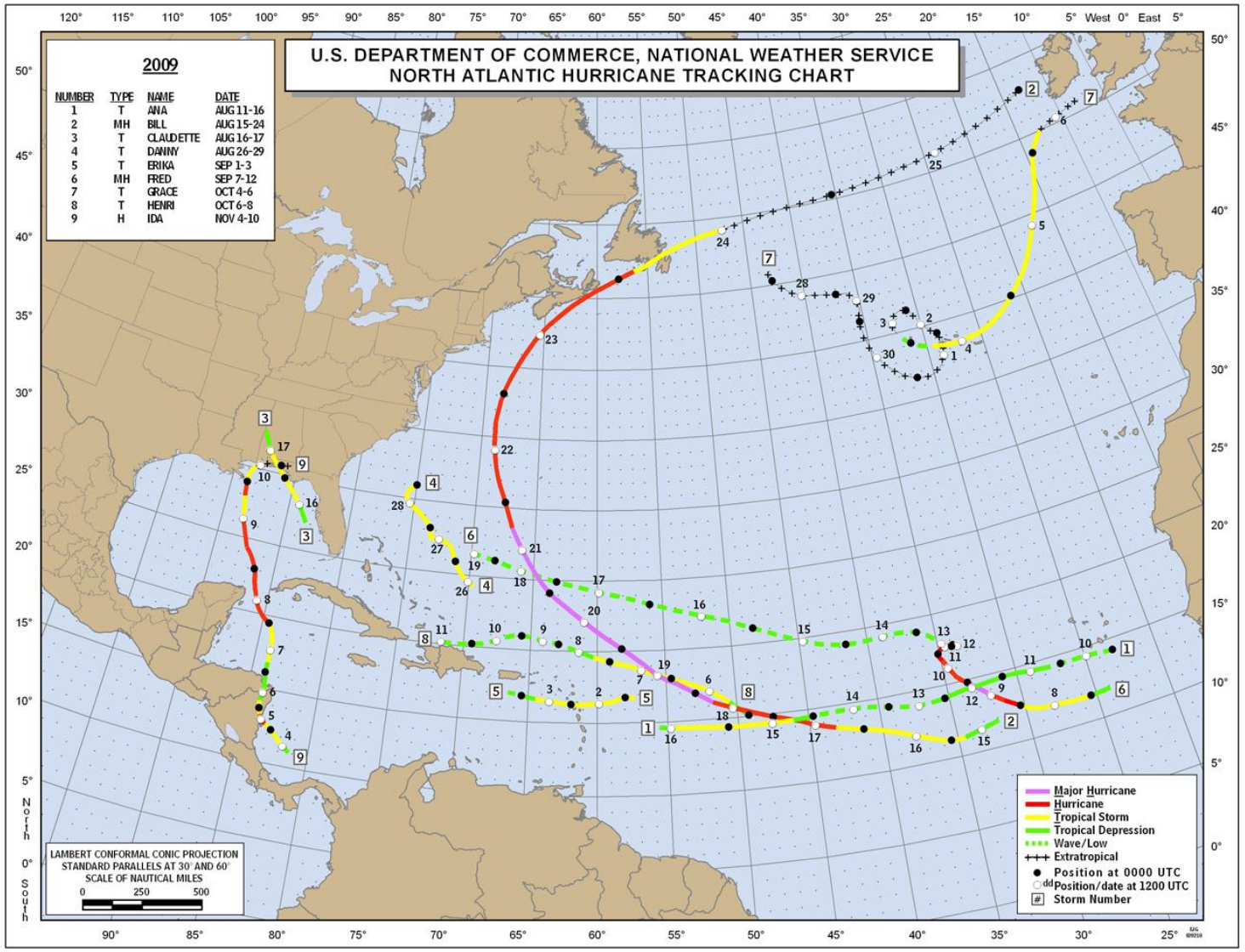
EMC/MMM/DTC Joint Hurricane Workshop, NCAR February 22-23, 2010

Storms during the 2009 Atlantic Hurricane Season



Only 9 named storms during the 2009 season

Courtesy: NHC website http://www.nhc.noaa.gov/tracks/2009atl.jpg

HIGHLIGHTS OF THE 2009 HFIP DEMO SEASON

Demo season started on August 1, 2009

Member Institutions Participating:

- NRL (Dr. Jim Doyle)
- HRD (Dr. Gopal)
- NCEP (Dr. Naomi Surgi)
- GFDL (Dr. Morris Bender)
- NCAR (Dr. Christopher Davis)
- FSU (Dr. T. N. Krishnamurti)

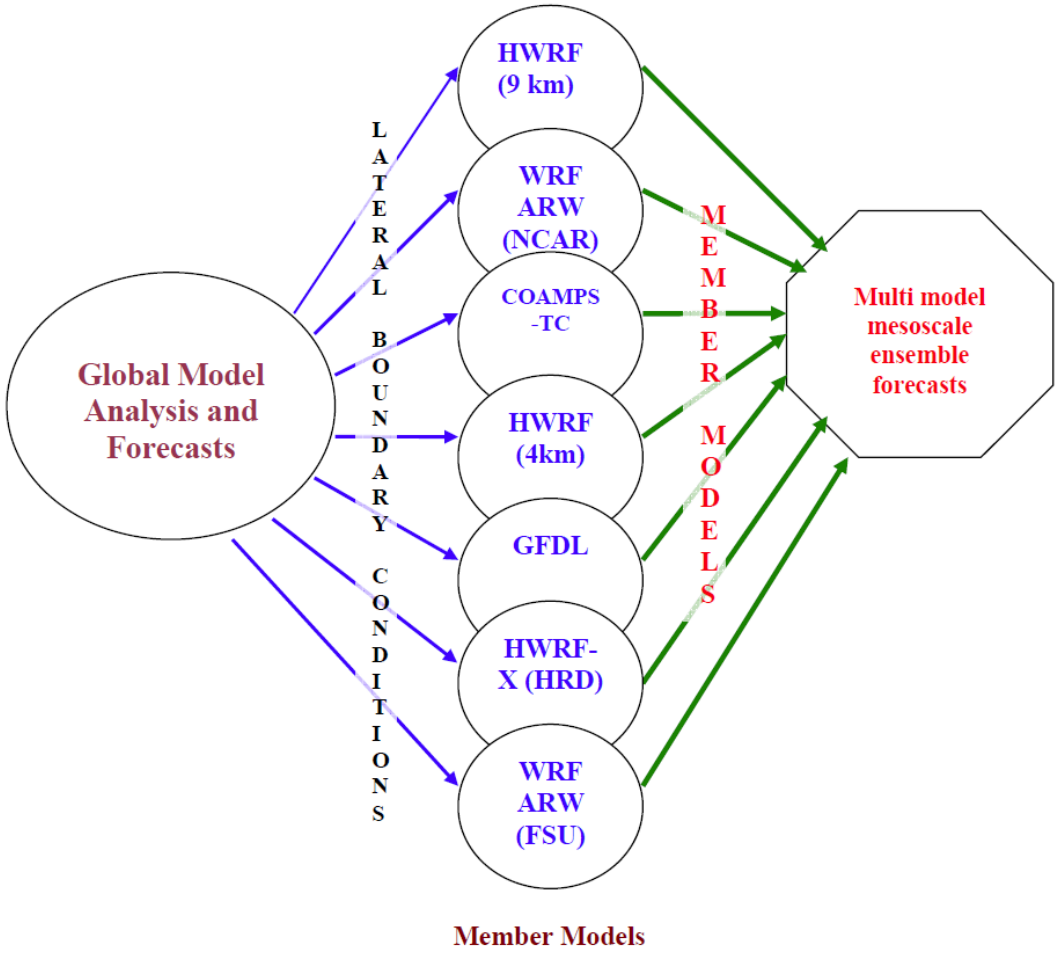
Models included in the ensemble

- COAMPS TC
- HWRF-X
- HWRF (9km)
- HWRF (4km)
- GFDL
- ARW (NCAR)
- ARW (FSU)

Model Descriptions for Mesoscale Models for ensemble forecasts

Models	Nesting Horizontal resolution (km)	Vertical levels	Cumulus Parameterization	Microphysics	PBL	Land Surface	Radiation	Initial and boundary conditions	Initialization
HWRF	2 27/9	43	Simplified Arakawa Schubert	Ferrier	GFS Non-Local PBL	GFDL Slab Model	Schwarzkopf and Fels (1991) (longwave) / Lacis and Hansen (1974) (shortwave)	GFS	Advanced vortex initialization that uses GSI 3D-var assimilation of Doppler radar data to run in development parallel.
HWRF	2 13.5/4.5	42	Simplified Arakawa Schubert	Ferrier	GFS Non-Local PBL	GFDL Slab Model		GFS	
HWRF-X HRD version of HWRF	2 9/3	42	Simplified Arakawa Schubert	Ferrier	GFS scheme	NCEP LSM	RRTM (longwave) / Dudhia (shortwave)	GFS	HWRF
WRF ARW (NCAR)	2 12/4	36	New Kain Fritsch (12 km only)	WSM5	YSU	5-layer thermal diffusion soil model	RRTM (longwave) / Dudhia (shortwave)	GFS	EnKF method in a 6-hour cycling mode
COAMPS-TC	3 45/15/5 (15/5 km following the storm)	40	Kain Fritsch	Explicit microphysics (5 class bulk scheme)	Navy 1.5 order closure	Force and restore slab land surface model	Harshvardardet et al. (1987)	NOGAPS	3D-Var data assimilation with synthetic observations
GFDL	3 30/15/7.5	42	Arakawa Schubert	Ferrier	GFS Non-Local PBL	Slab Model	Schwarz-kopf-Fels scheme	GFS	GFDL synthetic bogus vortex
WRF ARW	2 12/4	27	Simplified Arakawa Schubert	WSM5	YSU	5-layer thermal diffusion soil model	RRTM (longwave) / Dudhia (shortwave)	GFS (initial and boundary condition)	GFS

Flow Chart showing the Multimodel Mesoscale Ensemble Initiative



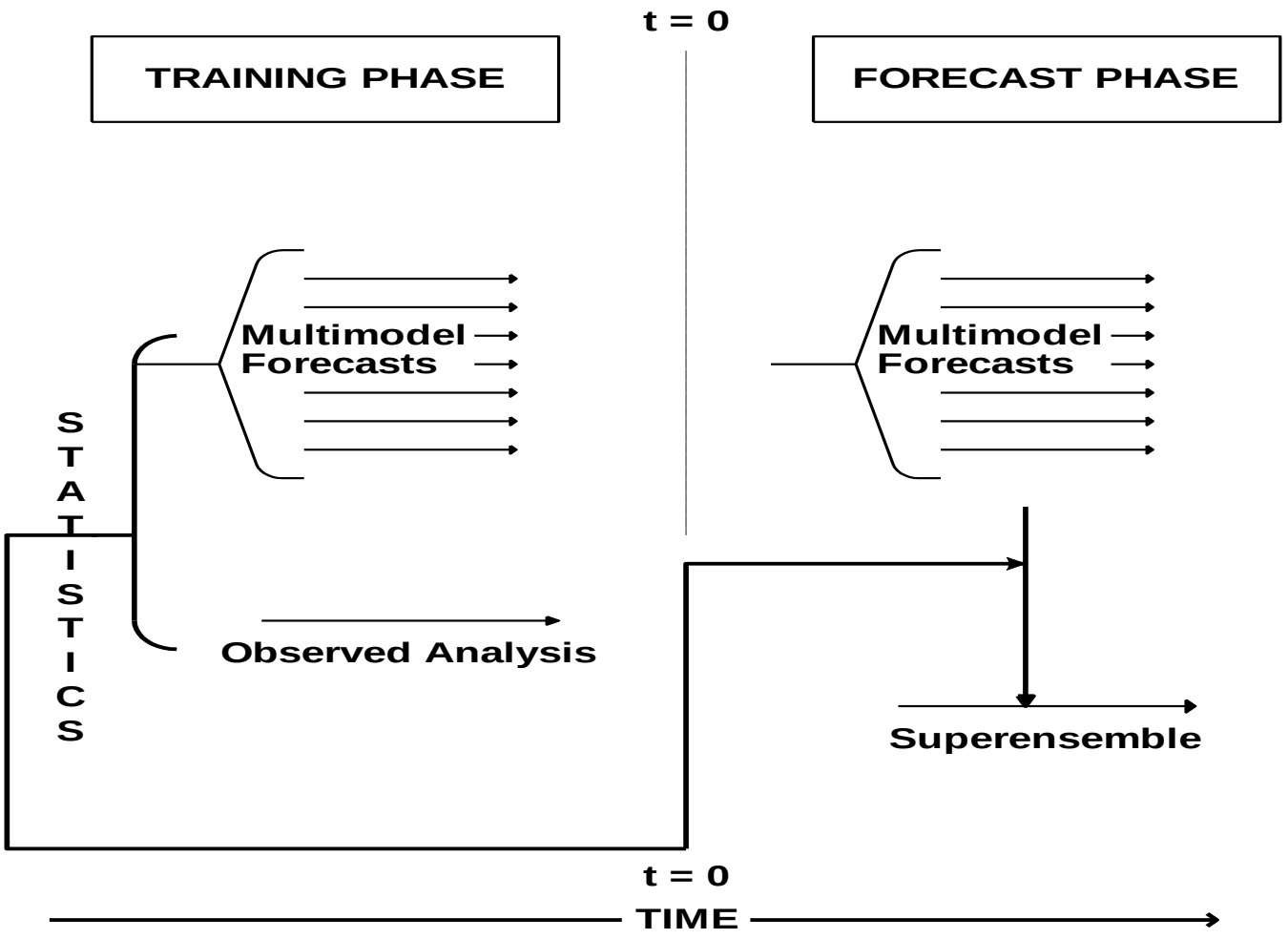
Ensemble Mean of Mesoscale models

As per operational requirements make a forecast up to 120 hours if at least two models are present which is the minimum requirement for a mean. If all model forecasts are not available through 120 hours, the ensemble mean is made up to the lead time when at least two models are present. For a particular forecast hour the mean is the average of the member model forecasts available at that particular forecast time.

Bias Corrected Ensemble Mean Methodology

The bias of a forecast F_{ij} (at a geographical location i,j) is given by $\overline{F_{ij}} - \overline{O_{ij}}$ where $\overline{O_{ij}}$ is observed value and the bar denotes a time mean. Then if a new forecast F_{Nij} is made then the bias corrected forecast is $F_{BCij} = F_{nij} + \left(\overline{F_{ij}} - \overline{O_{ij}}\right)$. If there are n models then the bias corrected mean of the member models is given by $F_{BCEMij} = \sum_{k=1}^{n} \frac{1}{n} F_{BCij} \Big)_k$.

Superensemble Methodology



Formulation of the Superensemble

- The superensemble forecast is constructed as,

where, $$S = \sum_{i-1}^{N} a_i (F_i - \bar{F}_i) + \bar{O}$$

F_i are the i[th] model forecasts increments.

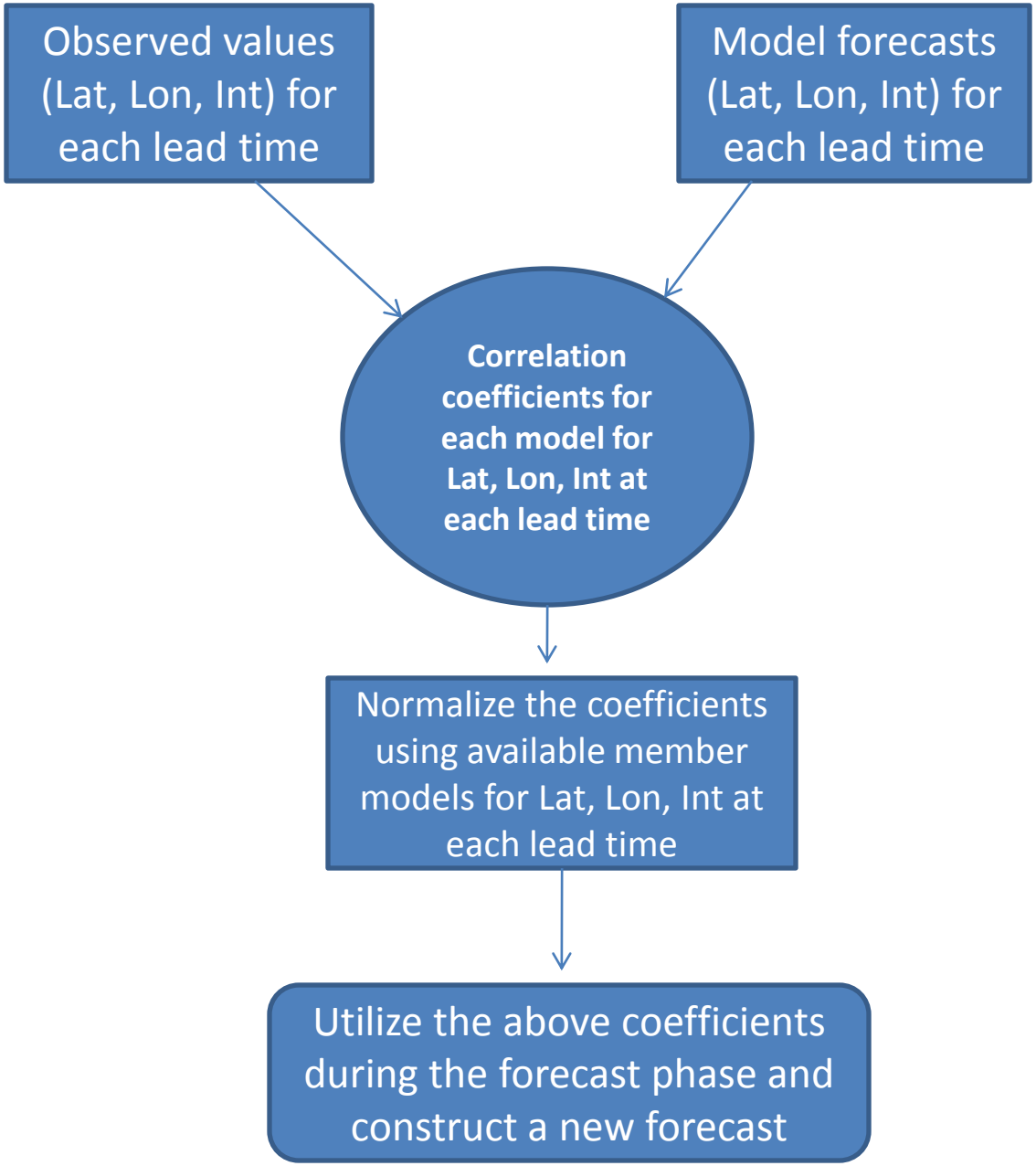
$\bar{F}_i$ are the mean of the i[th] model forecasts increments over the training period.

$\bar{O}$ is the observed increments mean of the training period.

a_i are the regression coefficient obtained by a minimization procedure during the training period.

N is the number of forecast models involved.

Correlation based model ensembles



Motivation for this Work

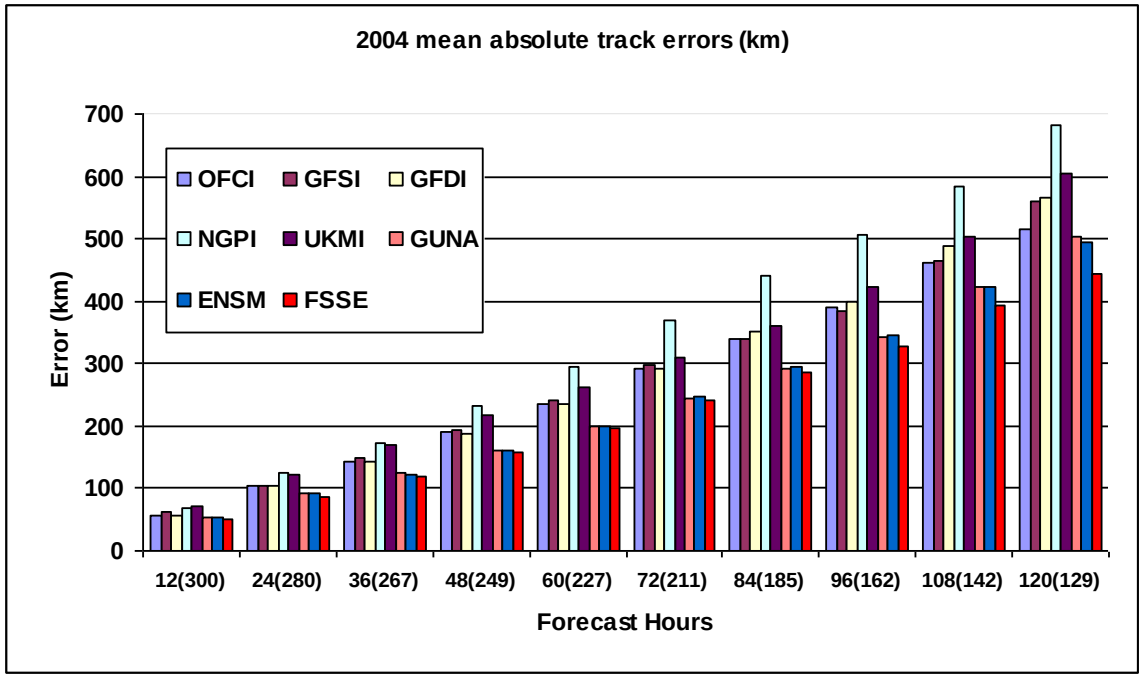
Based on previous work

- **FSU Superensemble**

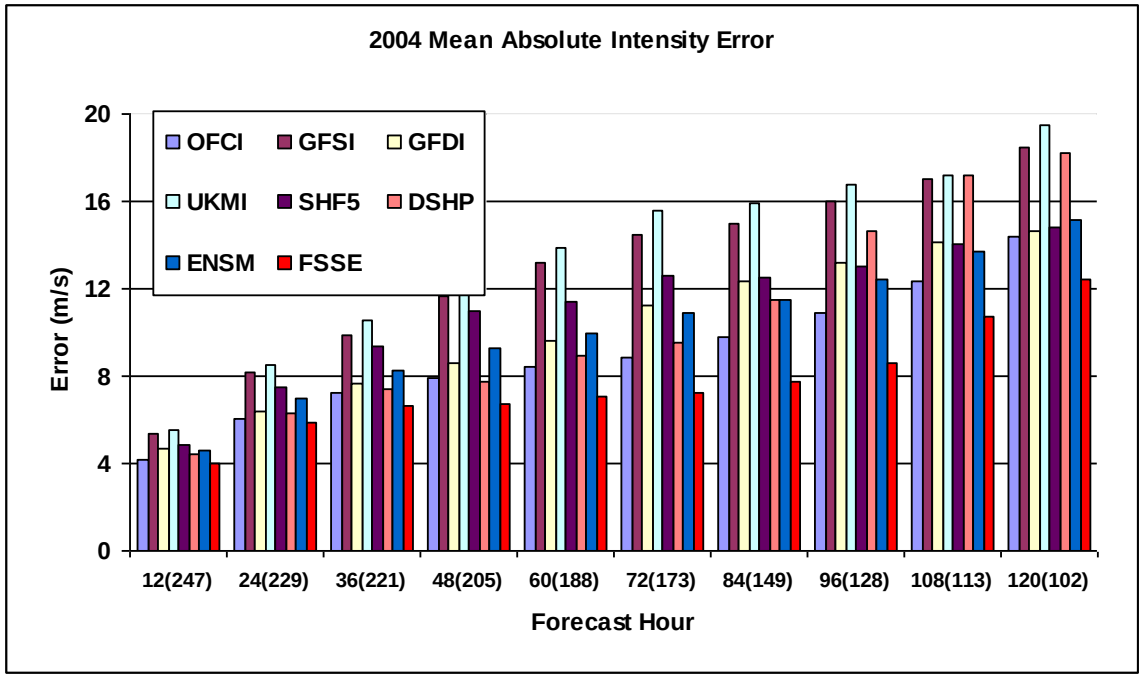
- **Multimodel Mesoscale Ensemble**

T.N. Krishnamurti, M.K. Biswas, B.P. Mackey, R.G. Ellingson and P. Ruscher, 2010a. Recent real-time hurricane forecasts with the FSU multimodel superensemble. ***Mon. Wea. Rev***. (Under revision)

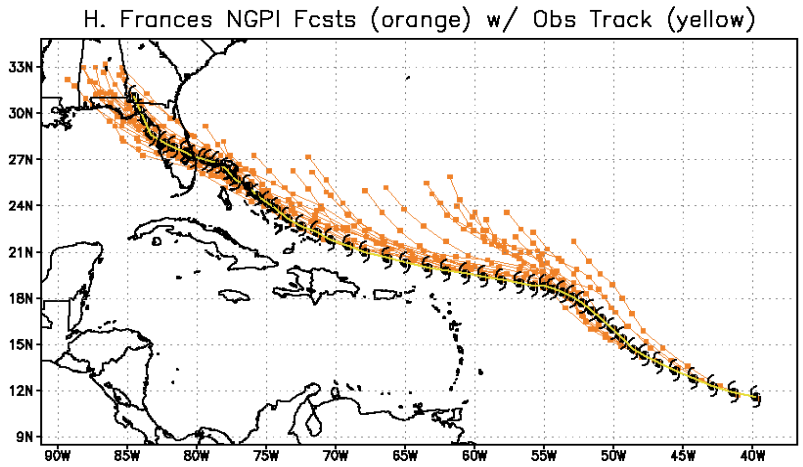
T.N. Krishnamurti, S. Pattnaik, M.K. Biswas, M. Kramer, Ed Bensman, N. Surgi and T.S.V. Kumar, 2010b. Multimodel ensemble forecasts of hurricane for a suite of mesoscale models. ***Tellus A*** (Under revision)

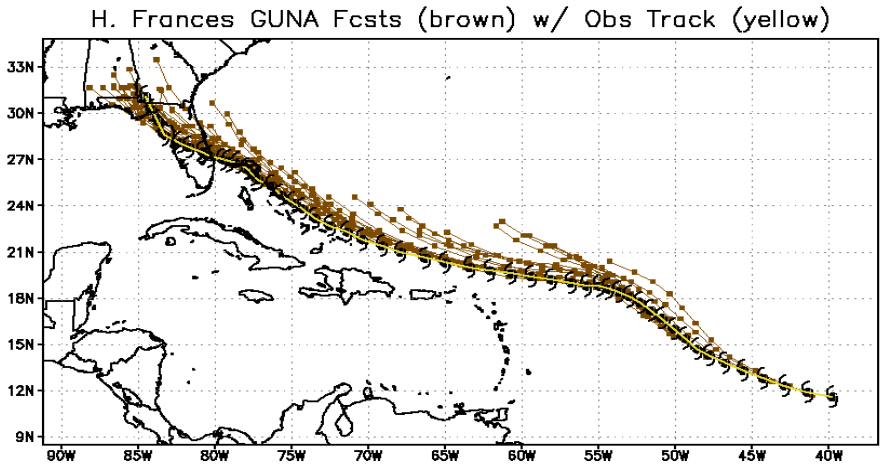


Realtime forecast errors during 2004 Season

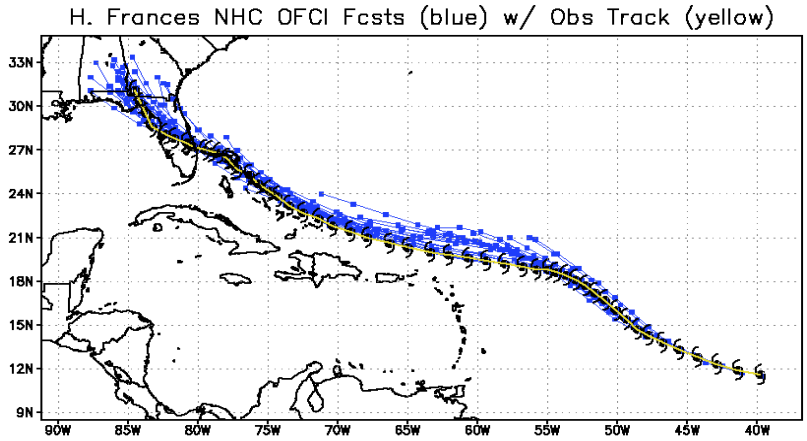


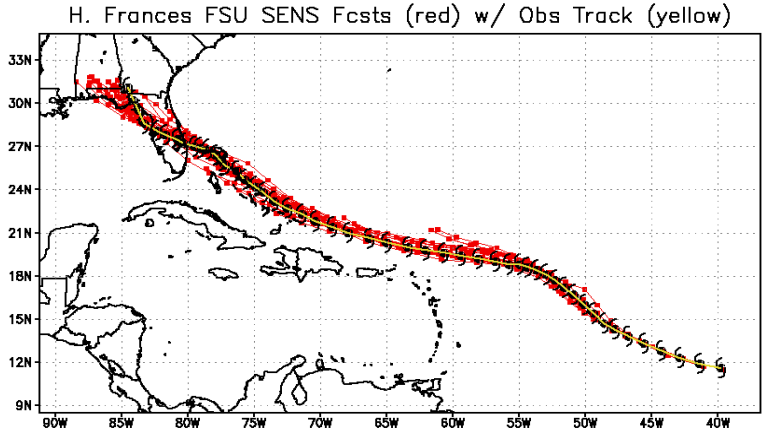
Reduction of biases and consistency of forecasts for Frances (2004)



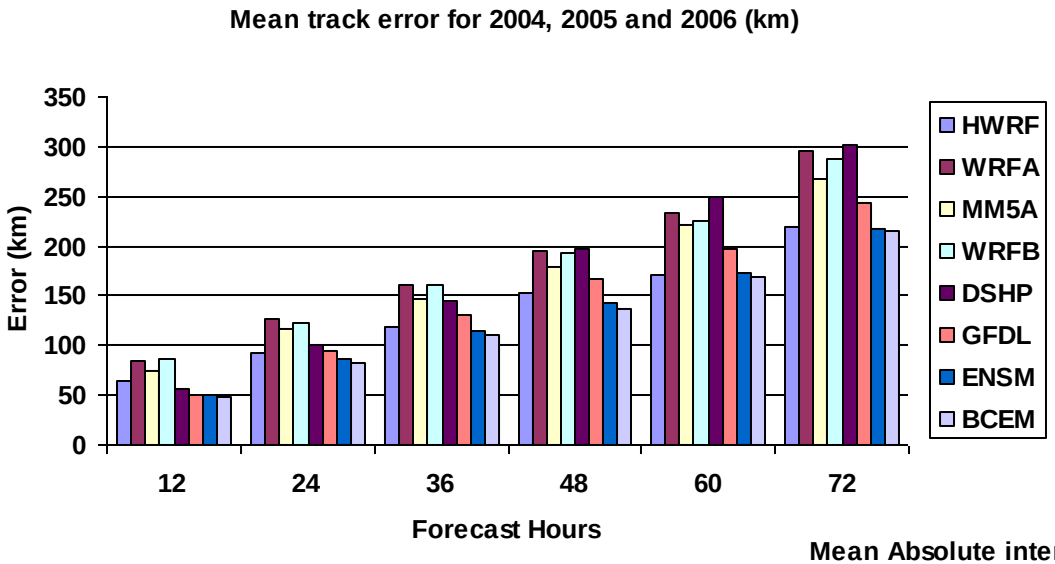


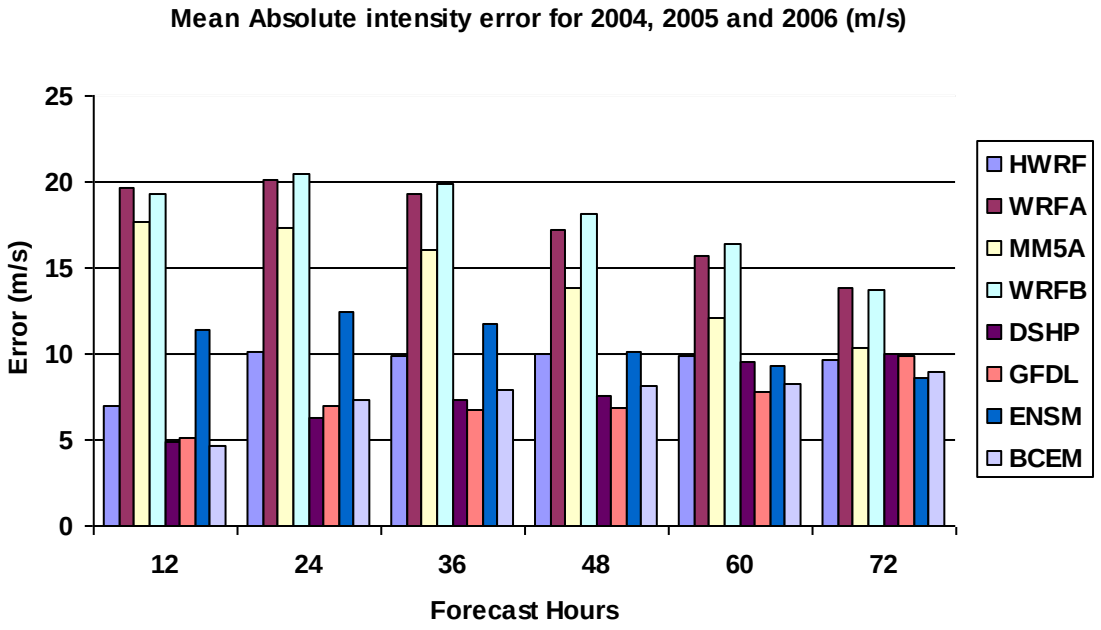
Realtime Forecasts



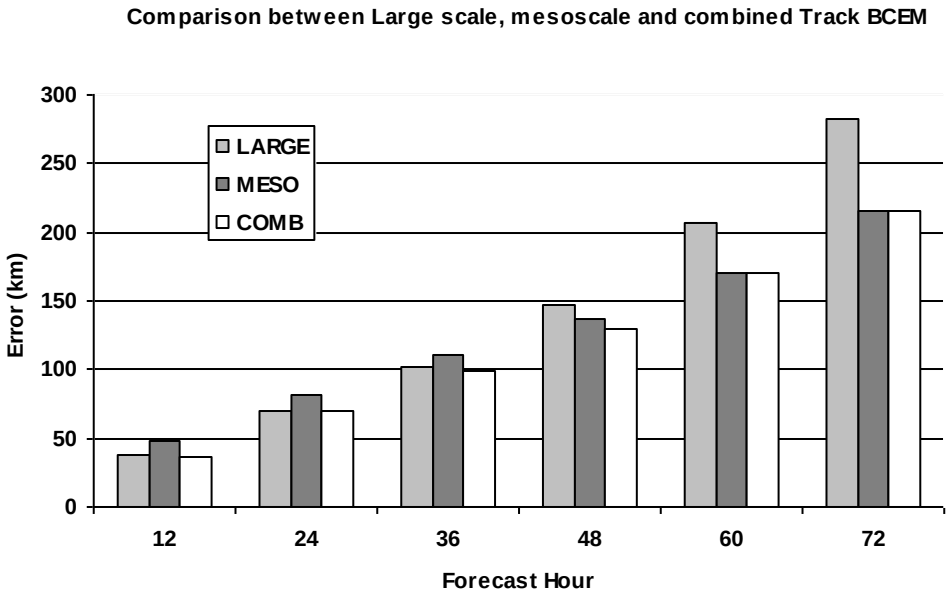


Multimodel Mesoscale Ensemble forecasts for 2004, 2005 and 2006 selected storms

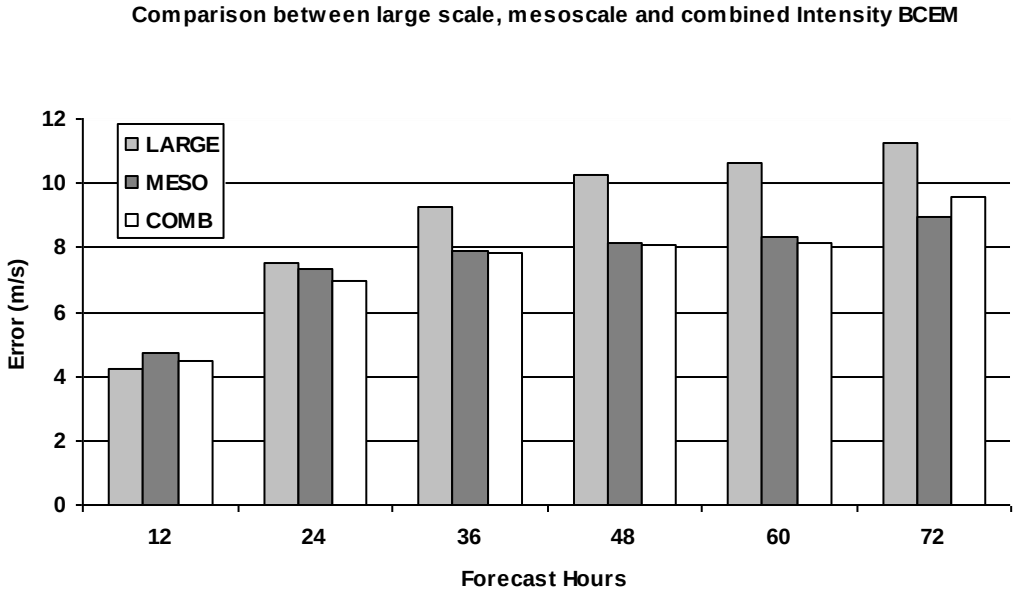




Forecasts using a combination of Largescale and Mesoscale models



Mesoscale forecasts were superior than the large scale forecasts after 48 hours for tracks

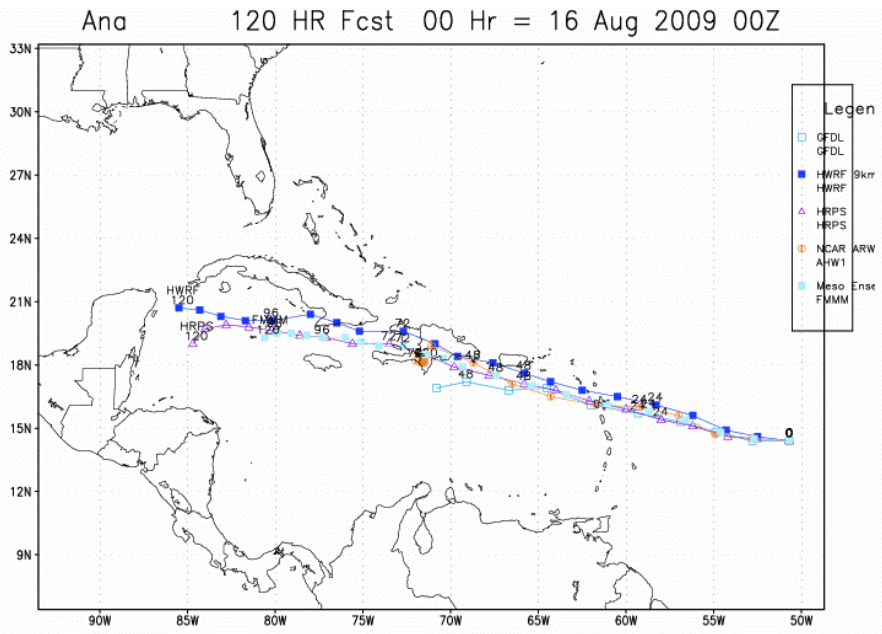


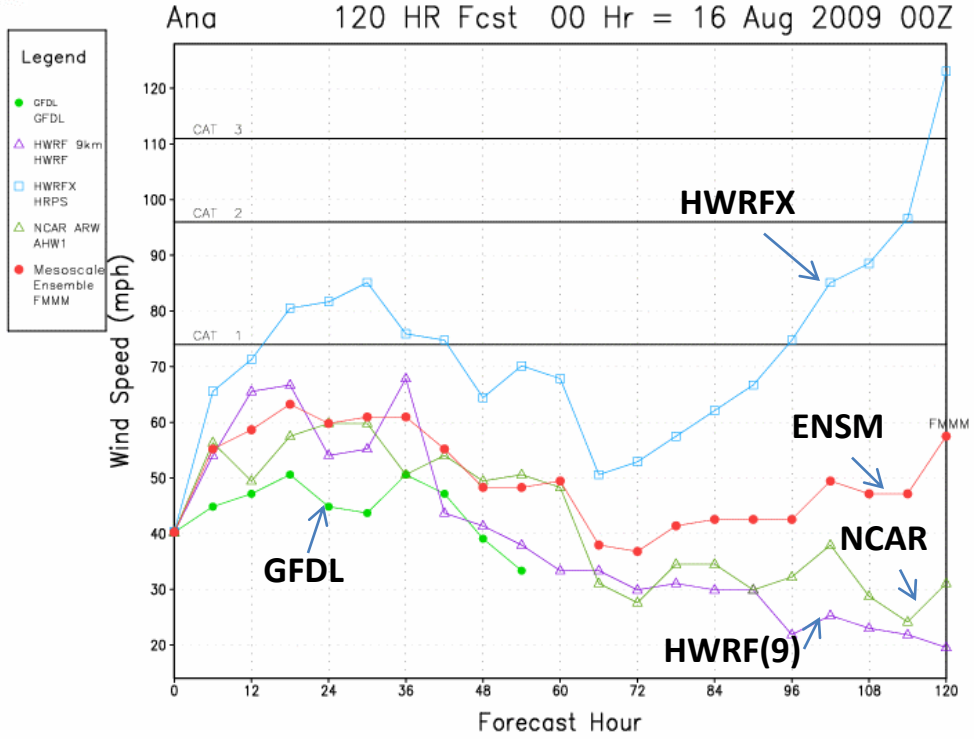
Combined forecasts were superior for most forecast hours

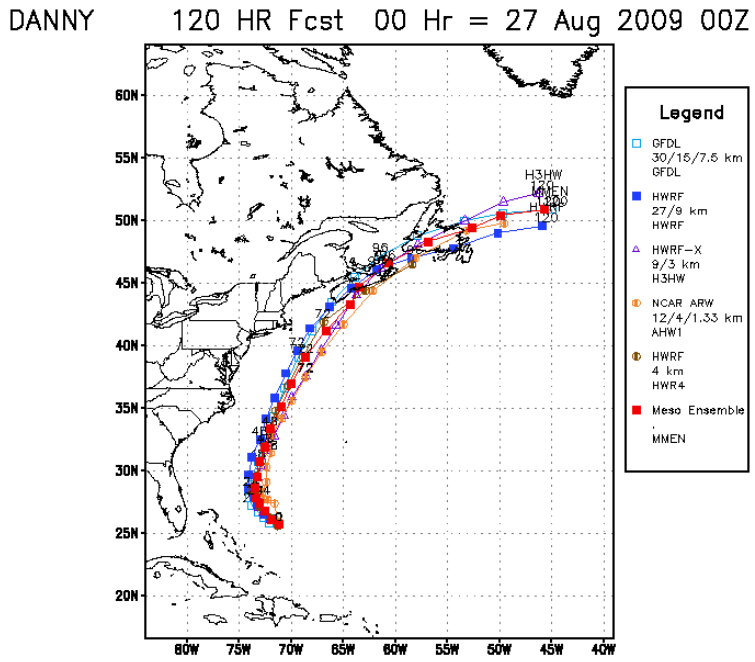
Performance of the member models during the 2009 demo season

- Ana
- Danny
- Erika
- Fred
- Grace
- Henri
- Overall performance

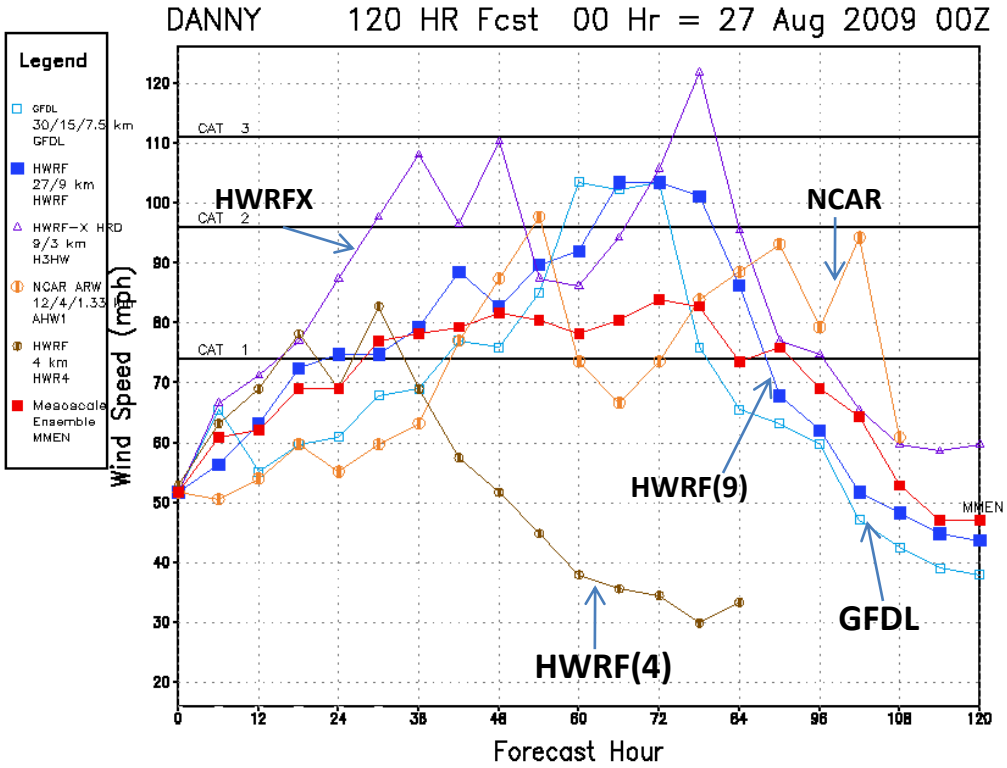
ANA of 2009


Ana
120 HR Fcst 00 Hr = 16 Aug 2009 00Z
Legen
GFDL GFDL
HWRF 9km HWRF
HRPS HRPS
NCAR ARW AHW1
Meso Ense FMMM
33N
30N
27N
24N
21N
18N
15N
12N
9N
90W
85W
80W
75W
70W
65W
60W
55W
50W


Ana
120 HR Fcst 00 Hr = 16 Aug 2009 00Z
Legend
GFDL GFDL
HWRF 9km HWRF
HWRFX HRPS
NCAR ARW AHW1
Mesoscale Ensemble FMMM
Wind Speed (mph)
Forecast Hour
CAT 3
CAT 2
CAT 1
HWRFX
ENSM
NCAR
GFDL
HWRF(9)
FMMM


DANNY 120 HR Fcst 00 Hr = 27 Aug 2009 00Z
DISCLAIMER: "These products are experimental in nature and should be for research purposes only. For decisions regarding personal safety, please refer to official National Weather Service (NWS) products, which are available on the National Hurricane Center web site (http://hurricanes.gov) and the website of your local NWS Weather Forecast Office."
Legend
GFDL 30/15/7.5 km GFDL
HWRF 27/9 km HWRF
HWRF-X 9/3 km H3HW
NCAR ARW 12/4/1.33 km AHW1
HWRF 4 km HWR4
Meso Ensemble MMEN
H3HW
MMEN
60N
55N
50N
45N
40N
35N
30N
25N
20N
80W
75W
70W
65W
60W
55W
50W
45W
40W

DANNY 2009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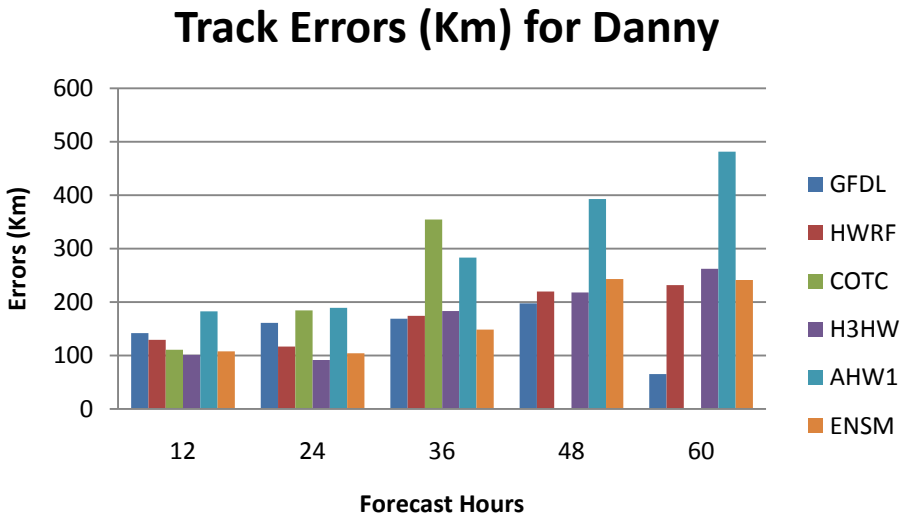
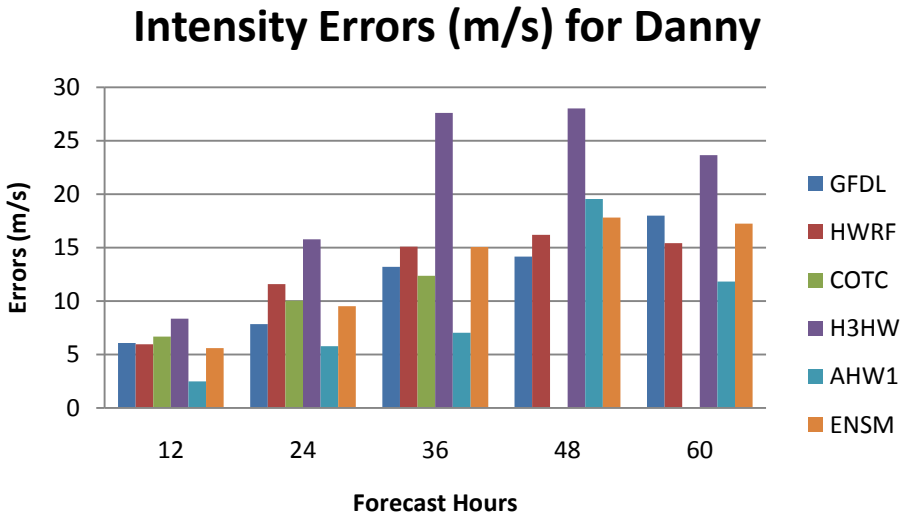
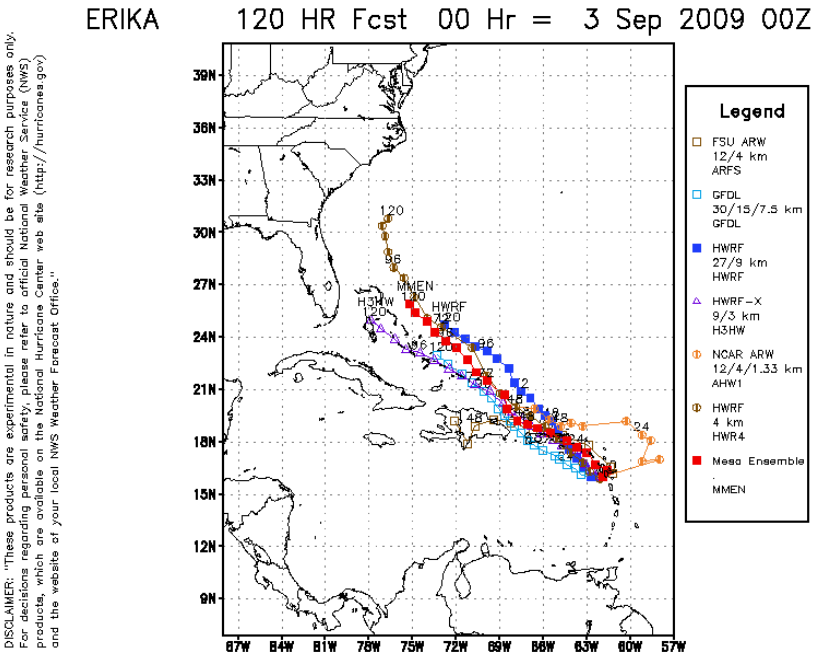
Mesoscale Ensemble MMEN
CAT 3
CAT 2
CAT 1
HWRFX
NCAR
HWRF(9)
GFDL
HWRF(4)
MMEN
Wind Speed (mph)
Forecast Hour
120
110
100
90
80
70
60
50
40
30
20
0
12
24
36
48
60
72
84
96
108
120

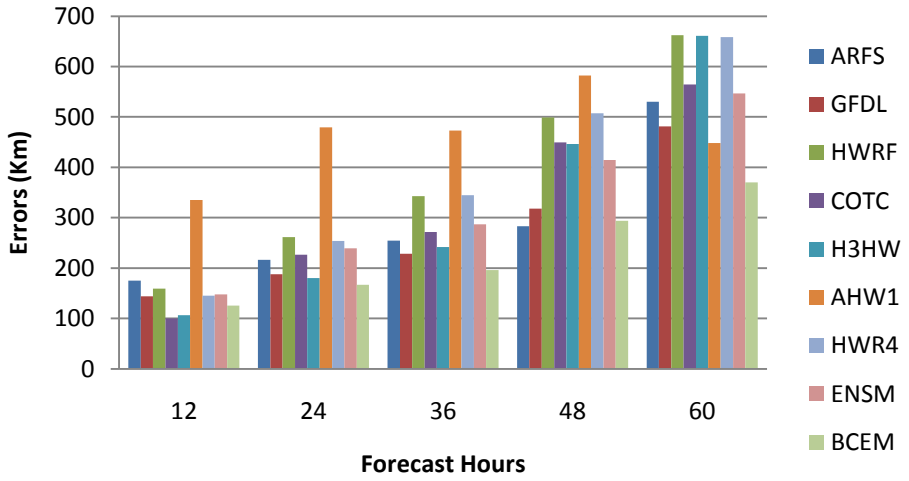
Absolute error Calculations for Danny 2009



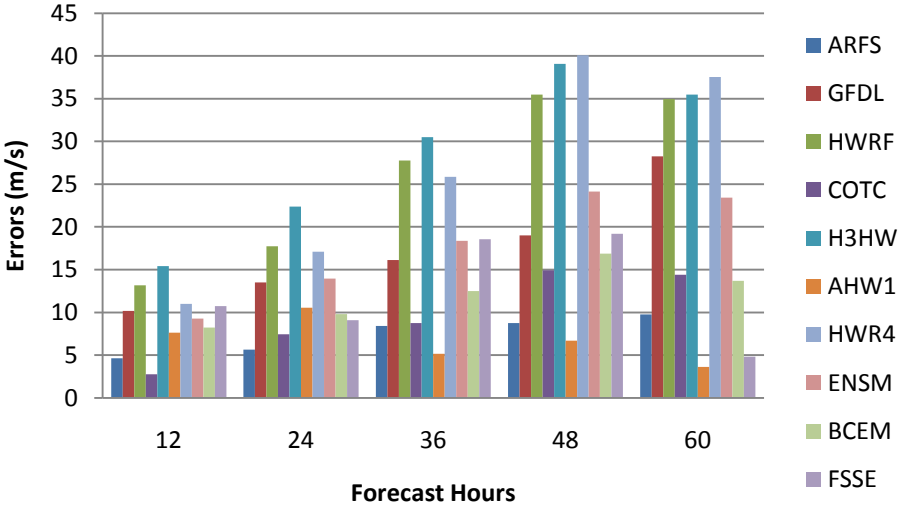


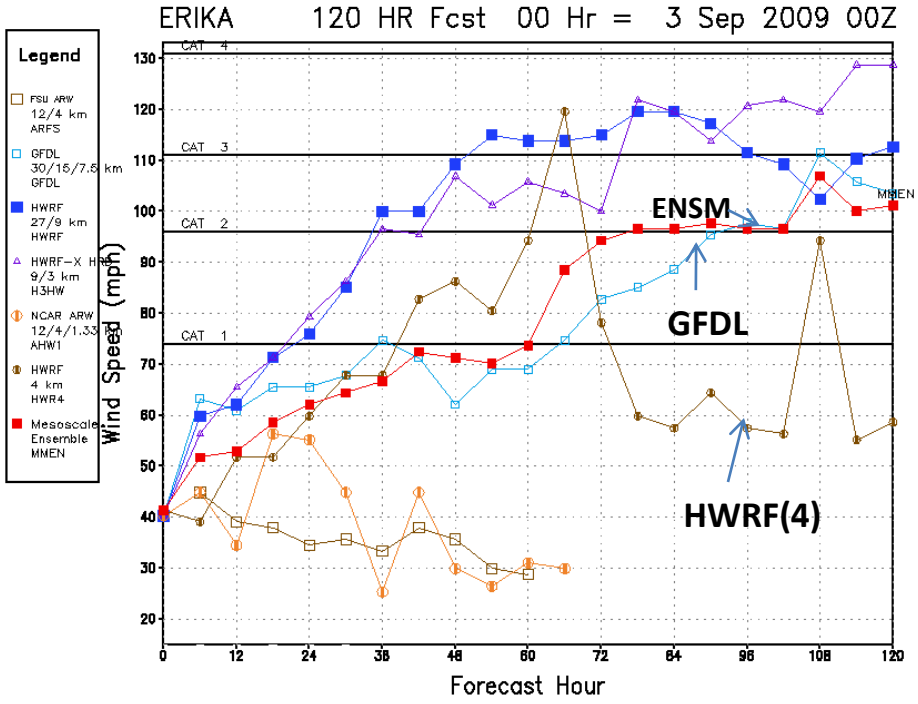


Track Errors (Km): Erika

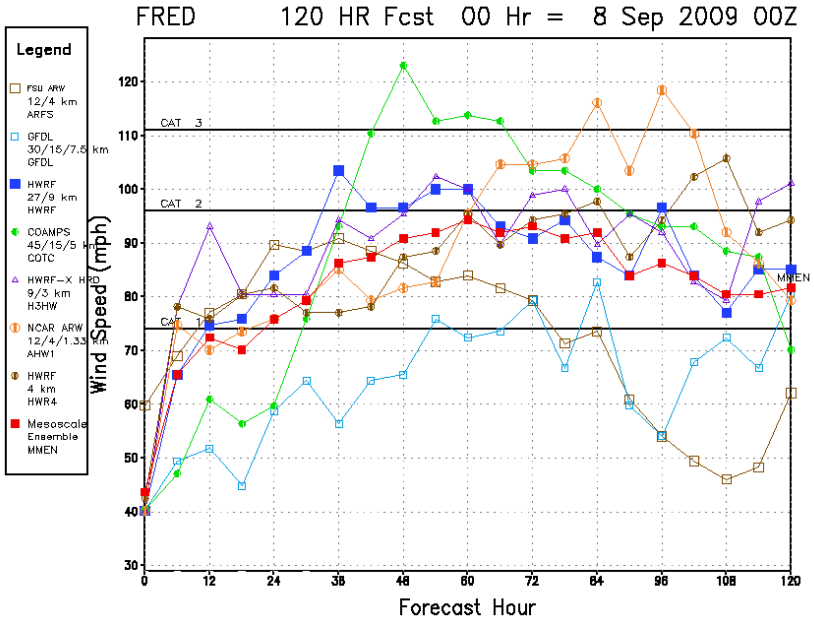


Intensity Errors (m/s): Erika





FRED 2009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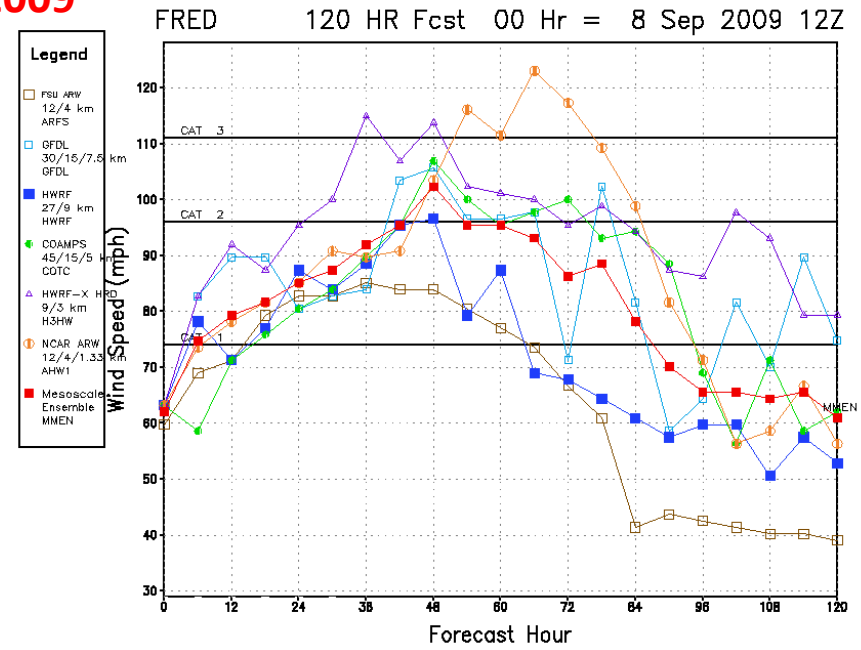
Legend
FSU ARW 12/4 km ARFS
GFDL 30/15/7.5 km GFDL
HWRF 27/9 km HWRF
COAMPS 45/15/5 km COTC
HWRF-X HRD 9/3 km H3HW
NCAR ARW 12/4/1.33 km AHW1
HWRF 4 km HWR4
Mesoscale Ensemble MMEN
CAT 3
CAT 2
CAT 1
MMEN
Wind Speed (mph)
Forecast Hour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Mesoscale Ensemble MMEN
CAT 3
CAT 2
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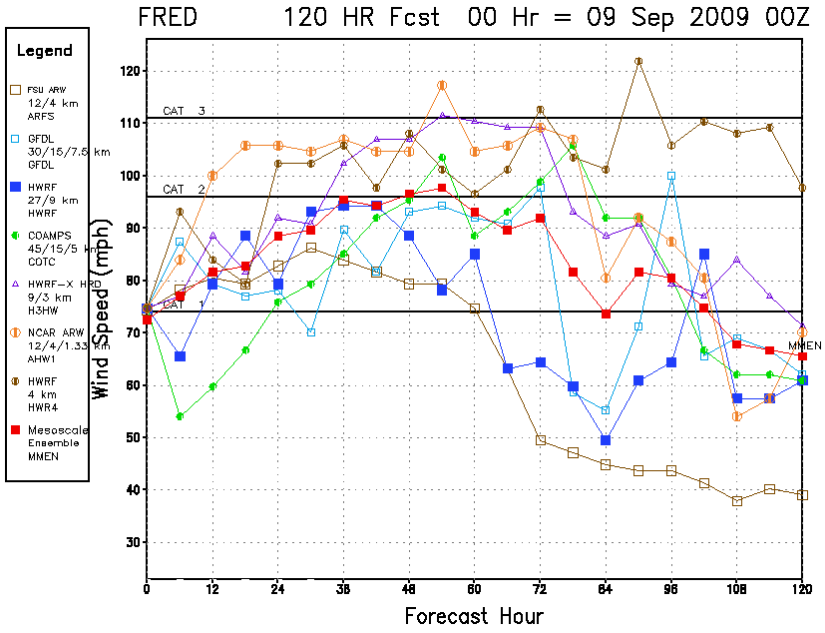
Wind Speed (mph)
Forecast Hour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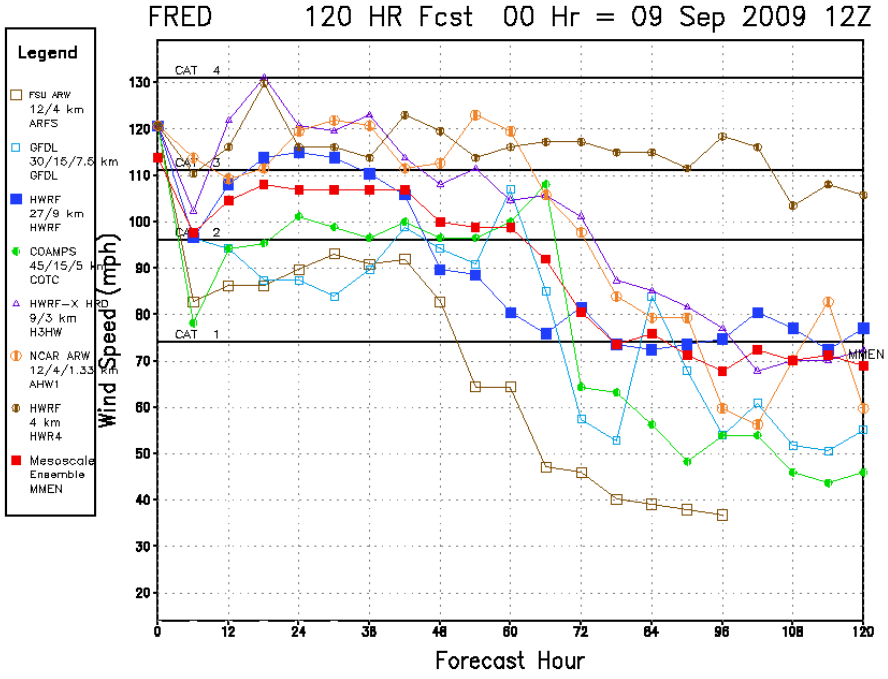
Mesoscale Ensemble MMEN
CAT 3
CAT 2
CAT 1
MMEN
Wind Speed (mph)
Forecast Hour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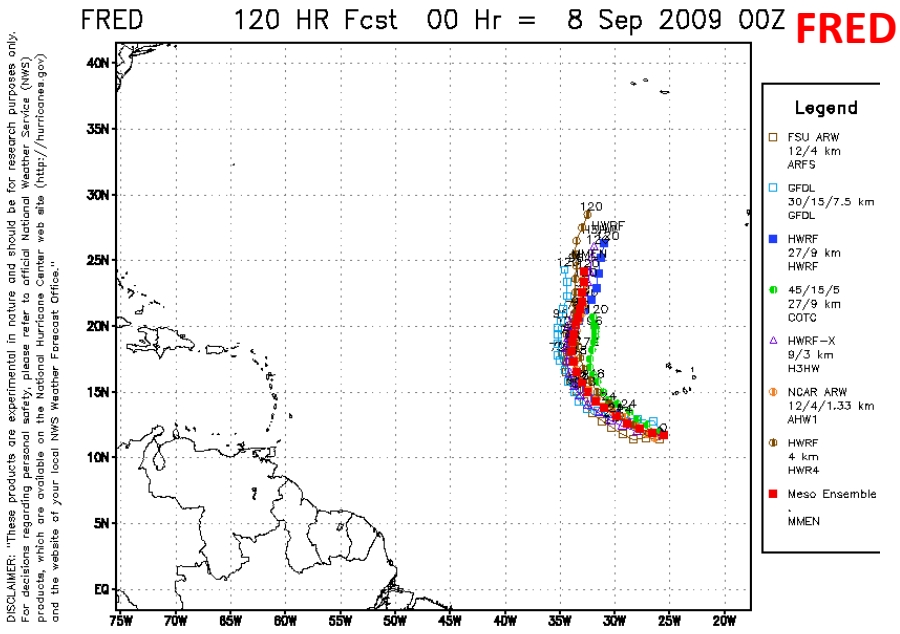
HWRF 4 km HWR4
Mesoscale Ensemble MMEN
CAT 4
CAT 3
CAT 2
CAT 1
MMEN
Wind Speed (mph)
Forecast Hour

FRED 2009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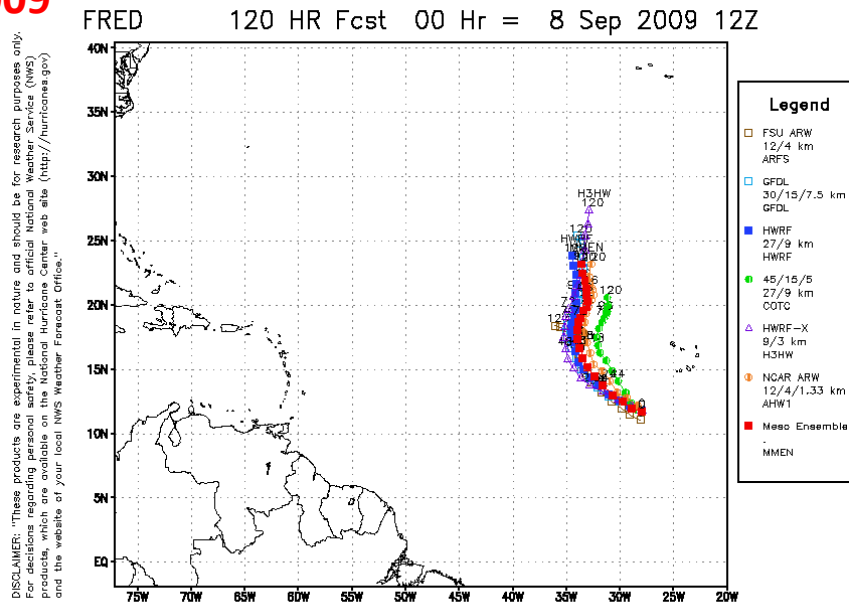
Meso Ensemble . MMEN
DISCLAIMER: "These products are experimental in nature and should be for research purposes only. For decisions regarding personal safety, please refer to official National Weather Service (NWS) products, which are available on the National Hurricane Center web site (http://hurricanes.gov) and the website of your local NWS Weather Forecast Office."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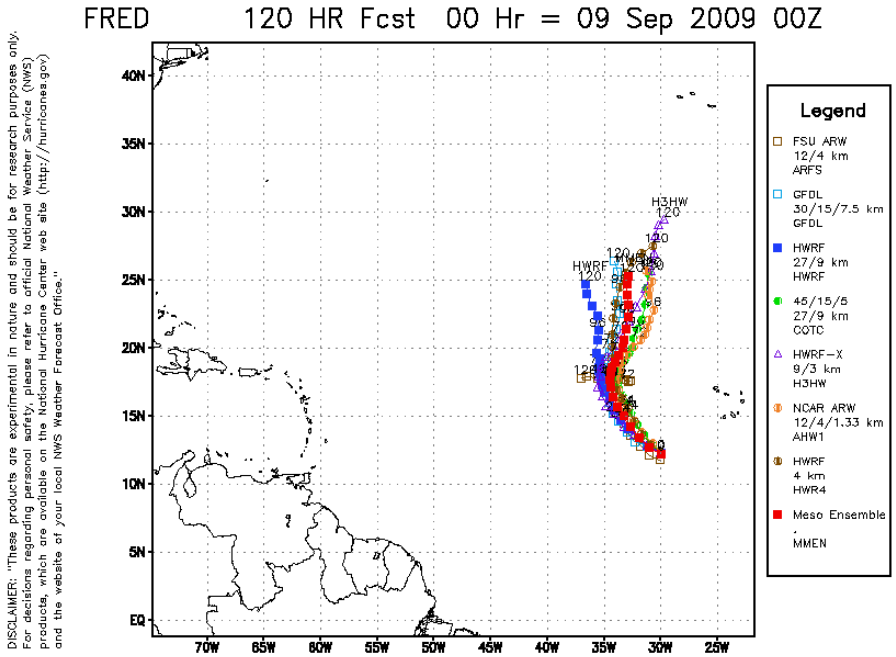
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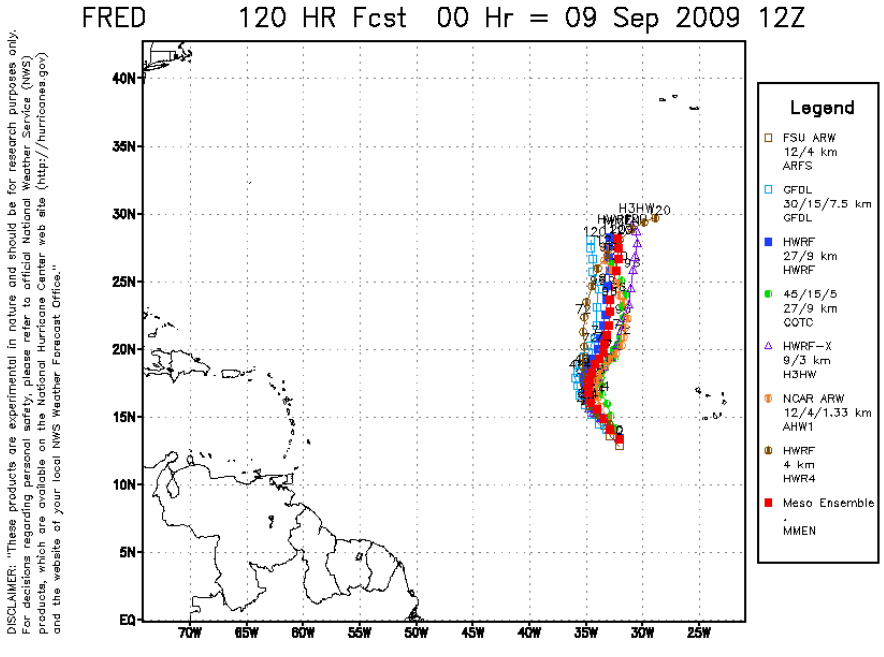
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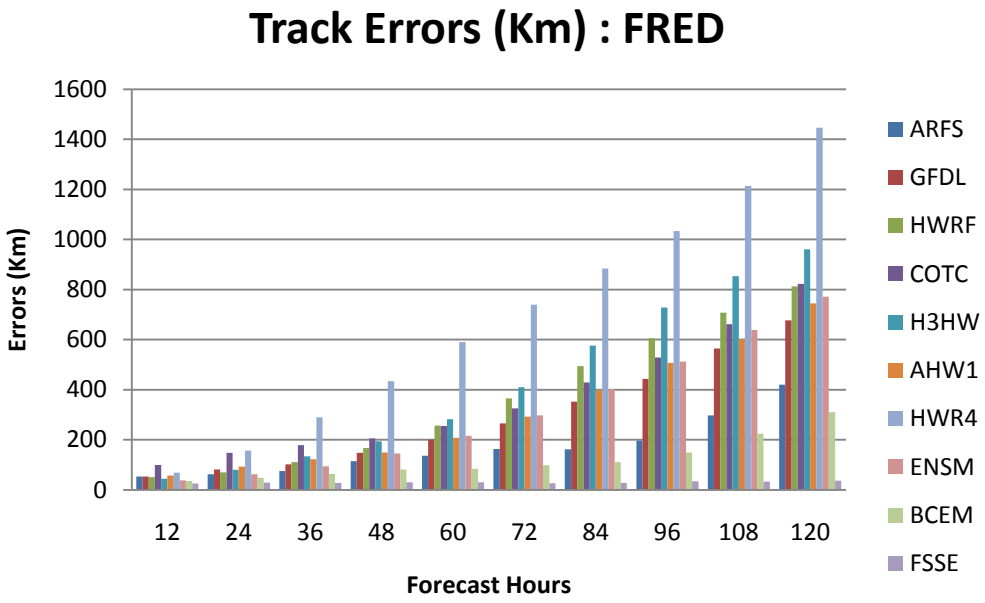
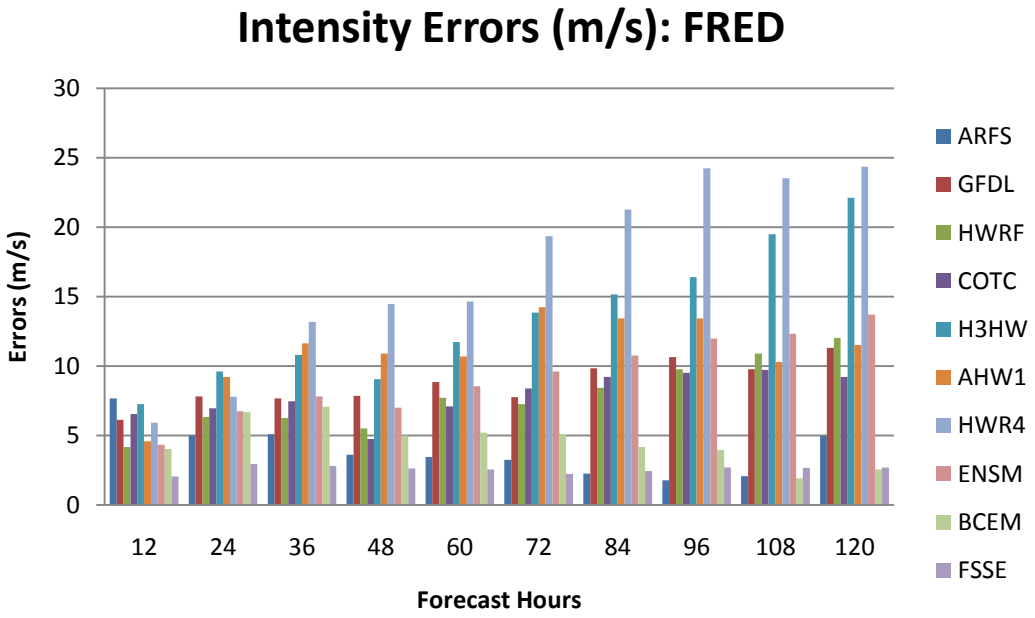
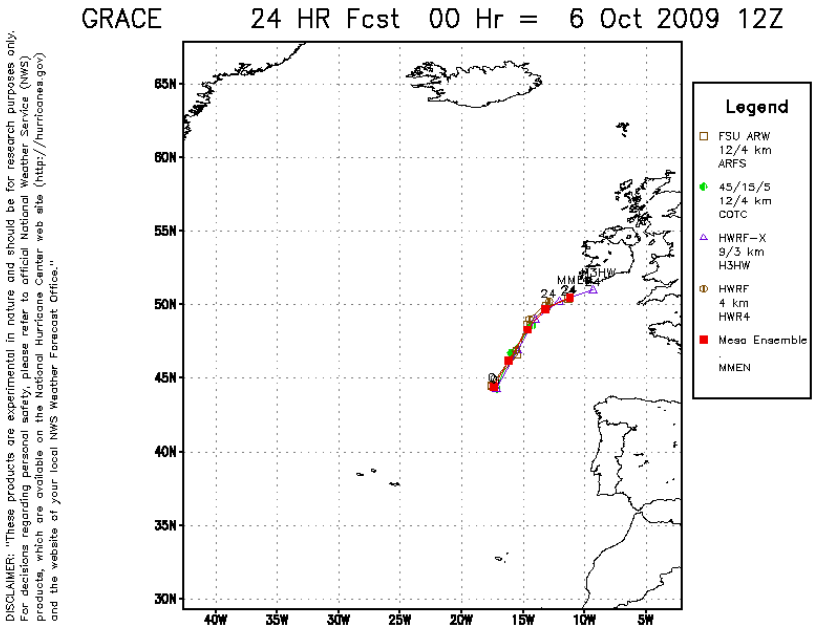
Error calculations for Fred



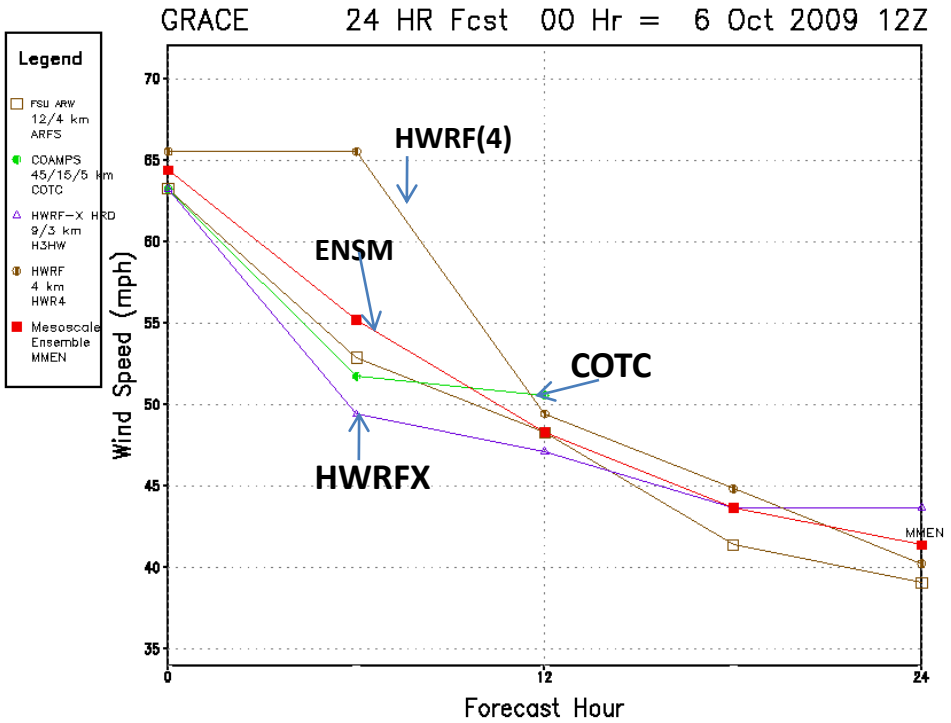
Note the error of the FSU Superensemble

Fred was a long lived storm compared to others during the 2009 season, hence, ample number of cases were available

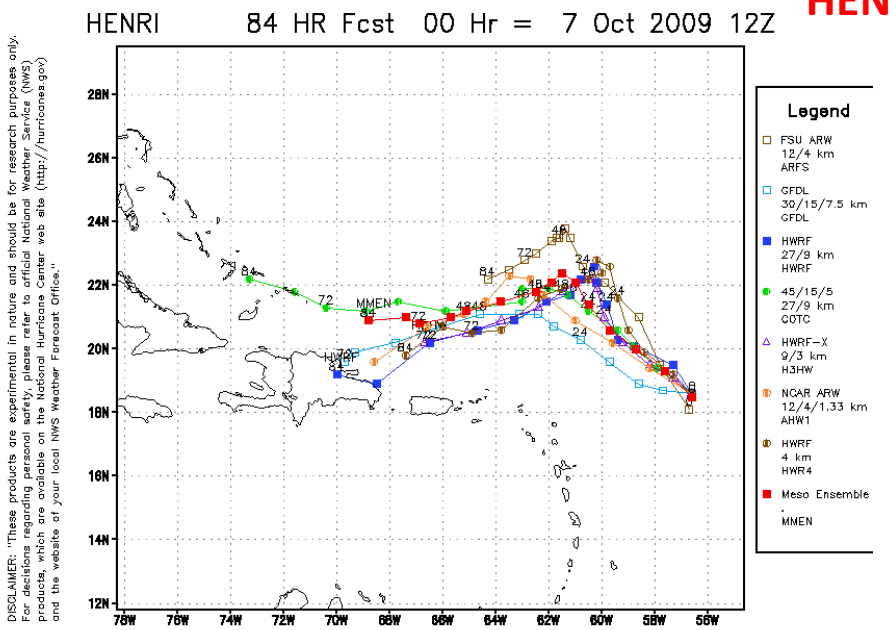


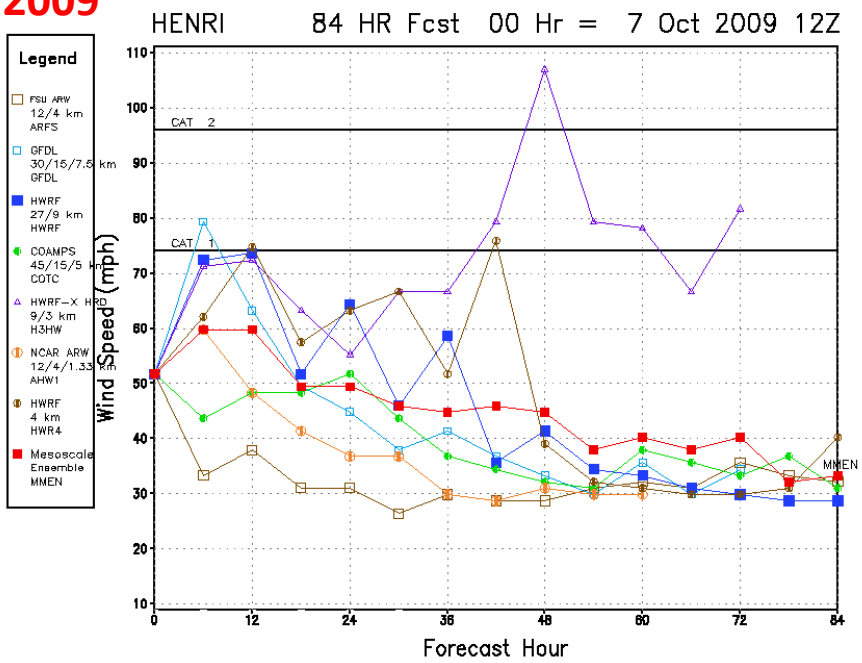

GRACE 24 HR Fcst 00 Hr = 6 Oct 2009 12Z
DISCLAIMER: "These products are experimental in nature and should be for research purposes only. For decisions regarding personal safety, please refer to official National Weather Service (NWS) products, which are available on the National Hurricane Center web site (http://hurricanes.gov) and the website of your local NWS Weather Forecast Office."
Legend
FSU ARW 12/4 km ARFS
45/15/5 12/4 km COTC
HWRF-X 9/3 km H3HW
HWRF 4 km HWR4
Meso Ensemble MMEN
65N
60N
55N
50N
45N
40N
35N
30N
40W
35W
30W
25W
20W
15W
10W
5W

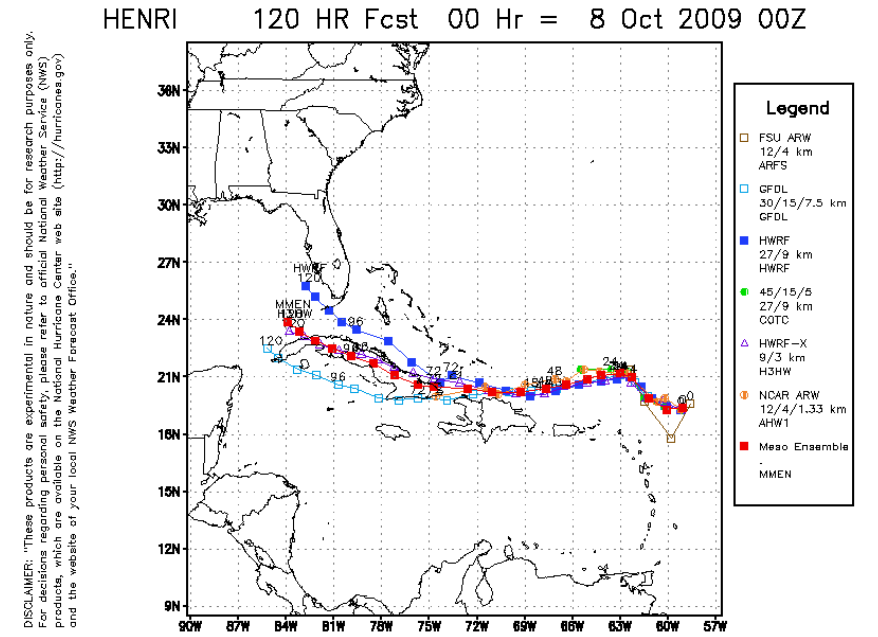
GRACE 2009

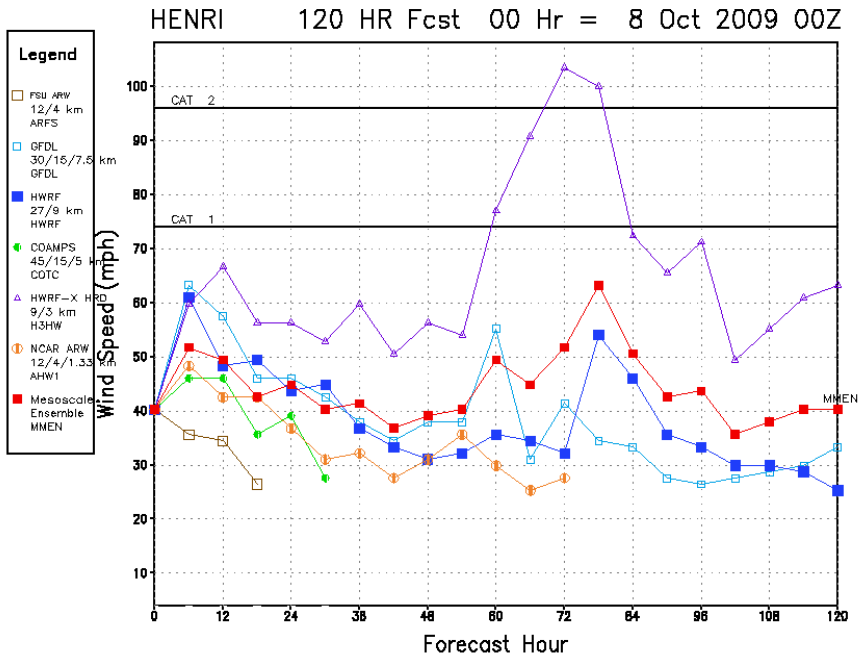

GRACE 24 HR Fcst 00 Hr = 6 Oct 2009 12Z
Legend
FSU ARW 12/4 km ARFS
COAMPS 45/15/5 km COTC
HWRF-X HRD 9/3 km H3HW
HWRF 4 km HWR4
Mesoscale Ensemble MMEN
HWRF(4)
ENSM
COTC
HWRFX
MMEN
Wind Speed (mph)
Forecast Hour
70
65
60
55
50
45
40
35
0
12
24

HENRI 2009

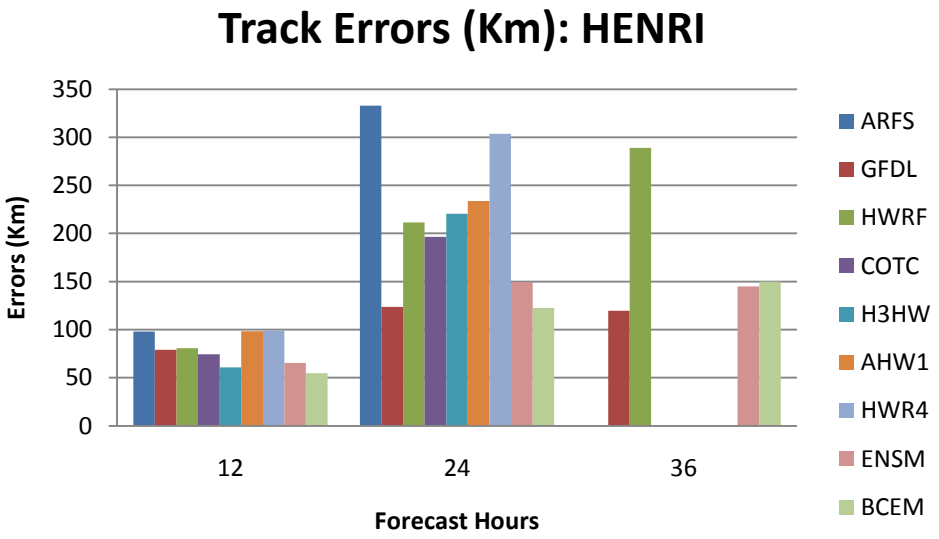

HENRI 84 HR Fcst 00 Hr = 7 Oct 2009 12Z
DISCLAIMER: "These products are experimental in nature and should be for research purposes only. For decisions regarding personal safety, please refer to official National Weather Service (NWS) products, which are available on the National Hurricane Center web site (http://hurricanes.gov) and the website of your local NWS Weather Forecast Office."
Legend
FSU ARW 12/4 km ARFS
GFDL 30/15/7.5 km GFDL
HWRF 27/9 km HWRF
45/15/5 27/9 km COTC
HWRF-X 9/3 km H3HW
NCAR ARW 12/4/1.33 km AHW1
HWRF 4 km HWR4
Meso Ensemble MMEN
MMEN


HENRI 84 HR Fcst 00 Hr = 7 Oct 2009 12Z
Legend
FSU ARW 12/4 km ARFS
GFDL 30/15/7.5 km GFDL
HWRF 27/9 km HWRF
COAMPS 45/15/5 km COTC
HWRF-X HRD 9/3 km H3HW
NCAR ARW 12/4/1.33 km AHW1
HWRF 4 km HWR4
Mesoscale Ensemble MMEN
CAT 2
CAT 1
Wind Speed (mph)
Forecast Hour
MMEN

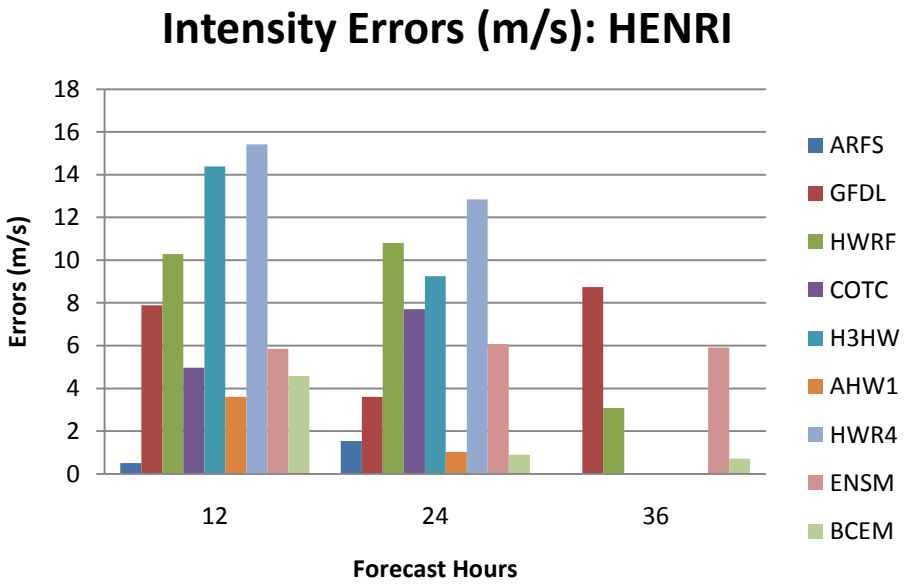

HENRI 120 HR Fcst 00 Hr = 8 Oct 2009 00Z
DISCLAIMER: "These products are experimental in nature and should be for research purposes only. For decisions regarding personal safety, please refer to official National Weather Service (NWS) products, which are available on the National Hurricane Center web site (http://hurricanes.gov) and the website of your local NWS Weather Forecast Office."
Legend
FSU ARW 12/4 km ARFS
GFDL 30/15/7.5 km GFDL
HWRF 27/9 km HWRF
45/15/5 27/9 km COTC
HWRF-X 9/3 km H3HW
NCAR ARW 12/4/1.33 km AHW1
Meso Ensemble MMEN

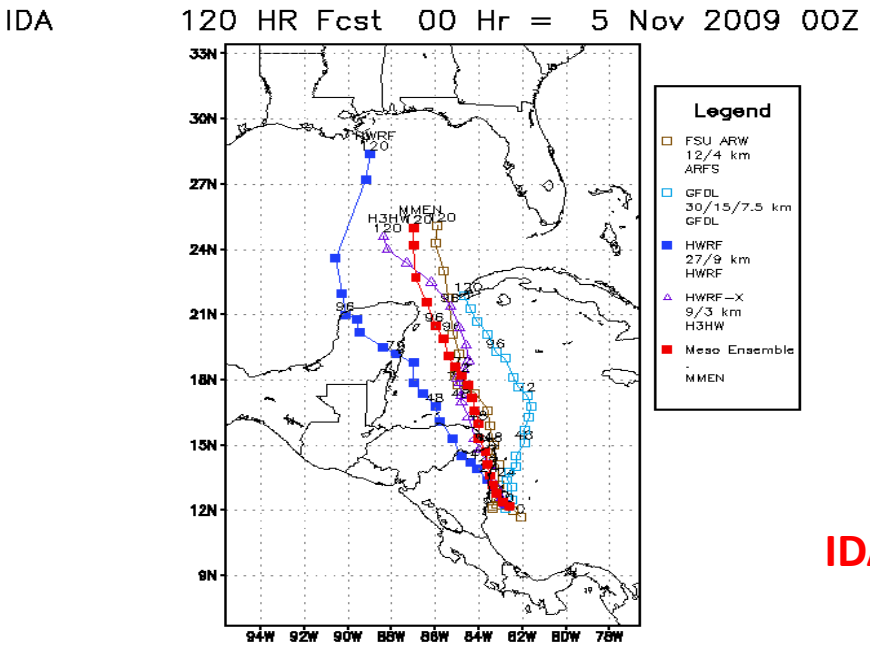

HENRI 120 HR Fcst 00 Hr = 8 Oct 2009 00Z
Legend
FSU ARW 12/4 km ARFS
GFDL 30/15/7.5 km GFDL
HWRF 27/9 km HWRF
COAMPS 45/15/5 km COTC
HWRF-X HRD 9/3 km H3HW
NCAR ARW 12/4/1.33 km AHW1
Mesoscale Ensemble MMEN
CAT 2
CAT 1
Wind Speed (mph)
Forecast Hour
MMEN

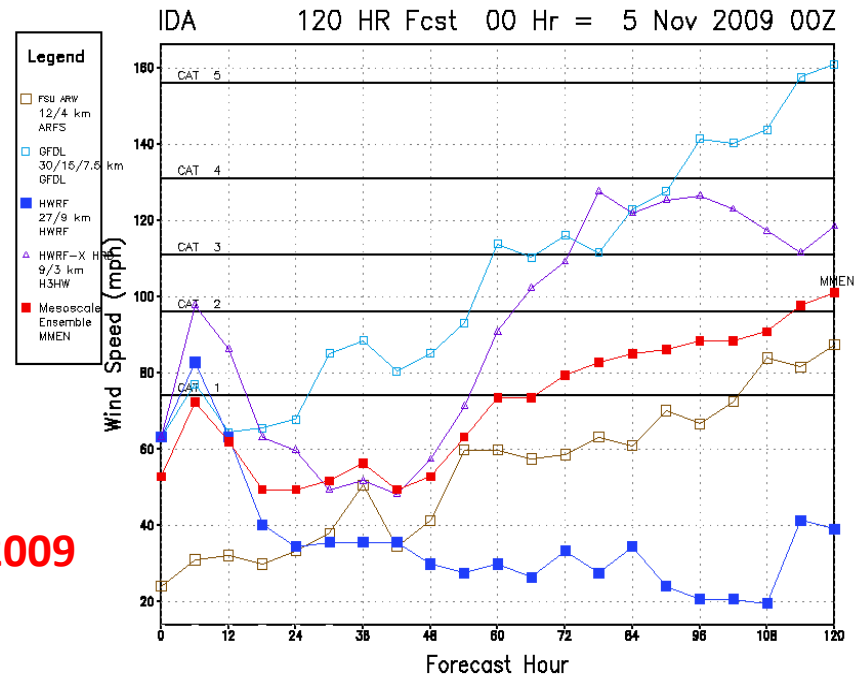
Error calculations for Henri



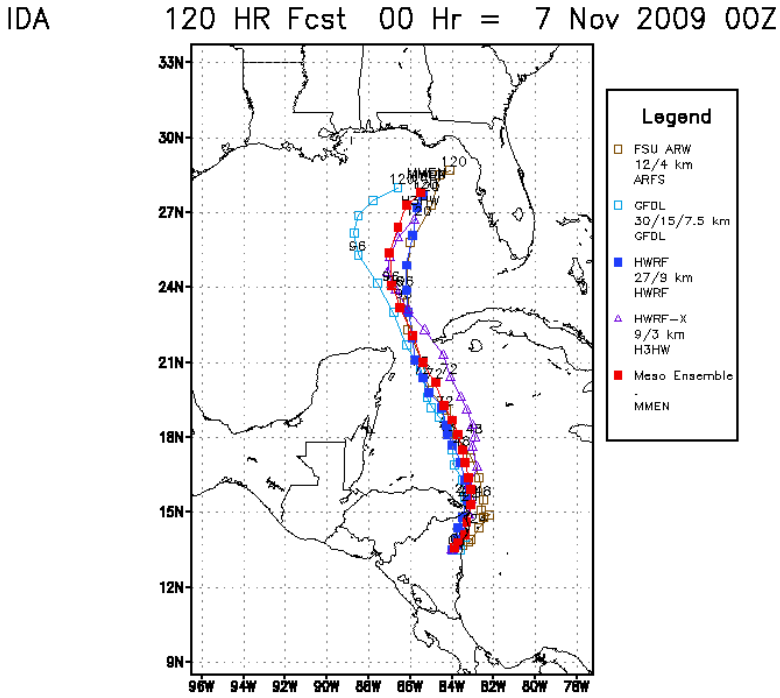
BCEM was superior than most of the member models

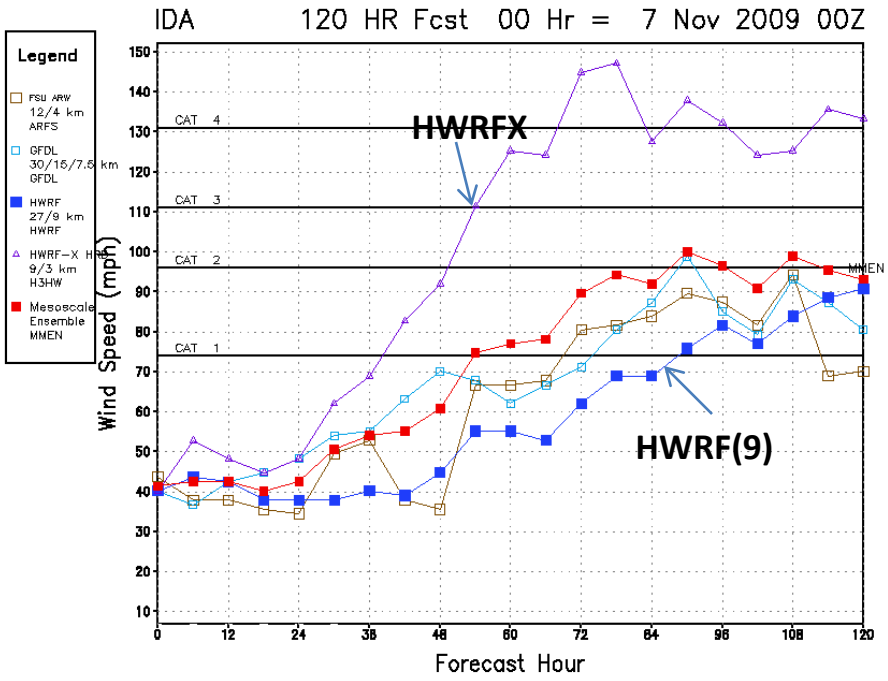



IDA
120 HR Fcst 00 Hr = 5 Nov 2009 00Z
Legend
FSU ARW 12/4 km ARFS
GFDL 30/15/7.5 km GFDL
HWRF 27/9 km HWRF
HWRF-X 9/3 km H3HW
Meso Ensemble . MMEN

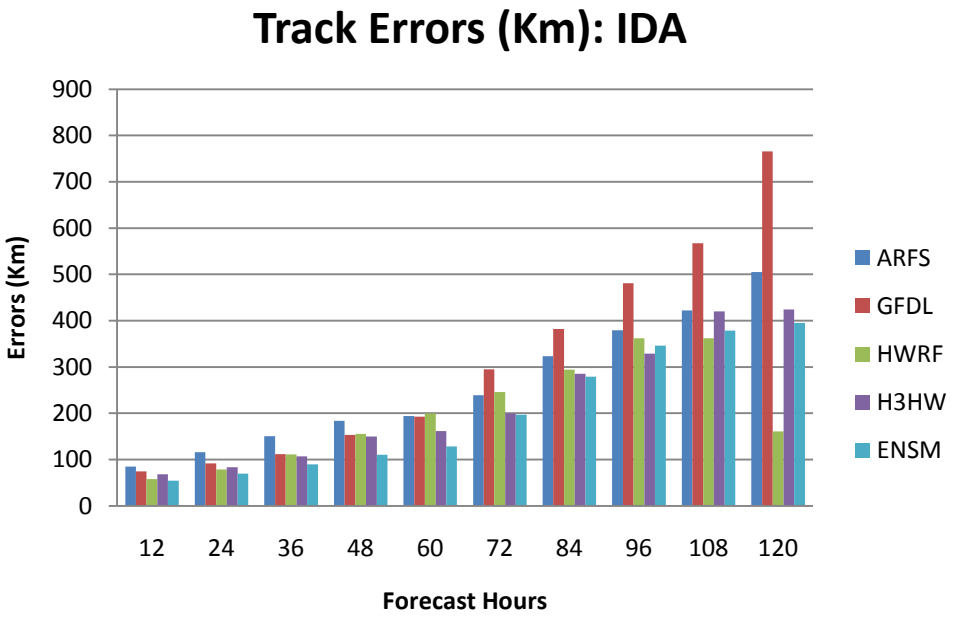

IDA
120 HR Fcst 00 Hr = 5 Nov 2009 00Z
Legend
FSU ARW 12/4 km ARFS
GFDL 30/15/7.5 km GFDL
HWRF 27/9 km HWRF
HWRF-X H3HW 9/3 km H3HW
Mesoscale Ensemble MMEN
CAT 5
CAT 4
CAT 3
CAT 2
CAT 1
MMEN
Wind Speed (mph)
Forecast Hour

IDA 2009

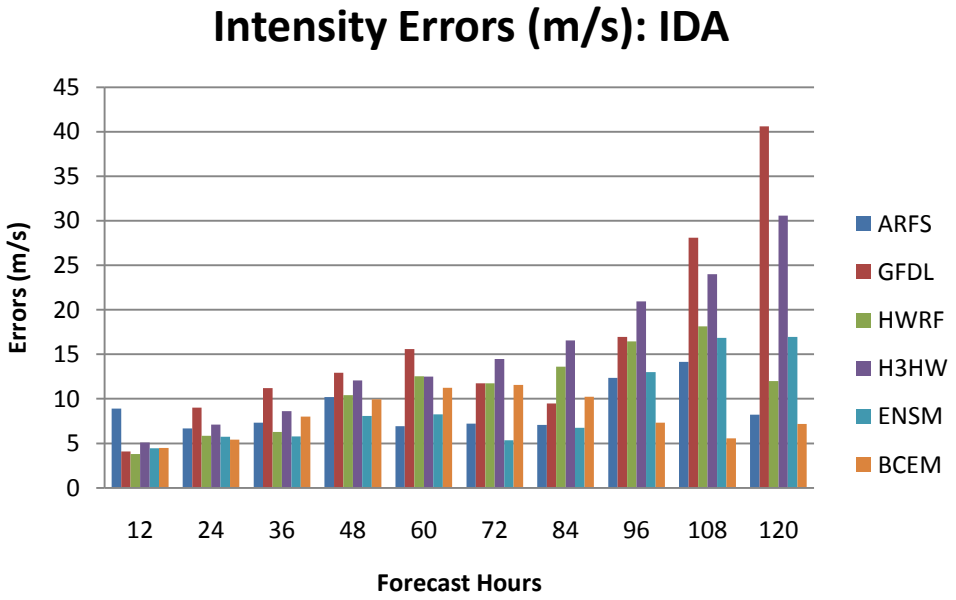

IDA
120 HR Fcst 00 Hr = 7 Nov 2009 00Z
Legend
FSU ARW 12/4 km ARFS
GFDL 30/15/7.5 km GFDL
HWRF 27/9 km HWRF
HWRF-X 9/3 km H3HW
Meso Ensemble . MMEN


IDA
120 HR Fcst 00 Hr = 7 Nov 2009 00Z
Legend
FSU ARW 12/4 km ARFS
GFDL 30/15/7.5 km GFDL
HWRF 27/9 km HWRF
HWRF-X H3HW 9/3 km H3HW
Mesoscale Ensemble MMEN
HWRFX
HWRF(9)
CAT 4
CAT 3
CAT 2
CAT 1
MMEN
Wind Speed (mph)
Forecast Hour

Error calculations for Ida



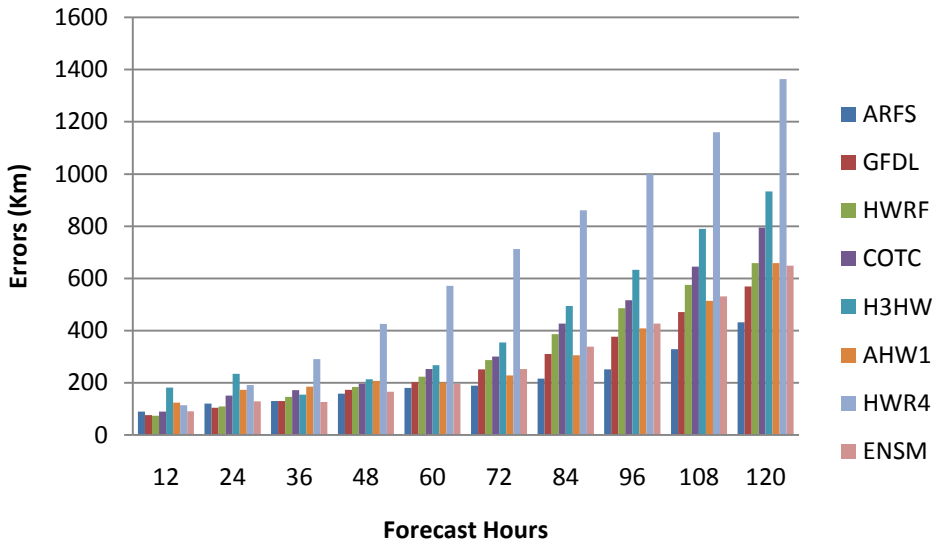
ENSM was better than member models except for 120 hours



For Intensity errors the ENSM errors were less compared to other models

Summary of the performances during the 2009 season

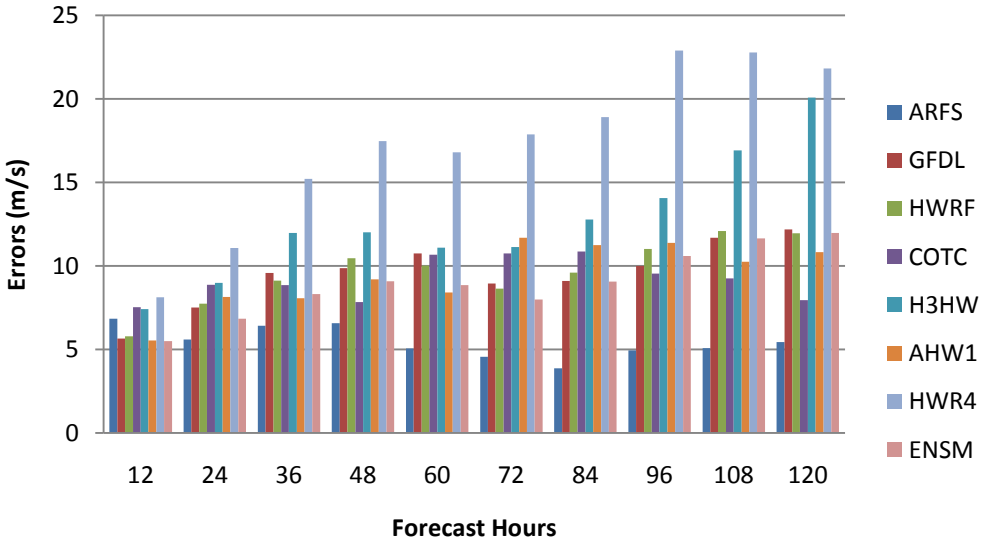
Track Errors (Km): 2009 Storm Season



Multimodel inter-comparison with Ensemble Mean

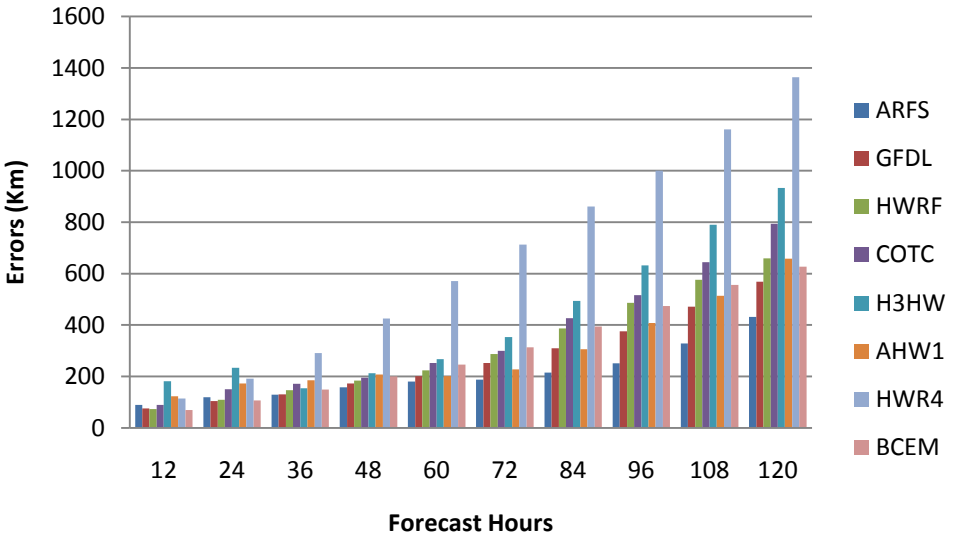
During 2009 season, ARFS track errors were minimum especially during 60-120 hour forecast. Intensity forecast errors were also considerately low during 24-120 hr forecasts. Track and Intensity errors in initial forecast hours may be due to model spin-up.

Intensity Errors (m/s): 2009 Storm Season



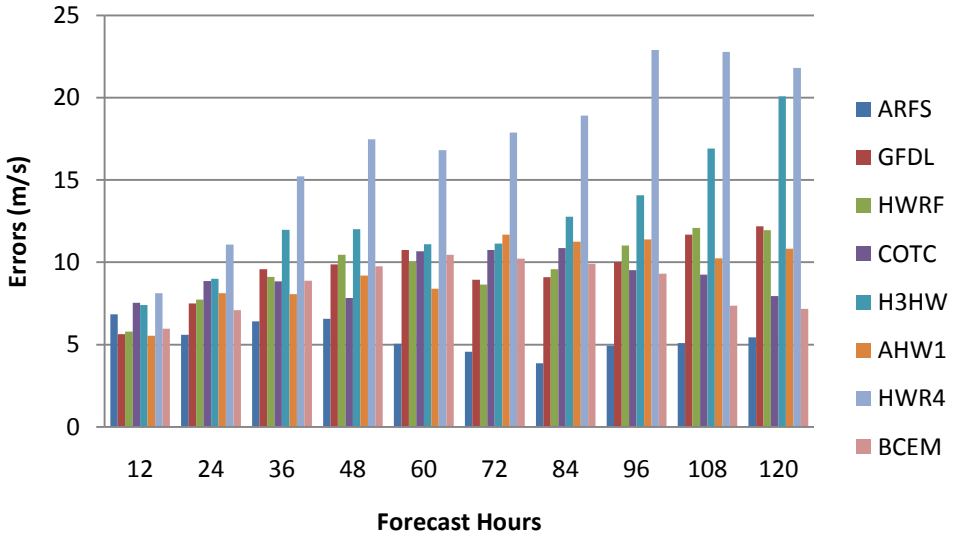
Summary of the performances during the 2009 season

Track Errors (Km): 2009 Season



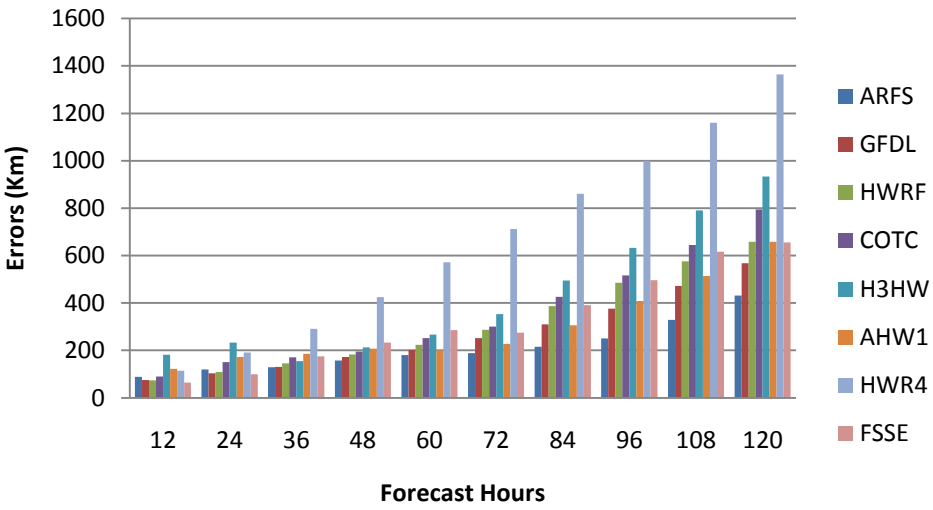
Multimodel inter-comparison with Bias corrected ensemble mean

Intensity Errors (m/s): 2009 Storm Season



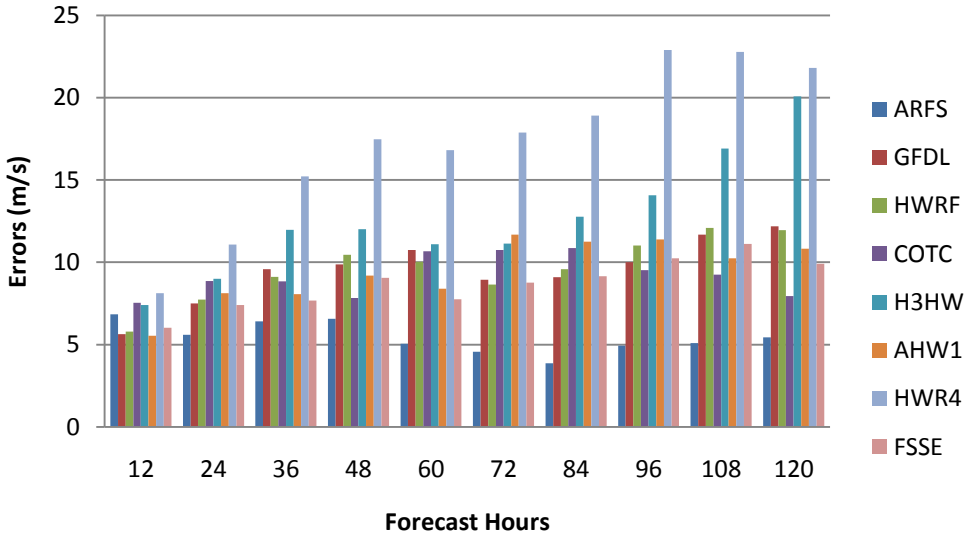
Summary of the performances during the 2009 season

Track Errors (Km): 2009 Season

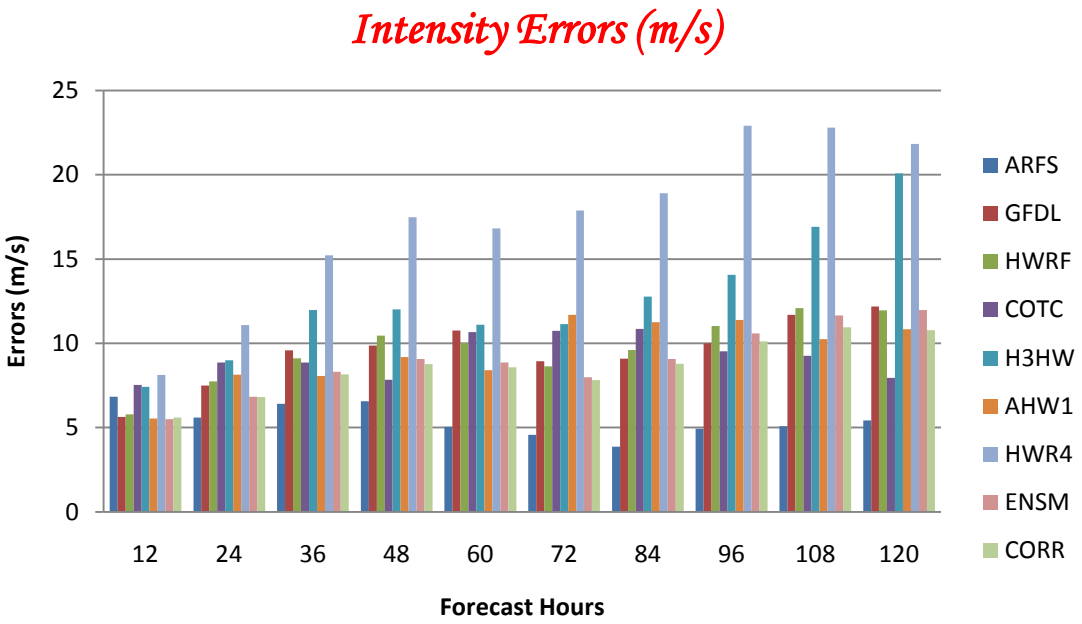


Multimodel inter-comparison with FSU Superensemble

Intensity Errors (m/s): 2009 Season



Intensity Errors (m/s) using the correlation based method

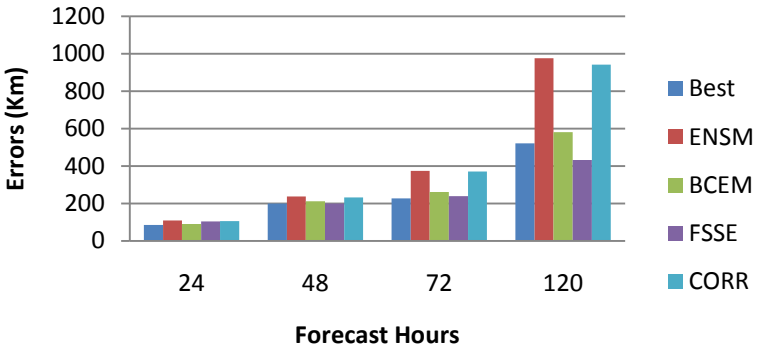


Due to the less number of homogeneous cases (28), a heterogeneous calculation was made using 58 cases and errors evaluated. Only the HWRF and the GFDL carried the largest number of cases and the ENSM and the CORR forecasts with those.

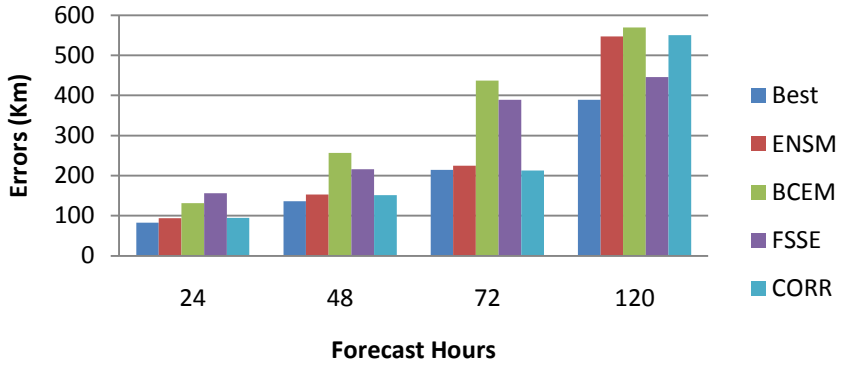
For all the lead times the correlation based method carried least errors compared to the ensemble mean the individual member models. The 2009 coefficients can be applied to the 2010 forecasts and as more cases become available the coefficients may become more stable.

Track Errors (Km)

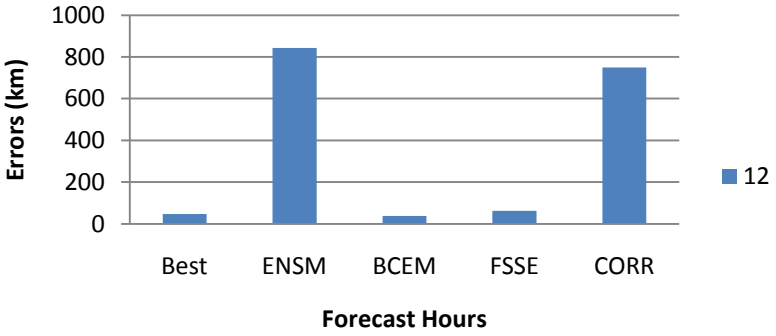
ANA



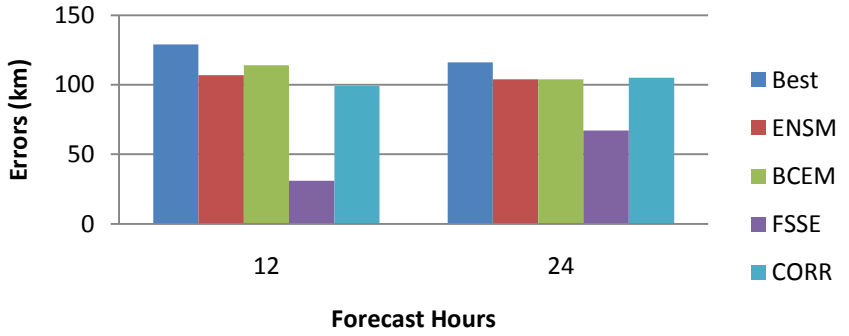
BILL



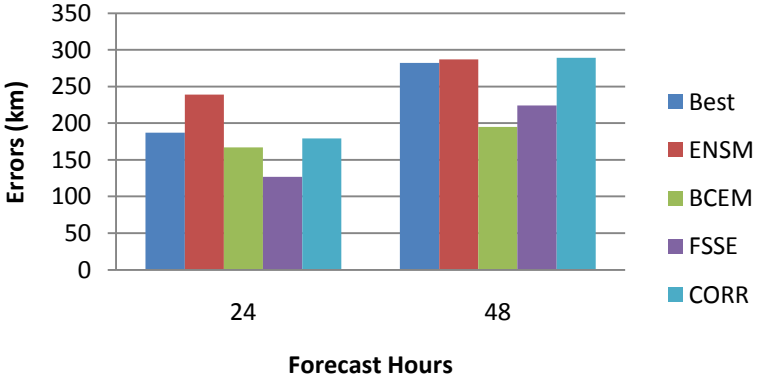
CLAUDETTE



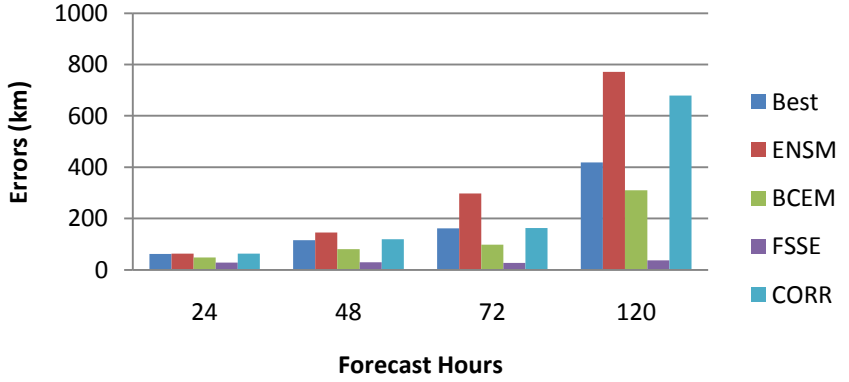
DANNY



ERIKA

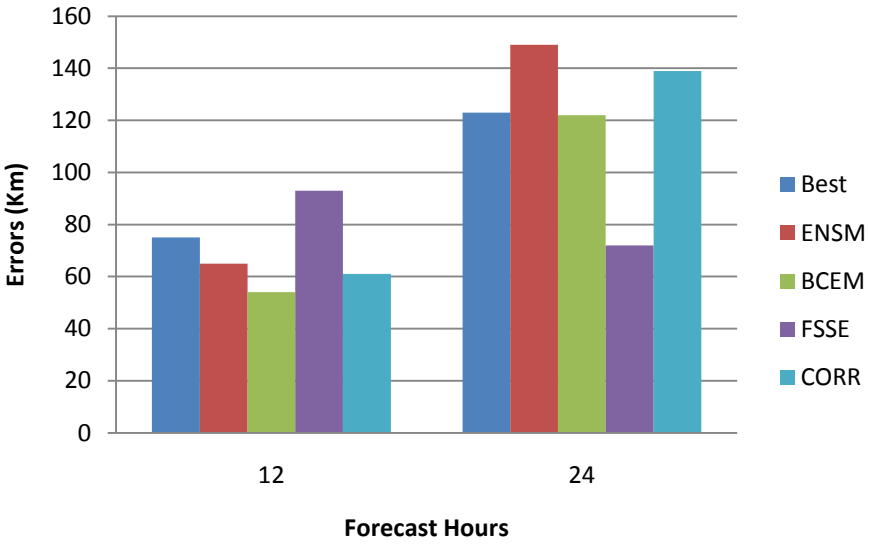


FRED

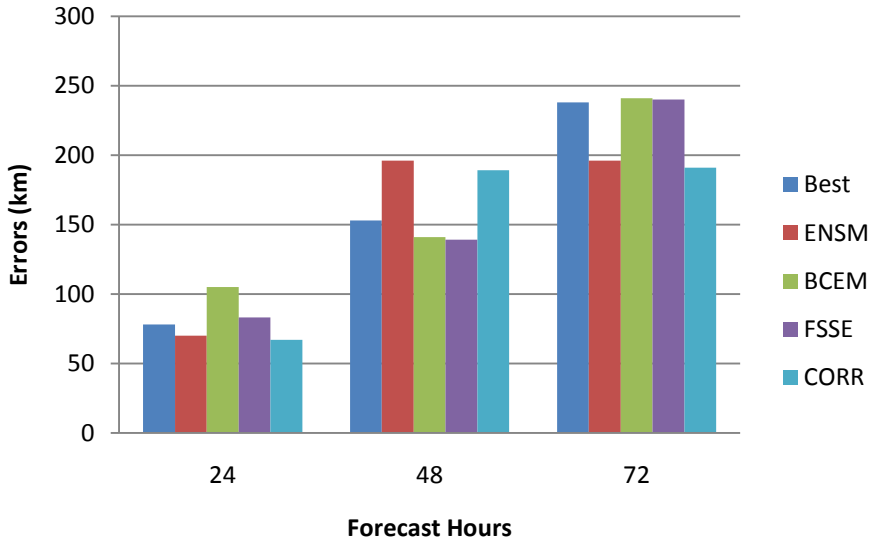


Track Errors (km)

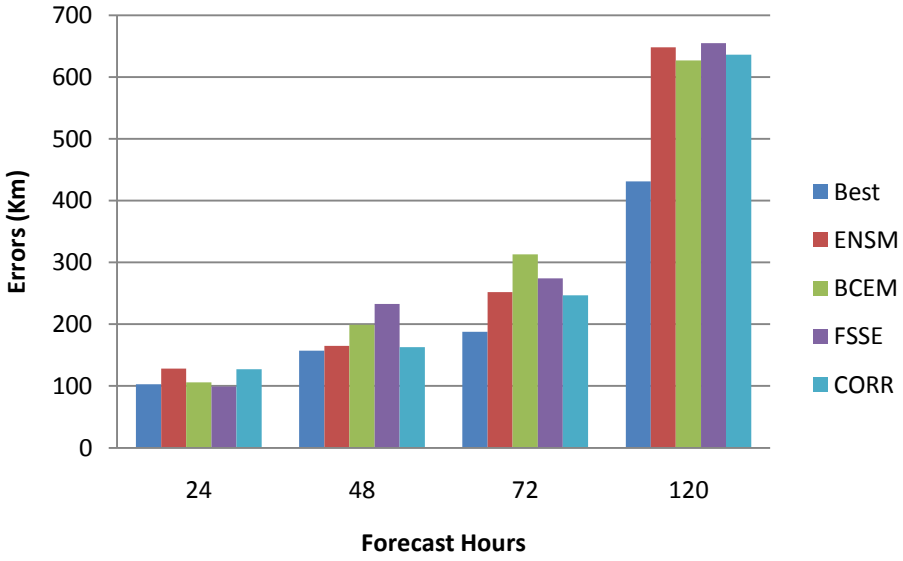
HENRI



IDA

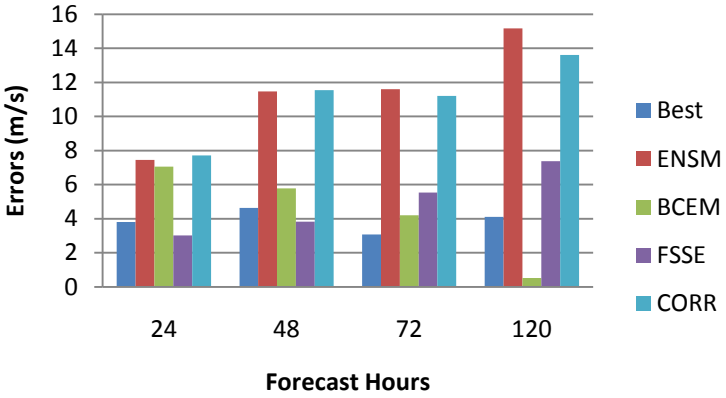


All Storm Combined for 2009 Season

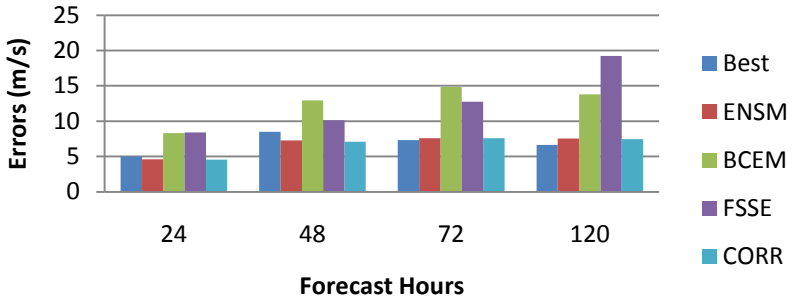


Intensity Errors (m/s)

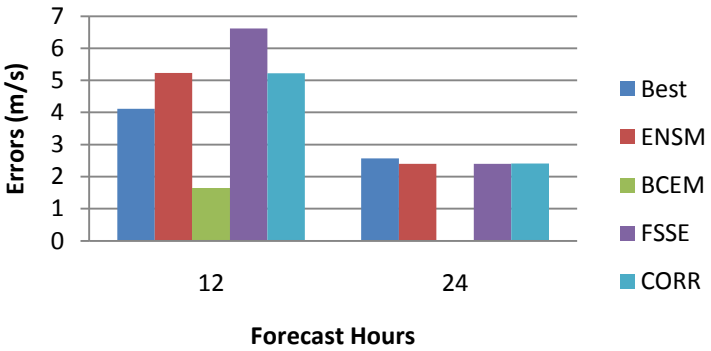
ANA



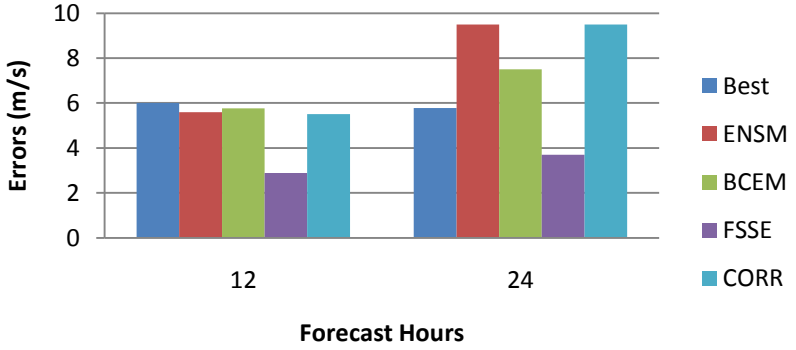
BILL



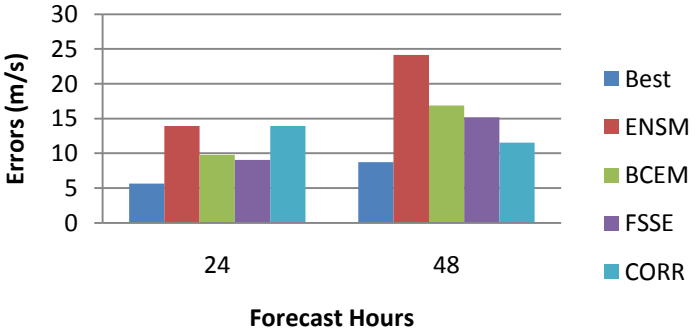
CLAUDETTE



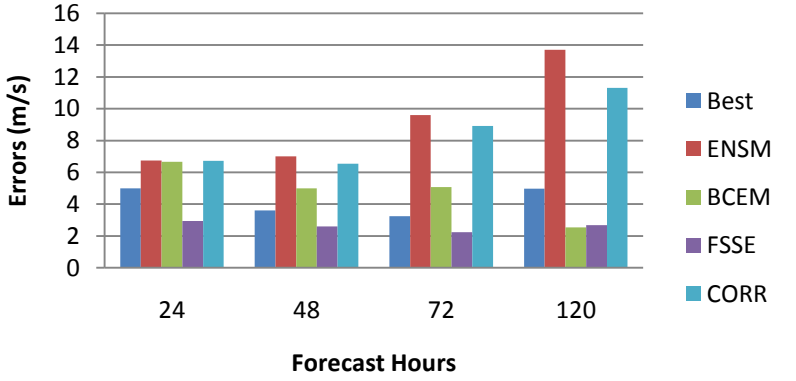
DANNY



ERIKA

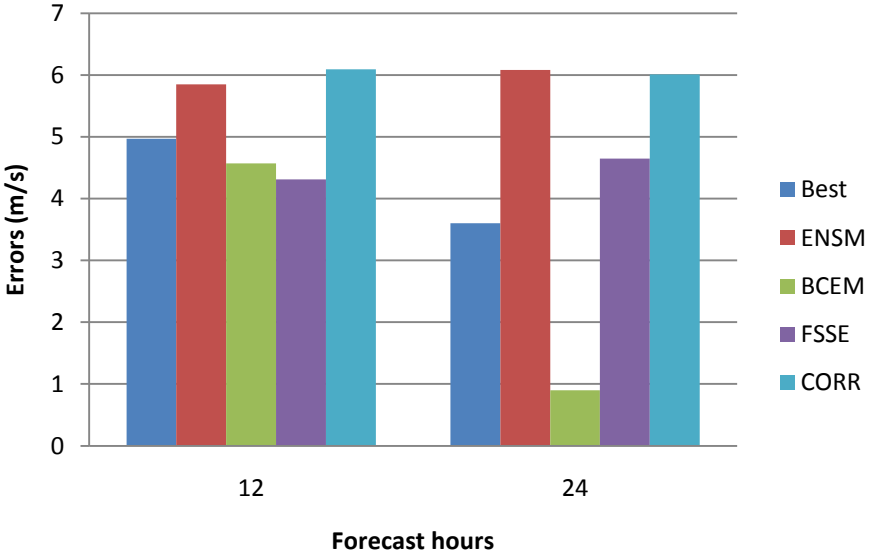


FRED



Intensity Errors (m/s)

HENRI



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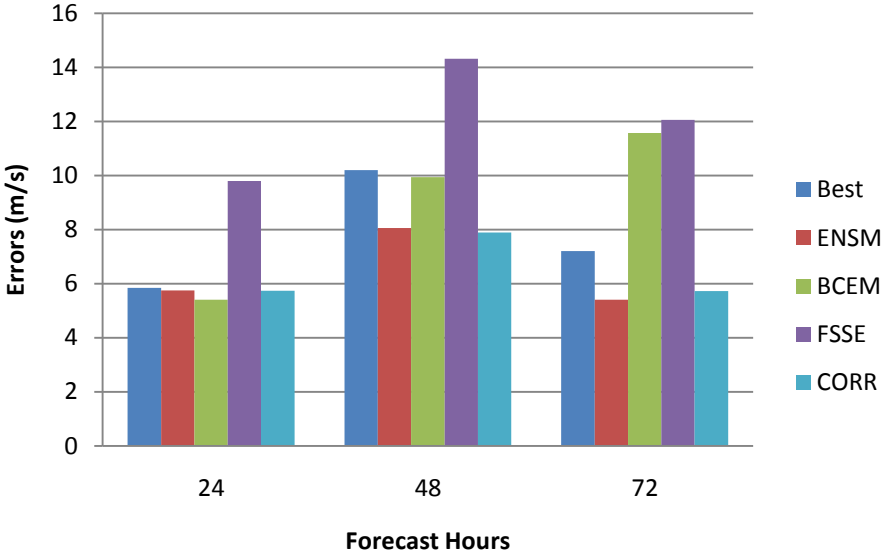
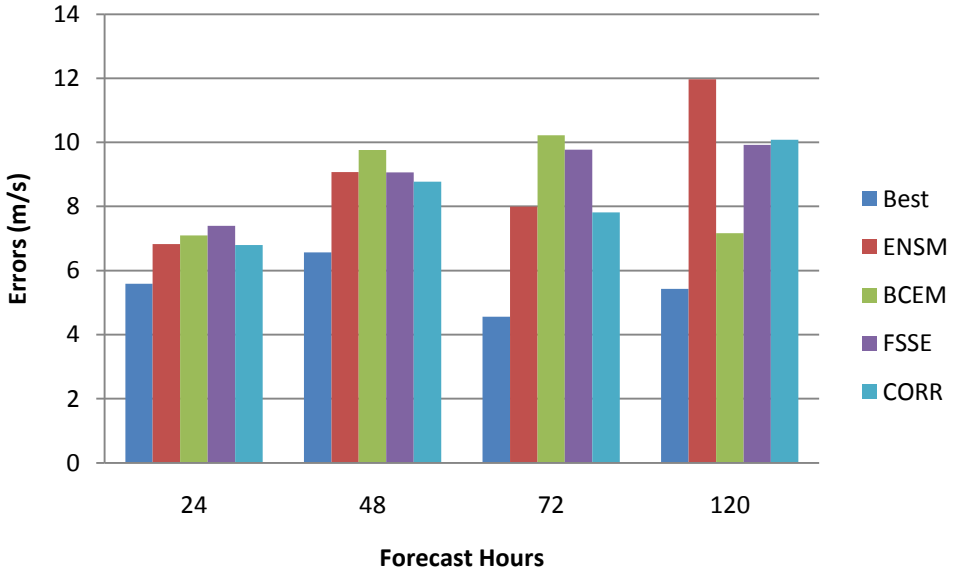


All Storms Combined 2009 Season



Summary and Future Work

❖ The above figures show the performance of the best model, the bias corrected ensemble mean, the FSU superensemble and the correlation based forecast errors for track and intensity for individual storms and the overall performance for different forecast hours.

❖ The three and five day position errors for the mesoscale ensembles for the 2009 season were of the order of 225 km and 600 km respectively. These are slightly in excess of the position errors for our large suite of models during the 2004, 2005 and 2006 seasons.

❖ The three and five day intensity errors for the mesoscale ensembles for the 2009 season were of the order of 8.5 m/s and 10 m/s. These were slightly better than the intensity errors of 2004, 2005 and 2006 seasons.
❖ The biggest problem area for this study was the lack of a sufficient number of forecast samples for demonstrating the strengths of the ensembles.

❖ The bias corrected ensemble mean, the correlation based ensemble and the FSU superensemble all require more samples of forecasts in order to stabilize the biases, correlation coefficients and weights. The sample of 9 storms was not adequate.

❖ The number of homogeneous cases were only 28 when all the models are present among 58 cases for the whole season.

❖ During the 2010 forecast season we shall be continuing on real time, the forecast from the ensemble mean, the bias corrected ensemble mean and the correlation based ensemble.

❖We will also be addressing comparison of results from a single model based ensembles versus multimodel based ensembles.
❖ It would be desirable to have the mesoscale modelers run a large number of past storm forecasts (as many as 60 forecasts) to stabilize the statistical ensemble coefficients.

Acknowledgements

- Our sincere thanks to different modeling groups for providing valuable forecasts in realtime.

- The ARFS forecasts were carried out on n-jet.

- Collaborators: Dr. Robert Gall, Dr. Naomi Surgi, Dr Jim Doyle, Dr. Sundararaman Gopalakrishnan, Dr. Christopher Davis, Dr. T. S. V. Vijaya Kumar.