Statistical Evaluation of the Response of Intensity to Large-Scale Forcing in the 2008 HWRF model

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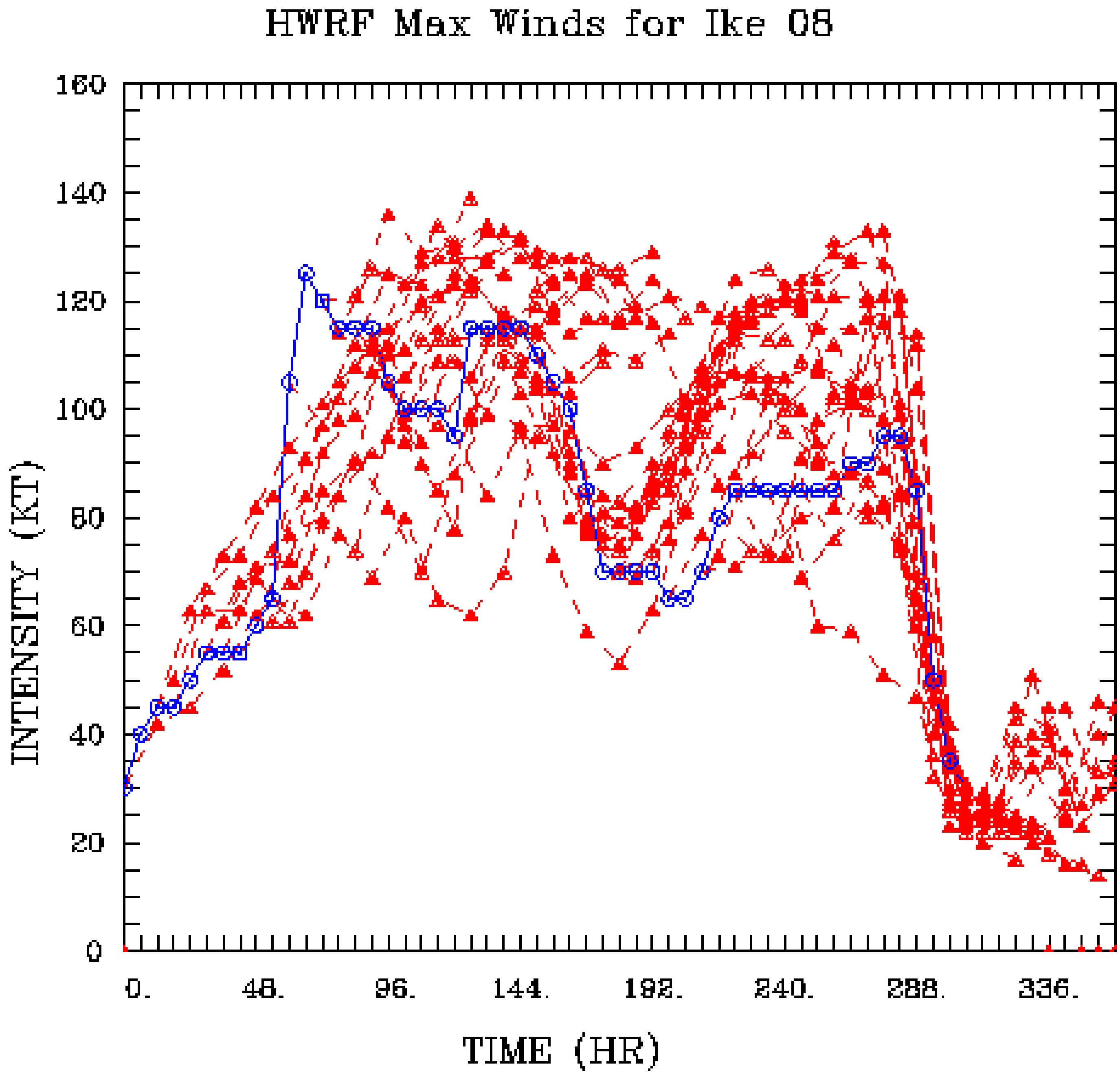
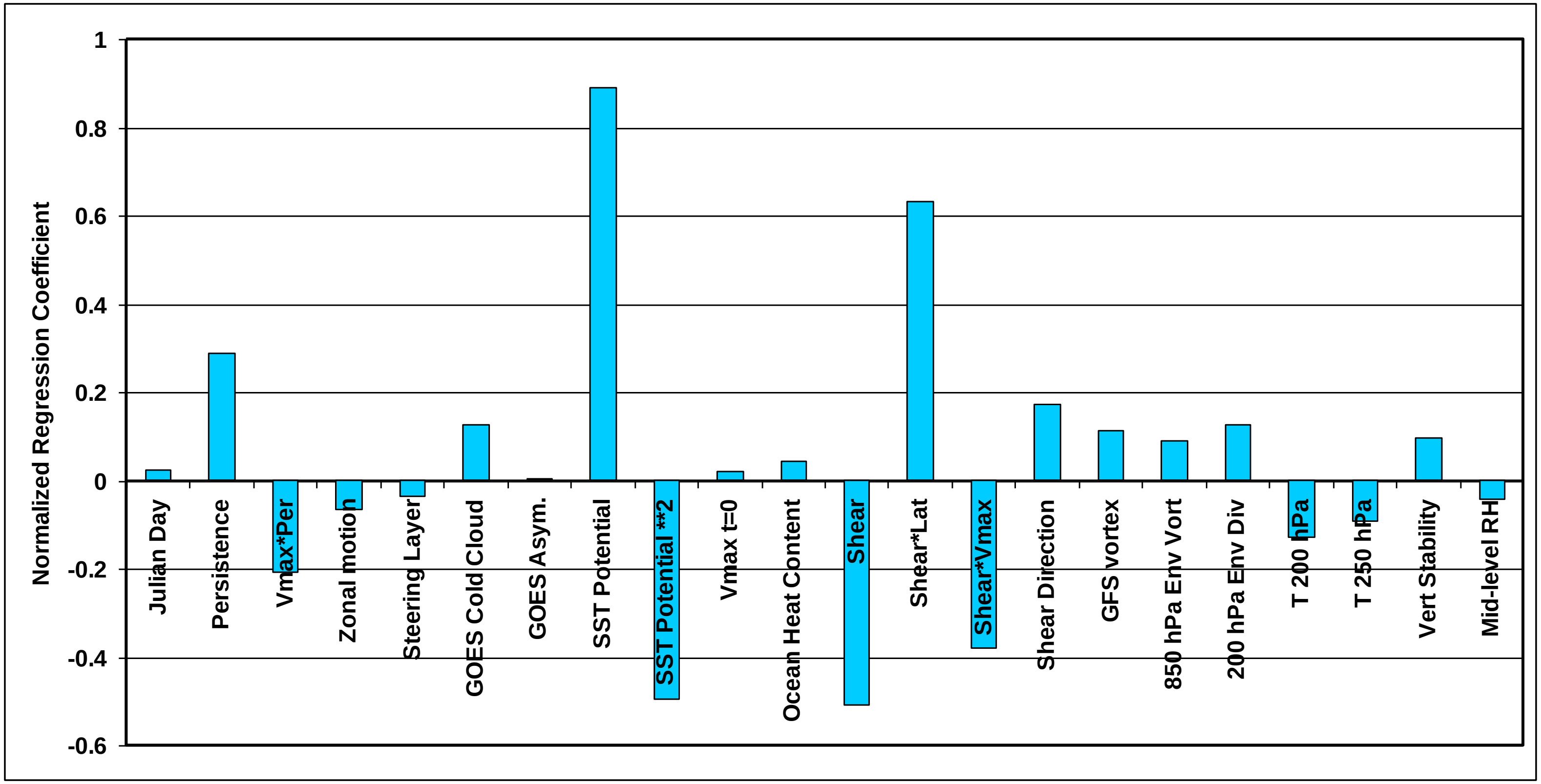
Outline

- Motivation
- HWRF Sample
- Evolution of large scale forcing in HWRF
  - Lower boundary
  - Vertical shear
- Evaluation of storm response to forcing
  - Fitting LGEM model to HWRF forecasts
  - Comparison with fitting LGEM to observations


HWRF Max Winds for Ike 08
INTENSITY (KT)
TIME (HR)
0
20
40
60
80
100
120
140
160
0.
48.
96.
144.
192.
240.
288.
336.

Intensification Factors in SHIPS Model

1) Center over Land
   - Time since landfall, fraction of circulation over land
2) Center over Water



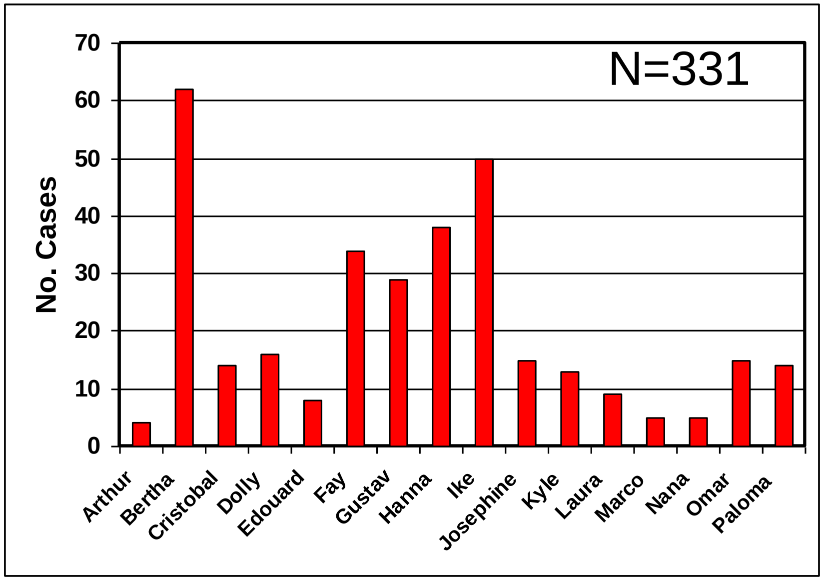
Normalized Regression Coefficients at 48 hr for 2009 SHIPS Model

Preliminary Analysis of HWRF

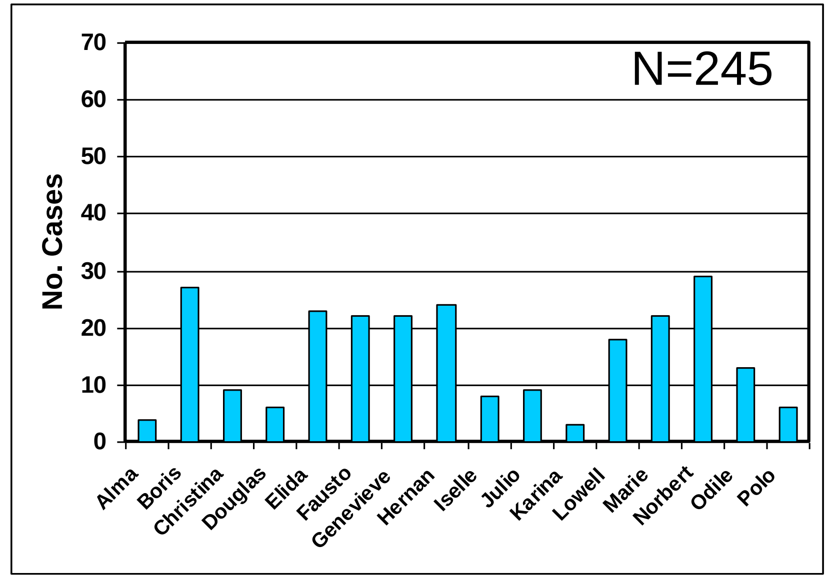
- Consider 3 error sources
  - Accuracy of track forecasts
    - Over land versus over water
  - SST along forecast track
    - Related to MPI
  - Shear along forecast track
- Compare track, SST and shear errors to HWRF intensity errors
- How to HWRF storms respond to SST and shear forcing compared to real storms?

Summary of HWRF Cases

- Atlantic



- East Pacific

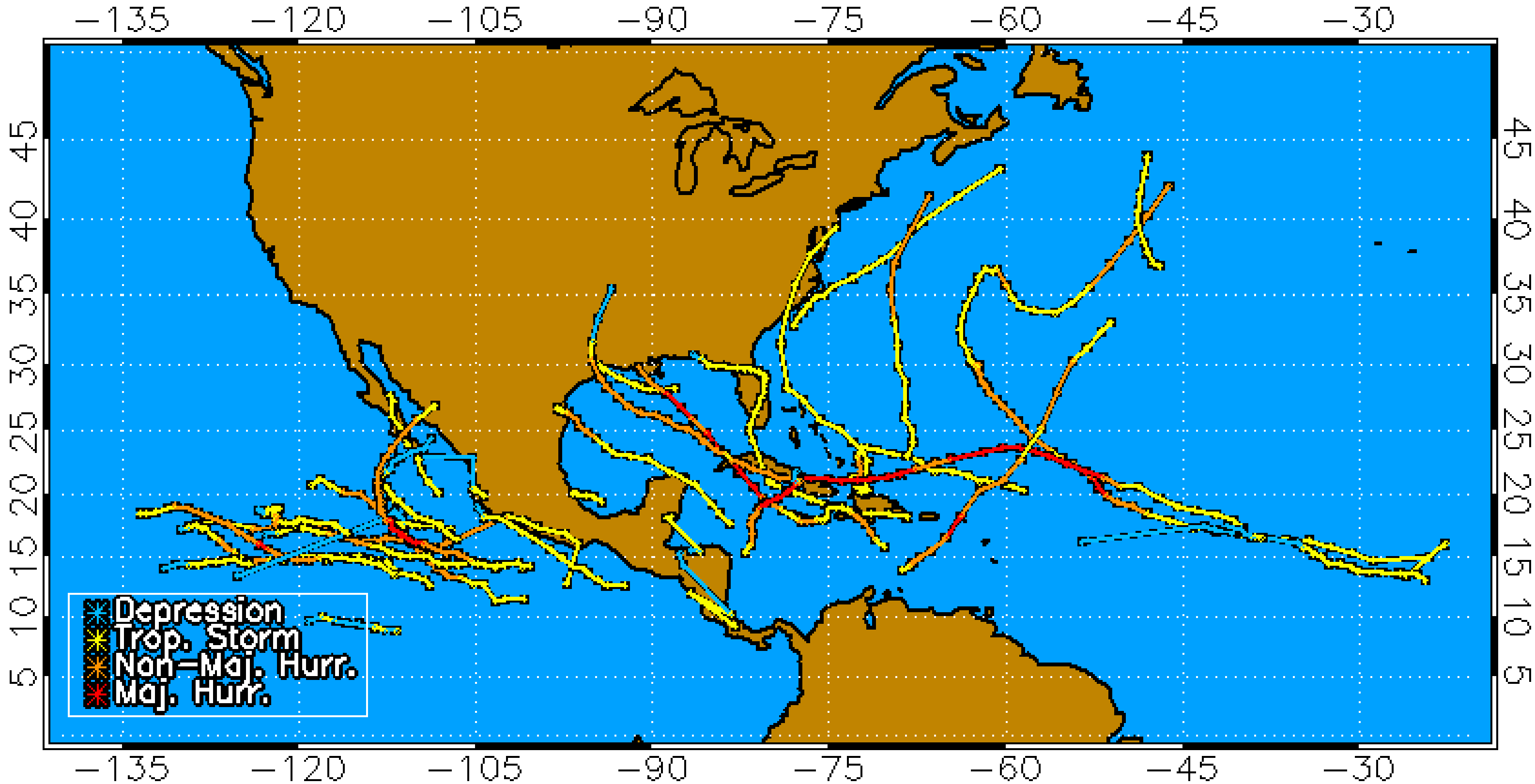


- Total

- 576 HWRF runs during 2008 *
- 7532 individual times to compare an HWRF analysis or forecast to Best Track data *

*** HWRF runs only counted for *named* storms in Best Track database**

Initial Positions of 2008 HWRF Cases



* HWRF MODEL OUTPUT *

* gustav07l 2008082712 *

FCST TIME (HR)	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126
LATITUDE	18.8	19.0	19.1	19.2	18.9	18.9	19.0	19.1	19.1	19.2	19.4	19.6	20.2	20.8	21.8	22.8	23.7	24.6	25.4	26.1	26.7	27.2
LONGITUDE	73.5	74.3	74.9	76.0	76.7	77.4	78.1	79.0	79.8	80.8	81.4	82.4	83.0	83.9	84.5	85.6	86.5	87.6	88.6	89.7	90.5	91.2
MAX WIND (KTS)	50	71	59	59	55	51	47	52	72	54	60	68	83	83	85	82	102	109	115	116	113	118
RADIUS MW (KM)	74	79	60	54	53	50	56	66	55	48	53	56	51	46	45	53	53	59	67	67	67	66
MIN SLP (MB)	997	986	982	980	983	981	985	984	980	976	973	969	965	954	947	942	937	929	921	918	916	912
STM SPD (KTS)	8	6	10	7	7	7	9	8	9	6	10	8	10	11	14	12	13	12	12	9	8	
STM HDG (DEG)	285	280	275	246	270	279	277	270	276	289	282	317	305	331	314	317	312	311	305	310	309	
SHR MAG (KTS)	18	22	17	16	18	21	18	16	16	18	17	16	20	17	15	9	10	7	7	12	10	13
SHR DIR (DEG)	311	336	336	347	7	17	24	25	20	32	26	17	13	9	4	353	322	301	286	254	230	239
MEAN SST (C)	29.5	29.6	29.6	29.6	29.6	29.6	29.6	29.5	29.5	29.4	29.5	29.5	29.5	29.6	29.5	29.4	29.2	29.1	28.9	28.9	28.6	28.1
200MB T (C)	-52.9	-52.1	-52.2	-52.5	-52.9	-52.8	-52.7	-52.6	-52.2	-52.5	-52.1	-51.7	-51.3	-51.3	-51.0	-50.4	-50.6	-50.0	-50.1	-49.7	-50.0	-49.9
700-500MB RH	85	81	76	62	58	62	63	64	62	60	56	56	50	48	47	45	45	44	44	48	55	56
LAND (KM)	41	49	80	79	70	54	57	116	190	286	291	284	216	117	-5	131	247	337	413	337	265	212
DK94 MPI (KTS)	153	155	155	155	155	155	155	153	153	151	153	153	154	155	153	152	149	146	144	142	138	131

* SST averaged in five closest points to storm center *

* SHR, 200MB T, and 700-500MB RH averaged from 300-350km around storm center *

* DK94 MPI is the DeMaria-Kaplan (1994) Maximum Potential Intensity *

-------------------- SOUNDING DATA --------------------

---------- ALL VALUES AVERAGED FROM 300-350km AROUND STORM CENTER ----------

FCST TIME (HR)	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126
p_sfc (MB)	1009	1007	1008	1005	1005	1004	1004	1002	1004	1002	1003	1001	1003	1001	1003	1002	1004	1003	1004	1003	1004	1004
T_sfc (C)	28.6	25.5	24.4	26.8	26.9	26.2	23.9	23.7	23.5	26.6	27.3	27.6	26.8	27.2	26.8	27.0	26.7	29.1	29.1	28.9	28.5	27.3
RH_1013 (%)	82	82	78	80	80	82	85	86	87	84	84	85	84	84	84	85	83	82	81	82	82	85
Z_1013 (DM)	-3	-5	-4	-6	-6	-8	-7	-9	-7	-9	-8	-10	-8	-10	-8	-9	-7	-8	-7	-8	-7	-7
u_sfc (KTS)	-5.2	-4.9	-6.0	-6.4	-4.7	-2.8	-2.2	-1.2	-2.2	-0.8	-2.1	-2.4	-0.8	-2.0	-4.0	-6.1	-8.5	-7.2	-7.7	-8.7	-6.2	-2.1
v_sfc (KTS)	0.8	1.8	1.0	1.5	3.4	3.8	3.4	3.7	2.2	2.4	3.5	4.4	5.9	6.8	6.7	6.4	5.0	5.2	4.2	4.0	0.5	-0.5
T_1000 (C)	27.8	27.1	27.1	27.1	27.5	27.4	27.0	26.6	26.2	27.2	27.6	27.5	27.4	27.5	27.9	27.9	27.9	28.4	28.6	28.5	28.0	27.2
RH_1000 (%)	81	81	78	79	79	80	83	84	85	82	82	83	82	83	83	83	82	80	80	80	81	84
Z_1000 (DM)	8	6	7	4	5	3	3	2	3	2	3	1	2	1	3	2	3	2	4	2	4	3
u_1000 (KTS)	-6.6	-6.3	-7.1	-7.7	-5.9	-3.9	-3.6	-2.8	-4.0	-1.6	-3.1	-3.3	-1.9	-2.6	-4.6	-6.3	-9.3	-8.3	-9.1	-10.0	-7.5	-3.4
v_1000 (KTS)	1.1	1.8	1.1	1.8	3.8	4.5	4.5	4.9	3.2	2.9	4.1	4.8	7.1	7.7	7.9	7.4	6.5	6.1	4.9	4.7	0.9	-0.6
T_950 (C)	24.4	23.8	23.8	23.7	23.7	23.7	23.9	23.6	23.6	23.8	23.9	24.0	24.0	24.1	24.3	24.4	24.4	24.5	24.7	24.7	24.3	23.8
RH_950 (%)	83	87	85	87	89	90	91	93	93	92	92	93	91	91	91	92	91	91	90	89	90	92
Z_950 (DM)	53	51	52	50	50	48	49	47	48	47	48	46	48	47	48	47	49	48	49	48	49	49
u_950 (KTS)	-7.9	-7.1	-8.8	-9.3	-7.0	-5.0	-5.3	-4.5	-4.7	-1.7	-3.9	-4.6	-3.3	-3.8	-5.5	-7.4	-10.1	-9.9	-10.4	-12.1	-9.3	-5.9
v_950 (KTS)	1.0	2.4	1.8	2.6	4.6	5.6	5.8	7.6	6.3	5.0	5.6	6.7	10.3	9.7	9.3	8.9	8.9	7.5	5.4	5.7	2.1	0.9
T_900 (C)	21.5	20.7	20.4	20.2	20.1	20.4	20.7	20.8	20.7	20.6	20.8	20.8	20.7	20.7	20.9	21.0	21.1	21.0	21.1	21.0	21.0	20.7
RH_900 (%)	82	92	90	95	98	97	96	96	97	99	99	99	99	99	98	99	97	99	99	99	98	99
Z_900 (DM)	100	98	99	97	97	96	96	94	96	94	95	93	95	94	96	94	96	95	96	95	96	96
u_900 (KTS)	-8.6	-7.4	-8.9	-9.6	-7.1	-5.3	-5.1	-4.2	-4.6	-1.6	-4.0	-5.0	-3.6	-4.3	-6.2	-8.3	-11.0	-10.4	-10.9	-12.8	-10.1	-7.1
v_900 (KTS)	1.6	3.6	3.3	3.7	5.5	6.7	6.3	8.4	7.9	6.2	6.7	7.9	11.7	10.5	9.9	9.2	9.5	8.0	5.6	6.0	2.9	2.1
T_850 (C)	18.8	18.2	17.8	17.6	18.0	18.4	18.6	18.8	18.7	18.5	18.9	18.5	18.4	18.5	18.6	18.5	18.9	18.5	19.0	18.2	18.3	18.3
RH_850 (%)	80	83	83	87	87	86	85	83	84	85	82	86	85	88	87	92	86	91	87	96	96	96
Z_850 (DM)	150	148	148	146	146	145	145	144	145	144	145	143	144	143	145	144	145	144	146	145	146	145
u_850 (KTS)	-9.2	-7.8	-8.9	-9.0	-6.0	-4.5	-3.7	-3.2	-4.1	-1.7	-3.3	-5.4	-3.5	-3.9	-5.5	-8.2	-11.0	-10.4	-10.6	-13.4	-10.6	-9.1
v_850 (KTS)	2.0	5.7	5.1	5.5	7.1	7.6	6.0	8.3	9.4	8.0	7.3	9.4	13.0	12.4	11.1	10.3	10.3	9.0	6.5	6.7	4.4	4.4
T_800 (C)	15.9	15.5	15.6	15.6	16.2	16.5	16.6	16.7	16.6	16.9	17.3	17.1	17.4	17.1	17.9	17.2	17.7	17.0	17.2	16.7	16.7	16.6
RH_800 (%)	81	79	75	75	72	72	73	72	72	68	63	60	54	63	55	63	58	66	65	71	76	79
Z_800 (DM)	202	200	200	198	198	197	197	196	197	196	197	195	196	195	197	196	197	196	198	197	198	197
u_800 (KTS)	-9.2	-8.1	-8.2	-7.6	-4.9	-4.0	-3.0	-3.3	-4.1	-1.4	-2.4	-4.4	-2.4	-1.8	-3.9	-5.9	-9.3	-8.6	-9.2	-10.8	-8.4	-8.0
v_800 (KTS)	2.2	6.7	5.9	5.9	6.4	6.8	5.4	8.2	9.3	8.1	7.0	9.1	12.5	12.4	12.2	11.5	11.2	10.6	8.4	8.7	5.4	6.0
T_750 (C)	12.6	12.5	12.9	13.2	13.8	13.8	14.0	14.0	13.9	14.2	14.9	14.6	15.1	14.8	15.6	15.2	15.5	14.9	15.3	14.6	14.6	14.8
RH_750 (%)	84	81	76	71	68	70	70	69	69	65	60	55	47	54	47	47	47	51	51	57	63	64
Z_750 (DM)	256	254	255	252	253	252	252	250	252	250	252	249	251	250	252	251	252	251	253	251	252	252
u_750 (KTS)	-8.5	-6.5	-7.1	-6.9	-4.3	-4.6	-3.6	-4.0	-4.8	-2.2	-3.4	-5.0	-3.2	-3.4	-4.6	-5.9	-9.7	-9.1	-9.5	-9.9	-8.4	-7.8
v_750 (KTS)	2.4	6.5	4.5	3.9	5.0	5.9	5.8	8.2	9.0	7.5	7.1	9.0	11.6	11.9	12.6	12.0	11.6	11.6	9.6	9.6	6.3	7.1
T_700 (C)	9.5	9.5	9.8	10.4	11.1	10.8	11.1	11.1	11.3	11.5	12.0	11.8	12.2	11.9	12.7	12.3	12.7	12.2	12.5	12.0	12.0	12.1
RH_700 (%)	87	81	79	69	64	67	67	68	66	62	59	54	45	51	47	45	46	46	46	52	58	59
Z_700 (DM)	314	312	312	310	311	309	310	308	310	309	310	308	309	308	310	309	311	309	311	310	311	310
u_700 (KTS)	-6.9	-3.8	-6.5	-6.1	-3.6	-4.9	-3.9	-5.0	-6.1	-2.8	-4.0	-5.6	-4.1	-4.9	-5.5	-6.4	-10.0	-9.7	-10.0	-9.3	-8.0	-7.4

Simple “SHIPS-type” text output files created from HWRF grid files for preliminary analysis

Error Methods

BIAS

$$\frac{1}{N}\sum_{i=1}^{i=N} HWRF_i - BTRK_i$$

MEAN ABSOLUTE ERROR

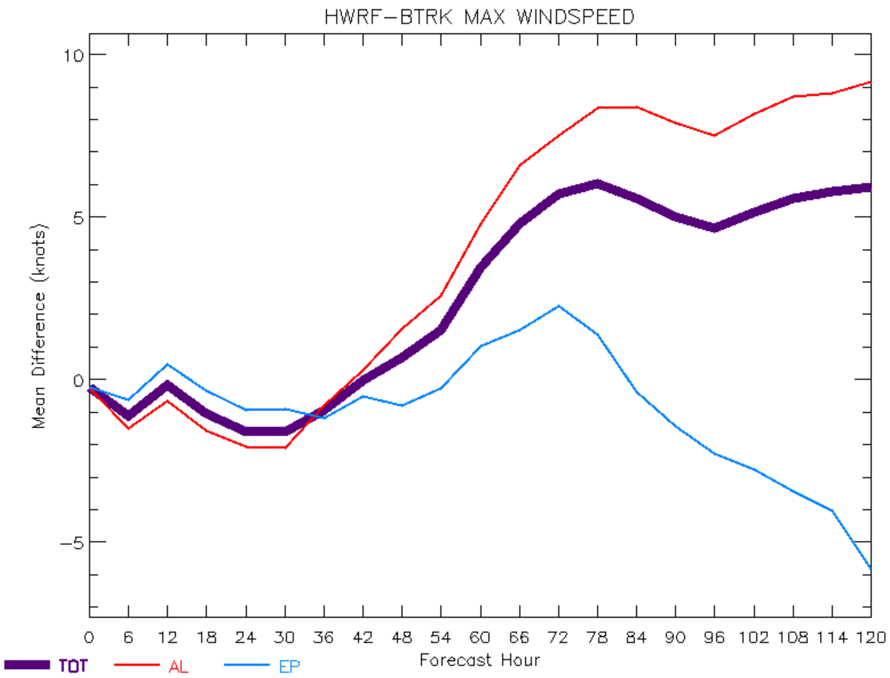
$$\frac{1}{N}\sum_{i=1}^{i=N} \left| HWRF_i - BTRK_i \right|$$

- **LATITUDE**: increasing toward north
- **LONGITUDE**: increasing toward east
- **CENTER LOCATION**: positioned at lowest SLP in HWRF nested grid
- **DISTANCE TO LAND**: positive over ocean, negative over land, HWRF and BTRK use identical land masks
- **SST**: five closest gridpoints under storm center in HWRF
- **VERT SHEAR**: 850-200hPa winds averaged from 300-350km around storm center in HWRF nested grid (200-800km in BTRK)
- **MAX WIND**: strongest 10m wind in HWRF nested grid

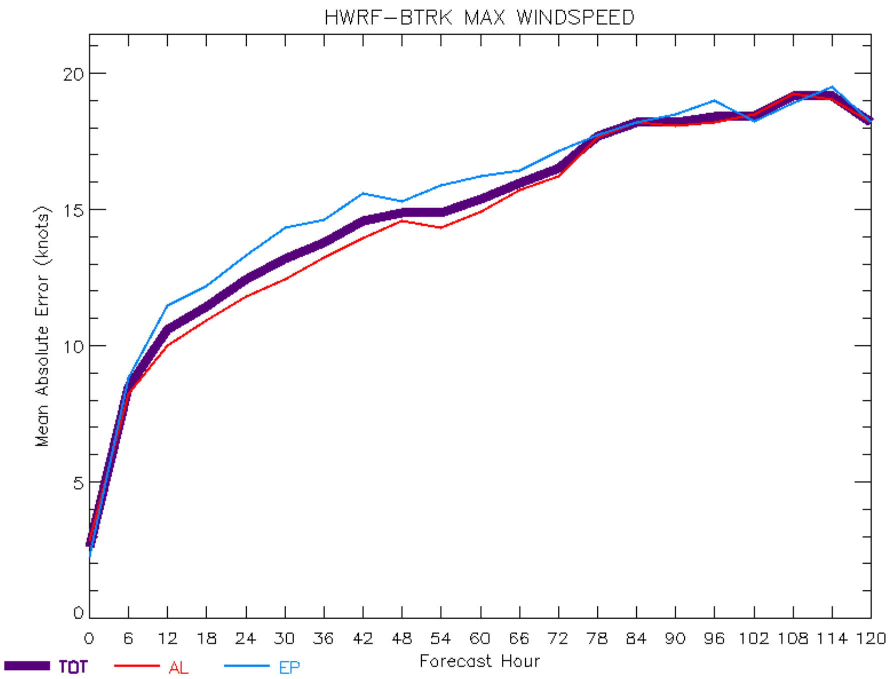
- Ground truth for lat, lon, max wind from NHC best track
- Ground "truth" for SST and Shear from SHIPS developmental dataset

Storm Errors : Maximum Wind

BIAS

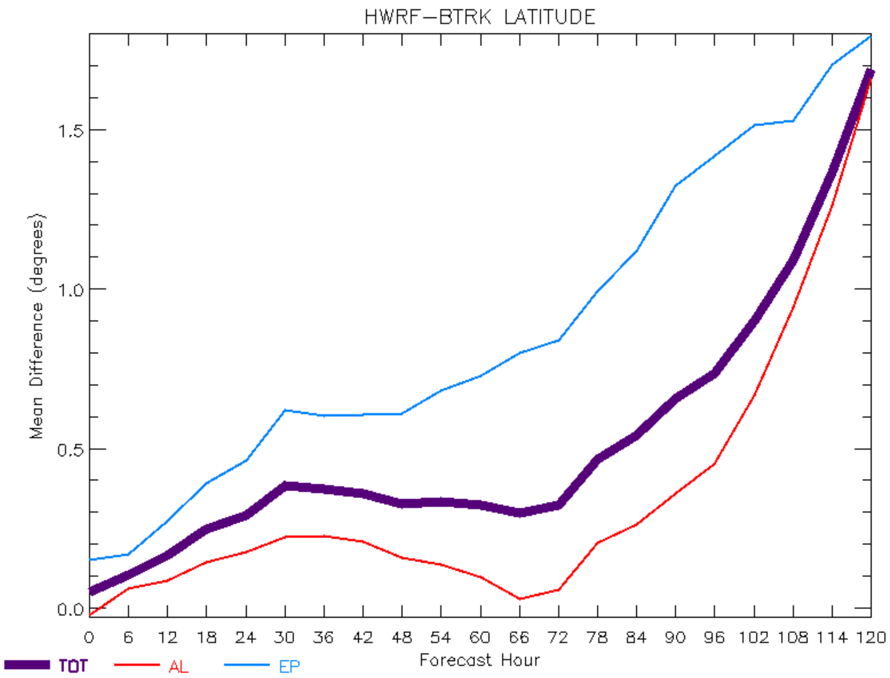


MEAN ABSOLUTE ERROR

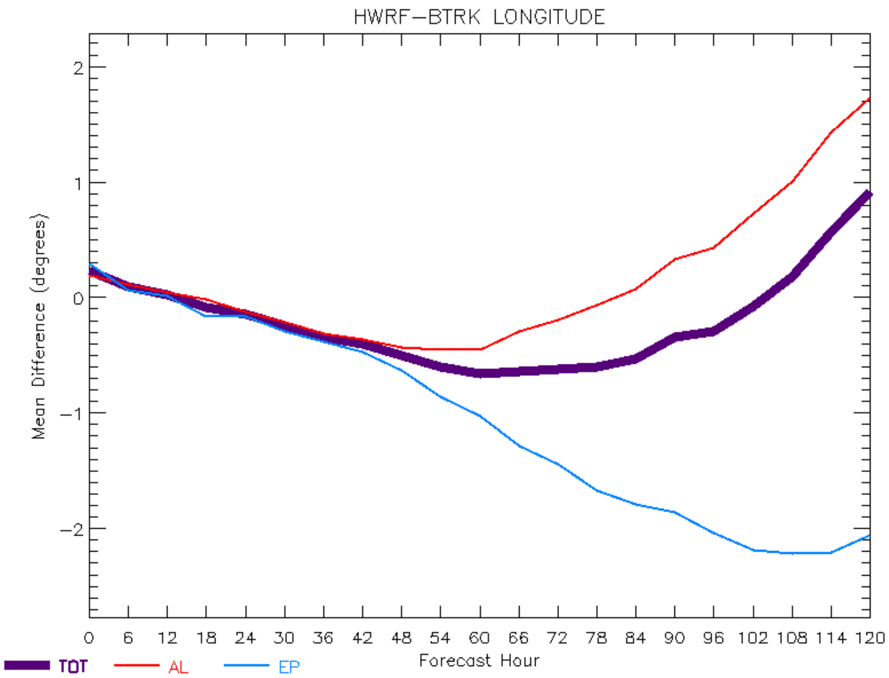


Lat/Lon Track Biases

Latitude Bias

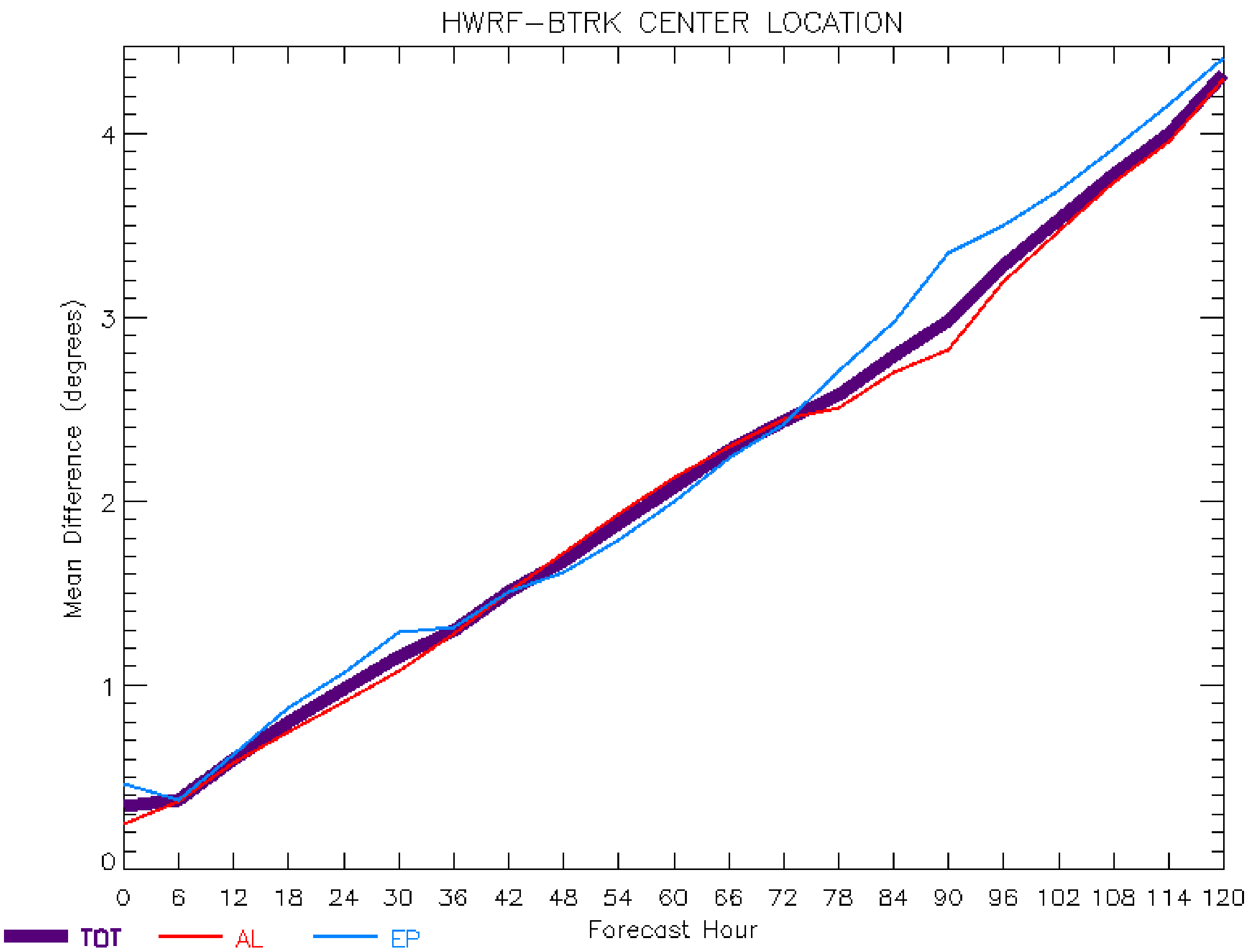


Longitude Bias



Track Errors : Center Location

Mean Absolute Errors



Track Errors : 30hr,60hr Truth Table

LAND/OCEAN TRUTH TABLE (t=30hr)

N_{TOT}= 457
N_{AL}= 274
N_{EP}= 183

HWRF \ BTRK	LAND	OCEAN
LAND	7.4% (11.3% / 1.6%)	2.8% (2.6% / 3.3%)
OCEAN	5.0% (6.9% / 2.2%)	84.7% (79.2% / 92.9%)

LAND/OCEAN TRUTH TABLE (t=60hr)

N_{TOT}= 345
N_{AL}= 222
N_{EP}= 123

HWRF \ BTRK	LAND	OCEAN
LAND	9.0% (13.1% / 1.6%)	1.4% (0.9% / 2.4%)
OCEAN	9.3% (13.5% / 1.6%)	80.3% (72.5% / 94.3%)

Track Errors : 90hr,120hr Truth Table

LAND/OCEAN TRUTH TABLE (t=90hr)

N_{TOT}= 249
N_{AL}= 172
N_{EP}= 77

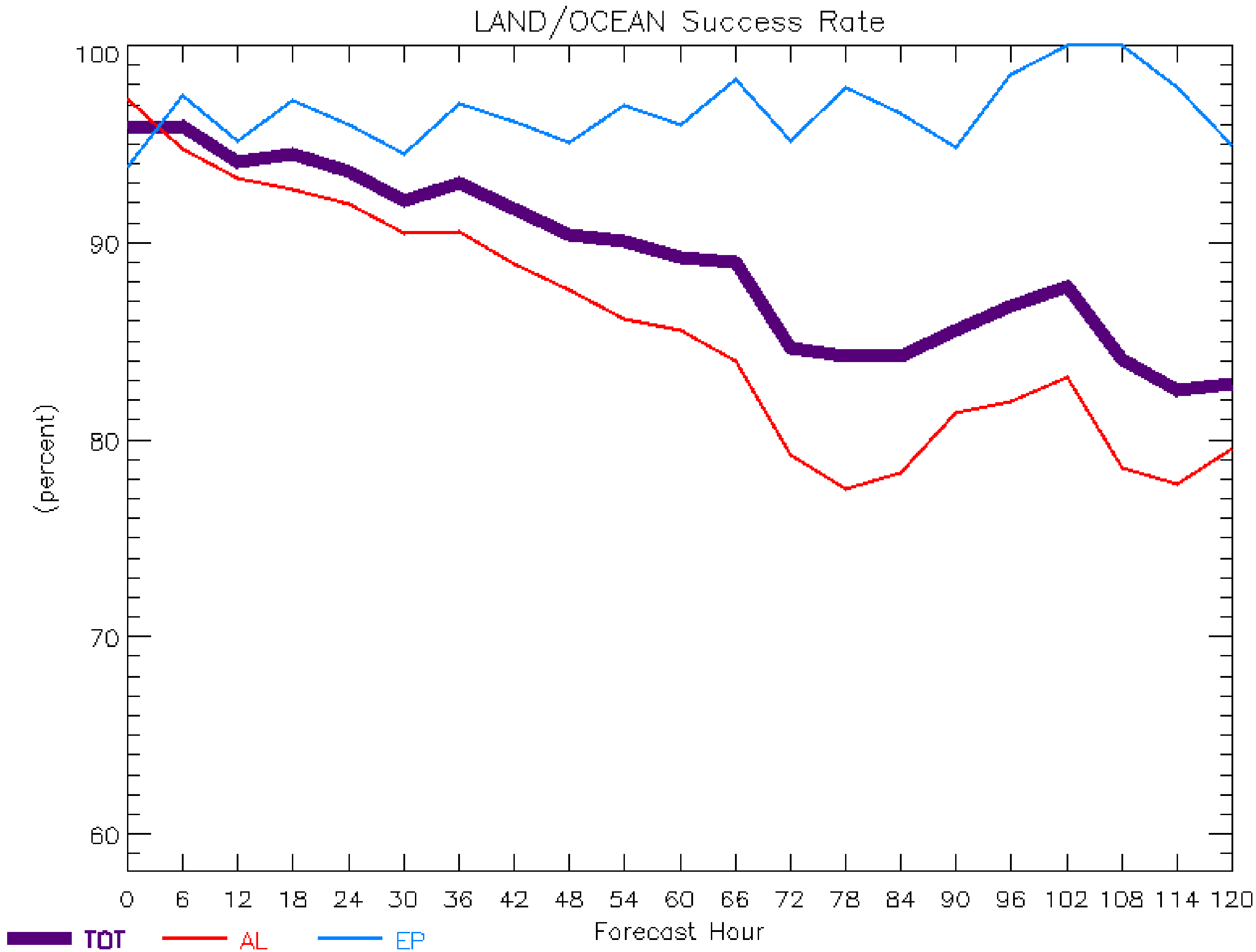
HWRF \ BTRK	LAND	OCEAN
LAND	14.1% (AL 18.6%, EP 3.9%)	4.8% (AL 5.2%, EP 3.9%)
OCEAN	9.6% (AL 13.4%, EP 1.3%)	71.5% (AL 62.8%, EP 90.9%)

LAND/OCEAN TRUTH TABLE (t=120hr)

N_{TOT}= 181
N_{AL}= 142
N_{EP}= 39

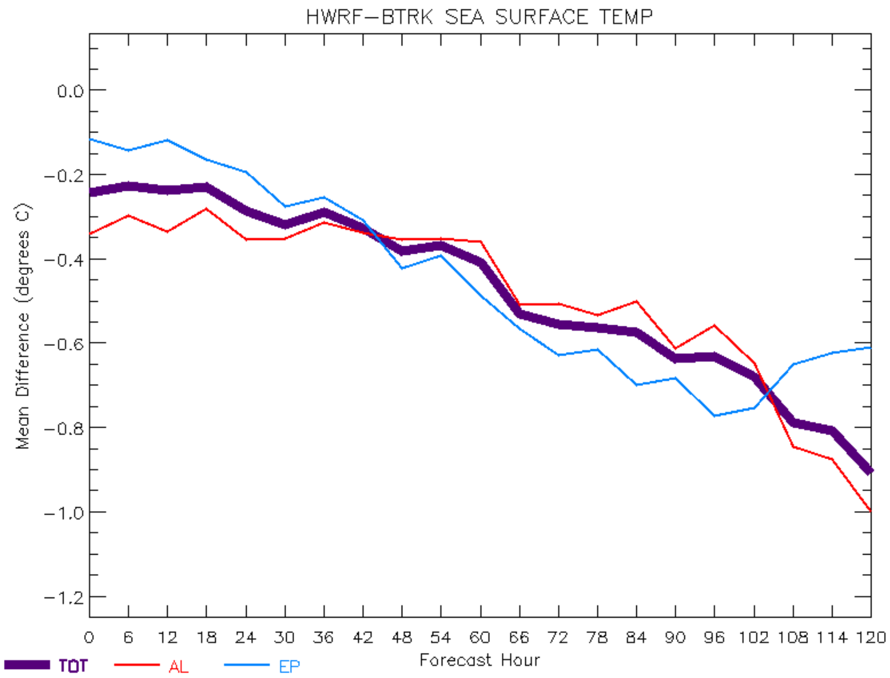
HWRF \ BTRK	LAND	OCEAN
LAND	16.6% (AL 18.3%, EP 10.3%)	6.6% (AL 7.0%, EP 5.1%)
OCEAN	10.5% (AL 13.4%, EP 0.0%)	66.3% (AL 61.3%, EP 84.6%)

Track Errors : Correct Surface Type

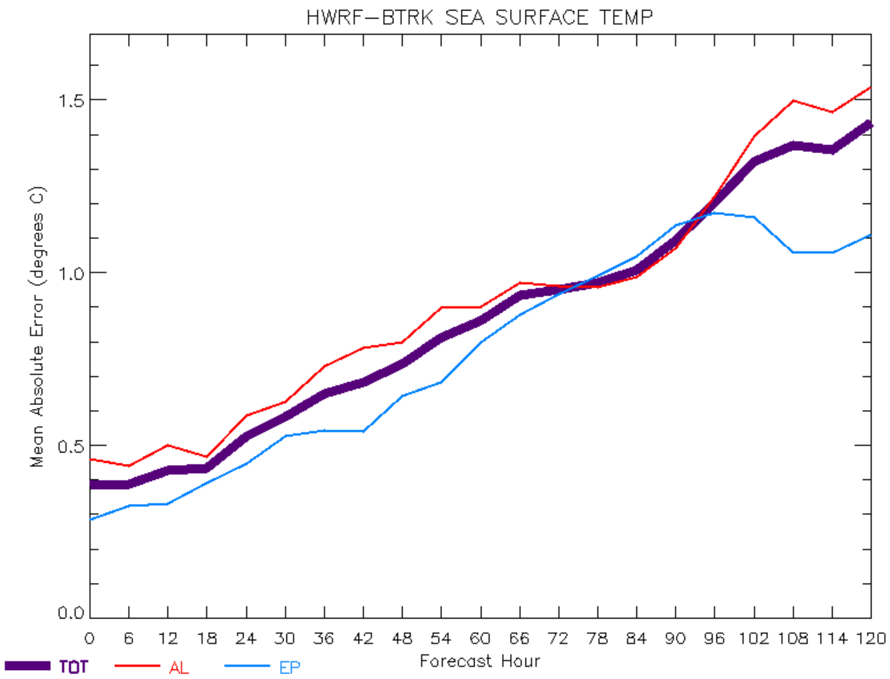


Storm Errors : Sea Surface Temp

BIAS

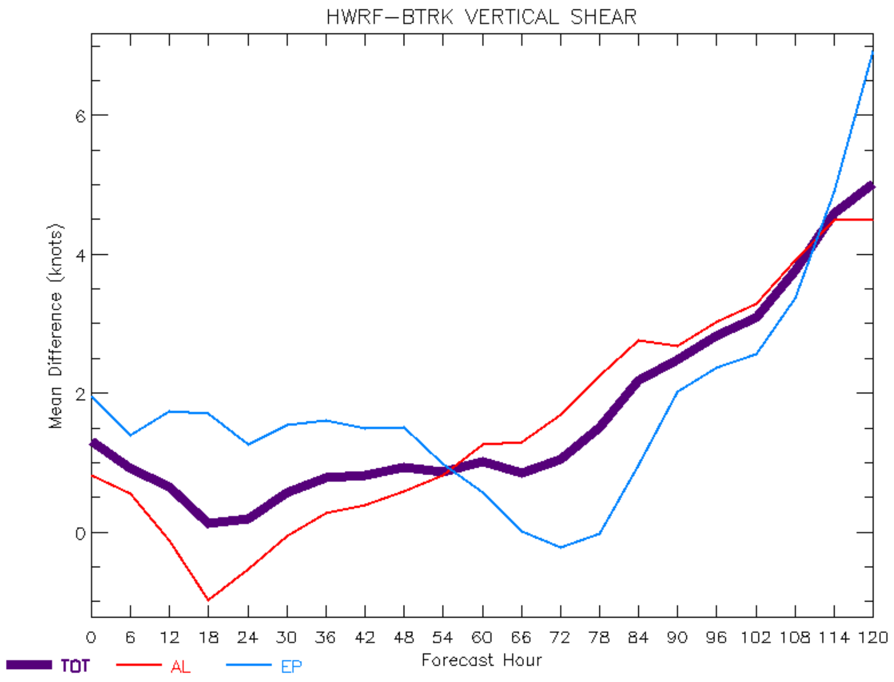


MEAN ABSOLUTE ERROR

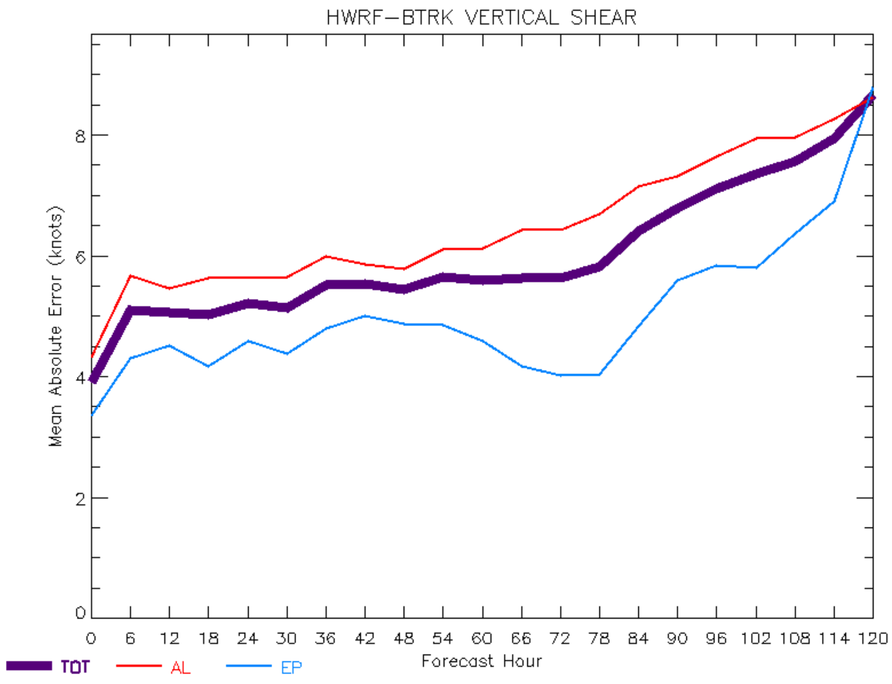


Storm Errors : Vertical Shear

BIAS



MEAN ABSOLUTE ERROR



Error/Bias Summary

- Track errors making significant contribution to intensity errors
- Bias Table

	Atlantic	East Pacific
Max Wind	+	-
Lat	+	+
Lon	+	-
Ocean/Land	+	neutral
SST	-	-
Shear	+	+

Evaluation of Storm Response to Forcing

- Use simplified version of LGEM model
  - Includes only MPI and vertical shear terms
- Use LGEM adjoint to find optimal coefficients for MPI and shear terms
- Fit to HWRF forecasts and to observations
- Compare fitted coefficients

Logistic Growth Equation (LGE) Model

$$dV/dt = \kappa V - \beta (V/V_{mpi})^n V$$

(A) (B)

Term A: Growth term, related to shear, structure, etc

Term B: Upper limit on growth as storm approaches its maximum potential intensity (V_{mpi})

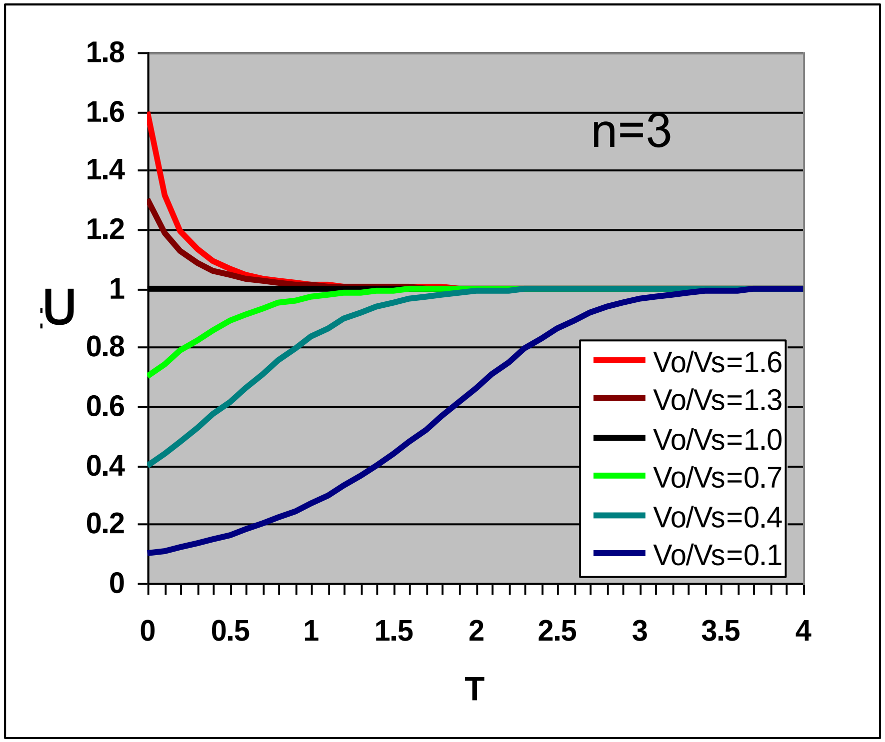
LGEM Parameters:

$\kappa(t)$	**Growth rate**
β	**MPI relaxation rate**
$V_{mpi}(t)$	**MPI**
n	**"Steepness" parameter**

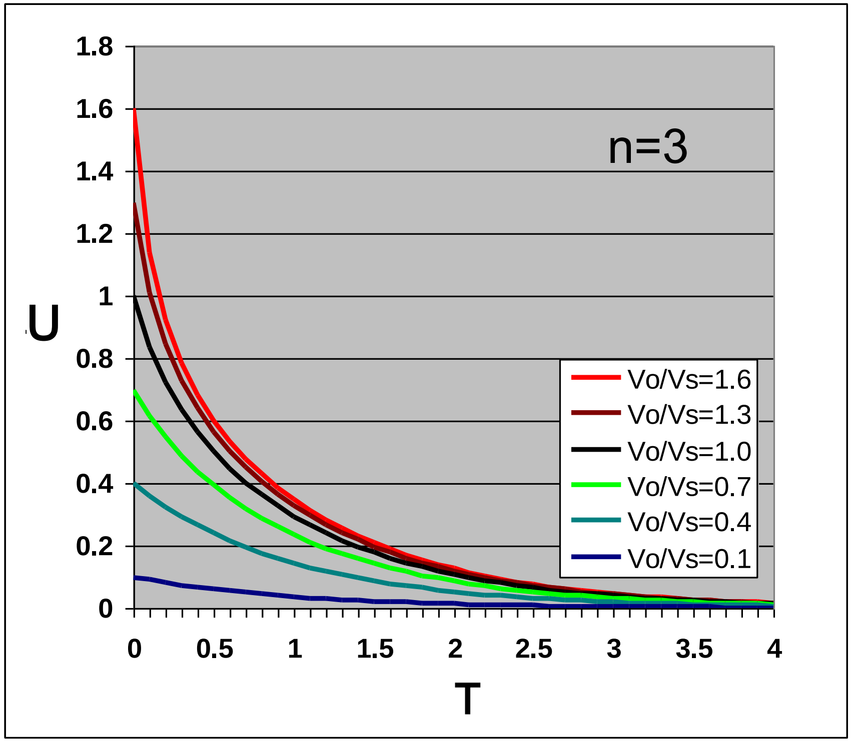
LGE replaced by Kaplan and DeMaria inland wind decay model over land

Analytic LGE Solutions for Constant β, κ, n, V_{mpi}

V_s = Steady State V = $V_{mpi}(\kappa/\beta)^{1/n}$
Let $U = V/V_s$ and $T = \kappa t$
$dU/dT = U(1-U^n)$
$U(t) = U_o\{e^{nT}/[1 + (e^{nT}-1)(U_o)^n]\}^{1/n}$



$\kappa > 0$



$\kappa < 0$

LGEM Parameter Estimation

- V_{mpi} from
  - DeMaria and Kaplan (1994)
    - empirical formula f(SST), SST from Reynolds analysis
- Find parameters n, β, κ to minimize model error
- LGEM model is dynamical system, so data assimilation techniques can be used
  - Adjoint model provides method for parameter estimation

Application of Adjoint LGE Model

- Discretized forward model:

  $V_0 = V_{obs}(t=0)$

  $V_{\tau+1} = V_\tau + [\kappa_\tau V_\tau - \beta(V_\tau / V_{mpi\,\tau})^n V_\tau]\Delta t, \quad \tau=1,2,\ldots T$
- Error Function:

  $E = ½\, \Sigma(V_\tau - V_{obs\,\tau})^2$
- Add forward model equations as constraints:

  $J = E + \Sigma\lambda_\tau\{V_{\tau+1} - V_\tau - [\kappa_\tau V_\tau - \beta(V_\tau / V_{mpi\,\tau})^n V_\tau]\Delta t\}$
- Set dJ/dV_τ = to give adjoint model for λ_τ

  $\lambda_T = -(V_T - V_{obsT}),$

  $\lambda_\tau = \lambda_{\tau+1}\{\kappa_\tau - \beta(n+1)(V_\tau / V_{mpi\tau})^n]\Delta t\} - (V_\tau - V_{obs\tau}), \ \tau=T-1,T-2,\ldots$
- Calculate gradient of J wrt to unknown parameters

  $dJ/d\beta = -\Delta t\, \Sigma\lambda_\tau V_{\tau-1}$

  $dJ/dn = \Delta t\, \Sigma\lambda_\tau (V_{\tau-1}/V_{mpi\tau-1})^n V_{\tau-1}$

  $dJ/d\kappa = \Delta t\, \Sigma\lambda_\tau (V_{\tau-1}/V_{mpi\tau-1})^n \ln(V_{\tau-1}/V_{mpi\,\tau-1})^n V_{\tau-1}$
- Use gradient descent algorithm to find optimal parameters

Estimation of Growth Rate κ

- Operational LGEM
  - κ linear function of SHIPS predictors
  - Adjoint currently not used for fitting
- HWRF study
  - Assume κ is linear function of shear (S)

    $\kappa = a_0 + a_1 S$
  - Use adjoint model to find a_0, a_1, β, n
  - a_1 determines shear response
  - β, n determine SST response through MPI term

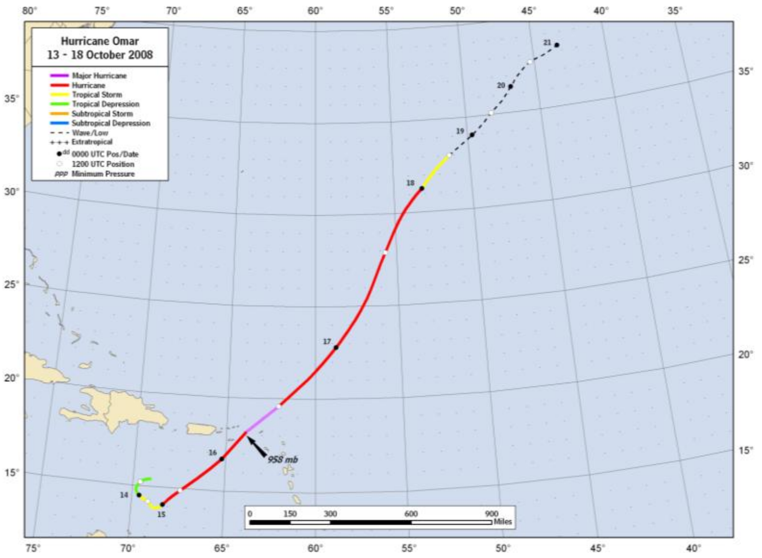
Example of LGEM Fitting

- Hurricane Omar (2008)
- Find 4 constants to minimize 5-day LGEM forecast
- Input:
  - Observed track, SST, shear
- Optimal parameters

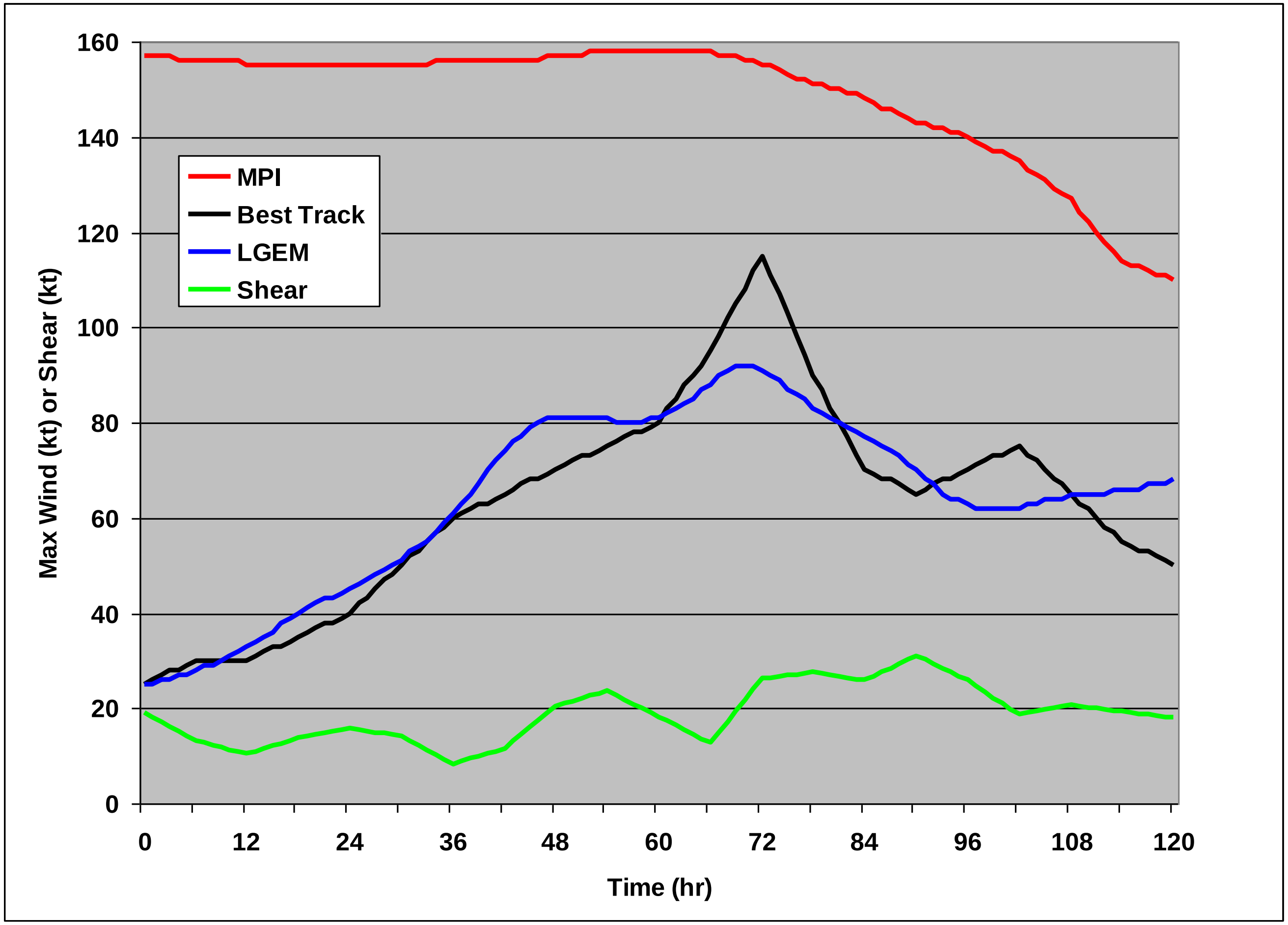
$\beta = 0.034 \quad n = 2.61$

$a_1 = -0.026 \quad a_0 = 0.017$

$\beta^{-1} = 29$ hr $\quad |a_1^{-1}| = 36$ hr



Optimal LGEM Forecast with Observational Input



Mean Absolute Intensity Error = 6.3 kt

Fitting LGEM to Entire 2008 Atlantic Season
Observations and HWRF Forecasts

- Obs β=0.050 n=1.7 a_0=0.018 a_1=-0.0032 MAE=11.2 kt
- HWRF β=0.022 n=1.1 a_0=0.011 a_1=-0.0080 MAE=13.2 kt

- Implications
  - **HWRF more sensitive to vertical shear than observations**
  - **SST signal mixed (consider β and n together)**
    - MPI coefficient = $\beta(V/V_{mpi})^n$
    - HWRF more sensitive to SST for low max winds
    - HWRF less sensitive to SST for high max winds
  - **HWRF forecasts harder to fit than Observations**
    - Other factors beside SST/Shear may be important
    - HWRF may have different MPI function

Summary

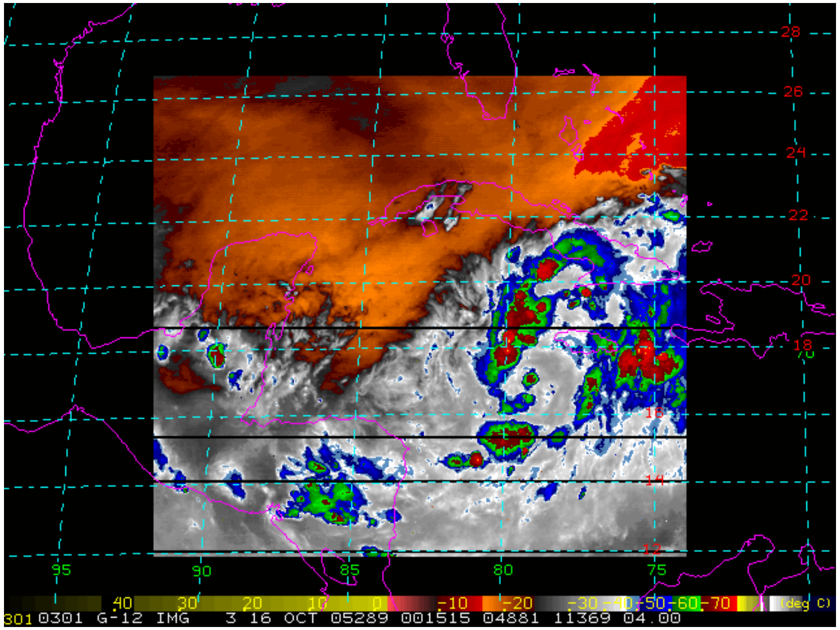
- Preliminary diagnostic analysis of 2008 HWRF runs
- Track error may be significant contribution to Atlantic intensity error
- Biases differ between Atlantic and east Pacific
  - Track, SST, Shear biases help explain East Pacific intensity bias, but not Atlantic
- Preliminary analysis using LGEM fit indicates response to SST and Shear in HWRF is different than observations

Future Plans

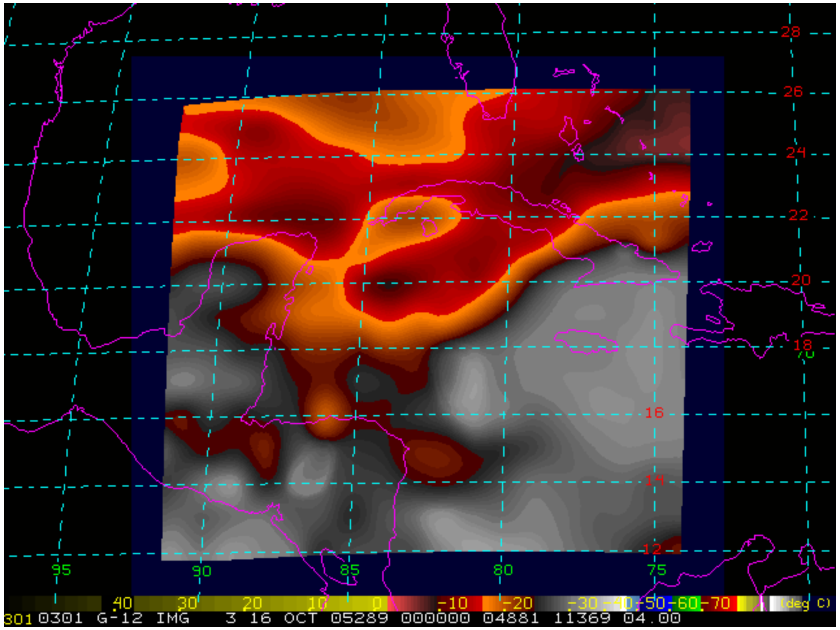
- Continue current analysis on east Pacific cases
- Investigate vertical instability impact on intensity changes
- Examine HWRF MPI relationships
- Evaluation HWRF in “GOES IR space”
  - Apply radiative transfer to HWRF output to create simualted imagery
  - Need vertical profiles of T, RH and all condensate variables
- Develop applications of ensemble forecasts using NHC wind probability model framework

Example of Simulated Imagery
Hurricane Wilma 2005

GOES-East Channel 3



Channel 3 from RAMS Model Output



Back-Up Slides

Summary of Cases

• Atlantic

	# OF RUNS	# OF INDIV TIMES
ARTHUR	4	14
BERTHA	62	1155
CRISTOBAL	14	119
DOLLY	16	231
EDOUARD	8	44
FAY	34	678
GUSTAV	29	554
HANNA	38	603
IKE	50	840
JOSEPHINE	15	120
KYLE	13	104
LAURA	9	45
MARCO	5	15
NANA	5	20
OMAR	15	120
PALOMA	14	105
	331	4767

• East Pacific

	# OF RUNS	# OF INDIV TIMES
ALMA	4	18
BORIS	27	377
CHRISTINA	9	45
	6	27
	23	355
	22	291
	22	252
	24	294
	8	45
	9	63
	3	9
	18	171
	22	252
	29	431
	13	109
	6	26
	245	2765

• Total

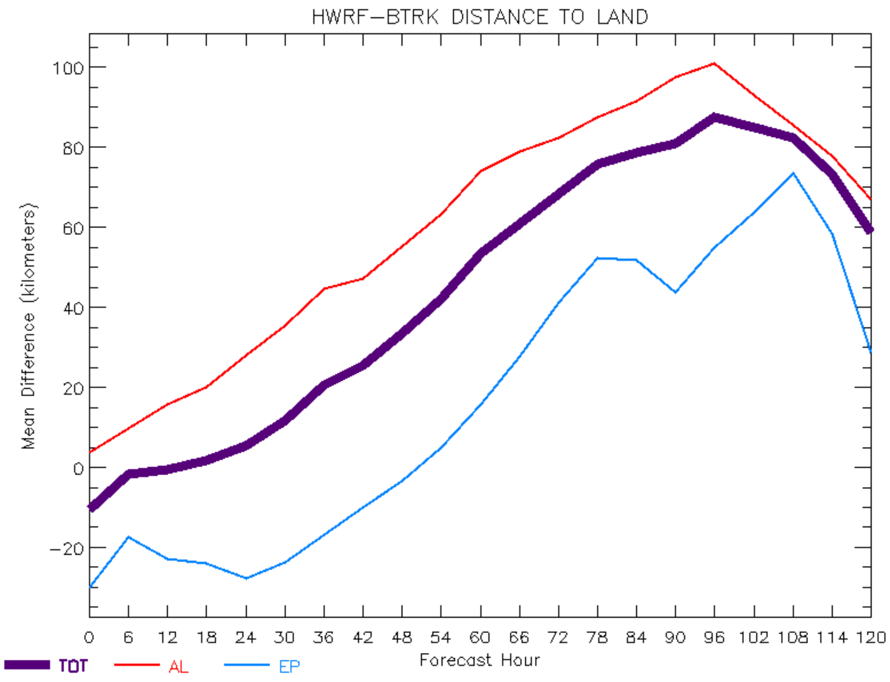
- 576 HWRF runs during 2008 *

- 7532 individual times to compare an HWRF analysis or forecast to Best Track data *

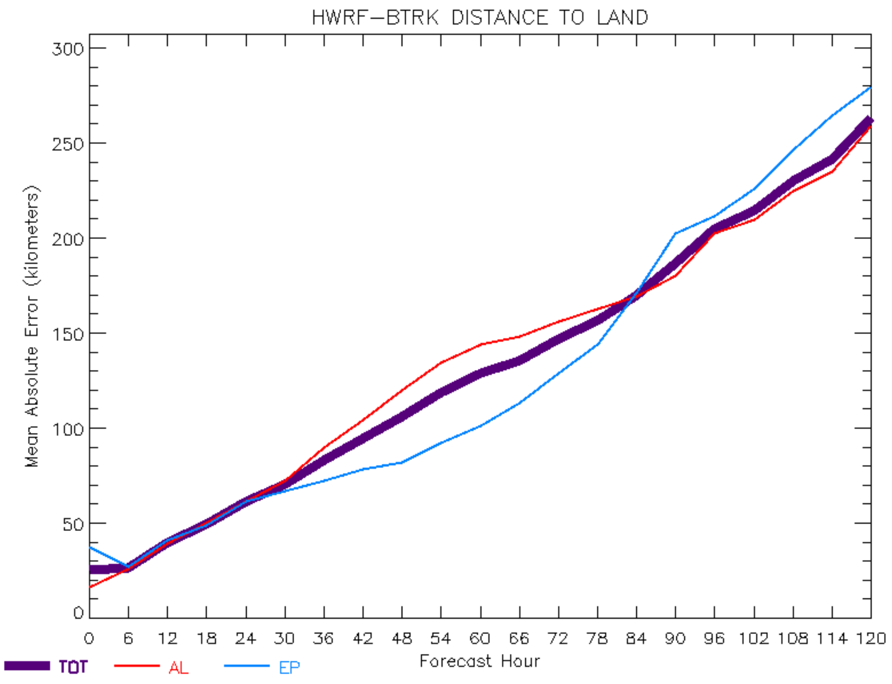
*** HWRF runs only counted for *named* storms in Best Track database**

Track Errors : Distance to Land

BIAS



MEAN ABSOLUTE ERROR



Track Errors : 0hr Truth Table

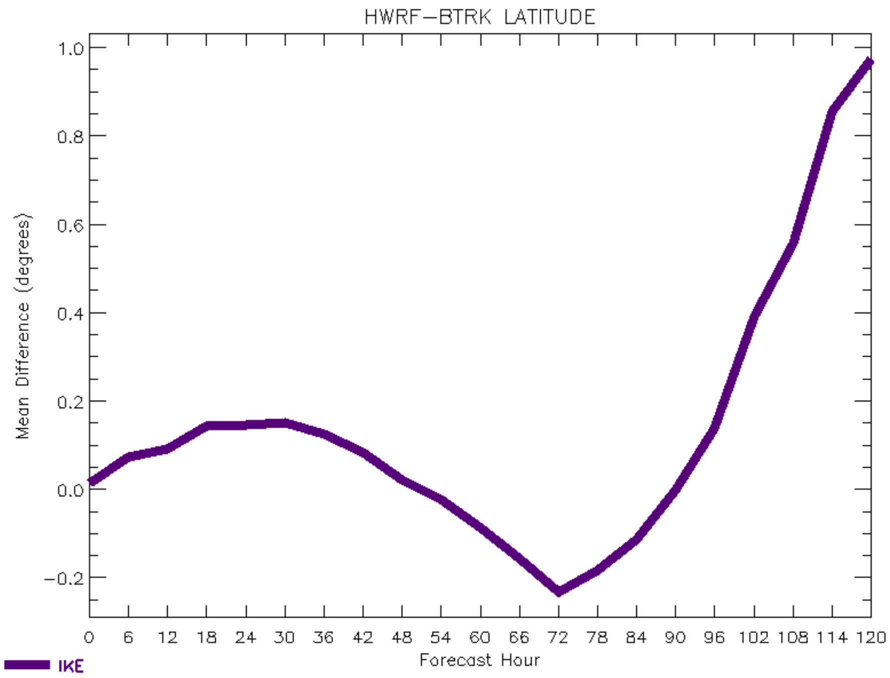
LAND/OCEAN TRUTH TABLE (t=0hr)

N_{TOT}= 576
N_{AL}= 331
N_{EP}= 245

HWRF \ BTRK	LAND	OCEAN
LAND	7.3% (10.9% / 2.4%)	2.3% (0.0% / 5.3%)
OCEAN	1.9% (2.7% / 0.8%)	88.5% (86.4% / 91.4%)

IKE Track Errors : Latitude

BIAS



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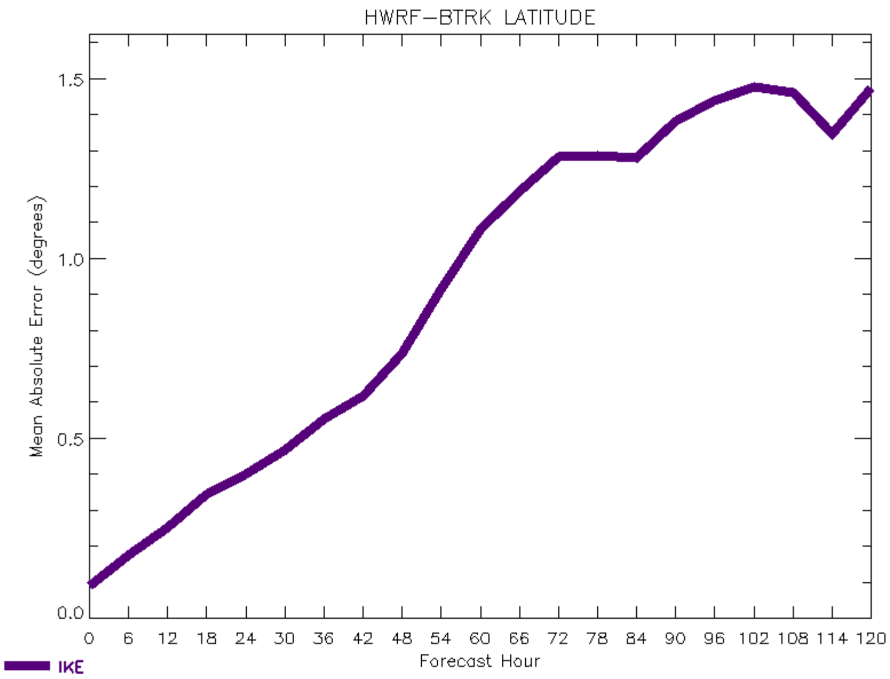
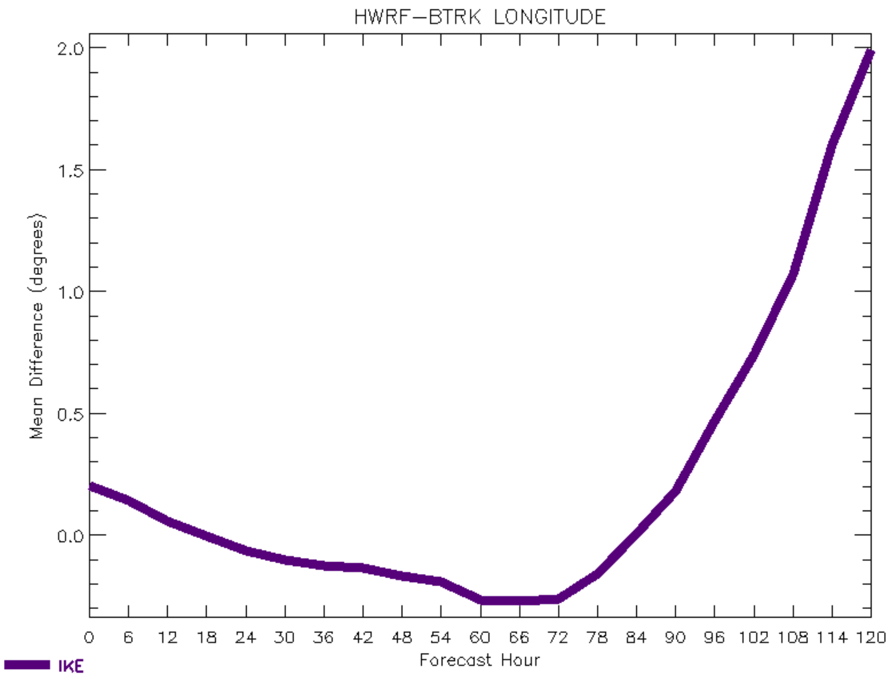


IKE Track Errors : Longitude

BIAS



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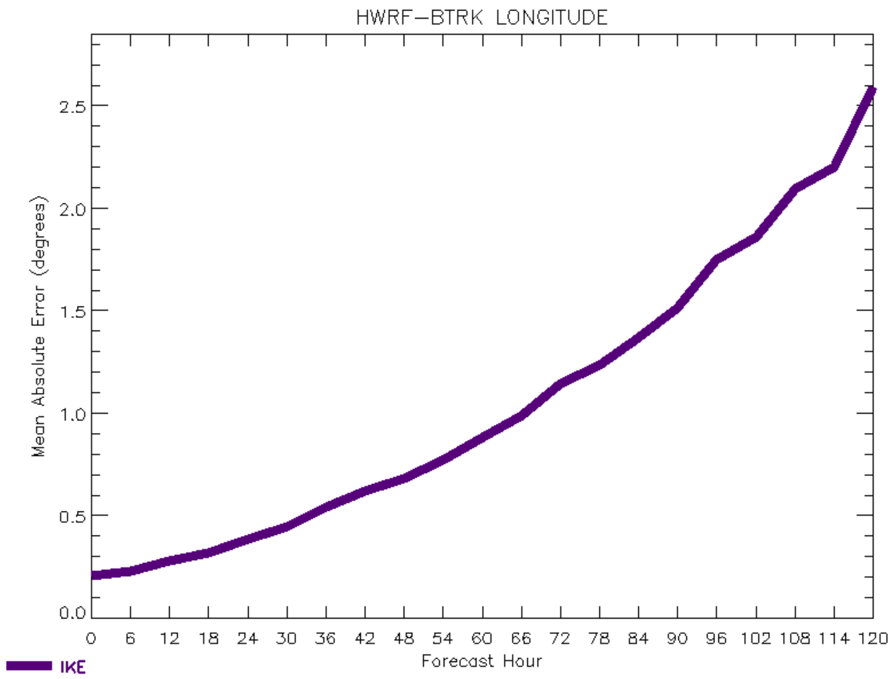
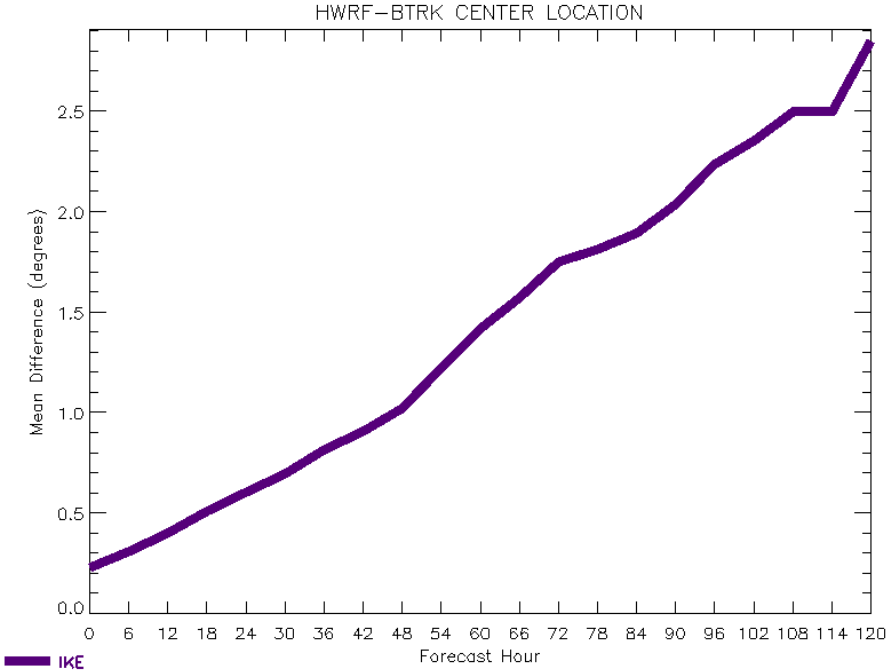


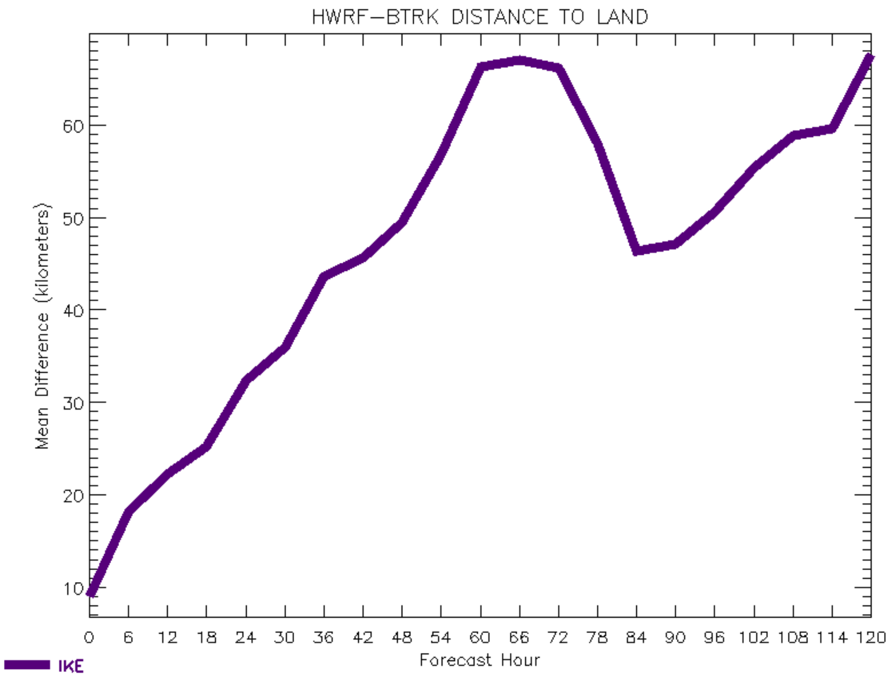
IKE Track Errors : Center Location

BIAS

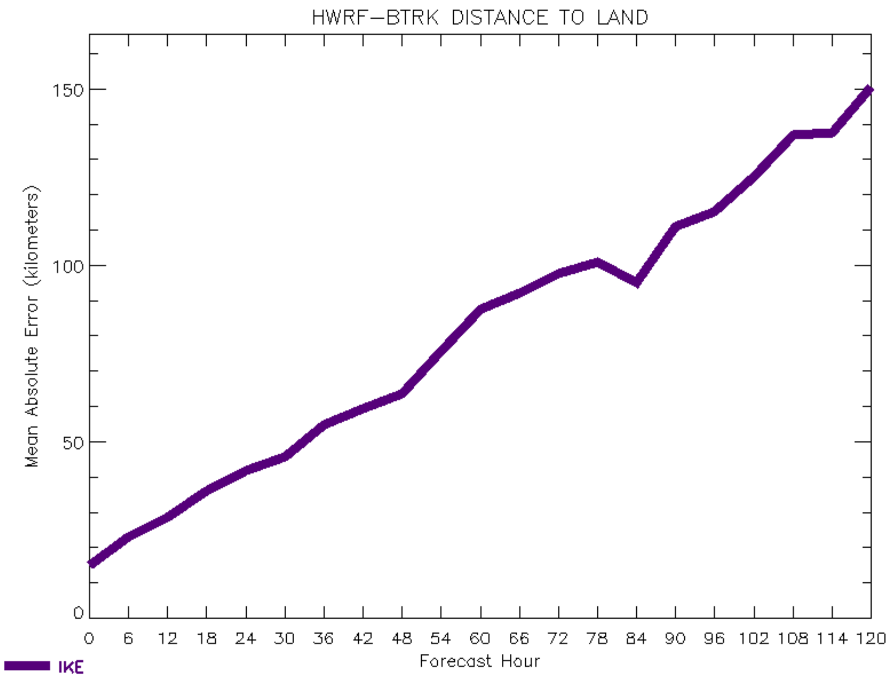


IKE Track Errors : Distance to Land

BIAS



MEAN ABSOLUTE ERROR



IKE Track Errors : 0hr Truth Table

LAND/OCEAN TRUTH TABLE (t=0hr)

N_{IKE}= 50

HWRF \ BTRK	LAND	OCEAN
LAND	12.0%	0.0%
OCEAN	2.0%	86.0%

IKE Track Errors : 30hr,60hr Truth Table

LAND/OCEAN TRUTH TABLE (t=30hr)

N_{IKE}= 45

HWRF \ BTRK	LAND	OCEAN
LAND	11.1%	6.7%
OCEAN	4.4%	77.8%

LAND/OCEAN TRUTH TABLE (t=60hr)

N_{IKE}= 40

HWRF \ BTRK	LAND	OCEAN
LAND	10.0%	5.0%
OCEAN	5.0%	80.0%

IKE Track Errors : 90hr,120hr Truth Table

LAND/OCEAN TRUTH TABLE (t=90hr)

N_{IKE}= 35

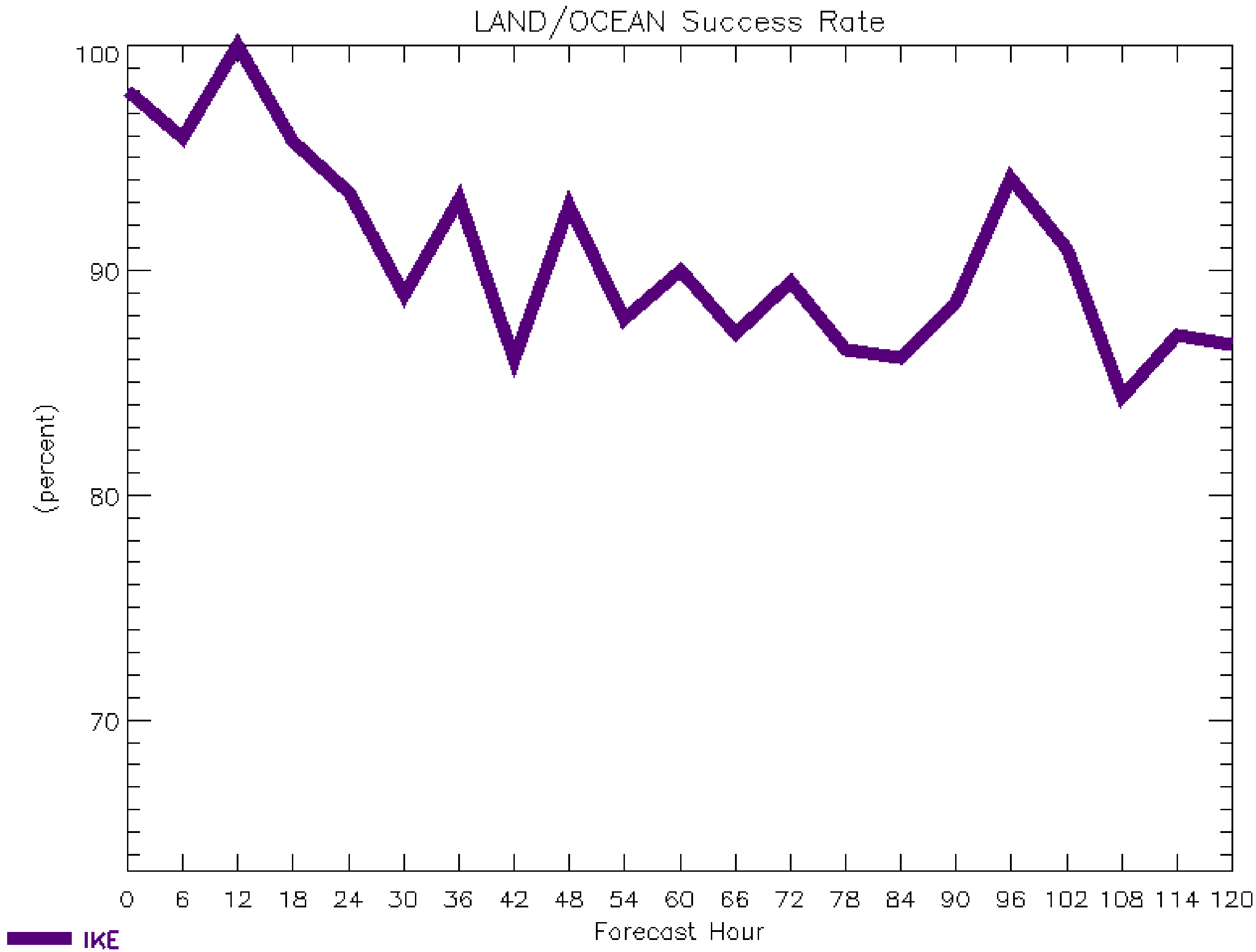
HWRF \ BTRK	LAND	OCEAN
LAND	11.4%	2.9%
OCEAN	8.6%	77.1%

LAND/OCEAN TRUTH TABLE (t=120hr)

N_{IKE}= 30

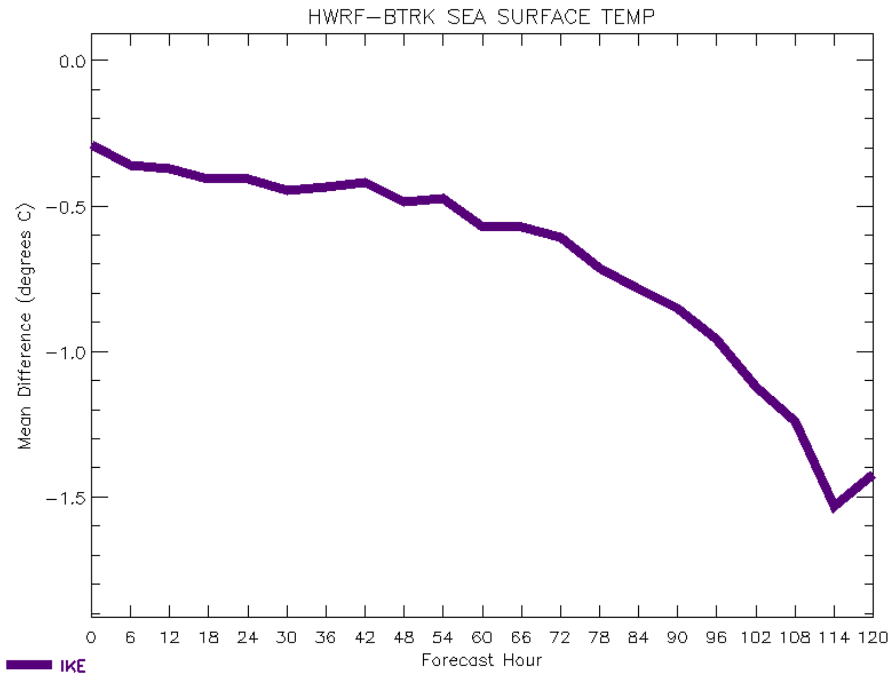
HWRF \ BTRK	LAND	OCEAN
LAND	13.3%	3.3%
OCEAN	10.0%	73.3%

IKE Track Errors : Correct Land Type



IKE Storm Errors : Sea Surface Temp

BIAS



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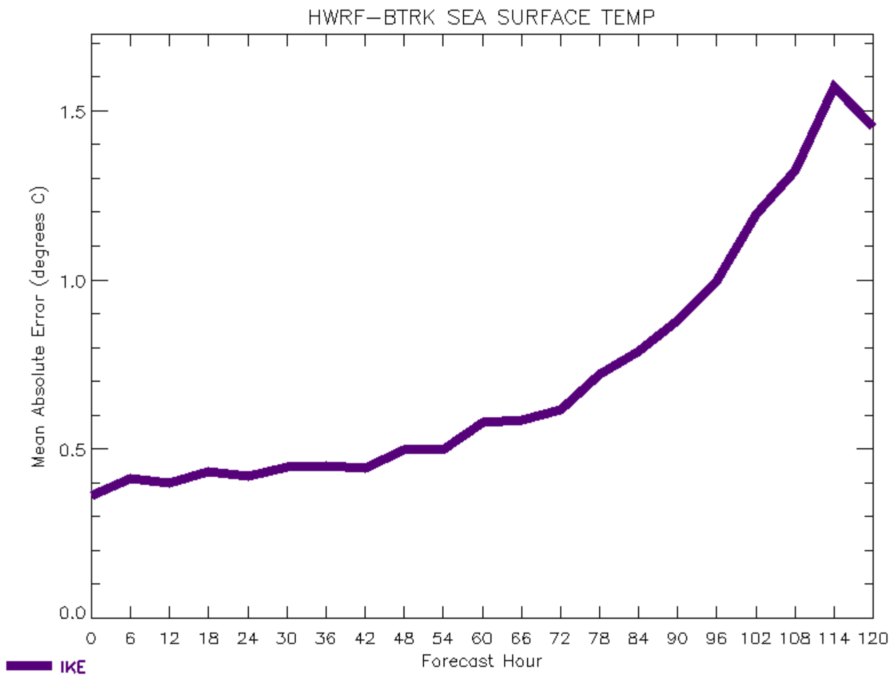
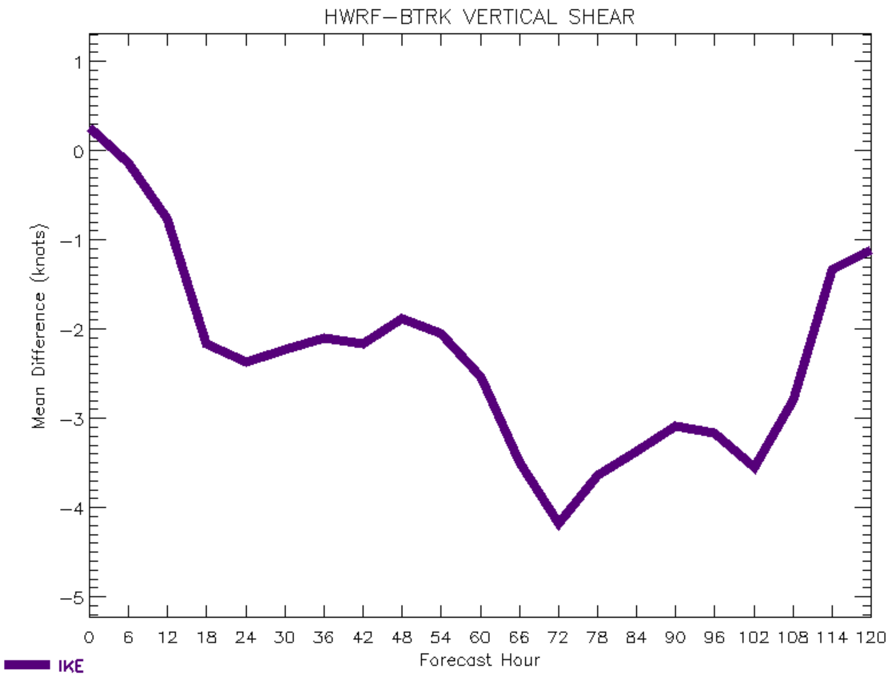


IKE Storm Errors : Vertical Shear

BIAS



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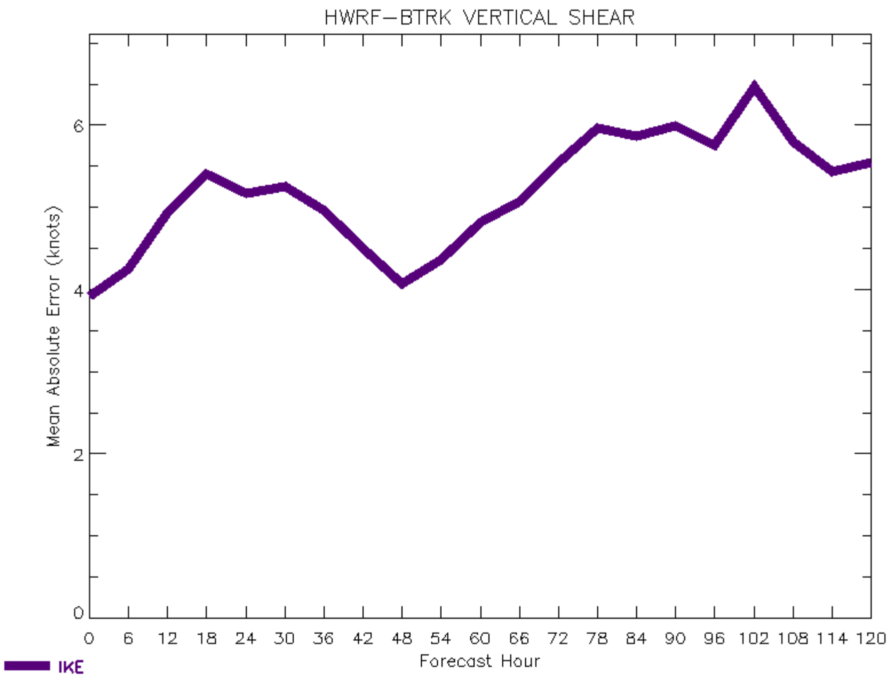
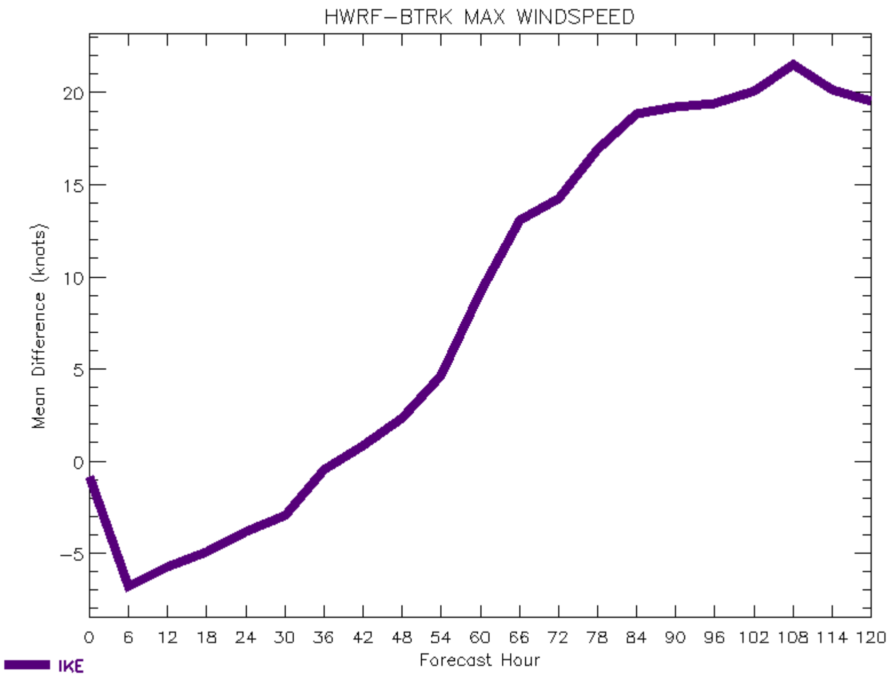


IKE Storm Errors : Maximum Wind

BIAS



MEAN ABSOLUTE ERROR