Development and Performance of a Statistical-Dynamical Ensemble Technique for Tropical Cyclone Intensity Guidance

Kate D. Musgrave[1] and Mark DeMaria[2]

[1]*CIRA/CSU, Fort Collins, CO*

[2] *NOAA/NWS/National Hurricane Center, Miami, FL*

HFIP Ensemble Workshop – 11/17/2015

Acknowledgements: Brian McNoldy, University of Miami
Yi Jin, Naval Research Lab
Michael Fiorino, Jeffrey Whitaker, Philip Pegion, NOAA/ESRL
Vijay Tallapragada, NOAA/NWS/NCEP/EMC

Kate.Musgrave@colostate.edu

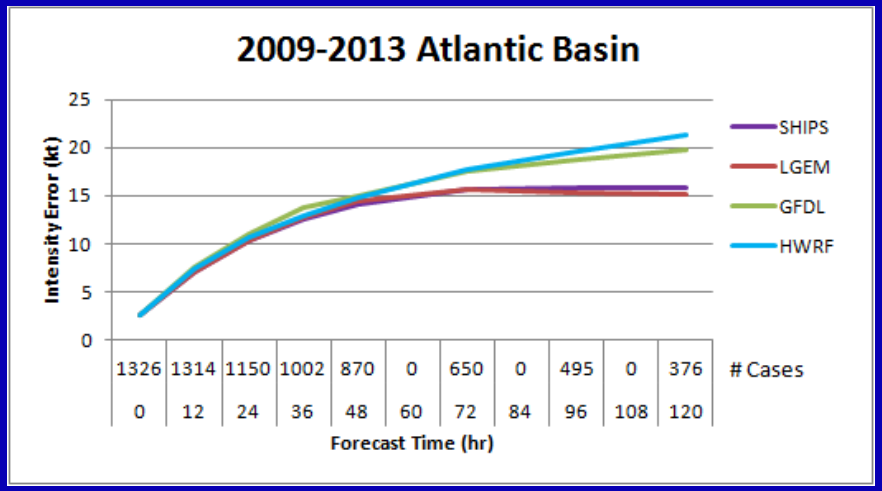
CIRA

NOAA HURRICANE FORECAST IMPROVEMENT PROJECT

Motivation for Statistical Ensemble

- The Logistic Growth Equation Model (LGEM) and the Statistical Hurricane Intensity Prediction Scheme (SHIPS) model are two statistical-dynamical intensity guidance models
- SHIPS and LGEM are competitive with dynamical models
- JTWC experience with an ensemble of statistical models shows improvements with multiple inputs

Atlantic Operational Intensity Model Errors 2009-2013



Ensemble Design

We focus on using Decay-SHIPS (DSHP) and LGEM, initialized with model fields from:

-the Global Forecasting System (GFS),

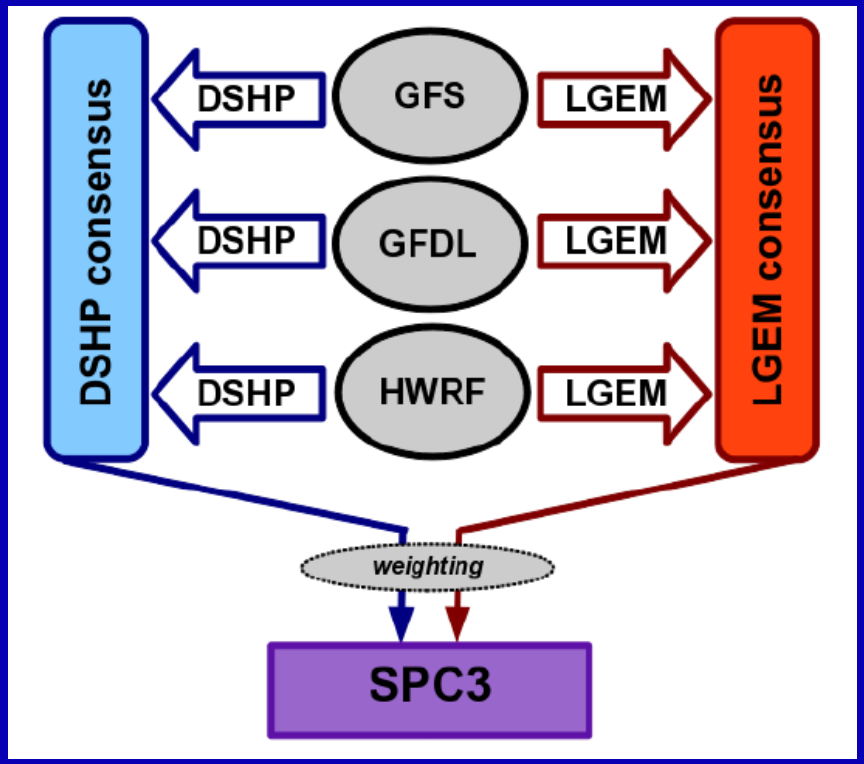
-the Hurricane Weather Research and Forecasting (HWRF) model,

-and the Geophysical Fluid Dynamics Laboratory (GFDL) model

to create an ensemble.

SPICE (Statistical Prediction of Intensity from a Consensus Ensemble)

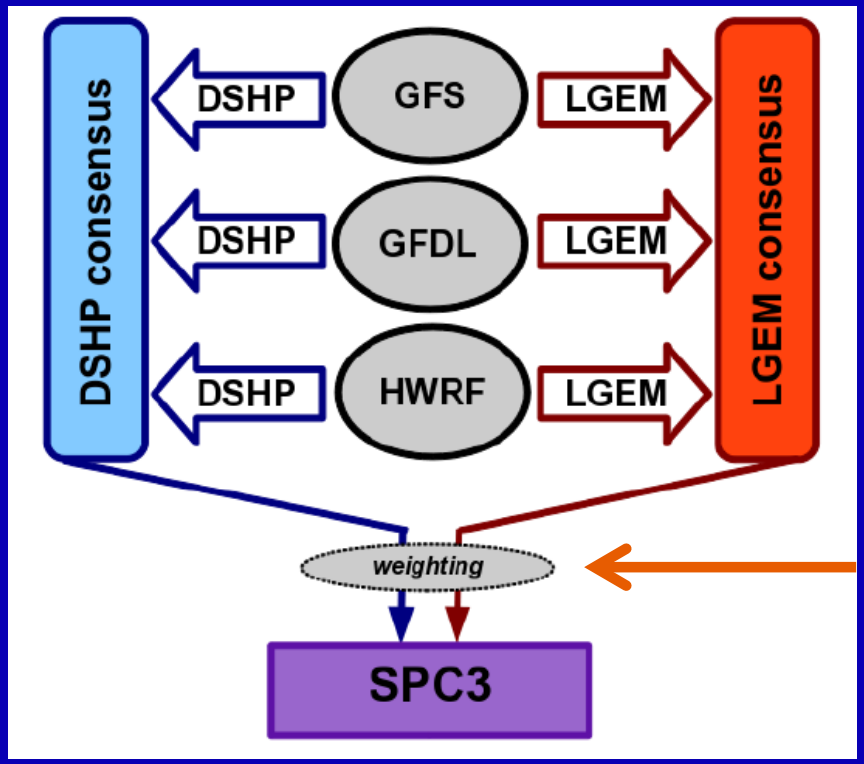
Model Configuration for Consensus



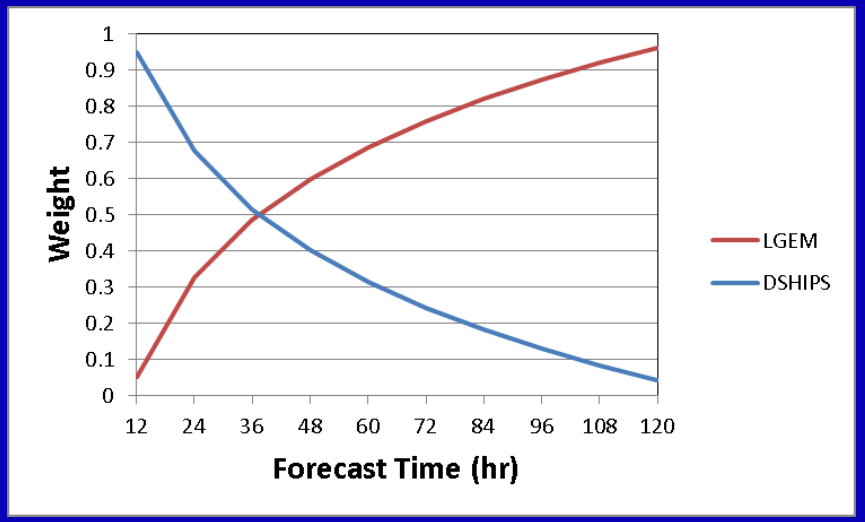
- SPICE forecasts TC intensity using a combination of parameters from:
  - Current TC intensity and trend
  - Current TC GOES IR
  - TC track and large-scale environment from GFS, GFDL, and HWRF models
- These parameters are used to run DSHP and LGEM based off each dynamical model
- The forecasts are combined into two unweighted consensus forecasts, one each for DSHP and LGEM
- The two consensus are combined into the weighted SPC3 forecast

SPICE (Statistical Prediction of Intensity from a Consensus Ensemble)

Model Configuration for Consensus



DSHP and LGEM Weights for Consensus

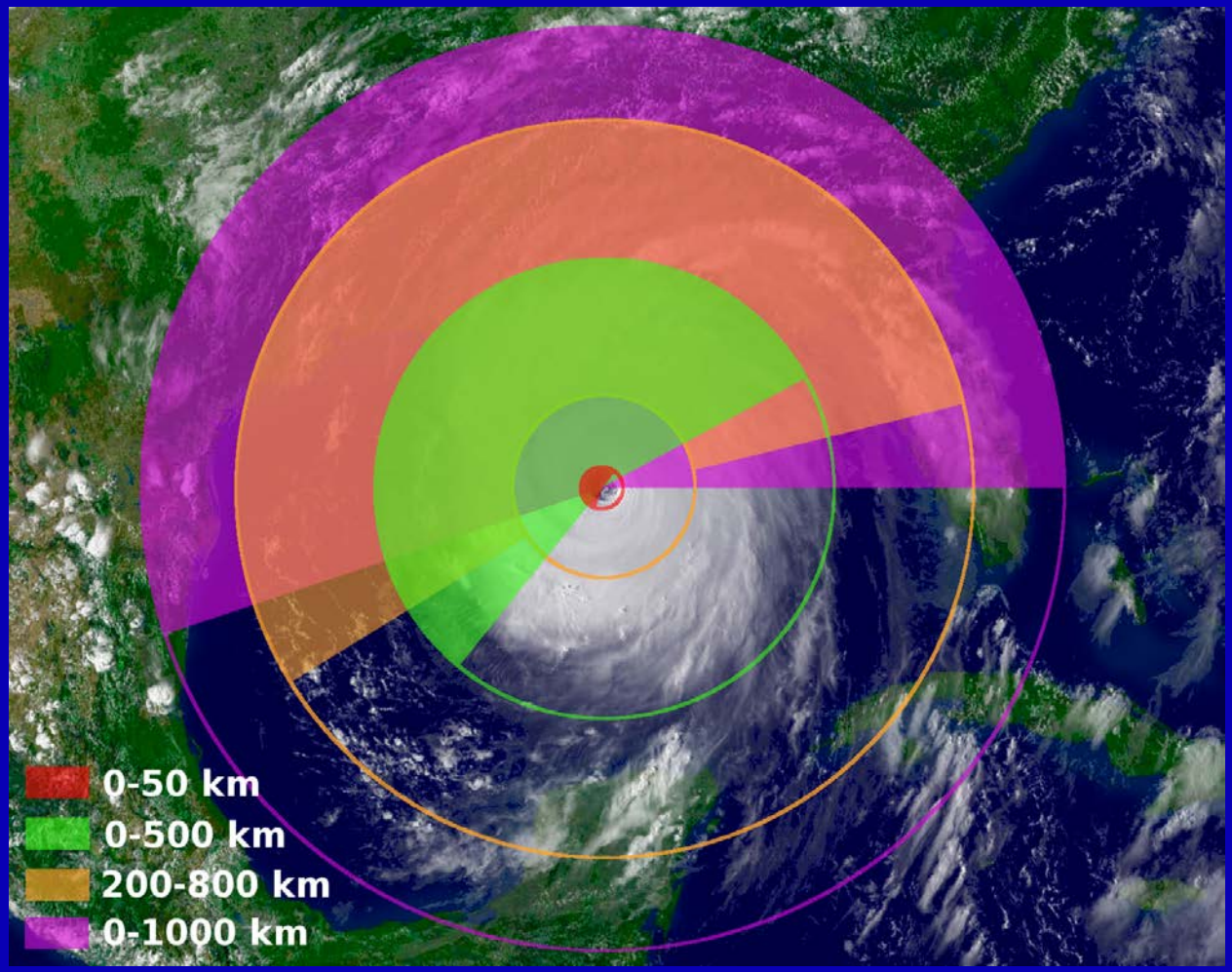


Weights determined empirically from 2008-2010 Atlantic and East Pacific sample

Large-Scale Model Diagnostic Files

Key parameters are calculated in prescribed areas...

This is already done with GFS output to create SHIPS "predictor" files available on NHC's FTP server



Sea surface temp (RSST)
850-200 mb shear (SHDC); 200 mb zonal wind (U20C)
200 mb temp (T200); 850-700 mb RH (RHLO)
700-500 mb RH (RHMD); 500-300 mb RH (RHHI)
200 mb divergence (D200); 850 mb vorticity (Z850)

Large-Scale Model Diagnostic Files

Diagnostic files available from http://www.hfip.org/products/

Three sections: *Storm Data*, *Sounding Data*, and *Custom Data*

* HWRF 2011091018 *
* AL14 MARIA *

STORM DATA

NTIME 022 DELTAT 006

TIME	(HR)	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126
LAT	(DEG)	17.5	18.3	19.0	20.1	21.0	21.7	22.2	22.8	23.4	23.9	24.3	24.9	25.7	26.6	27.8	29.3	30.8	32.4	34.1	36.0	38.2	40.9
LON	(DEG)	298.1	297.3	296.7	296.1	295.6	294.9	294.4	294.0	293.4	292.7	292.1	291.8	291.4	291.3	291.1	291.1	291.2	291.7	292.4	293.8	295.9	299.0
MAXWIND	(KT)	41	45	41	42	44	49	52	56	63	71	76	83	83	93	91	93	92	91	95	99	98	91
RMW	(KM)	164	142	152	147	132	89	48	49	51	38	41	41	46	52	52	53	56	59	64	67	66	74
MIN_SLP	(MB)	1006	1005	1003	1004	1001	997	990	987	979	970	962	956	951	951	945	945	942	942	943	946	946	951
SHR_MAG	(KT)	18	19	19	20	18	17	16	16	16	14	11	12	17	20	22	25	28	27	26	32	39	44
SHR_DIR	(DEG)	237	229	235	244	246	248	260	246	254	253	246	227	221	223	209	190	180	183	180	180	189	202
STM_SPD	(KT)	11	9	12	10	10	7	7	8	8	7	7	9	9	12	15	15	17	18	22	28	36	9999
STM_HDG	(DEG)	316	321	333	333	317	317	328	317	308	306	336	336	354	352	0	3	15	19	31	37	42	9999
SST	(10C)	294	291	291	291	290	292	291	290	290	289	288	285	285	284	283	282	278	275	273	275	258	250
OHC	(KJ/CM2)	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999
TPW	(MM)	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999
LAND	(KM)	412	316	264	275	324	368	413	478	529	538	551	604	680	776	906	941	837	780	775	730	601	453
850TANG	(10M/S)	104	108	107	102	109	116	114	117	122	130	134	142	148	154	151	157	168	170	170	177	177	180
850VORT	(/S)	18	15	8	-1	3	9	5	2	11	19	16	26	49	66	61	68	80	77	72	91	98	113
200DVRG	(/S)	90	61	34	48	71	64	50	39	39	31	29	29	57	48	62	77	107	106	105	138	145	137

SOUNDING DATA

NLEV 020 SURF 1000 0950 0900 0850 0800 0750 0700 0650 0600 0550 0500 0450 0400 0350 0300 0250 0200 0150 0100

TIME	(HR)	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126
T_SURF	(10C)	287	286	286	285	284	284	284	283	283	282	282	281	280	279	277	274	271	267	261	249	233	209
R_SURF	(%)	79	79	79	79	78	78	78	78	78	78	78	78	78	79	79	78	78	78	78	78	76	74
P_SURF	(MB)	1012	1013	1013	1015	1015	1016	1015	1017	1014	1016	1013	1014	1012	1013	1010	1011	1009	1010	1008	1009	1008	1009
U_SURF	(10KT)	-117	-121	-121	-112	-105	-102	-85	-85	-85	-82	-68	-65	-68	-75	-59	-37	-13	-2	39	60	85	106
V_SURF	(10KT)	11	-5	13	17	19	9	28	12	22	15	29	19	23	26	35	25	26	31	48	30	24	26
T_1000	(10C)	277	277	274	270	269	269	266	264	266	267	266	265	268	269	267	265	265	264	257	242	229	210
R_1000	(%)	73	73	75	77	78	79	80	81	81	81	81	81	80	79	79	78	76	75	78	80	80	81
Z_1000	(DM)	11	12	11	13	13	14	13	15	12	14	11	13	10	11	9	10	8	9	7	8	7	7
U_1000	(10KT)	-141	-143	-142	-132	-124	-122	-101	-102	-101	-99	-81	-78	-80	-89	-68	-43	-14	-1	45	70	96	121
V_1000	(10KT)	14	-5	17	23	24	13	35	17	27	19	35	25	29	34	44	32	32	40	58	39	32	35
T_0950	(10C)	235	235	232	228	228	227	225	223	225	226	225	224	226	227	226	224	224	223	217	204	192	175

Storm Data section contains: LAT, LON, VMAX, RMW, MSLP, shear magnitude and direction, TC speed and heading, SST, OHC, TPW, distance to land, 850 mb tangential winds and vorticity, and 200 hPa divergence

Sounding Data section contains: U, V, T, RH, and Z at specified pressure levels, and surface U, V, T, RH, and P

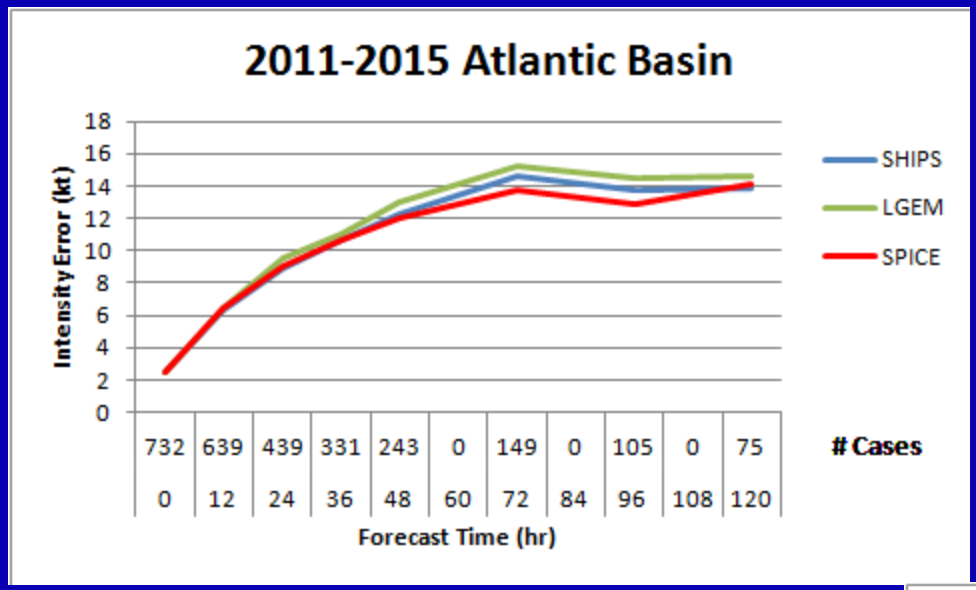
SPICE Operations for HFIP

SPICE has been run as part of HFIP's real-time demonstration since 2011.

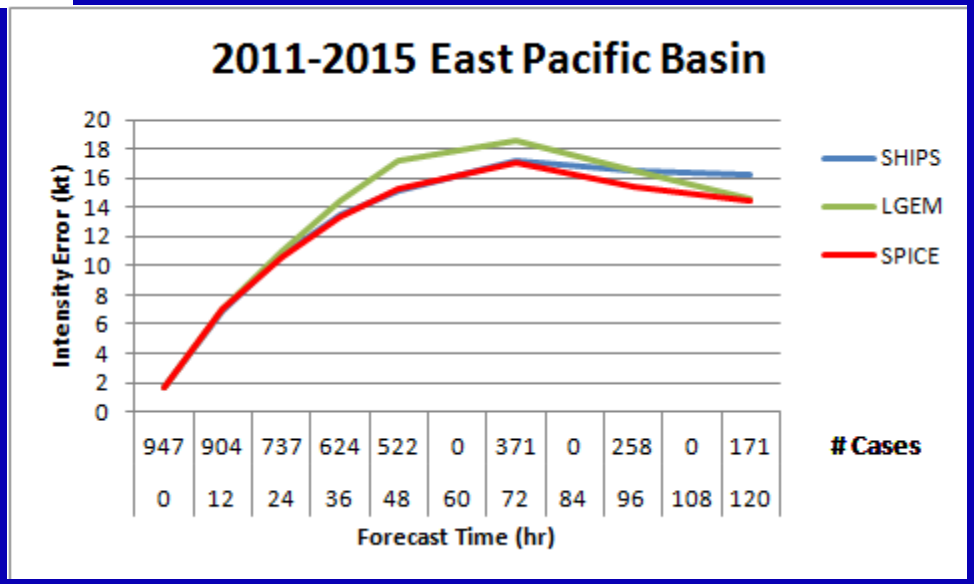
In May 2015, the diagnostic file code was updated to a global version and delivered to the HFIP community.

In August 2015, ECMWF was added to the list of models that can be used as input to SHIPS and LGEM.

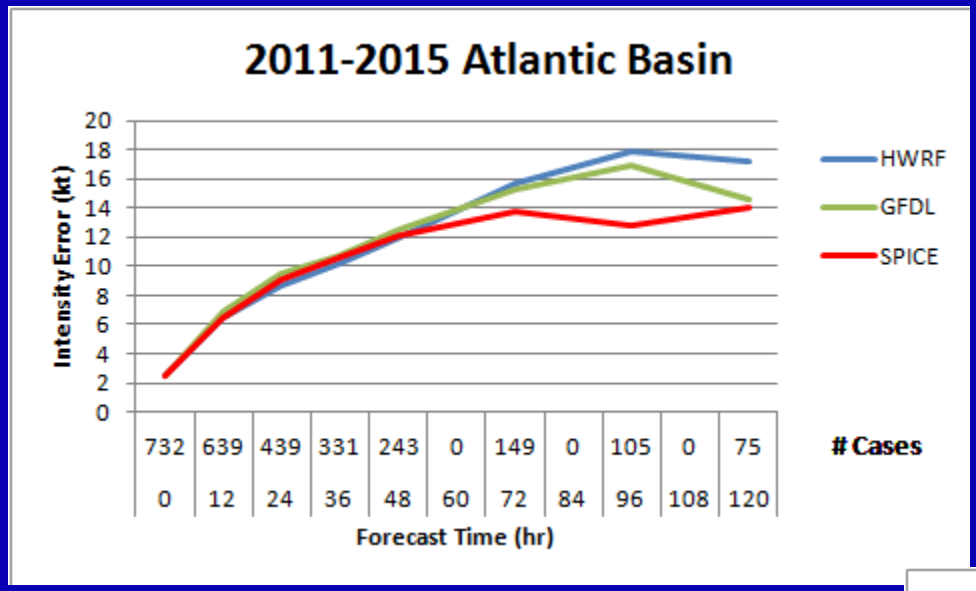
SPICE Real-Time Demonstration – 2011-2015



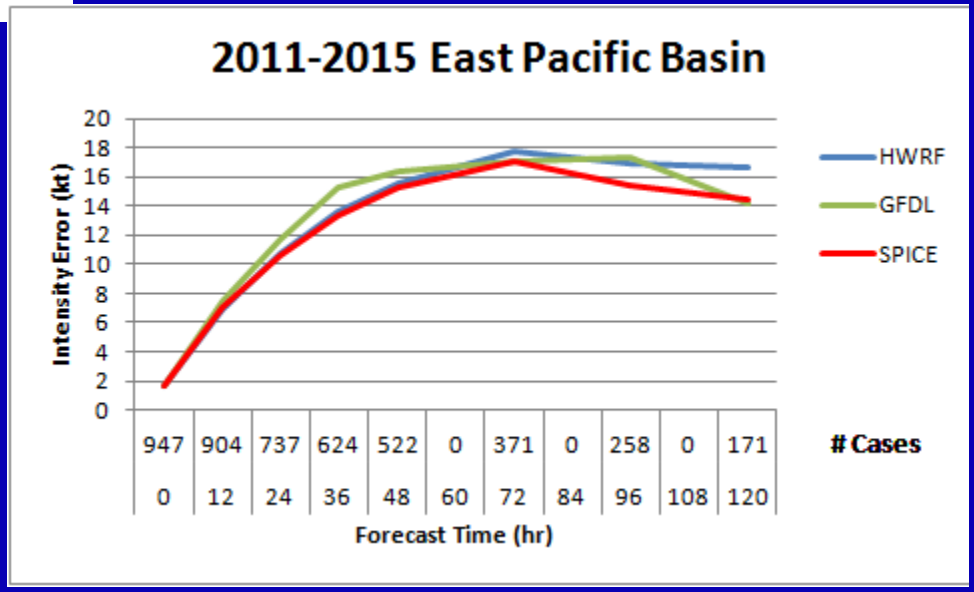
- SPICE verification for the 2011-2015 Atlantic and East Pacific seasons show SPICE has lower average errors than Decay-SHIPS and LGEM at longer lead times



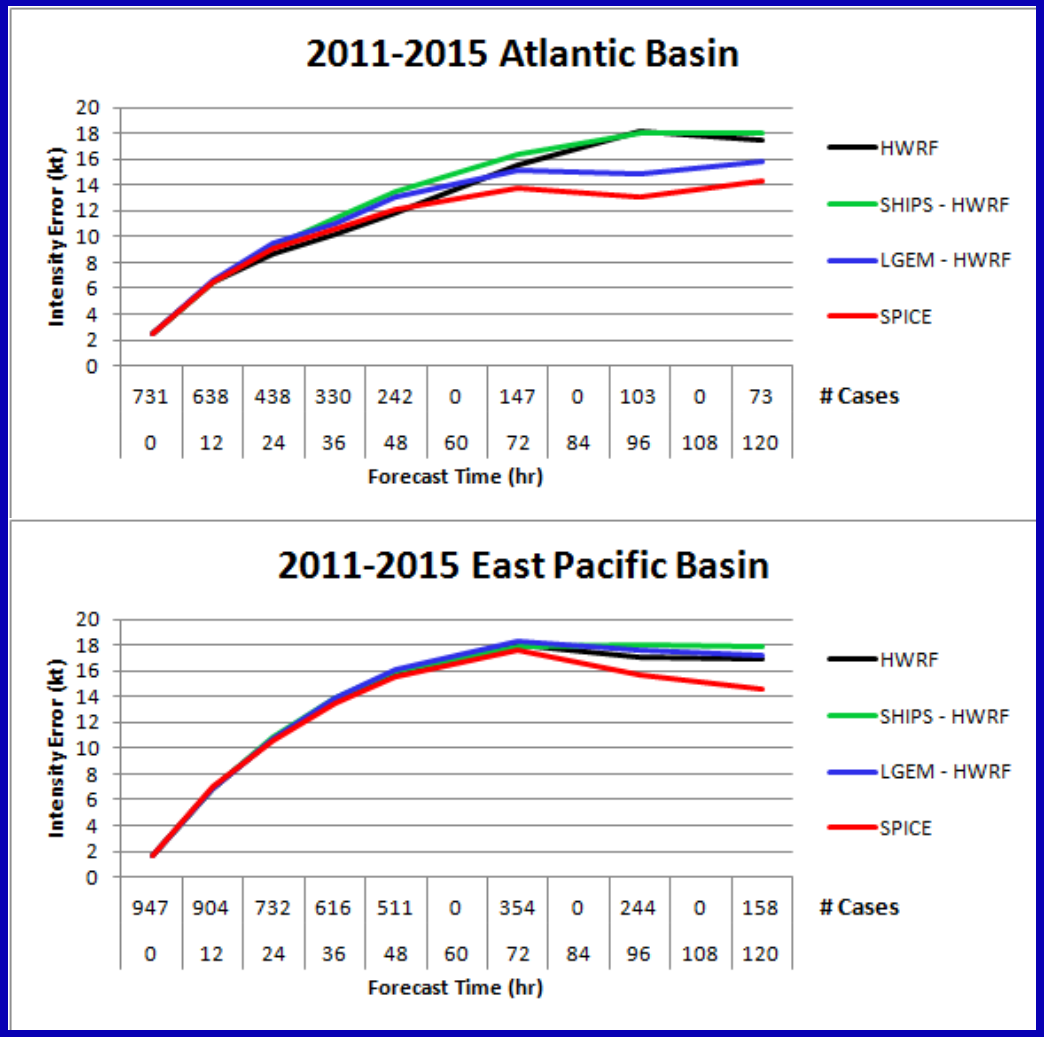
SPICE Real-Time Demonstration – 2011-2015



- SPICE showed an improvement over HWRF and GFDL at longer lead times in both basins

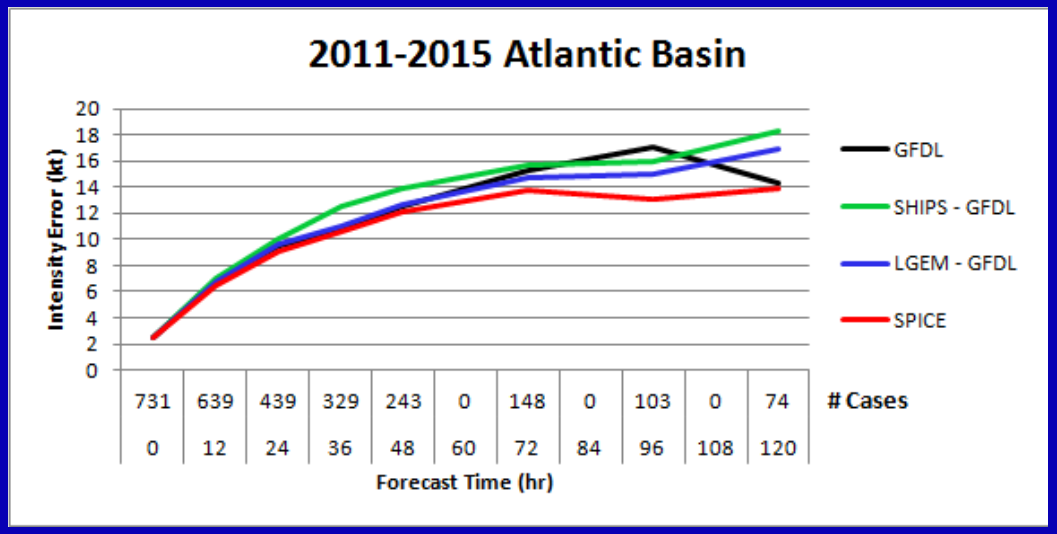


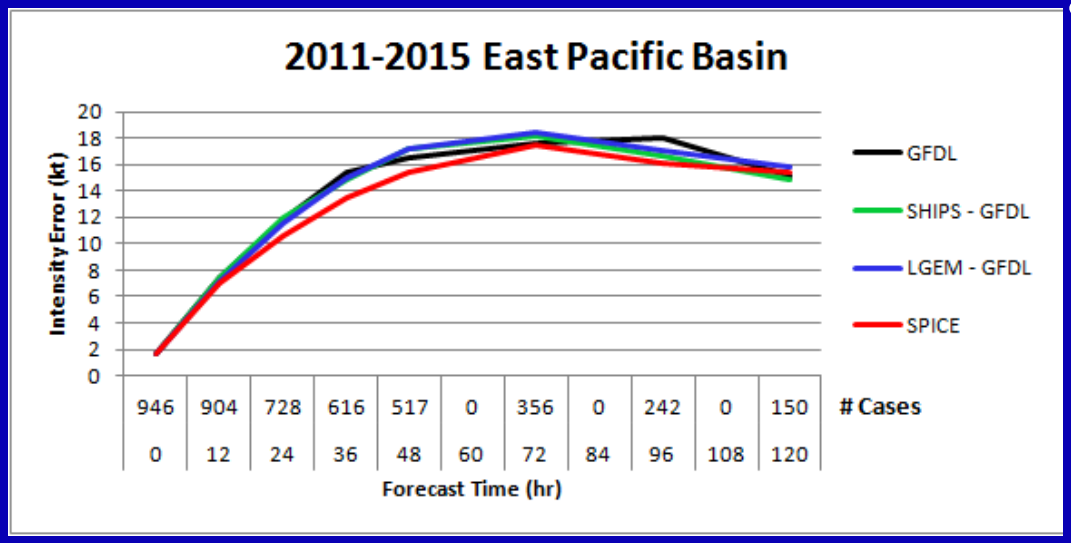
SPICE Real-Time Demonstration – 2011-2015 HWRF Components



- Both SHIPS and LGEM run from HWRF model fields have lower average errors than HWRF at longer forecast periods
- SPICE has lower average errors than the components run from HWRF, as well as HWRF, at longer forecast periods
- East Pacific shows similar average errors to Atlantic

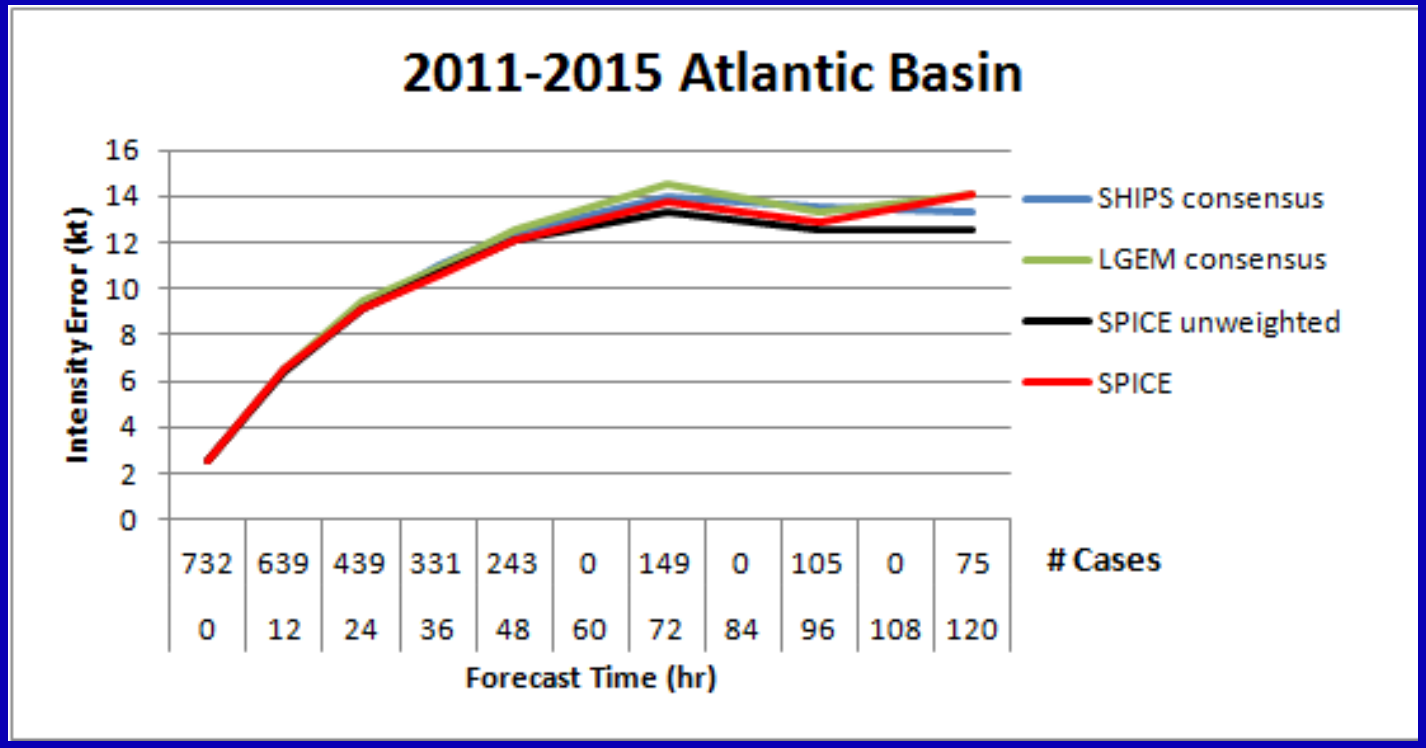
SPICE Real-Time Demonstration – 2011-2015 GFDL Components





- In the Atlantic SPICE has lower average errors than the components run from GFDL, as well as GFDL
- SHIPS and LGEM components in the East Pacific basin show similar average errors to the Atlantic basin

SPICE Real-Time Demonstration – 2011-2015 Effects of Weighting



- The weighting used in SPICE did not show real-time results consistent with the retrospective testing
- Related to the performance of LGEM at longer forecast times

Summary

- Statistical ensemble (SPICE) is a weighted consensus of DSHP and LGEM, run from multiple dynamical models

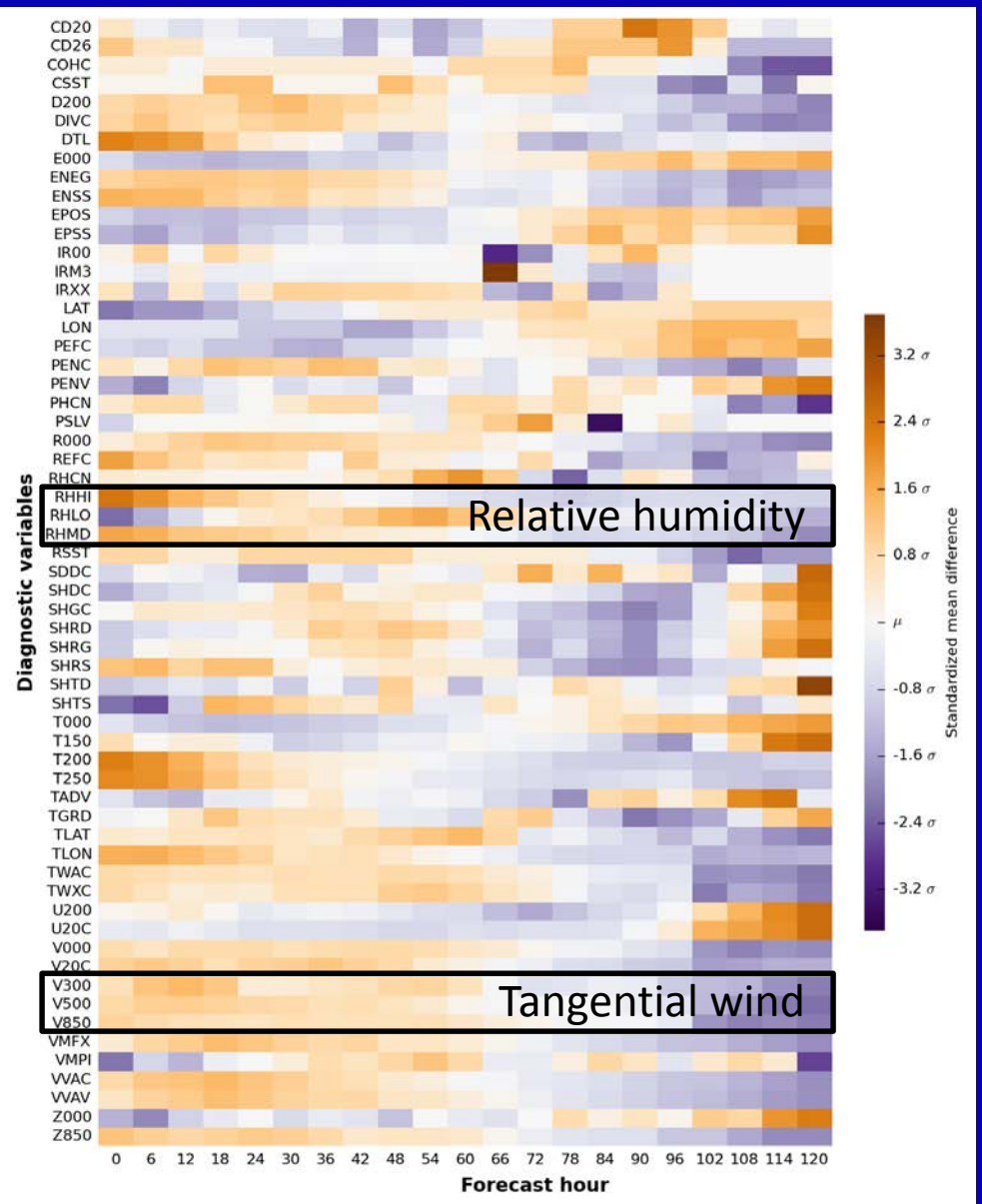
- SPICE has been run as part of the HFIP real-time demonstration since 2011

- In the 2011-2015 real-time demonstration:
  - SPICE had lower average errors than SHIPS and LGEM in the Atlantic and East Pacific basins at longer forecast times
  - SPICE also had lower average errors than HWRF and GFDL in the Atlantic and East Pacific basins at longer forecast times

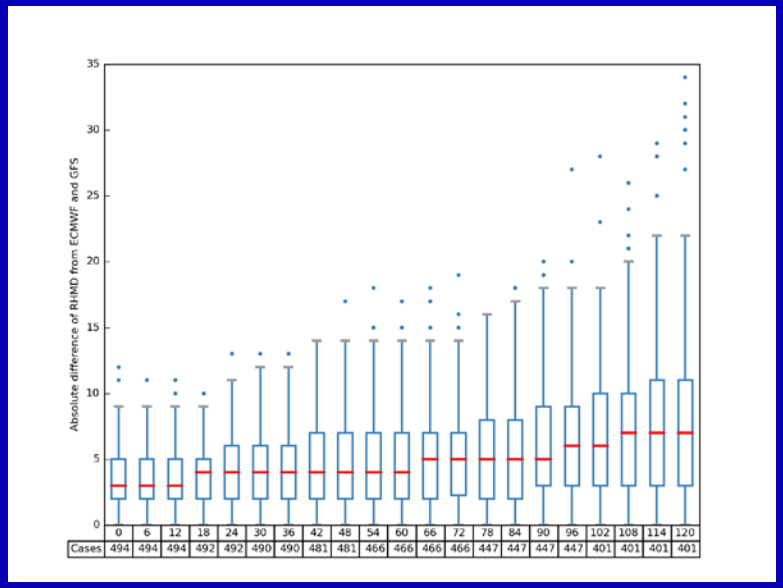
Future Work

- Further assessment of weighting
- Update to 2015 global version of SHIPS/LGEM
- Incorporating additional models into SPICE
  - ECMWF
  - GFS using GFS forecast track
- Experiments with observational datasets
- Test variation of initial conditions
- Further exploration of synthetic satellite imagery

Comparison of 2015 GFS and ECMWF Large-Scale Diagnostics

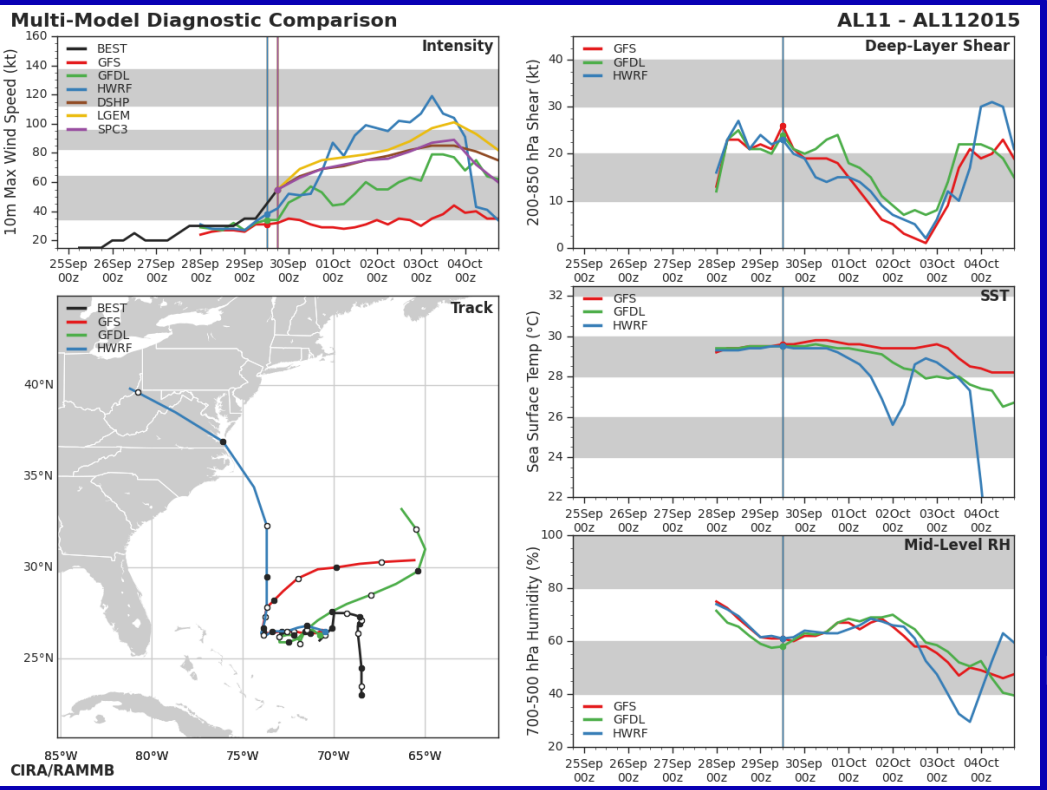


- Cool colors represent GFS having the larger value, warm colors represent ECMWF having larger values
- Differences in mid-level relative humidity average less than 10% out through 120 hours; some cases in excess of 30% difference at 120 hours



Multi-Model Diagnostic Comparison Plots

Model inter-comparison available from http://www.hfip.org/products/



Purpose

- Provides overview of TC environment
- Comparison of model track, intensity, and basic dynamic and thermodynamic environment

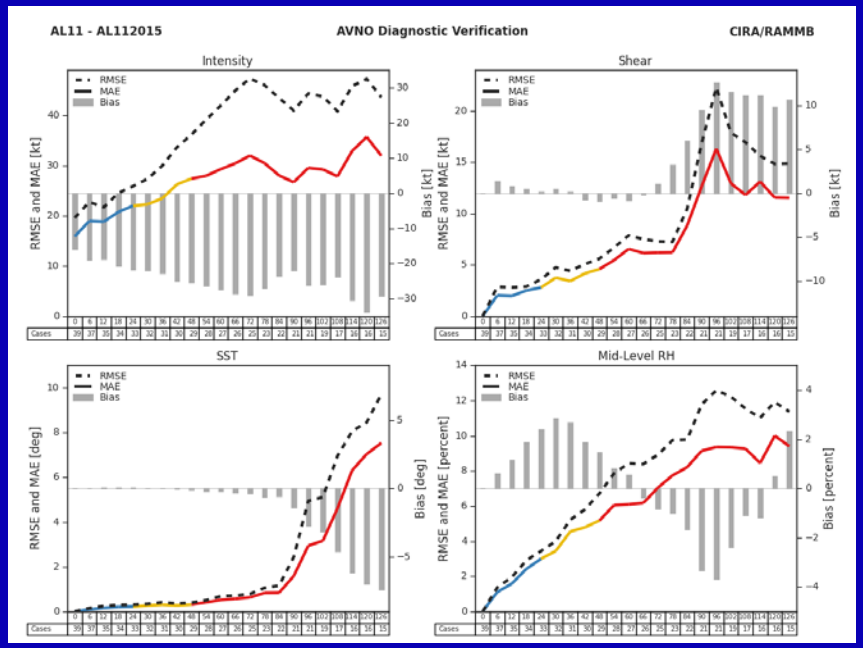
Panel Design

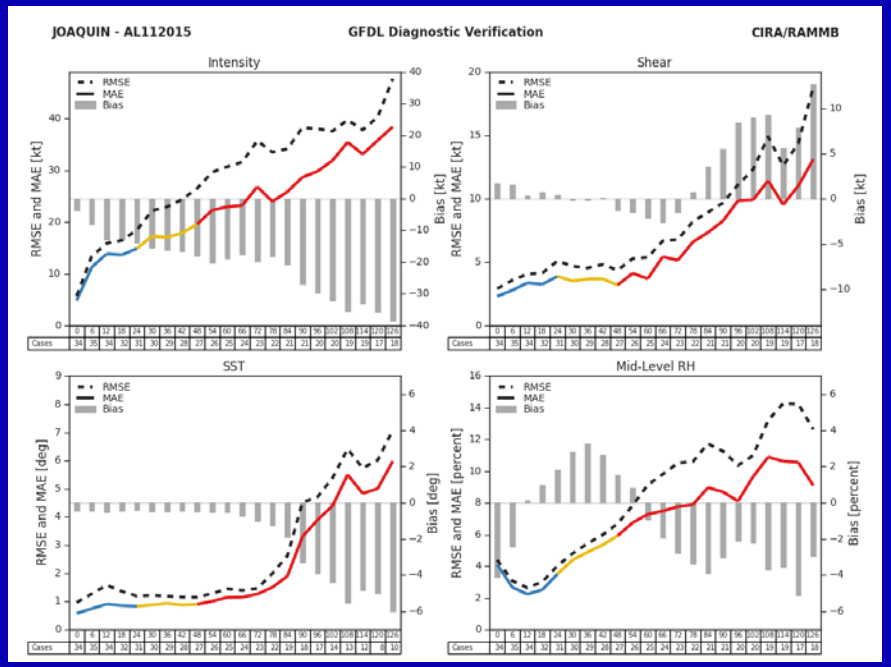
- 5 panels:
  - Intensity (top left)
  - Track (bottom left)
  - Deep-Layer Shear (850-200 hPa , top right)
  - SST (middle right)
  - Mid-Level RH (700-500 hPa , bottom right)
- Non-track panels show previous and next 5 days, centered at current time
  - Vertical lines indicate the initial time of the most recent available forecast, color-coded by model
  - Previous times are analysis values
- Track panel shows five day forecasts and recent best track

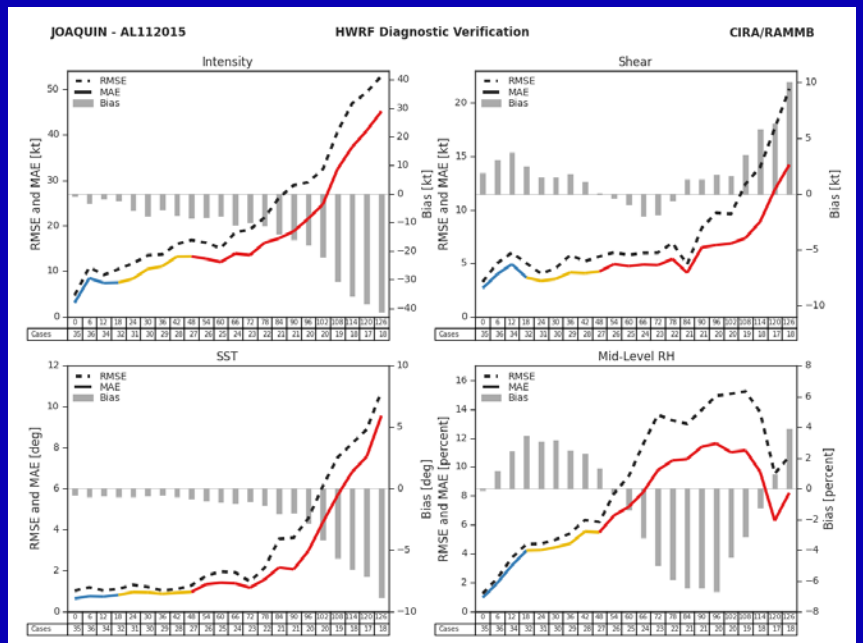
Models Selected

- Intensity: GFS, HWRF, GFDL, DSHP, LGEM, OFCL, BEST
  - Upcoming: SPC3 will be re-introduced
- Track: GFS, HWRF, GFDL, OFCL, BEST
- Deep-Layer Shear: GFS, HWRF, GFDL
- SST: GFS, HWRF, GFDL
- Mid-Level RH: GFS, HWRF, GFDL

Diagnostic Verification Plots







Panels (CW from top left):

Intensity, Deep-Layer Shear, Mid-Level RH, SST

Dashed Line: RMSE; Solid Line: MAE (left-hand axis)

Avg. track error indicated in MAE line shading

[<100, 100 to 200, >200 nmi]

Gray Shaded Bars: Bias (right-hand axis)