Hurricane Model Diagnostics: Synoptic to Cloud Scale

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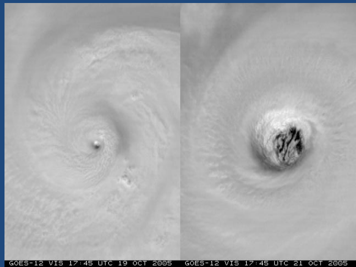
HWRF Tutorial Workshop
April 2011



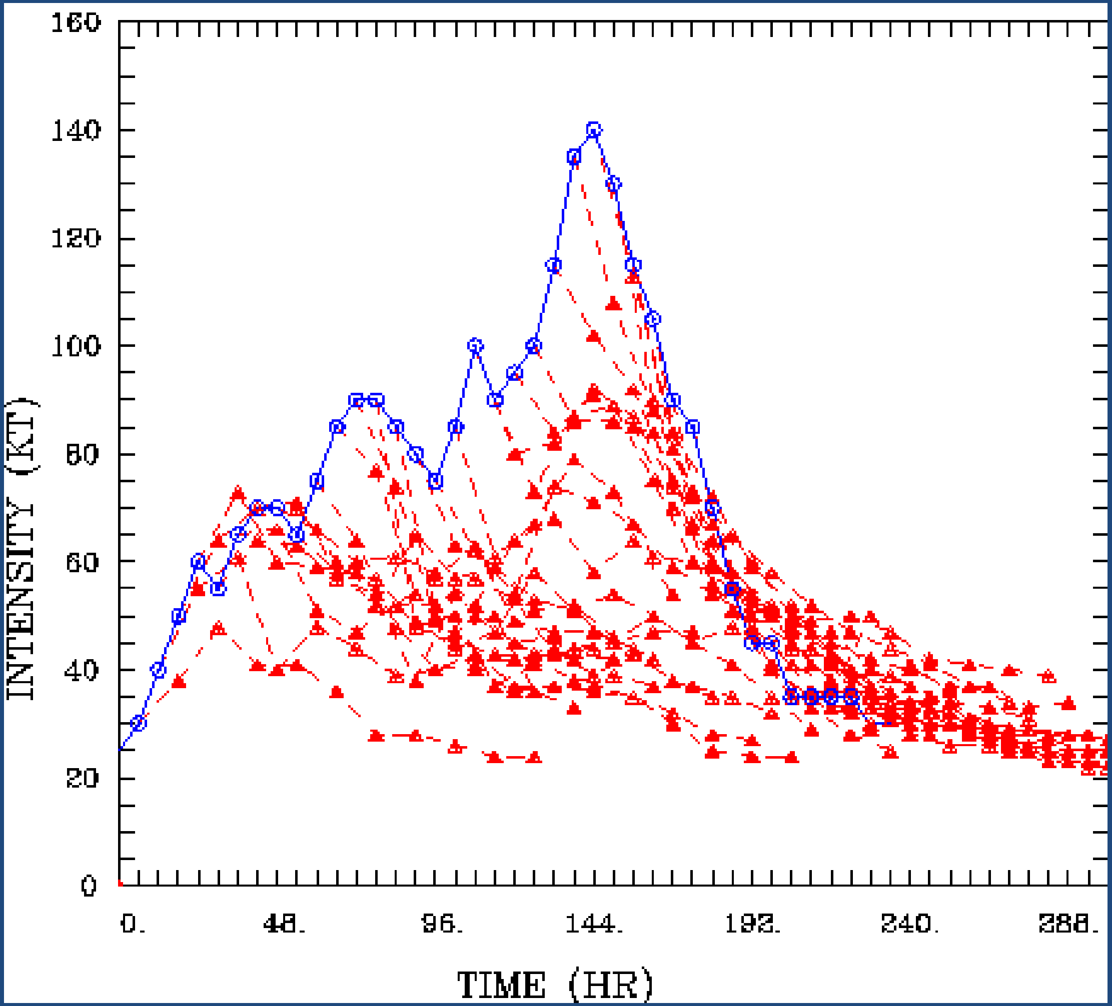
Outline

- Purposes of Model Diagnostics
- Examples
  1. Climate models
  2. TC genesis forecasts
  3. Vortex structure analysis
  4. Vortex asymmetries
  5. Statistical diagnostics of inner core
  6. Forward radiative transfer model diagnostics
- Diagnostic software packages

Why are Model Diagnostics Needed?

- Lorenz (Tellus, 1960), Maximum Simplification of the Dynamic Equations
  – Numerical model forecasts, even if they were someday perfect, don’t lead to physical insight.
- Implication: If models are a good representation of the chaotic atmosphere-ocean-land system, they will be almost as hard to understand as nature
  – Bad forecast models will be hard to fix

HWRF Intensity Forecasts for Hurricane Celia (2010)



Diagnostic Studies

- Evaluate variables derived from a model in the context of a conceptual or theoretical framework for improved understanding
  - Expected response to storm translation
  - Gradient balance
  - Energy and angular momentum budgets
- Model to model inter-comparisons
- Comparison with observations
  - Case studies and statistical comparisons
- Use model output as “data” to understand physical processes
  - Ocean feedback
  - Impact of vertical shear on vortex tilt

Example 1: Model Inter-comparisons

- Program for Climate Model Diagnosis and Inter-comparison (PCMDI)
- Develops improved methods and tools for the diagnosis and intercomparisons of GCMs
- Comparisons must be systematic between models
  - Shared tools and standardized climate runs
- Being applied to Intergovernmental Panel on Climate Change (IPCC) models

http://www.clivar.org/organization/wgcm/references/Taylor_CMIP5.pdf

From: A Summary of the CMIP5 Experiment Design
Lead authors: Karl E. Taylor, Ronald J. Stouffer, and Gerald A. Meehl, 22 January 2011*

Table 6. Diagnostic experiments for understanding the long-term simulations.

	#	Experiment	Notes	# of years
CORE	6.1	Idealized 1%/yr run to 4x pre-industrial CO_2.	This run is initialized from the pre-industrial control (expt. 3.1) and CO_2 concentration is prescribed to increase at 1%/yr.	140
CORE	6.2a	Baseline for prescribed SST experiments (6.2b, 6.4a,b).	An atmosphere-only run driven by prescribed SST and sea ice consistent with the climatology of the pre-industrial control run (expt. 3.1)	≥30
CORE	6.2b	Perturbed run for Hansen-style diagnosis of "fast" climate system responses to $4xCO_2$.	As in expt. 6.2a above, but with atmospheric CO_2 concentration quadrupled, relative to pre-industrial level.	≥30
CORE	6.3	Gregory-style diagnosis of "slow" climate system responses.	Impose an instantaneous quadrupling of atmospheric CO_2 concentration (relative to pre-industrial) and then hold it fixed.	150
TIER 1	6.3-E	Ensemble of runs to improve the estimate of the "fast" climate response diagnosed with the Gregory method.	Generate an ensemble of runs initialized in different months of the year and terminated after year 5, but otherwise as in expt. 6.3. [Counting the initial segment of expt. 6.3, the ensemble size will be 12.]	11x5
TIER 1	6.4a & 6.4b	Hansen-style diagnosis of "fast" climate system responses to all anthropogenic aerosols (6.4a) and to sulfate aerosols (6.4b) alone for the year 2000.	As in expt. 6.2a above, but with aerosols consistent with conditions in year 2000 of the historical run (expt. 3.2)	≥2x30
TIER 1	6.5	Cloud response to imposed $4xCO_2$ (Hansen-style diagnosis of "fast" climate system responses).	Consistent with CFMIP requirements, the AMIP conditions are imposed (expt. 3.3, which is the control for this run), but the radiation code (only) sees quadrupled CO_2, relative to AMIP.	30
TIER 1	6.6	Cloud response to an imposed change in SST pattern.	Consistent with CFMIP requirements, add a patterned SST perturbation to the AMIP SSTs of expt. 3.3 (which is the "control" for this run).	30
TIER 1	6.7a	Aqua-planet : control run	Consistent with CFMIP requirements (with CO_2 set to AMIP mean concentration), impose zonally uniform SSTs on a planet without continents.	5
TIER 1	6.7b	Aqua-planet: cloud response to imposed $4xCO_2$ (Hansen-style diagnosis).	Consistent with CFMIP requirements, impose $4xCO_2$ (relative to AMIP mean CO_2) on the zonally uniform SSTs of expt. 6.7a (which is the control for this run).	5
TIER 1	6.7c	Aqua-planet: cloud response to an imposed uniform change in SST.	Consistent with CFMIP requirements, add a uniform +4K to the zonally uniform SSTs of expt. 6.7a (which is the control for this run).	5
TIER 2	6.8	Cloud response to an imposed uniform change in SST	Consistent with CFMIP requirements, add a uniform +4 K SST to the AMIP SSTs of expt. 3.3 (which is the "control" for this run).	30

*Available from http://www.clivar.org/organization/wgcm/references/Taylor_CMIP5.pdf

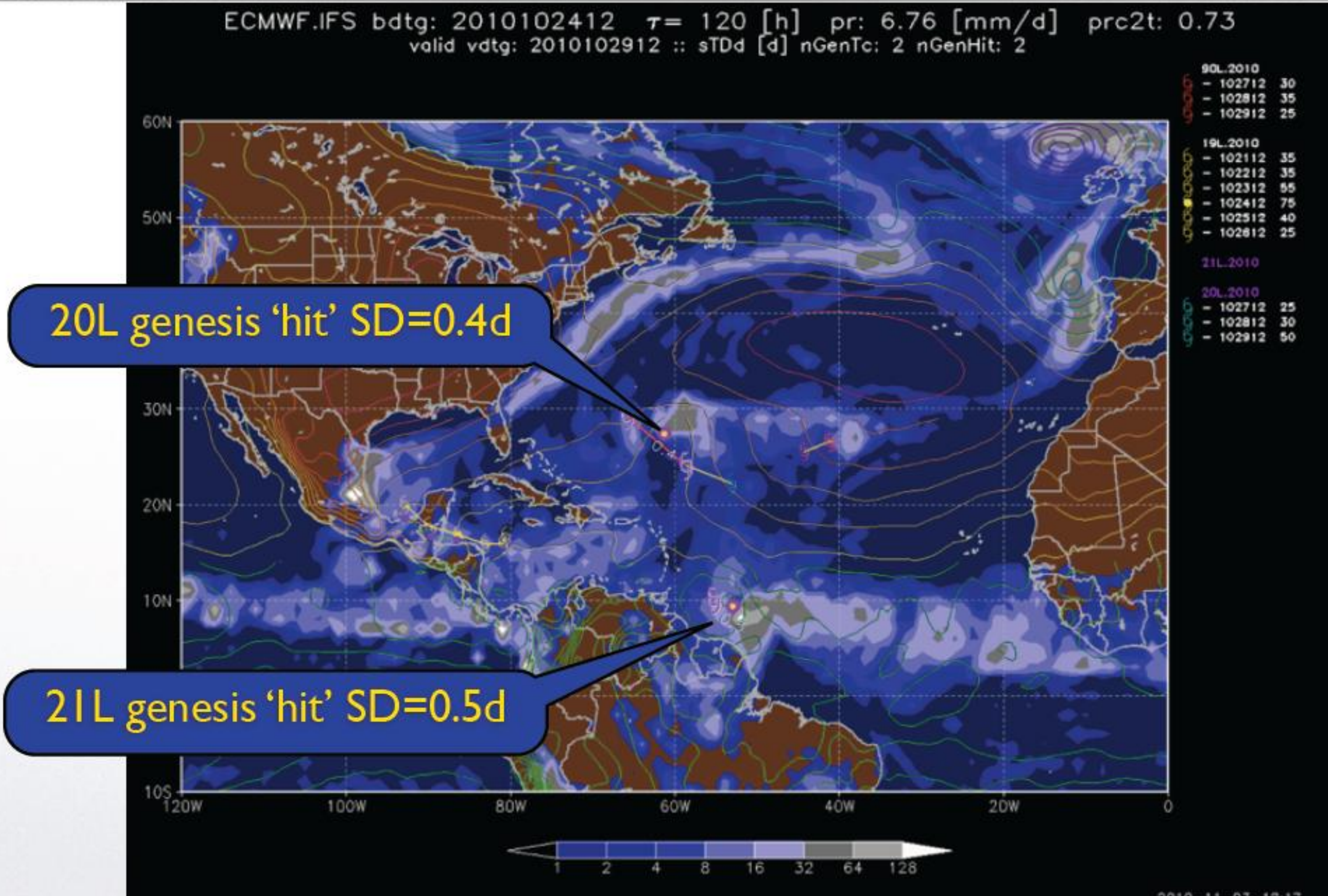
Example 2: Tropical Cyclone Genesis in Global Forecast Models

- Use understanding of tropical cyclone structure for automated storm “tracker”
  - Warm core, cyclonic vortices
  - Tropical and subtropical regions
- Apply quantitative thresholds appropriate for model resolvable scales
- Collect statistics on formation
  - Inter-model comparisons
  - Comparison with observed formations
    - Depends on choice of space/time windows for comparison with model
  - Relate formation statistics to other model variables

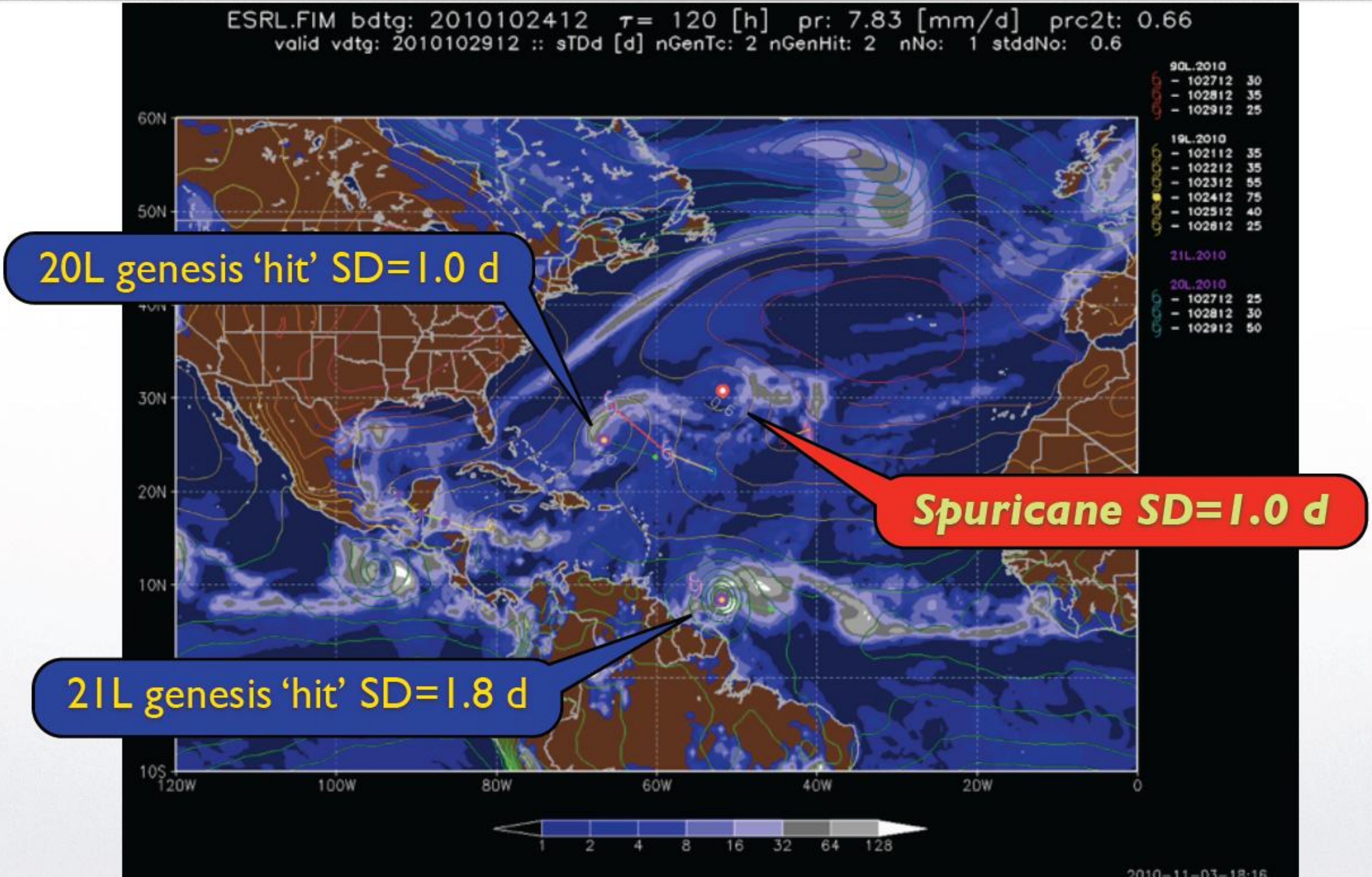
Input from Mike Fiorino, ESRL

120-h ECMWF forecast valid 2010102912

20L(shary)&21L(tomas).2010



120-h FIM forecast...



LANT 2010 ::120 h genesis forecast stats...

TCgen Stats :: **Gentau: 120 [h]** Basin: LANT Year: 2010 Models: GFS, ECM, UKM, NGP

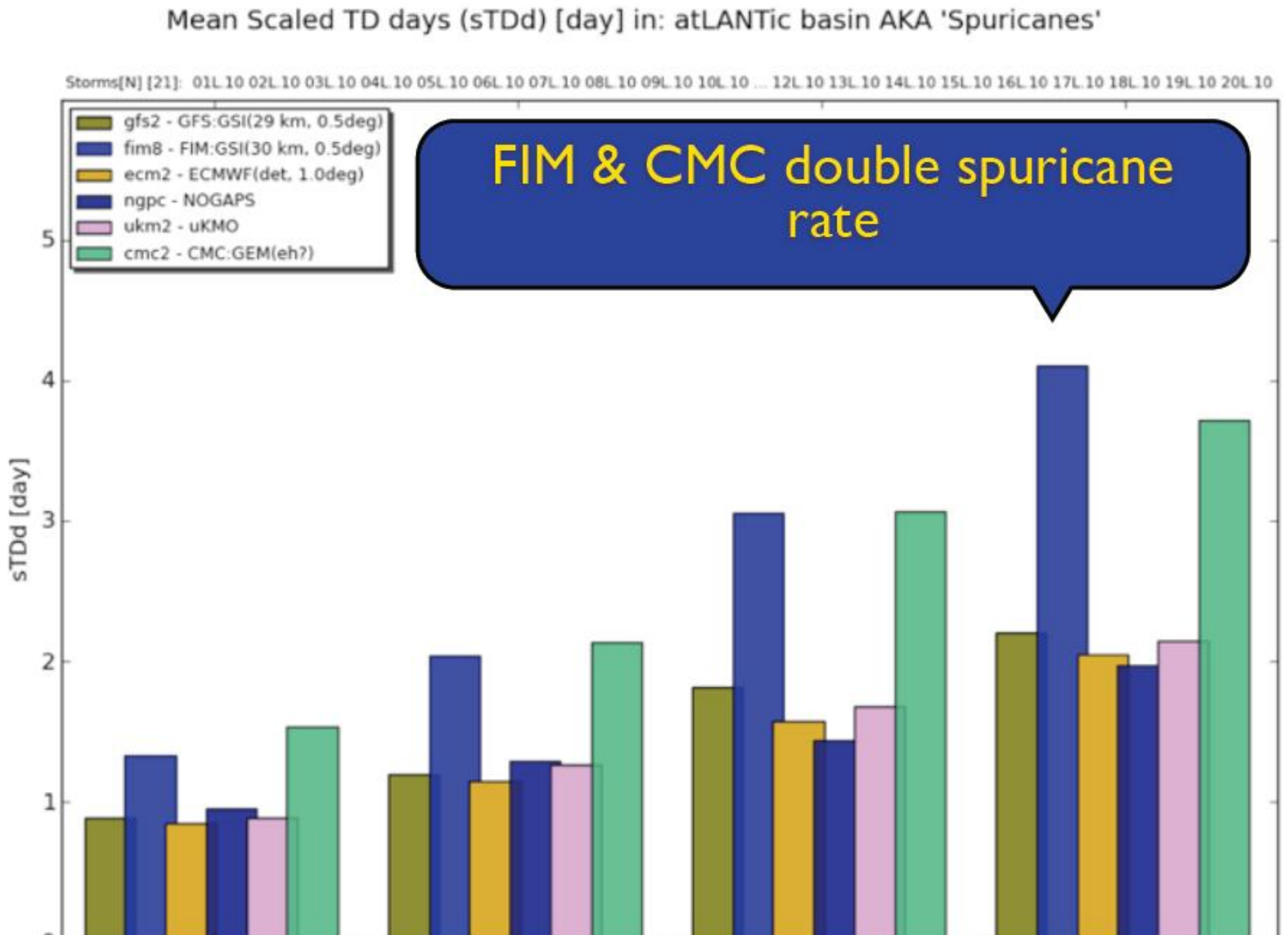
Storm	GFS	ECM	UKM	NGP	
01L.2010 [HU2 085 kt] ALEX	0/----	3/ 2.9	0/----	0/----	25
02L.2010 [TD 030 kt] TWO	0/----	0/----	1/ 1.7	0/----	25
03L.2010 [TS 035 kt] BONNIE	0/----	0/----	0/----	0/----	----
04L.2010 [TS 050 kt] COLIN	0/----	1/ 0.6	0/----	1/ 2.3	50
05L.2010 [TD 030 kt] FIVE	1/ 4.3	0/----	0/----	0/----	25
06L.2010 [HU4 115 kt] DANIELLE	0/----	2/ 2.5	1/ 0.8	2/ 1.3	75
07L.2010 [HU4 120 kt] EARL	1/ 0.3	2/ 1.3	0/----	1/ 0.2	75
08L.2010 [TS 055 kt] FIONA	0/----	0/----	0/----	0/----	----
09L.2010 [TS 035 kt] GASTON	0/----	0/----	1/ 0.3	0/----	25
10L.2010 [TS 055 kt] HERMINE	1/ 0.2	1/ 0.3	0/----	0/----	50
11L.2010 [HU4 135 kt] IGOR	2/ 2.5	2/ 0.7	0/----	0/----	50
12L.2010 [HU4 115 kt] JULIA	2/ 0.9	3/ 3.2	1/ 1.6	1/ 0.4	100
13L.2010 [HU3 105 kt] KARL	1/ 0.4	3/ 4.3	0/----	1/ 0.4	75
14L.2010 [HU1 070 kt] LISA	3/ 4.4	2/ 5.9	2/ 5.4	1/ 1.3	100
15L.2010 [TS 050 kt] MATTHEW	1/ 0.4	0/----	0/----	1/ 0.4	50
16L.2010 [TS 035 kt] NICOLE	3/ 2.0	3/ 1.0	2/ 4.8	2/ 8.3	100
17L.2010 [HU1 075 kt] OTTO	2/ 0.9	1/ 0.2	0/----	2/ 3.5	75
18L.2010 [HU2 085 kt] PAULA	3/ 3.0	3/ 4.6	3/ 7.5	1/ 2.2	100
19L.2010 [HU1 080 kt] RICHARD	3/ 5.4	2/ 0.4	3/ 3.5	1/ 2.6	100
20L.2010 [HU1 065 kt] SHARY	3/ 2.2	2/ 1.6	0/----	0/----	50
bottomline by model	62	67	38	52	

18/20 - 1 model
14/20 - 2&3 models

ECMWF/
GFS highest
success rate

LANT 2010 spuricanes

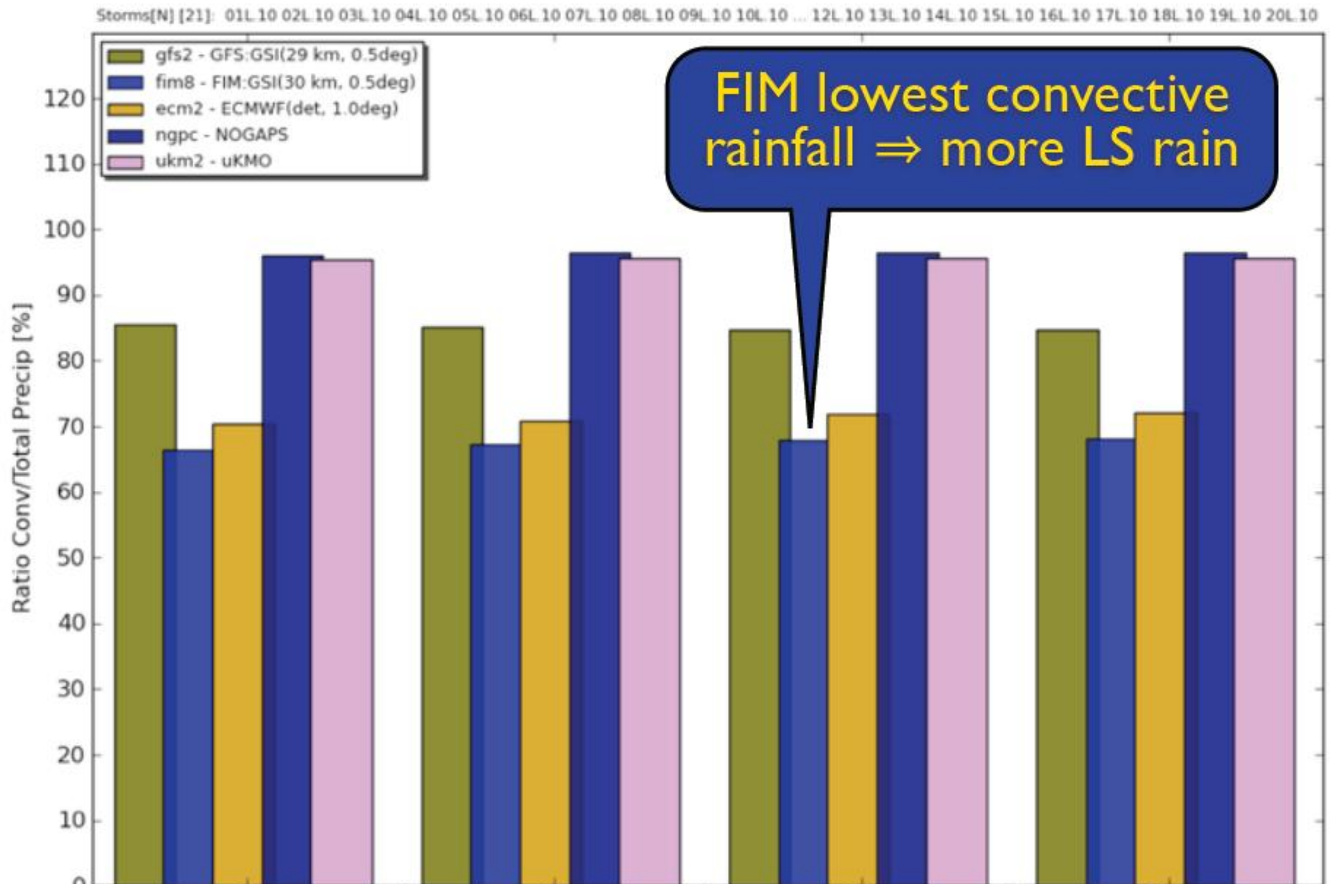
mean SD 20100600-110100



	72h	96h	120h	144h
gfs2	0.9[170]	1.2[177]	1.8[179]	2.2[195]
fim8	1.3[163]	2.0[172]	3.1[170]	4.1[173]
ecm2	0.8[158]	1.1[157]	1.6[171]	2.0[173]
ngpc	1.0[163]	1.3[143]	1.4[133]	2.0[105]
ukm2	0.9[112]	1.3[123]	1.7[118]	2.1[117]
cmc2	1.5[175]	2.1[199]	3.1[205]	3.7[235]

LANT 2010 spuricanes

mean pr_{conv}/pr_{tot} 20100600-110100



	72h	96h	120h	144h
gfs2	86[316]	85[316]	85[317]	85[317]
fim8	66[270]	67[269]	68[269]	68[259]
ecm2	70[313]	71[313]	72[313]	72[312]
ngpc	96[272]	96[271]	96[270]	96[270]
ukm2	95[291]	96[290]	96[289]	96[284]

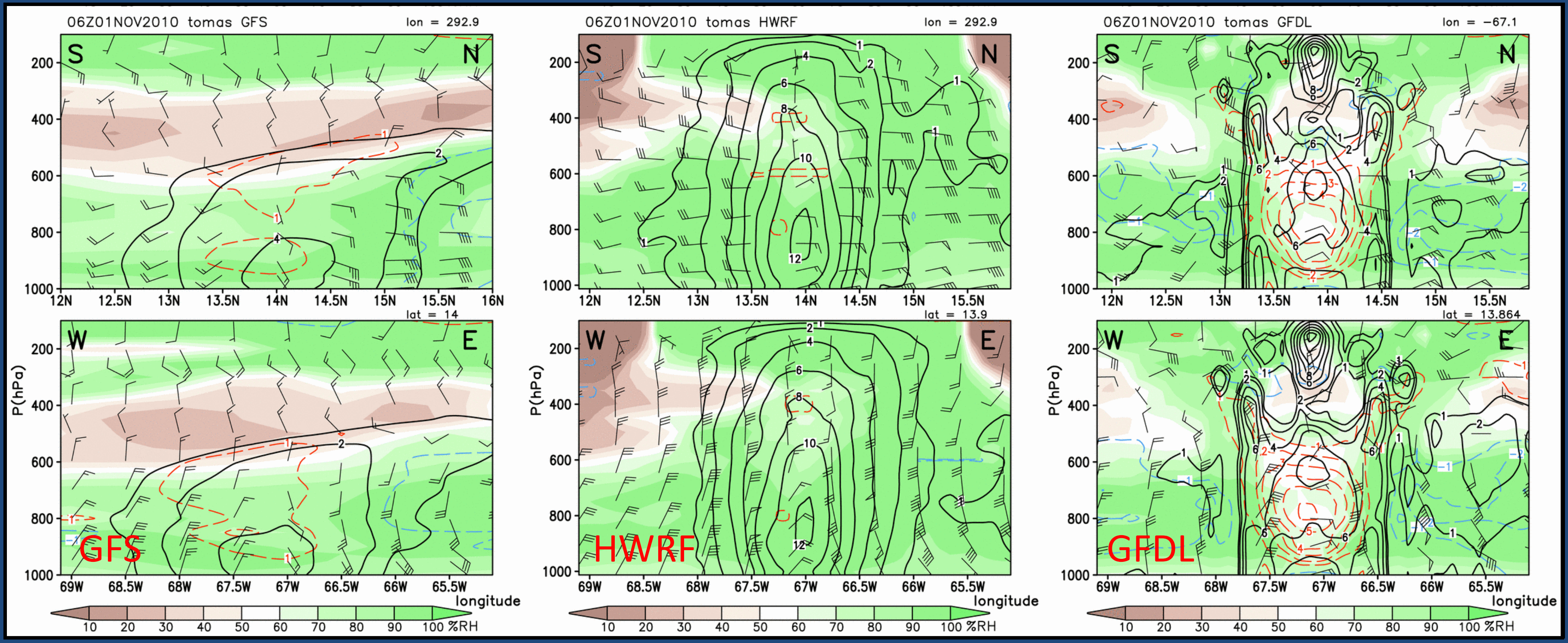
Example 3. Vortex structure diagnostics for HWRF initialization

- Operational HWRF showed consistent spin-down problem in early forecast periods
- Possible suspect is improper wind structure and pressure-wind balance
- Model intercomparison of wind structure
  - HWRF, GFDL, GFS models
- Study by NHC to provide guidance to EMC model developers

Input from Wallace Hogsett (NHC) and Ryan Torn (SUNYA)

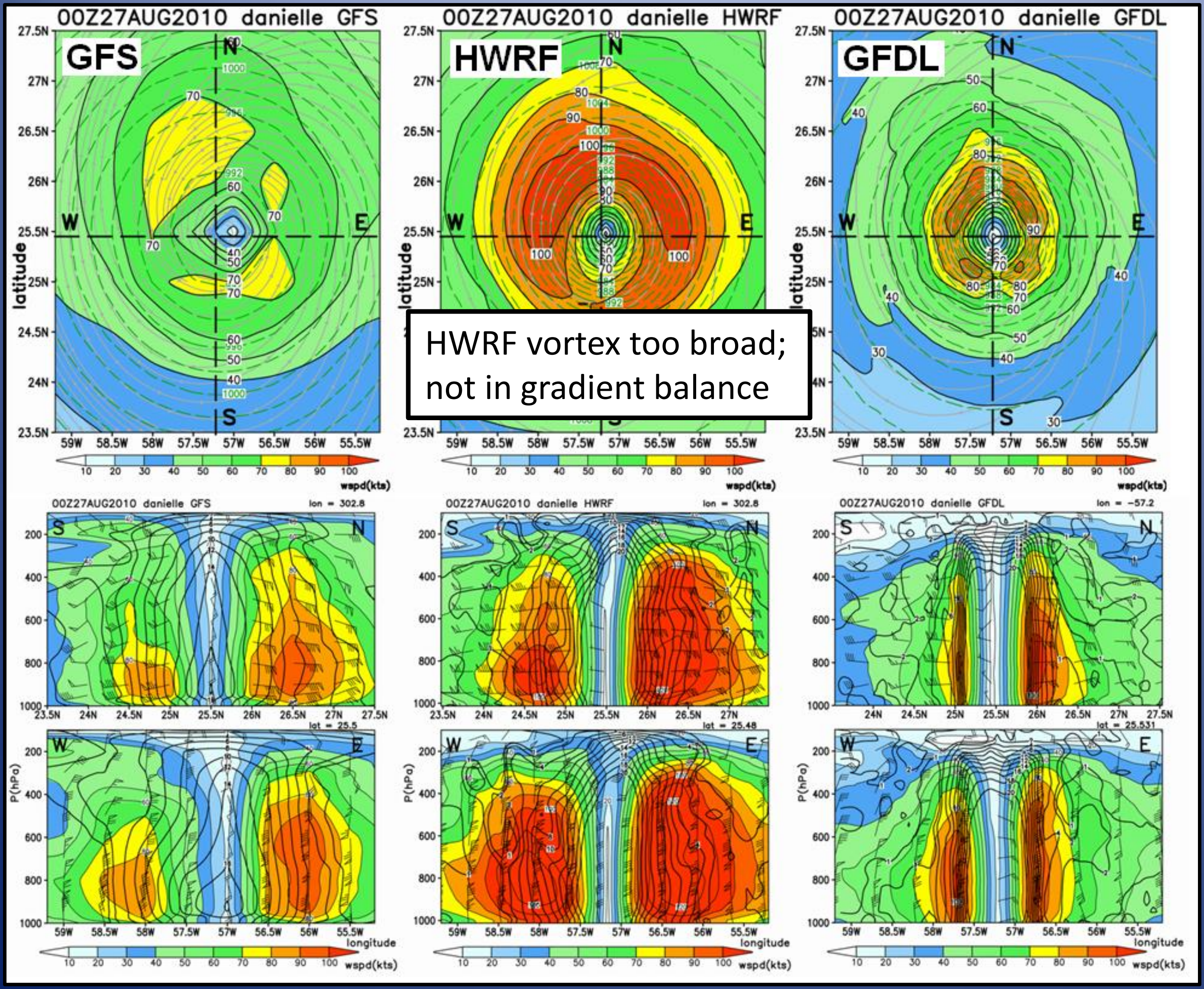
NHC Diagnostics

- NHC has developed a system to compare vortex structure among the models in real time.
- Results from the 2010 season have brought to light some important issues with the current models, e.g. the vortex initialization.



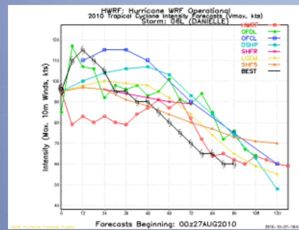
<u>Above</u>: South-north (top) and West-East (bottom) vertical cross sections from the GFS (left), HWRF (middle), and GFDL (right). Relative vorticity is contoured. Note the differences in vertical structure among the models.

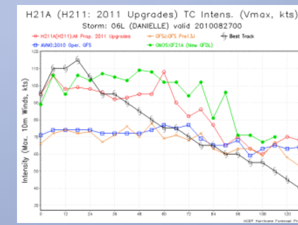
NHC Diagnostics, cont.

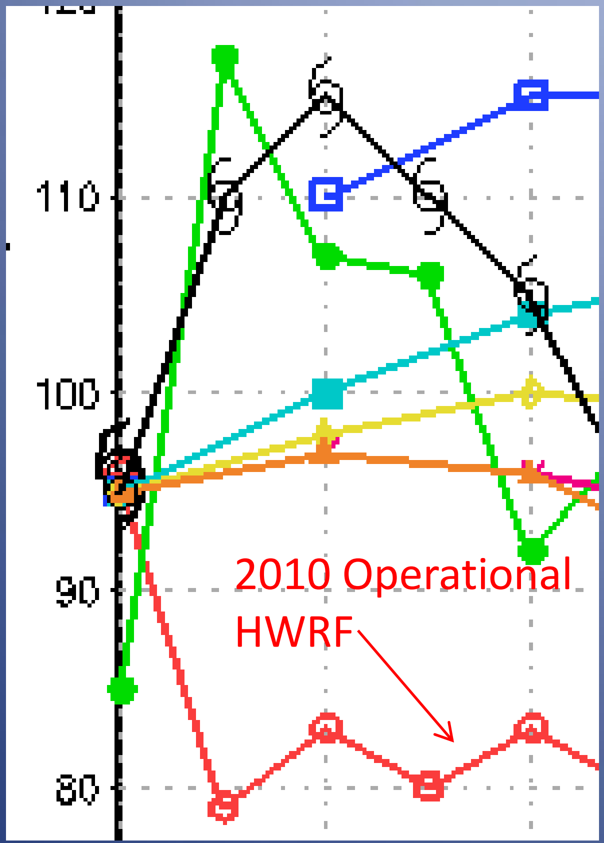


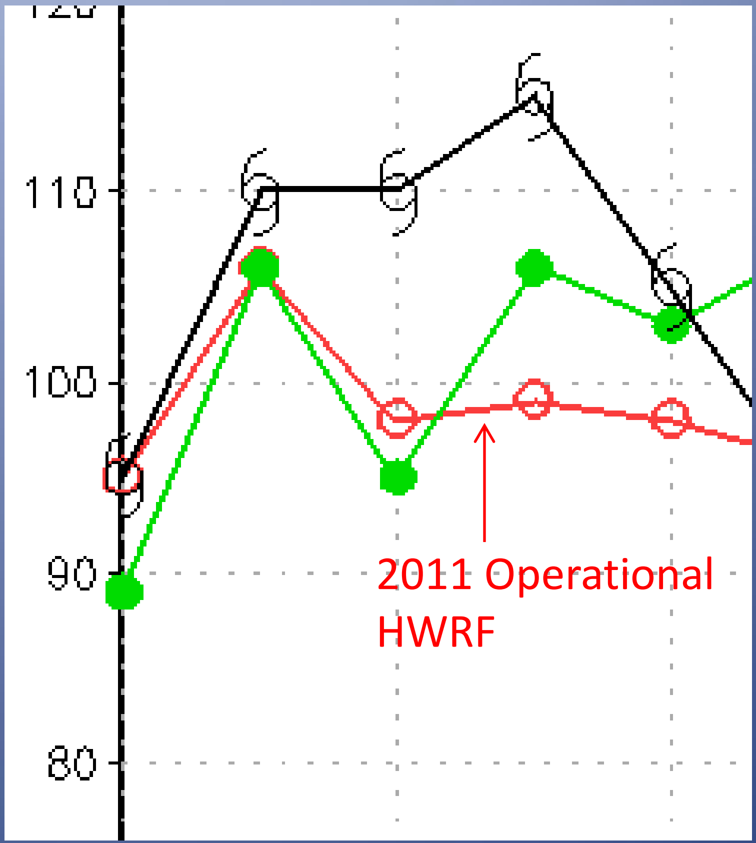
By archiving and analyzing the output from the new real-time diagnostic system, we have been able to identify some systematic characteristics of the various models, e.g. the excessive breadth (compared to other models and observations) of the HWRF vortex in some cases…

The too-large initial HWRF vortex led to a spin-down of the winds. This problem has been addressed for 2011.

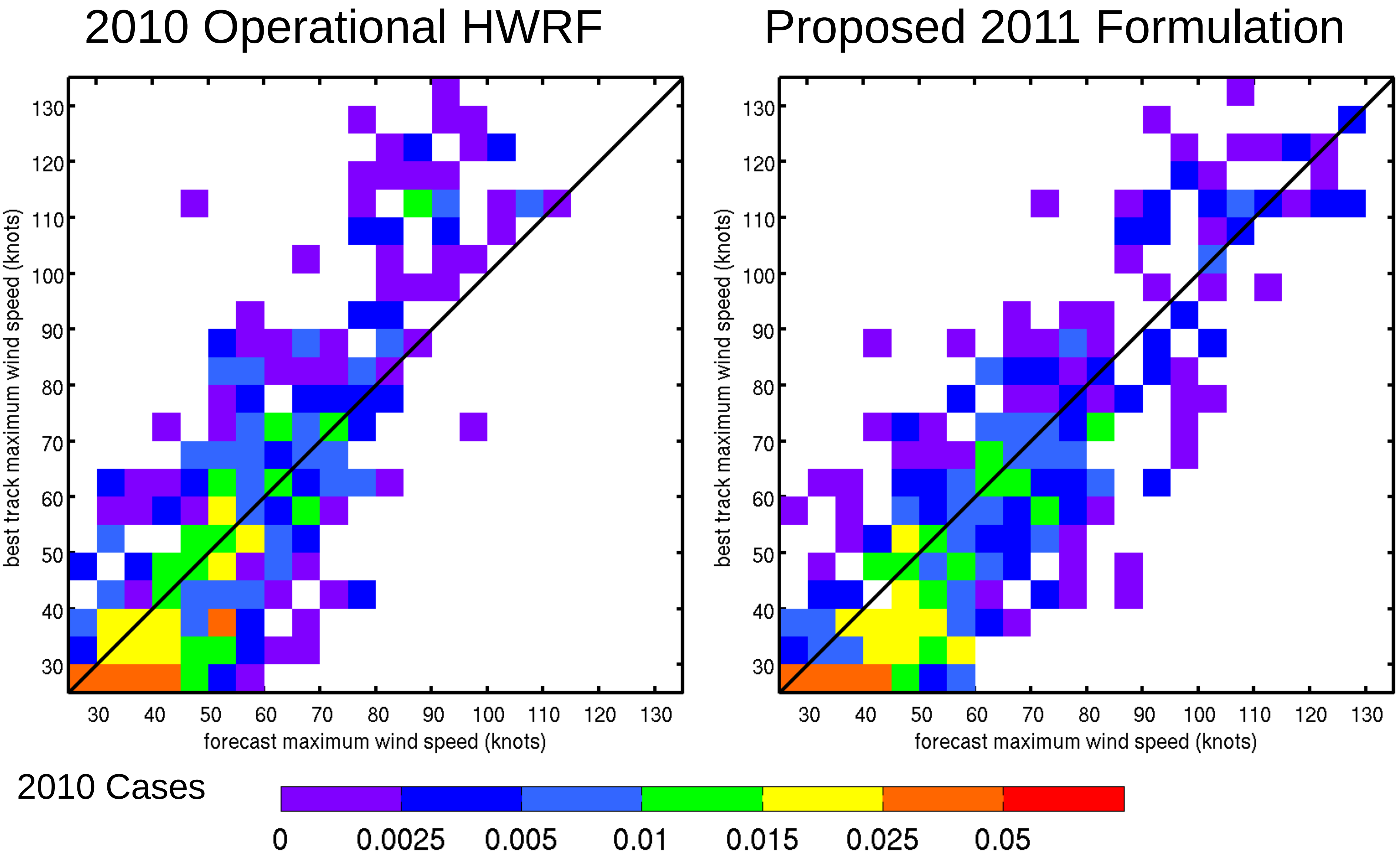

Forecasts Beginning: 00z27AUG2010


H21A (H211: 2011 Upgrades) TC Intens. (Vmax, kts)
Storm: 06L (DANIELLE) valid 2010082700


110
100
90
80
2010 Operational
HWRF


110
100
90
80
2011 Operational
HWRF

12 h Maximum Wind Speed



Example 4: Vortex Asymmetry Analysis

- Physical processes
  - Kinematic addition of storm translation increases wind to right
    - Friction asymmetries, advection by tangential wind moves wind maximum to right front
  - Vertical shear enhances convection on downshear side of storm
    - Increased convection and advection moves wind max to downshear left quadrant
  - Radial vorticity gradient can support Vortex Rossby Waves (RVW) that move against the tangential flow
    - Simple theory for VRW phase speed
    - C = V(1 – 1/n) , V = tangential wind, n = azimuthal wave number
    - For n=2, C = V/2
- Perform diagnostics on HWRFx simulations to evaluate physical processes (9 km grid)
- Five real data simulations for Hurricanes Emily (2), Katrina (1) and Wilma (2)

Input from Kate Maclay (CIRA/CSU) and M. DeMaria (NESDIS)

Low-Level Wind Asymmetries

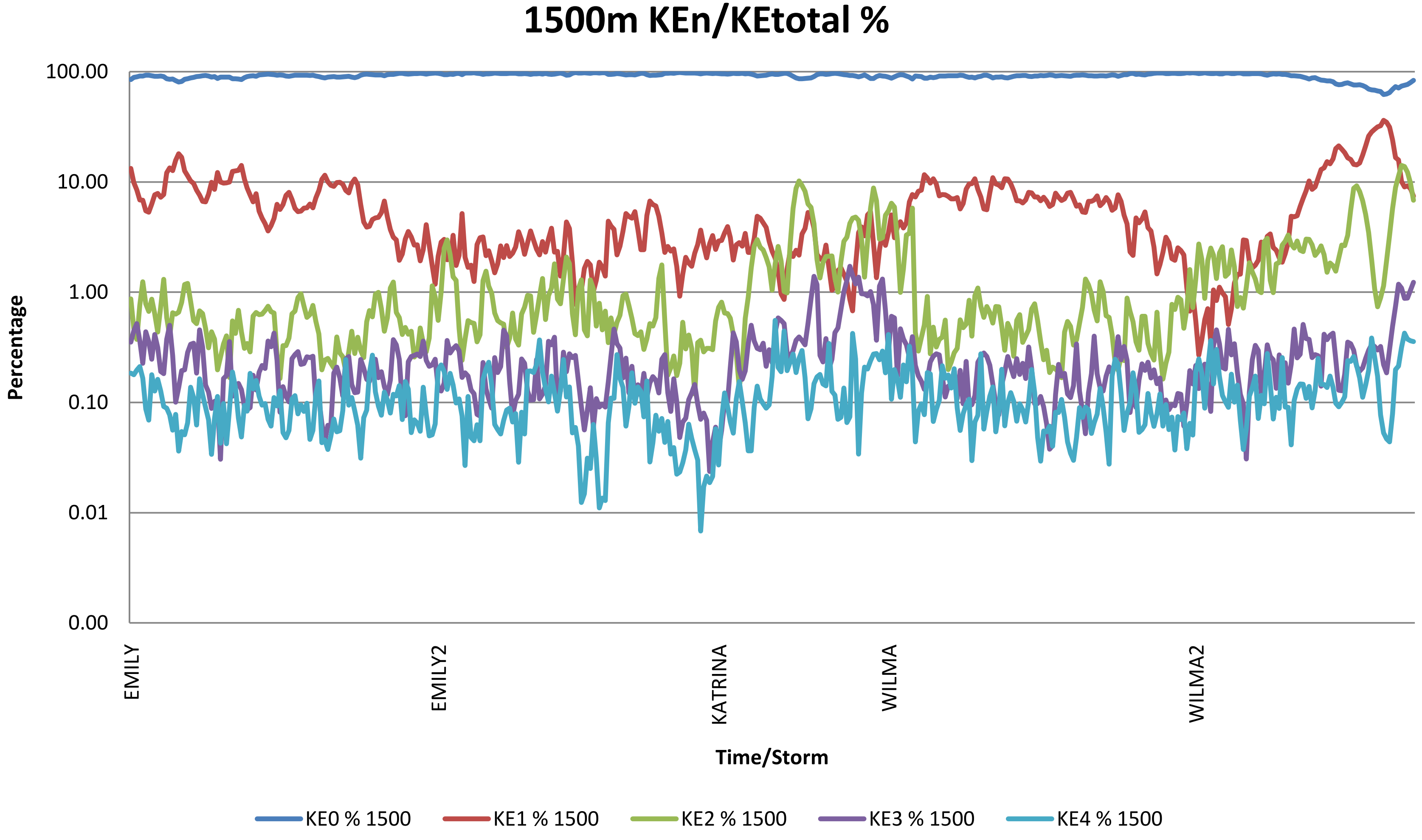
- Translation
  - Wavenumber 1 tied to motion vector
- Shear
  - Wavenumber 2 tied to shear vector
- Vortex Rossby Waves
  - Wavenumber 2 or higher, cyclonic rotation slower than tangential wind advection
- Composite wind fields relative to shear and motion vectors
- Use Fourier decomposition of wind field in azimuthal direction

$$u(r, \theta, P, t) = \Sigma u_n e^{-in\theta} \quad v(r, \theta, P, t) = \Sigma v_n e^{-in\theta}$$

$$u_n = (1/2\pi) \int u e^{in\theta} d\theta \quad v_n = (1/2\pi) \int v_n e^{in\theta} d\theta$$

Parseval's Identity: $\int (u^2+v^2) d\theta = 2\pi\Sigma(u_n u_n^* + v_n v_n^*)$

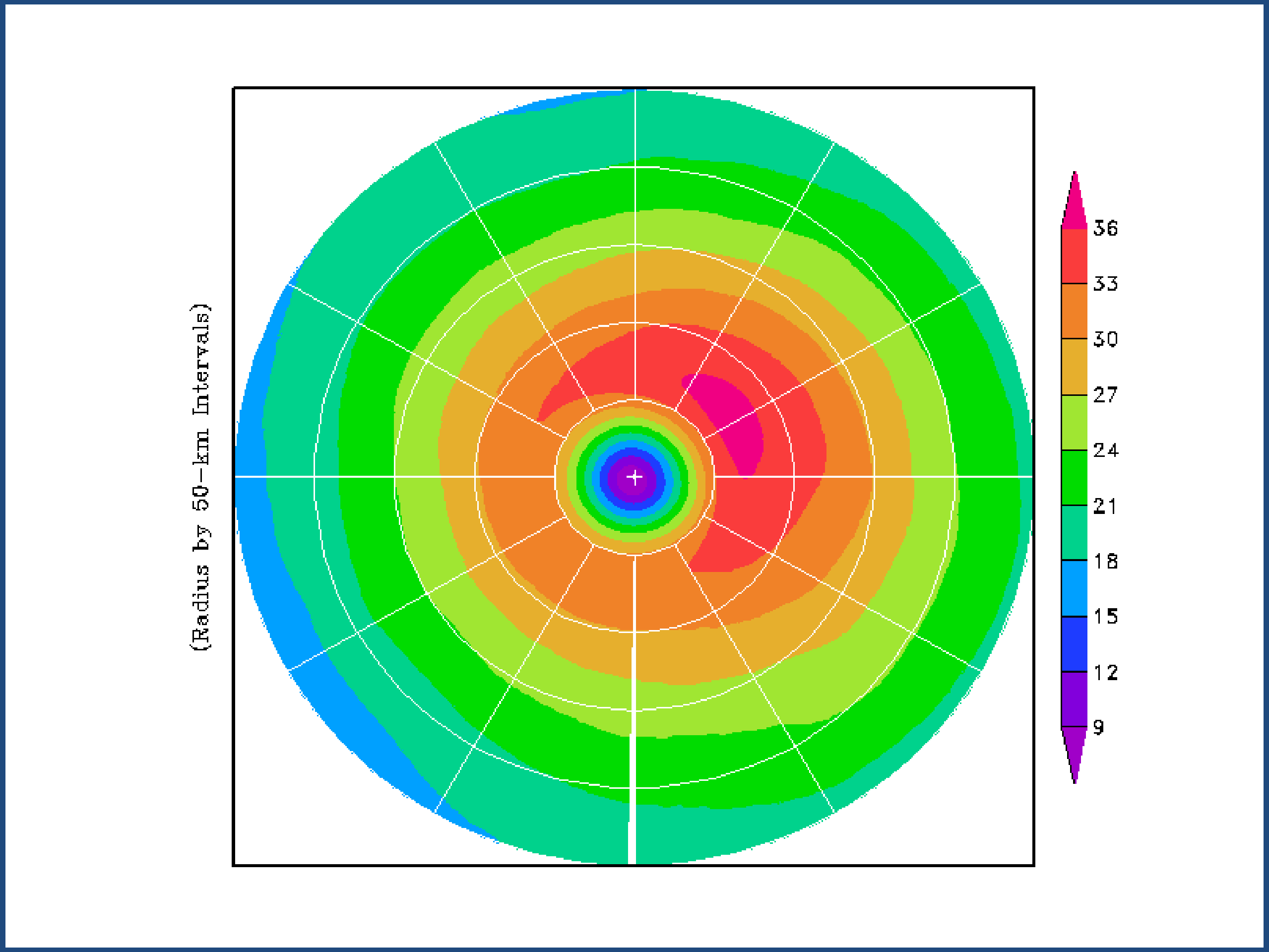
KE Wave Decomposition
r=0 to 200 km, 1 hourly data



Composite Analysis – Wind

- Hurricane Emily 2005
  - 07/13/00z HWRFx simulation
  - 07/15/00z HWRFx simulation
- Hurricane Katrina 2005
  - 08/26/00z HWRFx simulation
- Hurricane Wilma 2005
  - 10/18/00z HWRFx simulation
  - 10/22/00z HWRFx simulation

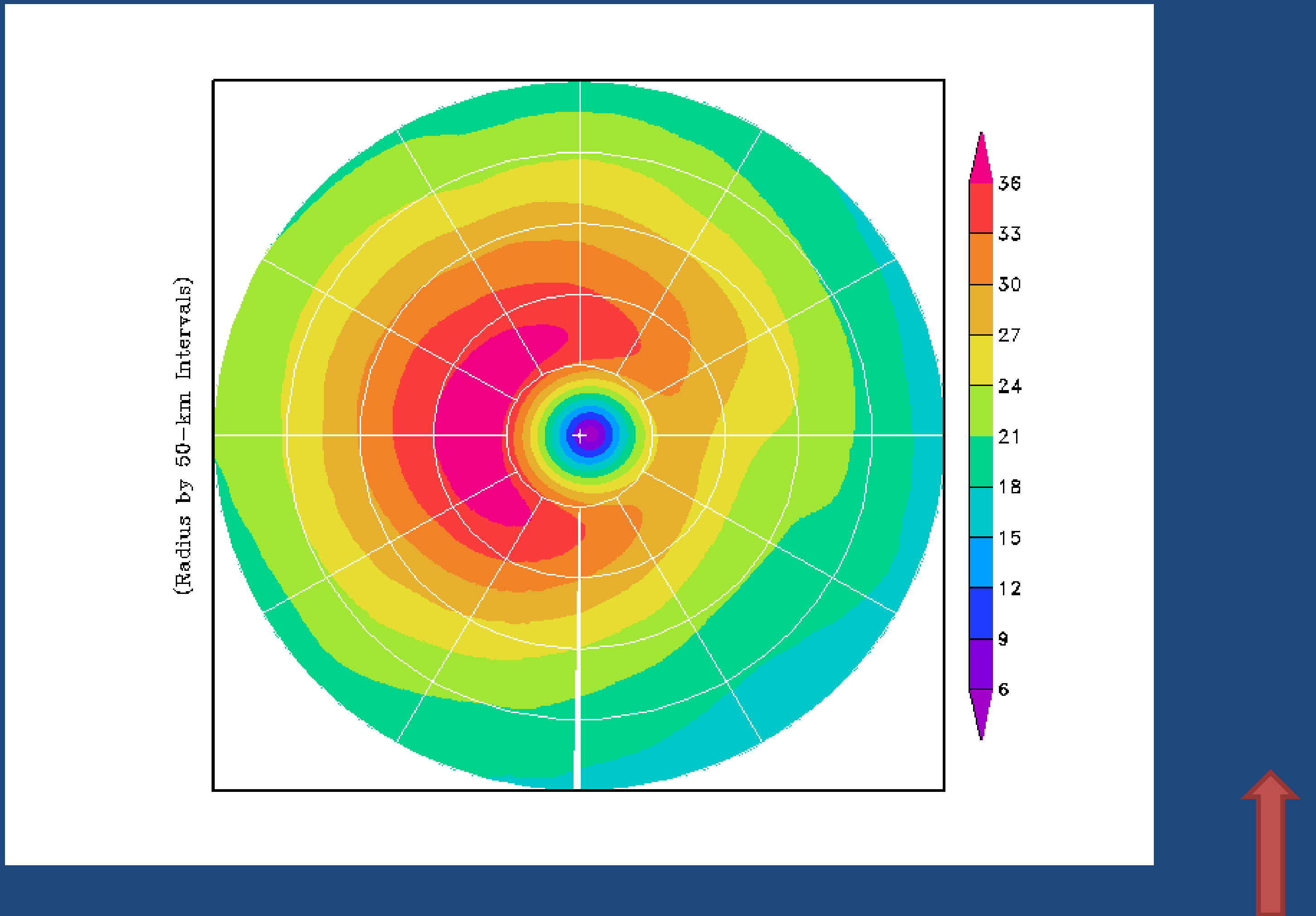
All Storms - 10m Winds – Motion Relative



N = 431

Storm Motion

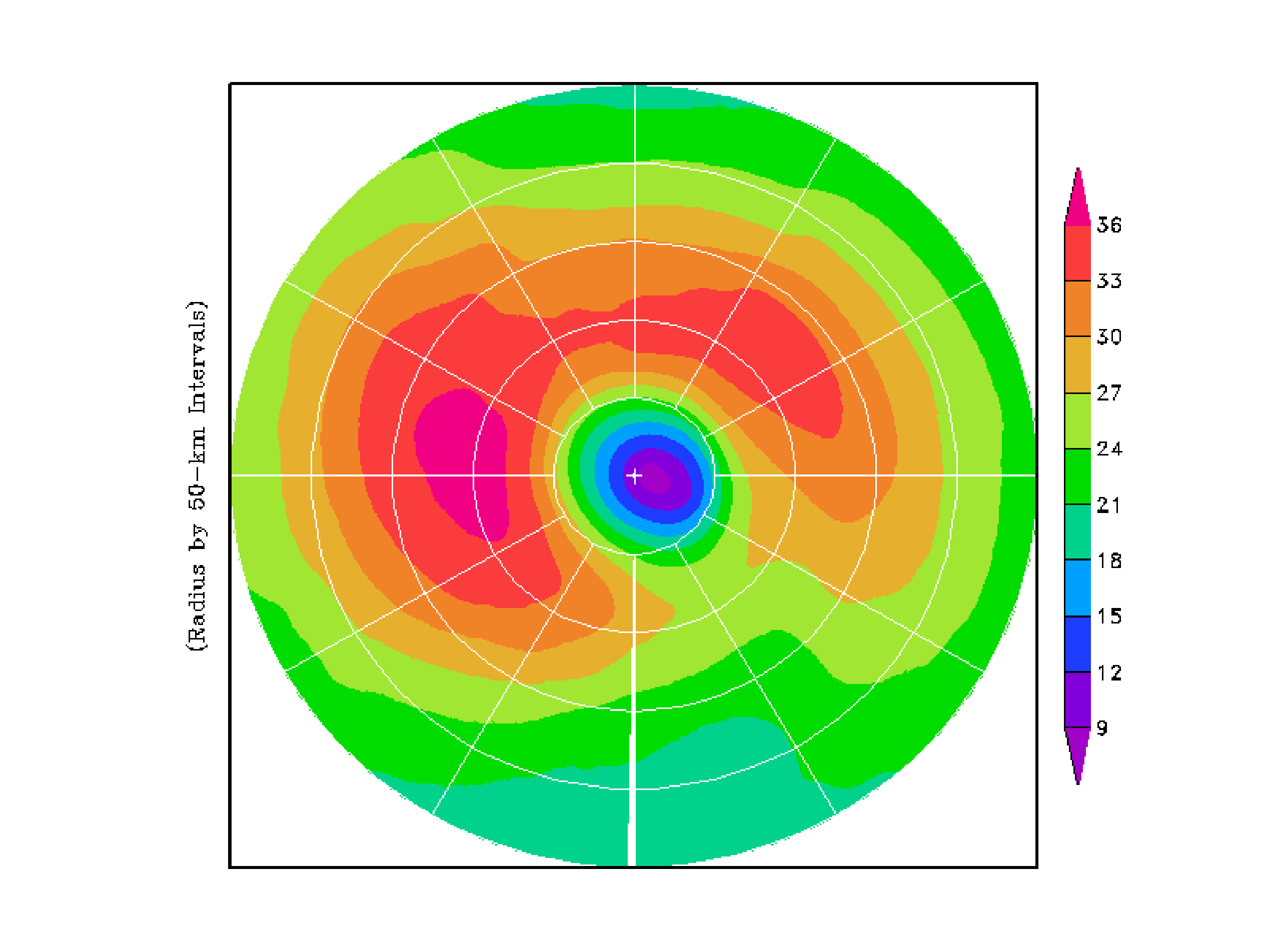
All Storms – 10m Winds – Shear Relative

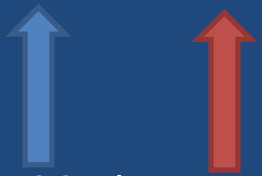


N = 431

Shear

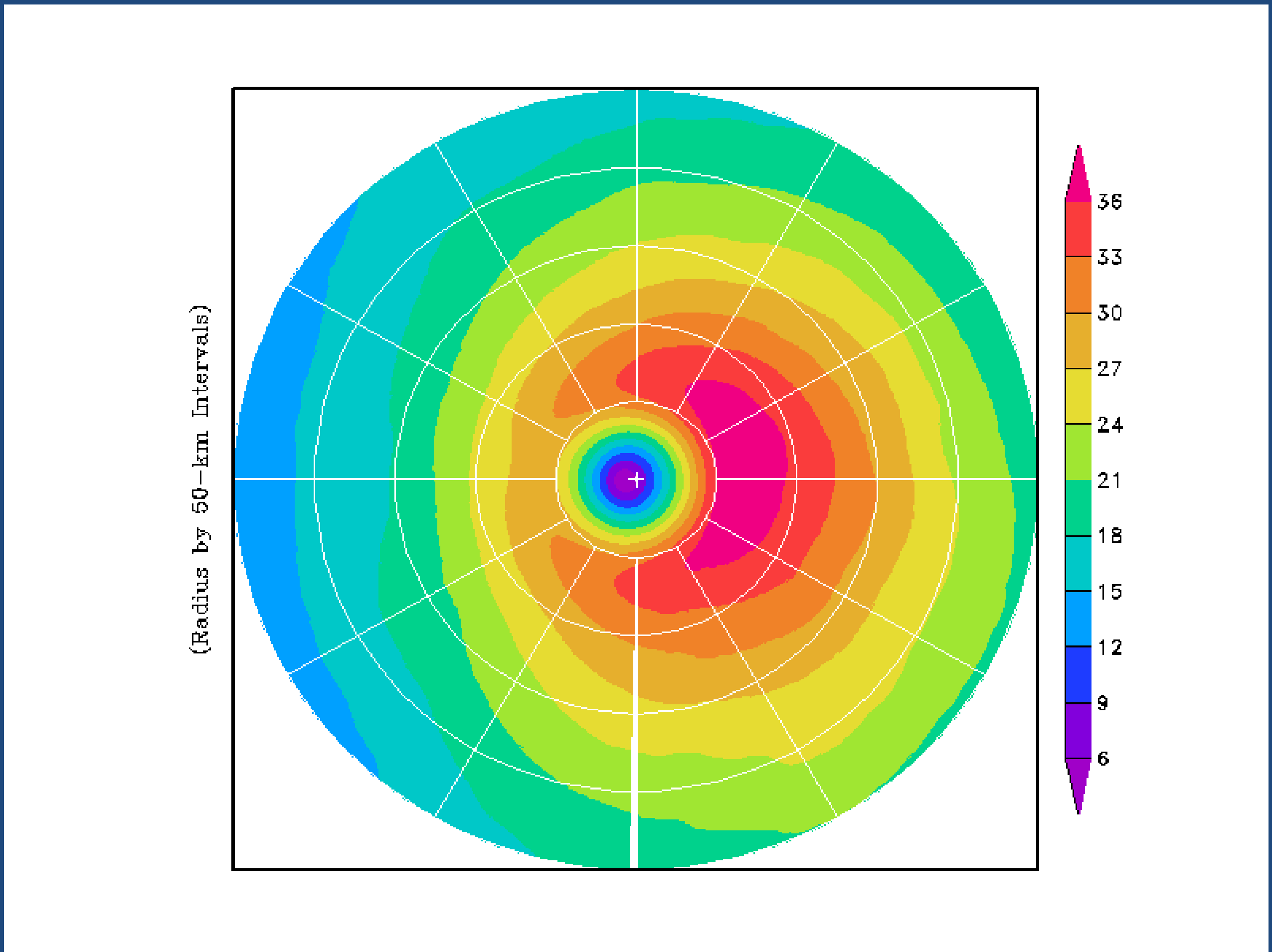
Aligned – 10m Winds – Motion Relative, cases with shear/motion aligned

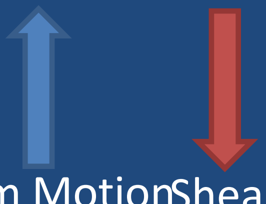




N = 96

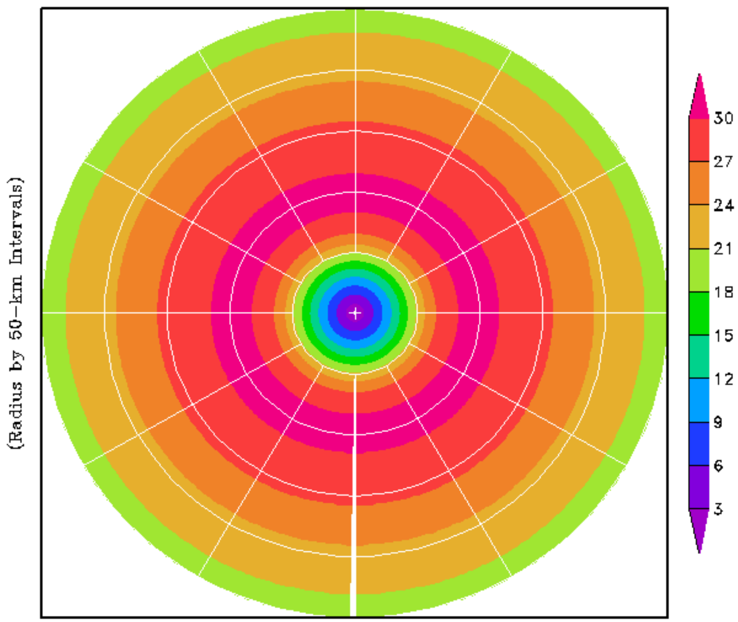
Opposed – 10m Winds – Motion Relative cases with motion, shear opposed



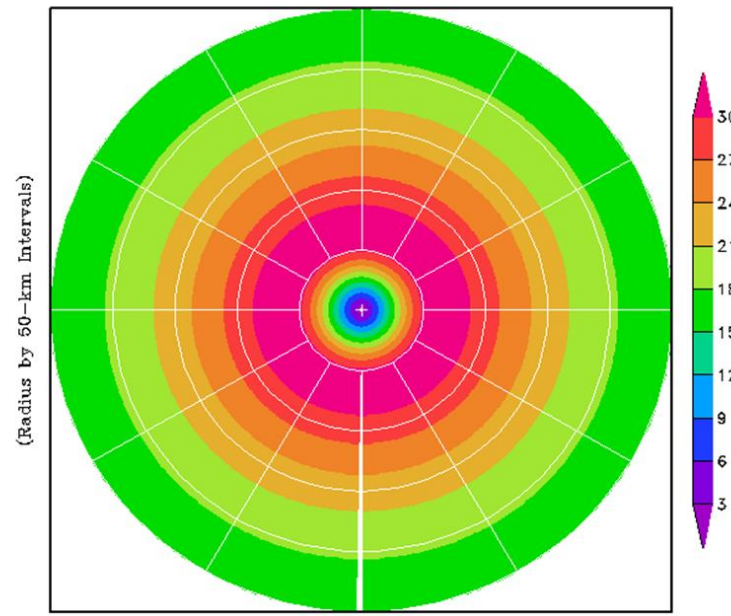


N = 171

Wavenumber 0

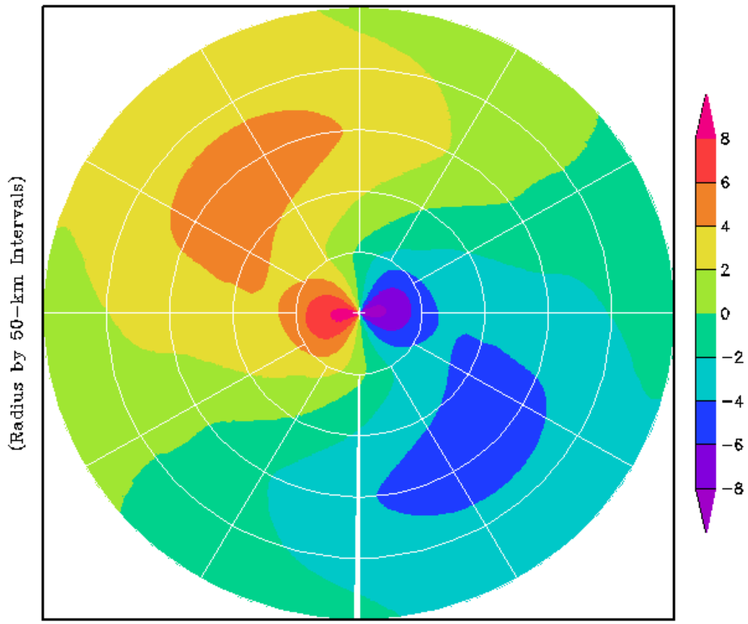


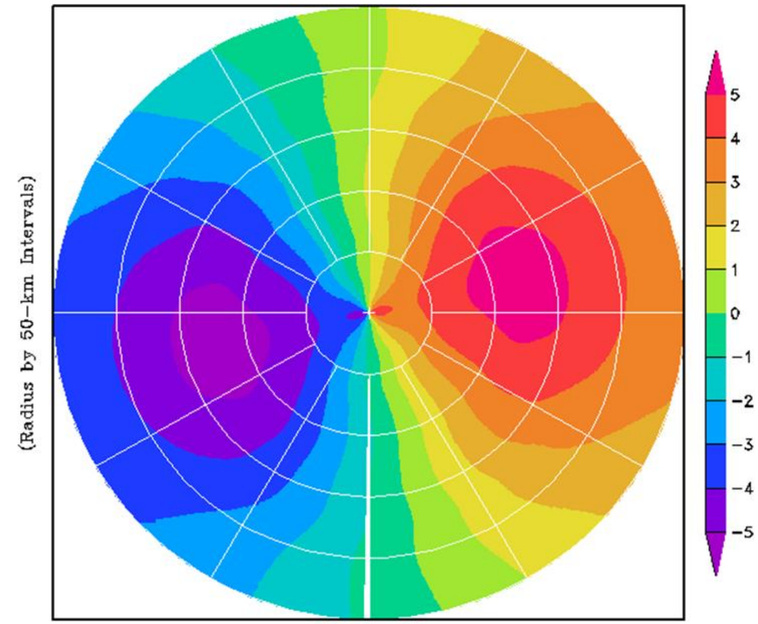
Storm Motion Shear



Storm Motion Shear

Wavenumber 1

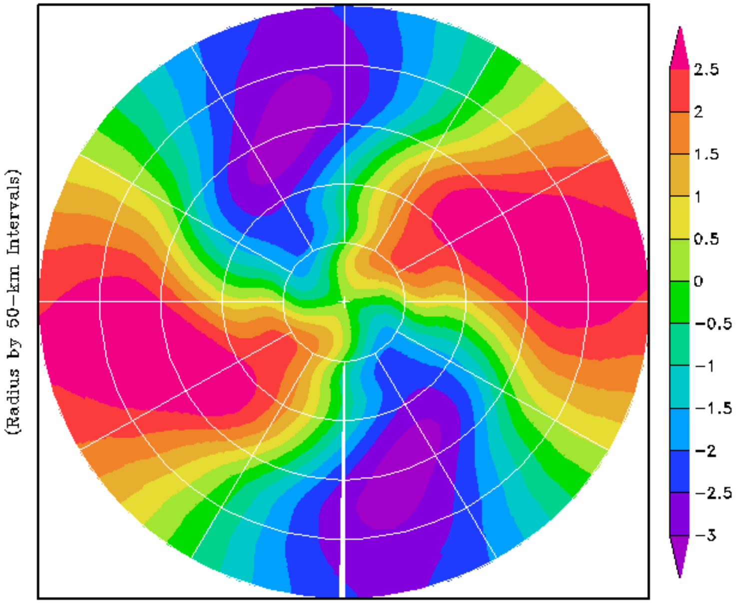


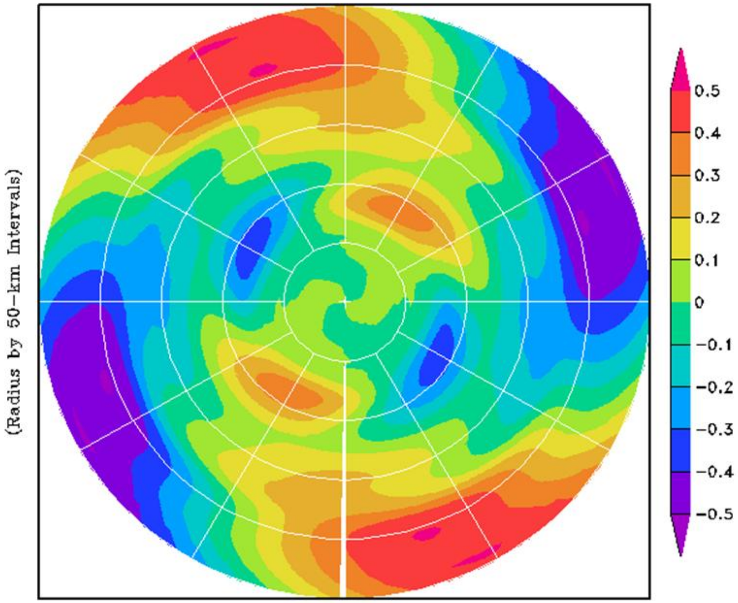


Storm Motion Shear

Storm Motion Shear

Wavenumber 2

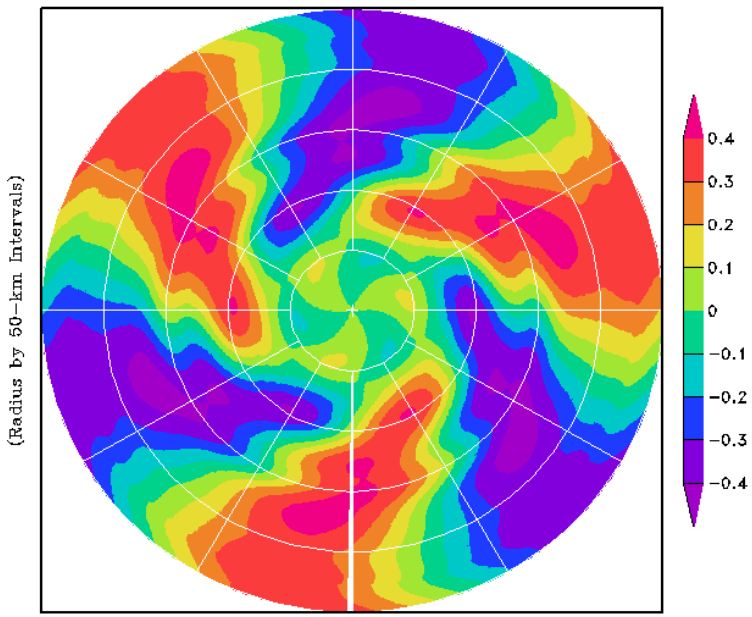


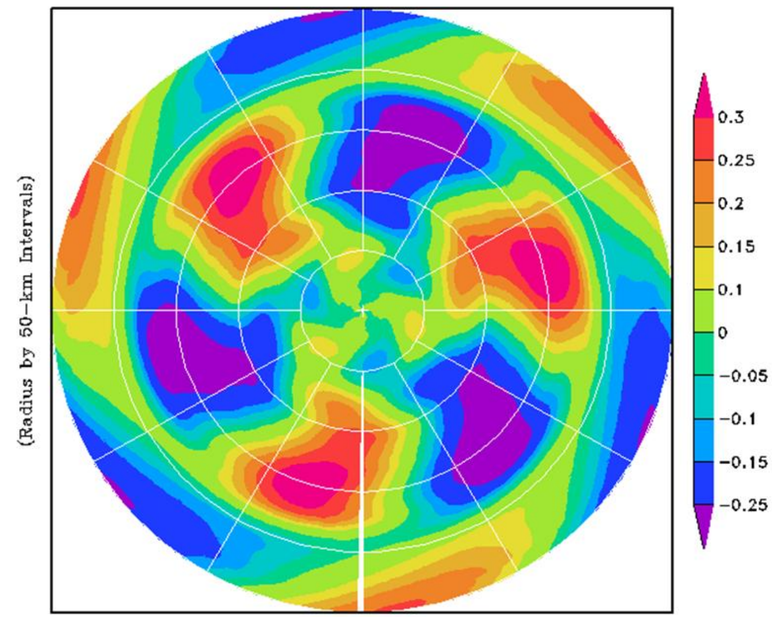


Storm Motion Shear

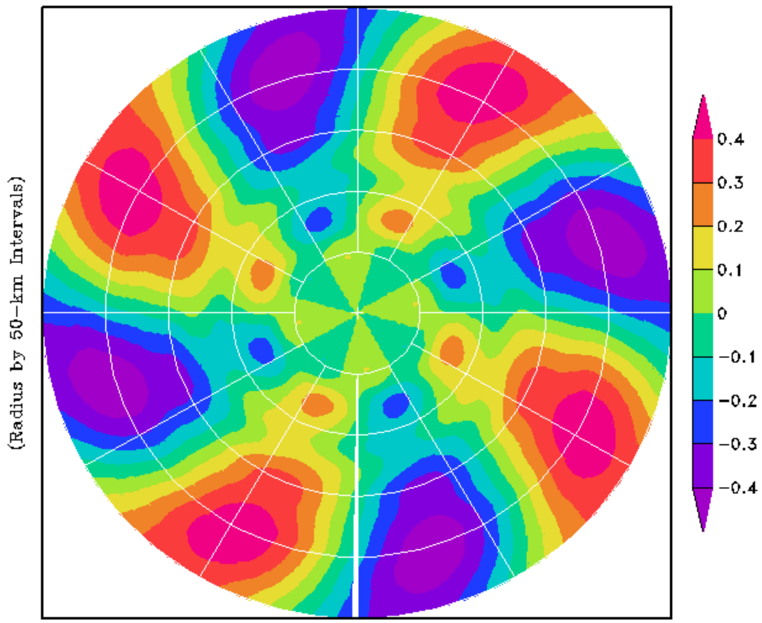
Storm Motion Shear

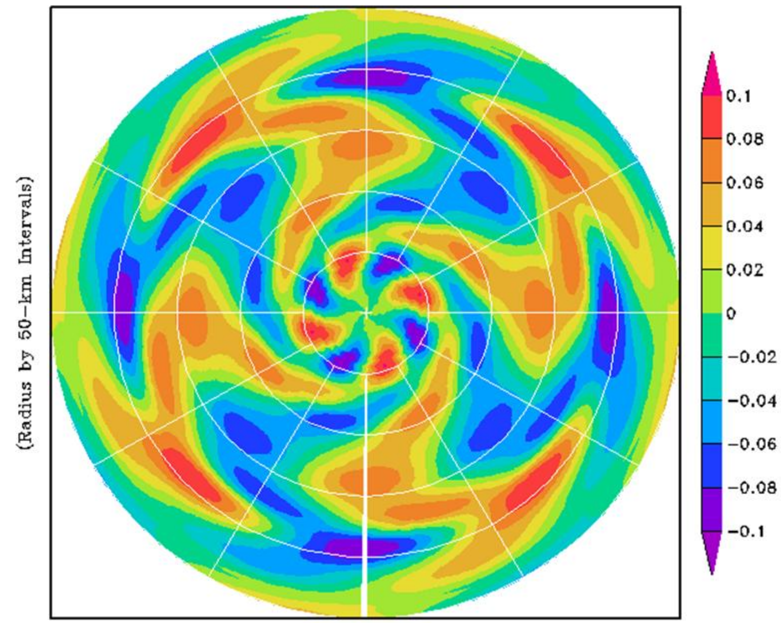
Wavenumber 3





Wavenumber 4

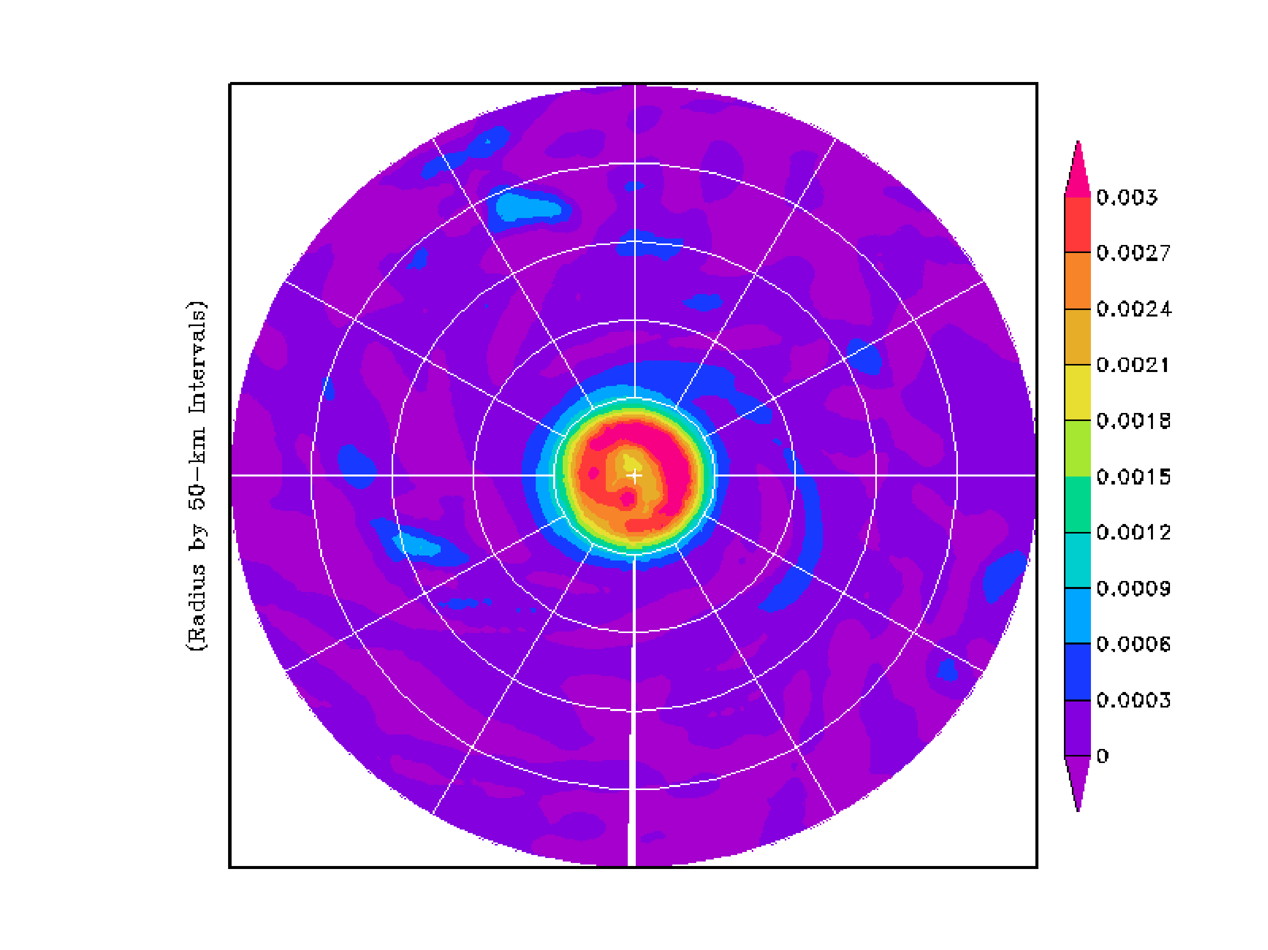




Storm Motion Shear

Storm Motion Shear

HWRF-x Emily 07/15/00Z Vorticity Animation



Phase speeds being calculated of wavenumber 2 and higher features

Summary of Asymmetry Diagnostics

- Motion and shear induced asymmetries are dominate features
- Propagating VRW features have smaller amplitude in wavenumber 2
- Fourier decomposition useful diagnostic tool

Example 5. Statistical Diagnostics of Inner Core

- Predictability time scale of convection and boundary layer processes is very short
  - Little opportunity for direct comparison with observations
- Diagnostics of statistical distributions of convection
  - Comparison with aircraft radar observations
- Impact of boundary parameterizations on average inner core wind structure
  - Comparison with aircraft GPS soundings
- Diagnostics from HWRFx 27:9:3 km resolution

Input from Rob Rogers (HRD)

Observational databases used in composites

Doppler database

40 radar analyses in 8 different storms

Storm name	Date (mm/dd/yyyy)	Number of analyses	best track intensity (kt)	t+24 h intensity change (kt)
Guillermo	8/2/1997	4	105	25
Fabian	9/3/2003	3	110	0
Isabel	9/12/2003	2	140	0
Isabel	9/13/2003	1	140	0
Isabel	9/14/2003	4	140	-25
Frances	8/30/2004	3	110	15
Frances	8/31/2004	2	125	-5
Frances	9/1/2004	3	120	-5
Ivan	9/7/2004	4	105	15
Katrina	8/28/2005	1	150	-70
Katrina	8/29/2005	3	110	-80
Rita	9/21/2005	3	145	-20
Rita	9/22/2005	3	125	-15
Paloma	11/8/2008	4	125	-100

Rogers et al., MWR, 2011
(in review)

GPS dropsonde database

794 dropsondes in 13 different storms

Storm name	Year	Storm Intensity range (kt)	Number of sondes
Erika	1997	83 – 110	40
Bonnie	1998	68 - 93	76
Georges	1998	66 - 78	39
Mitch	1999	145 - 155	28
Bret	1999	75 - 90	33
Dennis	1999	65 - 70	7
Floyd	1999	80 - 110	40
Fabian	2003	68 - 120	131
Isabel	2003	85 - 140	162
Frances	2004	68 - 83	62
Ivan	2004	65 - 135	123
Dennis	2005	65 - 70	7
Katrina	2005	68 - 100	46

Zhang et al., MWR, 2011
(in review)

Simulation databases used in composites

HWRFx Real-data database

34 model output times in 16 runs of 5 different storms

Storm	Initialization time	Forecast hour	Peak wind (kt)	24-h intensity change (kt, centered)
Wilma (2005)	2005101912	24	135	-7.5
		36	120	-67.5
	2005101900	24	120	20
		36	127.5	7.5
	2005101800	48	90	15
	2005101700	60	67.5	15
		72	70	7.5
Rita (2005)	2005092200	24	145	-27.5
		36	127.5	-25
	2005092100	24	105	12.5
		36	110	7.5
		48	112.5	0
	2005092000	48	97.5	15
		60	100	7.5
		72	105	5
Katrina (2005)	2005082800	24	120	17.5
		36	130	-35
	2005082700	24	97.5	10
		36	100	12.5
		48	110	12.5
	2005082600	48	67.5	10
		60	70	7.5
		72	75	-10
Karl (2010)	2010091600	36	100	-15
	2010091518	48	100	7.5
	2010091500	72	105	-45
Earl (2010)	2010083100	24	115	-10
		48	105	10
		60	105	-5
	2010082812	60	120	12.5
		72	110	-5
		84	115	2.5
		96	112.5	-2.5
	2010082700	96	110	-2.5

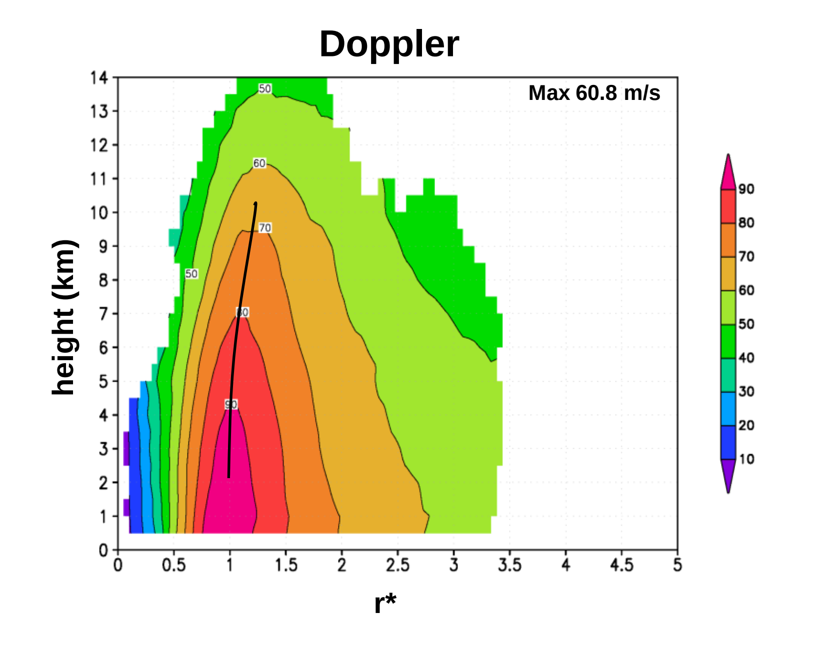
- All runs at 27:9:3 km with GFS PBL, Ferrier microphysics and SAS convection on all meshes

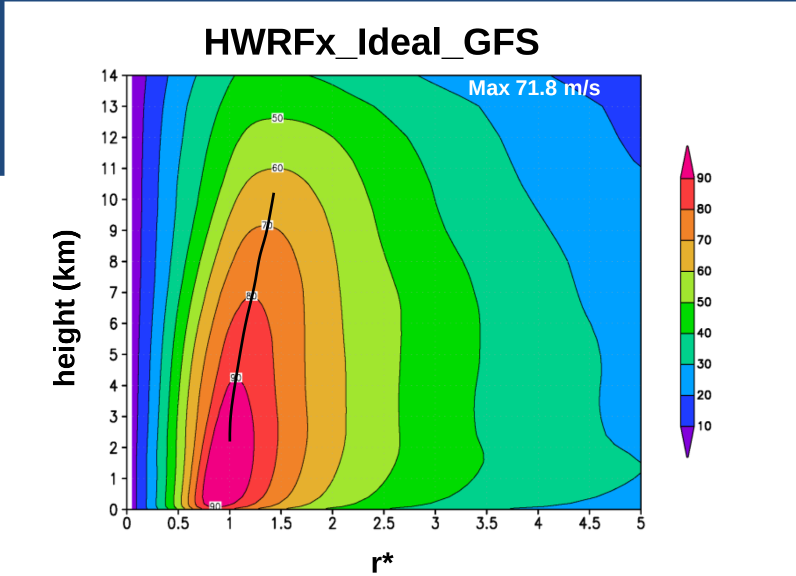
Idealized HWRFx runs

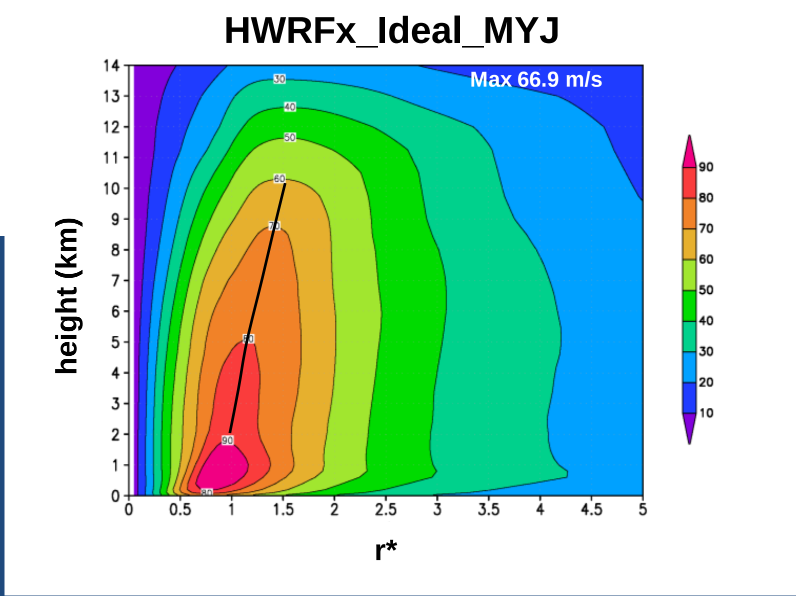
- 2 runs
    - GFS PBL
    - MYJ PBL
- both runs at 27:9:3 km, use Ferrier microphysics, SAS convection scheme on all meshes
- both runs taken at 6-hourly intervals between 48 and 96 h during simulation

Symmetric vortex-scale

Tangential wind (% of maximum)





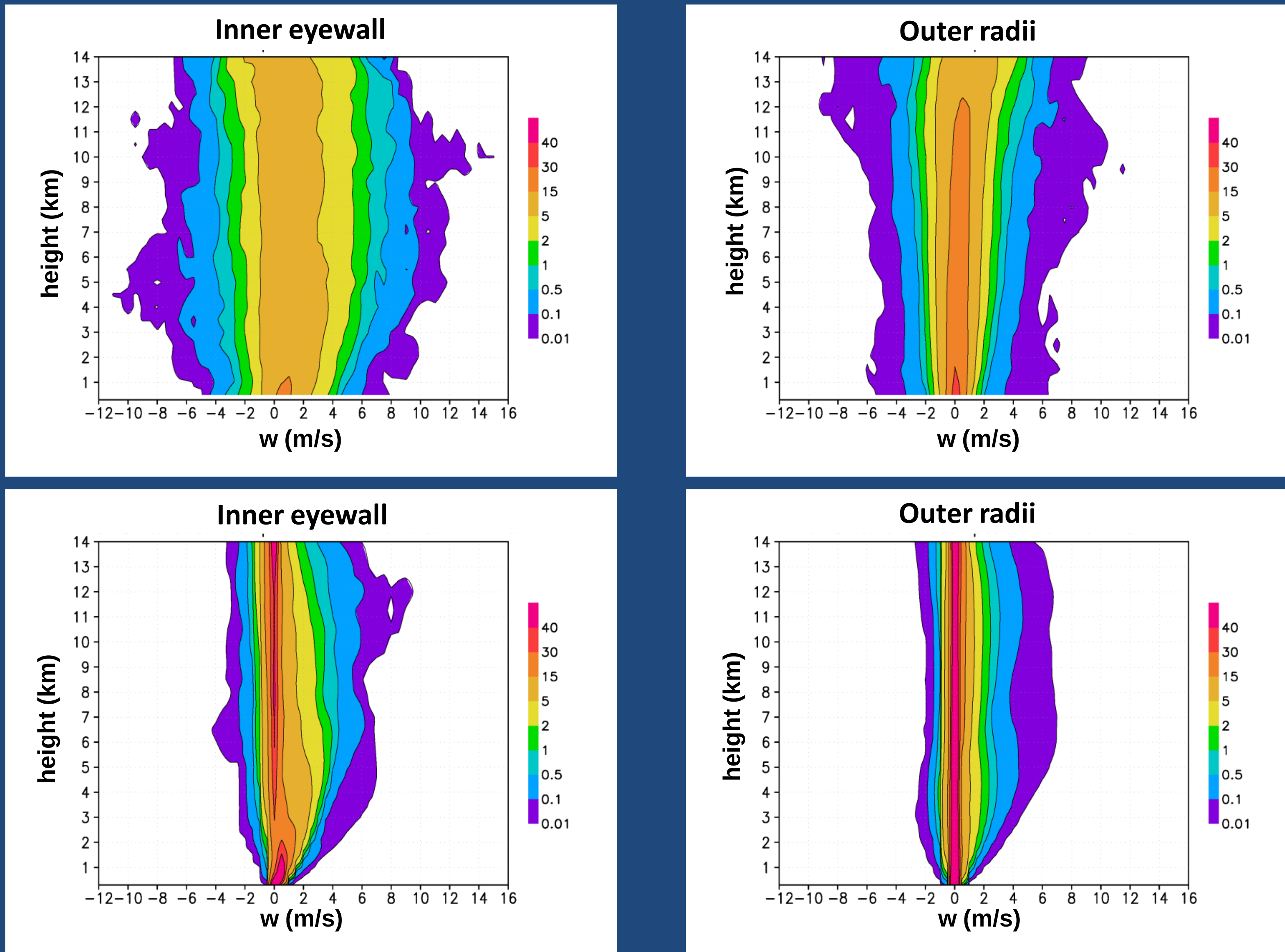


Convective-scale statistics as f(proximity to RMW)

Vertical velocity CFADs (%, no precipitation masking for HWRFx)

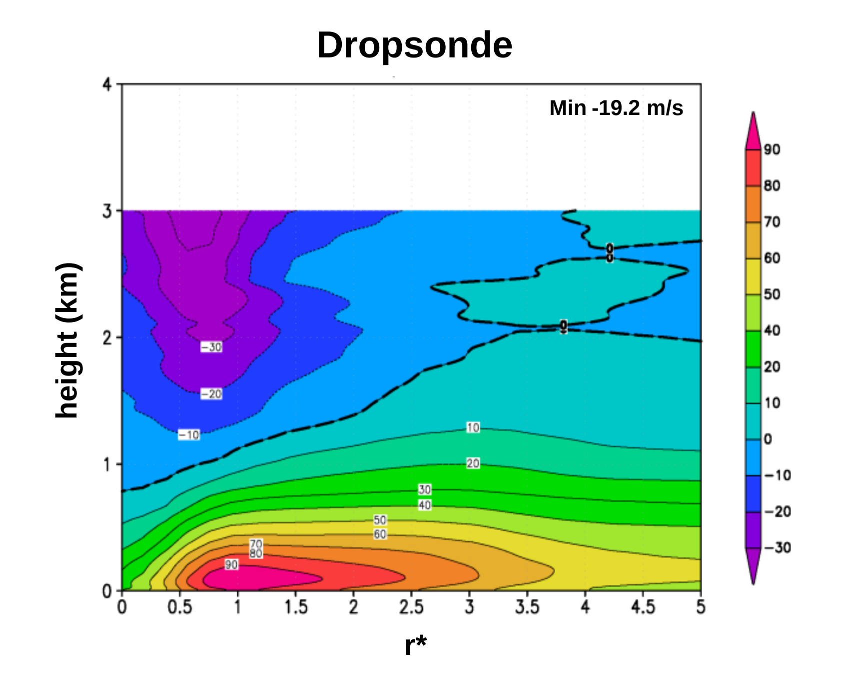
Doppler

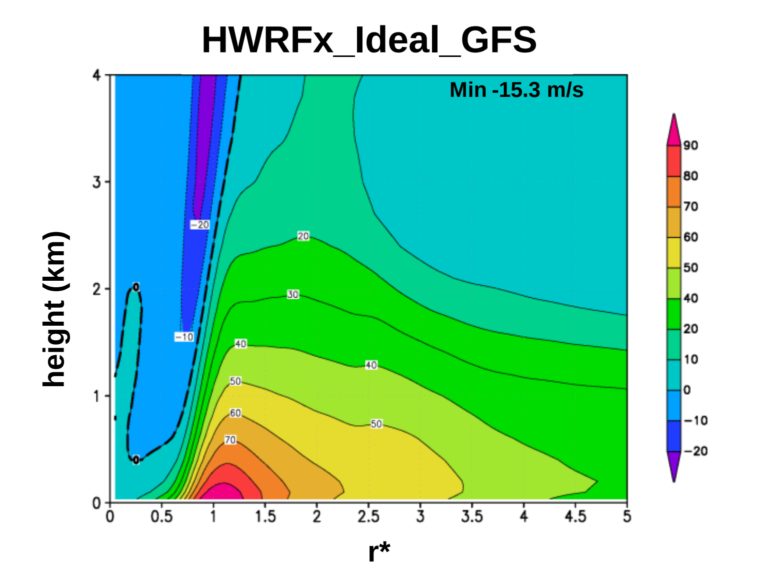
HWRFx_ Real

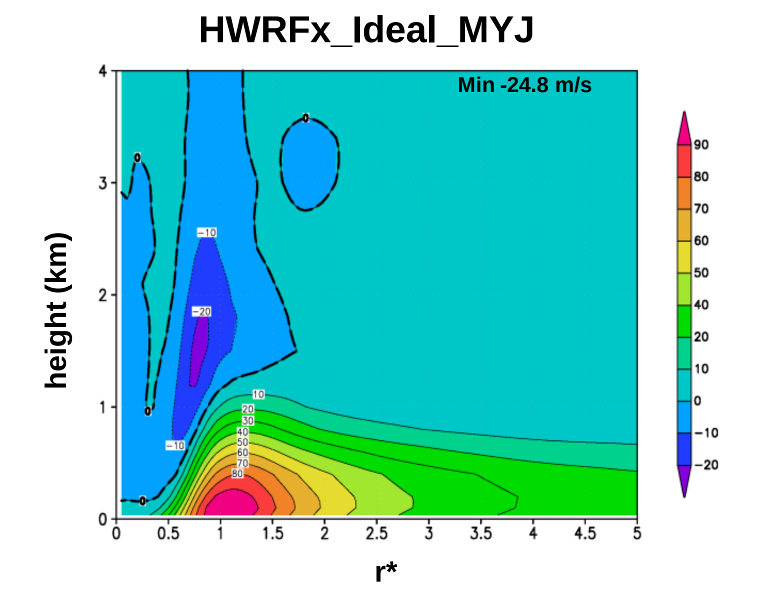


Symmetric boundary-layer

Radial wind (% of minimum, i.e.,peak inflow)



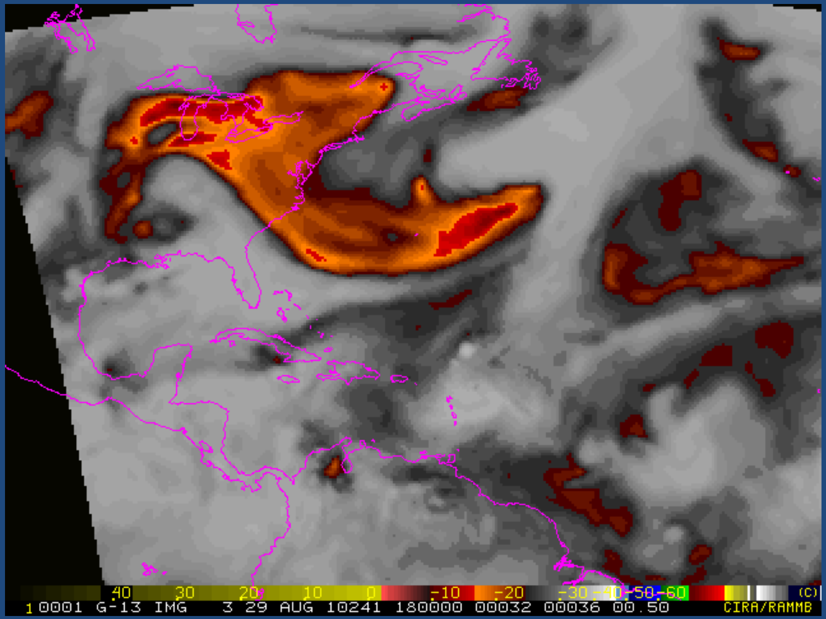


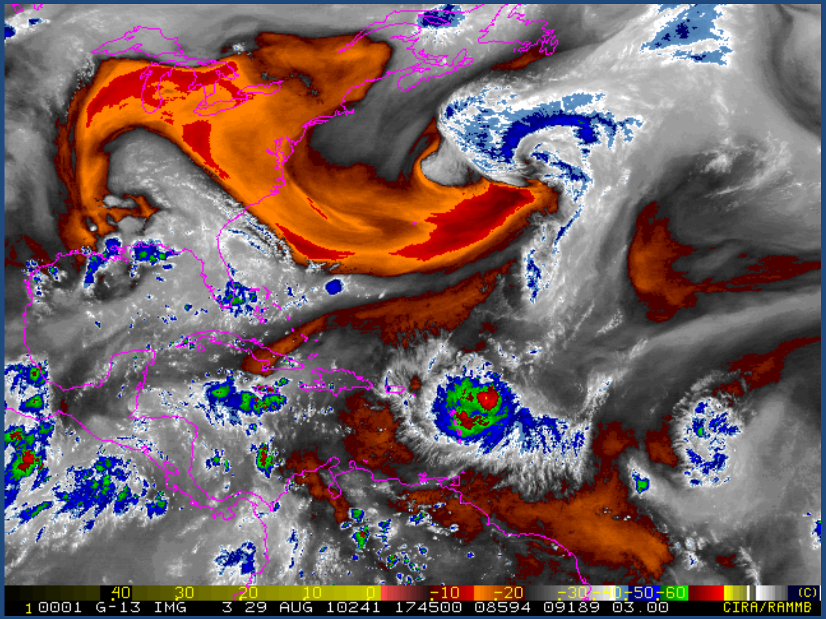


Example 6. Forward Radiative Transfer Model Diagnostics

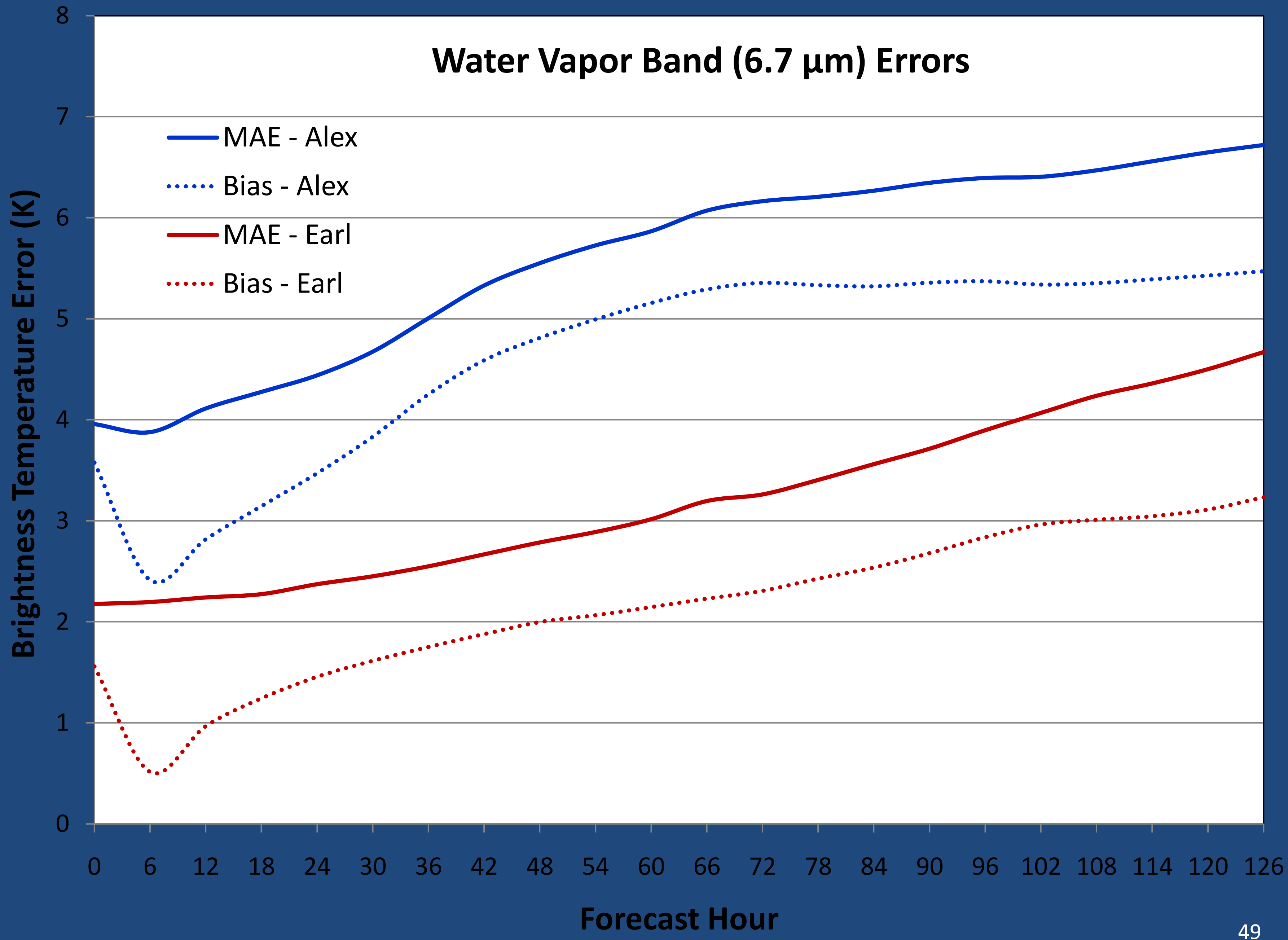
- Remote sensing observations are indirect measurements of model parameters
  - Radar
  - Satellite vis, IR and microwave
- Method 1: Retrieve model parameters from remote sensing observations
- Method 2: Apply radiative transfer code to model out to create “synthetic” model observations

HWRF Synthetic – Real GOES Comparison
GOES Channel 3 (Water Vapor)





6 hr Images 0 to 126 hr at 6 hr for Hurricane Earl starting 29 Aug 2010 at 18 UTC


Water Vapor Band (6.7 µm) Errors
MAE - Alex
Bias - Alex
MAE - Earl
Bias - Earl
Brightness Temperature Error (K)
Forecast Hour
0
1
2
3
4
5
6
7
8
0
6
12
18
24
30
36
42
48
54
60
66
72
78
84
90
96
102
108
114
120
126

Some Hurricane Model Diagnostics Utilities

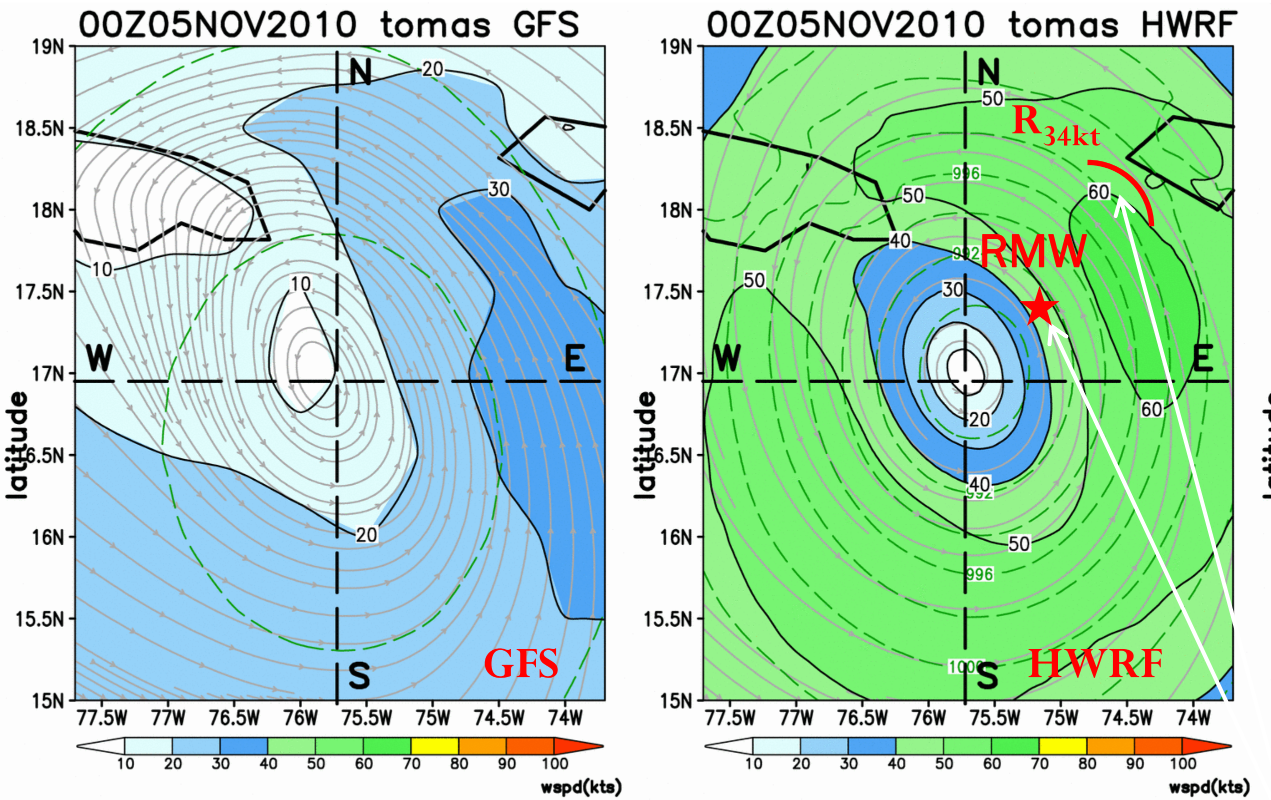
- NHC Diagnostic Module
- EMC HPLOT Program
- NESDIS/CIRA Large Scale Model Diagnostics
  - Used for statistical intensity model development
- AOML/HRD DiaPost

Input from Mrinal Biswas (DTC) and Wallace Hogsett (NHC)

NHC Diagnostic Module

- *Capabilities*
  - This diagnostics system inputs data from GFS/GFDL/HWRF and outputs figures of vortex structure.
  - Goal is to facilitate inter-model comparisons of initial vortex structure and gain insight into systematic characteristics of the various model initializations.

NHC Diagnostic Tool – Tomas Approaches Jamaica



Above: near-surface winds (shaded, kts), streamlines, and surface pressure (green dashed, hPa) from the GFS (left) and HWRF inner nest (center), and GFDL inner nest (right) ICs.

Approximate observed locations of RMW and 34kt radius (via P3 radar & SFMR).

* GFDL is superior to HWRF in this case in terms of constraining initial storm size, which is key factor in the initial balance/imbalance issue.

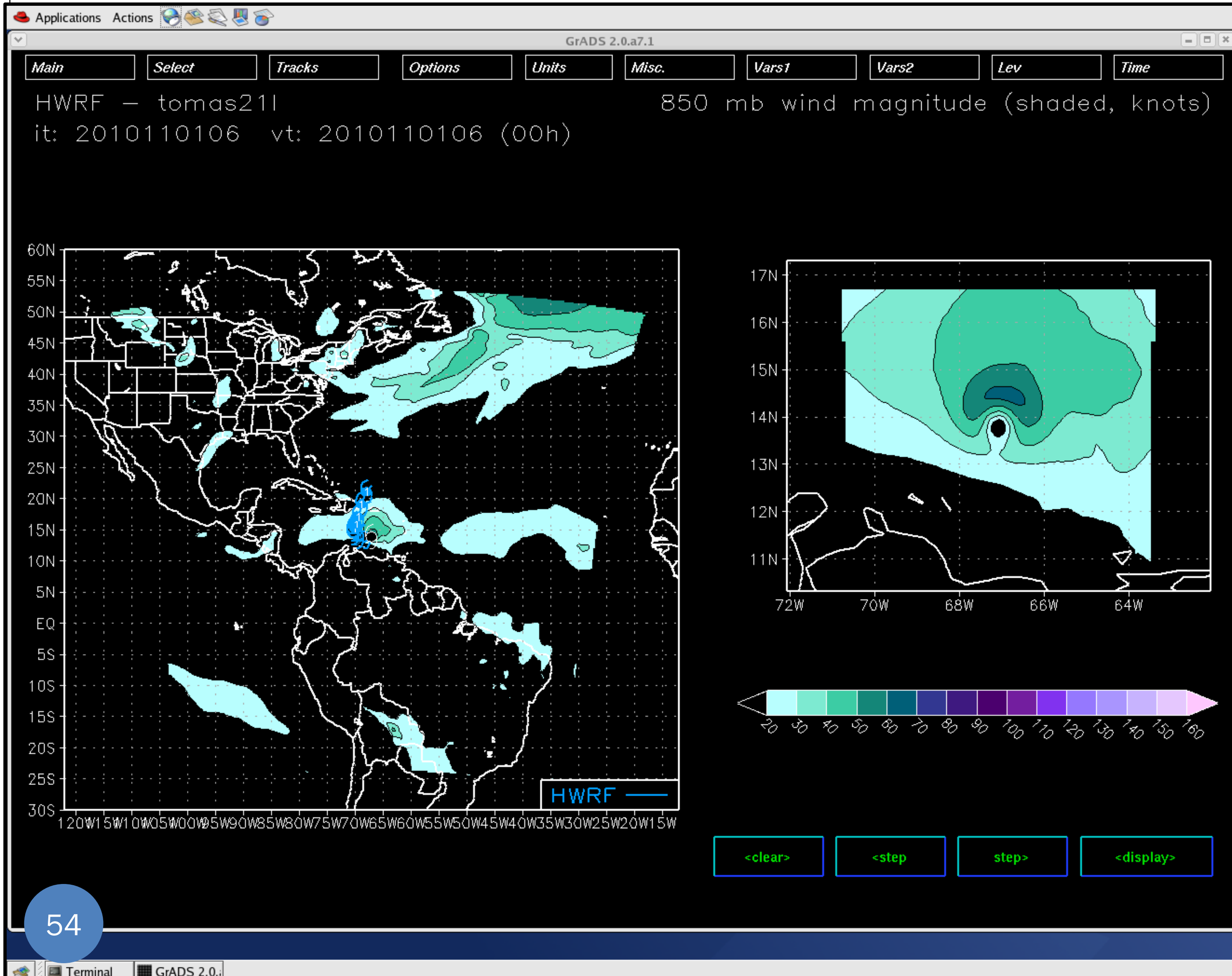
* Suggestion: Leverage GFDL size constraint methodology.

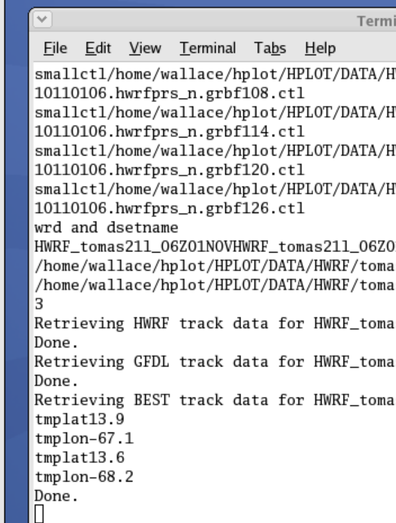
Diagnostic Tools: EMC HPLOT

- GUI based plotting program HPLOT (based on initial version developed by Tim Marchok and adapted for HWRF by Marshall Stoner) that allows visualization of several diagnostic components of the forecasts.
- Allows comparison of HWRF forecasts with other model forecasts as well as analysis/observations side by side (including difference plots on a uniform grid)
- Diagnostic measures include mean layer wind, vertical and zonal shear components, skew-T diagrams etc.
- Additional capabilities to compute statistical measures (RMS errors, anomaly correlation etc.) as well as filtering of storm component for evaluation of large-scale flow
- Vortex scale diagnostics include fixed/arbitrary horizontal/ vertical cross-sections of wind, temperature, heating rates, RH etc., azimuthally averaged winds, data on cylindrical coordinates.

HPLOT – EMC/NHC Collaboration

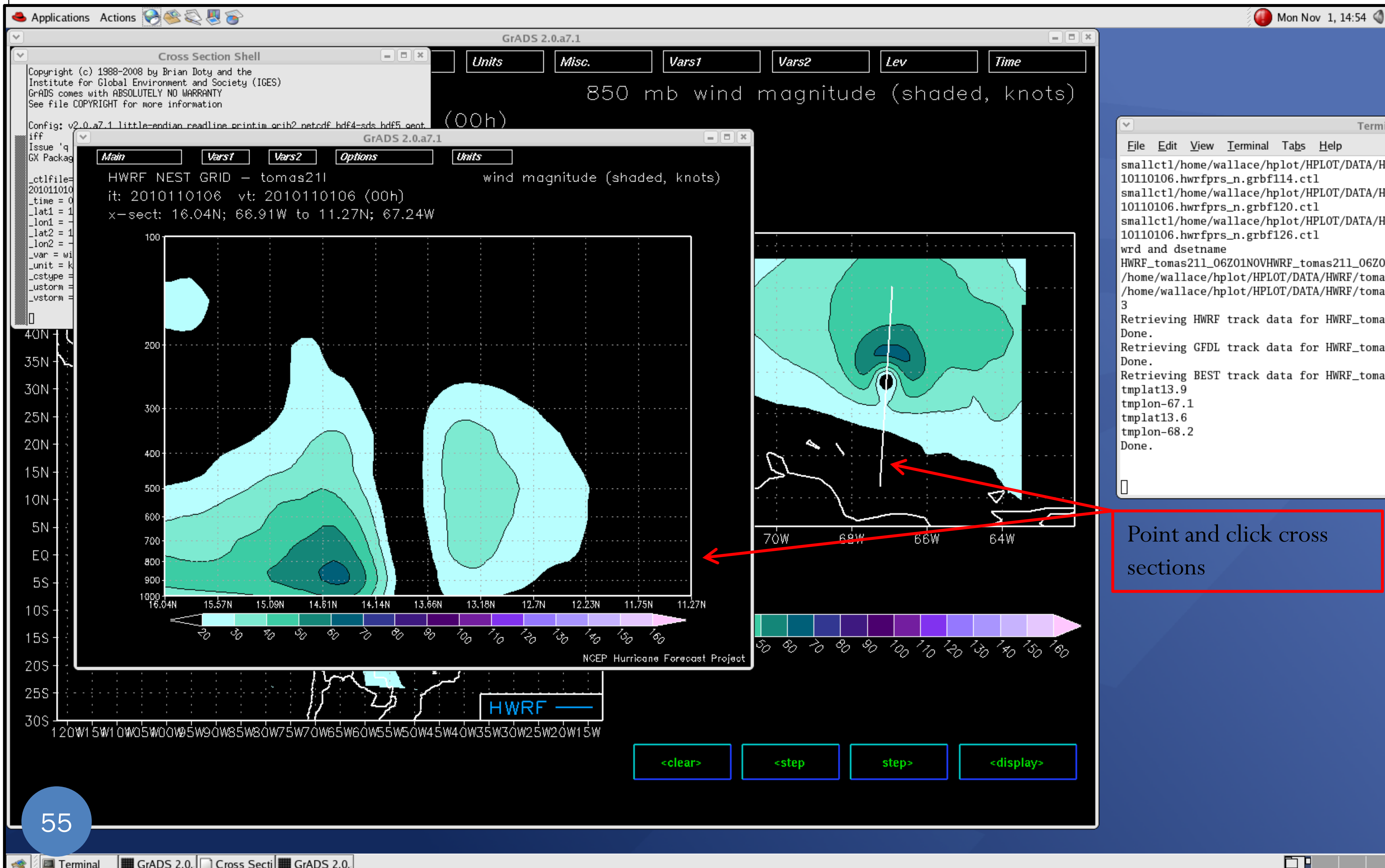
Analysis and forecast display tool





- Grads-based GUI,
- Launches from a terminal window,
- Facilitates analysis of HWRF/GFDL models,
- Executes analysis commands very quickly

HPLOT – Point-and Click Cross Sections



Point and click cross sections

Diagnostic Tools: Large Scale Model Parameters

SHIPS Intensity Model Development Code

*   HWRF 2010091312   *
*   AL11 IGOR   *

STORM DATA

NTIME 022

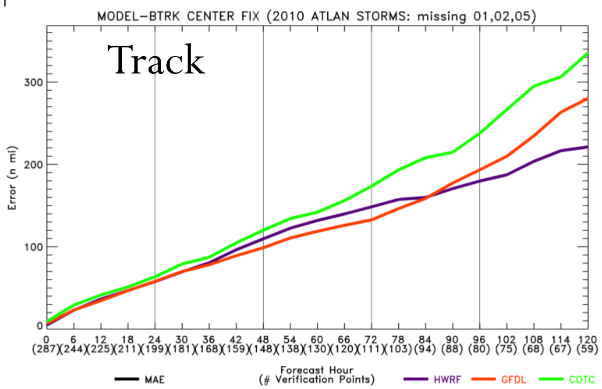
TIME	(HR)	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126
LAT	(DEG)	17.6	17.8	18.1	18.7	19.2	19.9	20.4	21.1	21.7	22.4	23.0	23.5	24.0	24.5	25.2	25.7	26.5	27.3	28.2	29.2	29.9	30.8
LON	(DEG)	310.9	310.1	309.6	308.9	307.9	307.2	306.5	305.7	304.8	303.9	303.0	302.3	301.5	300.7	299.7	298.7	297.8	296.9	296.1	295.4	294.8	294.5
MAXWIND	(KT)	130	101	104	105	98	94	90	104	95	91	89	86	91	92	85	87	84	93	92	92	90	90
RMW	(KM)	84	90	84	68	63	84	92	87	91	85	89	107	106	99	92	95	92	86	82	82	89	91
MIN_SLP	(MB)	934	918	924	925	929	929	928	929	934	933	935	934	937	935	939	939	940	936	937	936	939	938
SHR_MAG	(KT)	6	5	6	2	3	0	8	9	9	8	9	11	11	12	16	19	21	22	24	29	31	27
SHR_HDG	(DEG)	117	43	43	83	180	44	353	10	348	351	357	27	40	39	40	41	36	23	16	14	10	7
STM_SPD	(KT)	8	7	7	10	10	9	9	10	11	11	9	9	9	10	11	11	11	11	12	10	9	9
STM_HDG	(DEG)	285	292	308	304	307	312	310	309	308	308	307	306	304	306	304	307	315	318	325	326	334	344
SST	(10C)	282	282	281	278	282	284	283	279	279	281	281	279	276	277	288	291	288	286	286	288	289	288
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)	59	59	58	59	60	61	59	58	59	59	59	59	58	58	59	59	59	59	59	59	59	59
LAND	(KM)	1426	1417	1400	1379	1336	1340	1300	1233	1160	1099	1045	1012	979	956	948	935	971	1022	1099	1184	1176	1098
850TANG	(10M/S)	380	310	308	298	295	304	309	302	302	305	306	306	310	305	303	298	297	301	300	297	299	302
850VORT	(/S)	62	55	72	76	86	108	127	107	123	141	145	141	151	143	139	150	154	149	130	128	125	129
200DVRG	(/S)	48	48	89	92	73	91	115	71	64	56	45	48	71	75	44	39	43	60	45	40	63	82

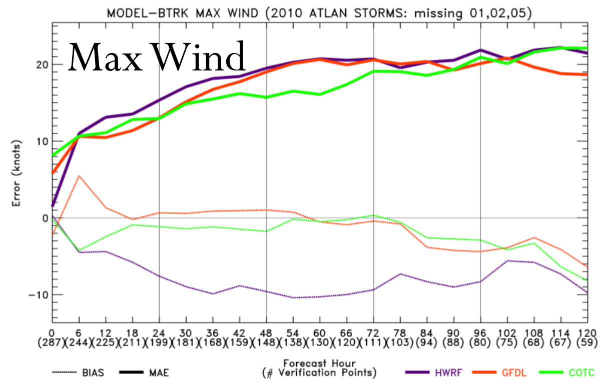
SOUNDING DATA

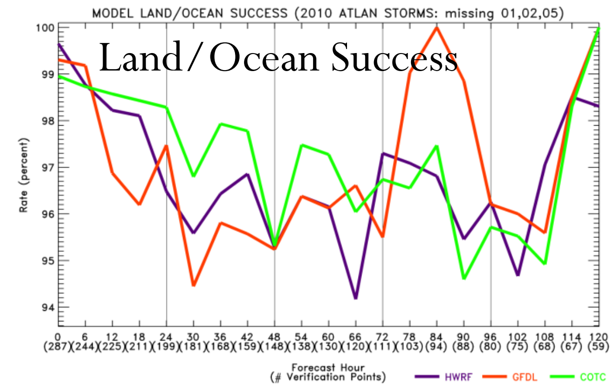
NLEV 022 SURF 1013 1000 0950 0900 0850 0800 0750 0700 0650 0600 0550 0500 0450 0400 0350 0300 0250 0200 0150 0100 0050

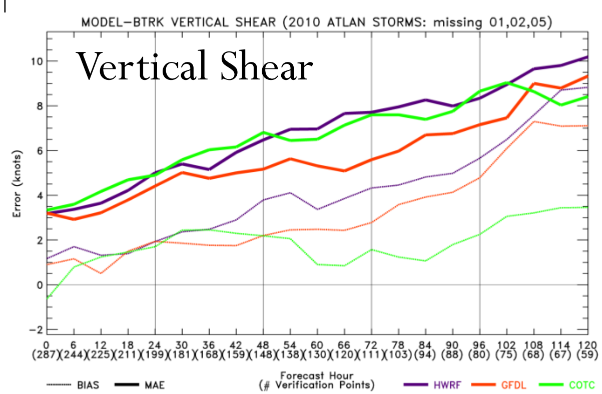
TIME	(HR)	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126
T_SURF	(10C)	281	292	287	281	280	279	283	280	279	285	281	286	283	284	284	285	284	283	283	277	280	283
R_SURF	(%)	83	80	82	84	85	85	85	85	85	84	84	83	83	81	82	82	82	82	83	82	82	82
P_SURF	(MB)	1010	1007	1008	1007	1009	1007	1009	1006	1008	1006	1007	1004	1005	1004	1005	1003	1005	1004	1006	1004	1006	1005
U_SURF	(10KT)	-46	-40	-45	-46	-22	-30	-37	-58	-43	-36	-34	-45	-49	-55	-66	-75	-71	-62	-60	-58	-42	-41
V_SURF	(10KT)	12	-13	0	24	30	19	1	-1	7	11	-10	-6	-15	-15	-37	-23	-30	-25	-33	-25	-33	-24
T_1013	(10C)	279	286	284	281	280	279	280	278	276	277	277	275	276	277	276	274	273	274	273	270	271	272
R_1013	(%)	79	77	79	82	82	83	81	84	83	82	82	82	81	80	81	81	80	80	80	80	80	79
Z_1013	(DM)	-3	-5	-4	-5	-3	-5	-4	-6	-4	-6	-5	-8	-7	-8	-7	-9	-7	-8	-6	-7	-6	-7
U_1013	(10KT)	-52	-47	-53	-53	-26	-33	-42	-65	-50	-41	-38	-51	-56	-63	-76	-85	-81	-70	-69	-65	-48	-46
V_1013	(10KT)	14	-10	3	32	38	23	2	0	11	15	-9	-4	-15	-15	-39	-23	-31	-26	-34	-26	-35	-26
T_1000	(10C)	273	281	280	275	274	274	274	273	270	272	272	271	271	272	271	269	268	268	268	265	265	266
R_1000	(%)	78	75	78	80	81	81	80	82	82	81	80	80	79	78	79	79	78	79	79	79	78	78
Z_1000	(DM)	9	6	8	7	8	7	8	5	7	5	7	4	5	3	5	3	5	4	5	4	5	4
U_1000	(10KT)	-55	-48	-55	-55	-28	-34	-44	-66	-52	-42	-39	-51	-56	-63	-76	-84	-81	-70	-69	-65	-48	-47
V_1000	(10KT)	16	-10	4	33	39	24	3	1	12	15	-9	-4	-15	-15	-39	-23	-31	-26	-34	-26	-35	-27
T_0950	(10C)	233	240	239	235	234	234	234	232	230	232	232	230	230	233	231	229	228	229	227	225	225	226
R_0950	(%)	89	86	89	92	93	93	92	94	94	93	92	92	90	89	90	90	89	90	90	90	90	89
Z_0950	(DM)	54	52	53	52	54	52	53	51	52	51	52	49	50	49	50	48	50	49	50	49	51	50

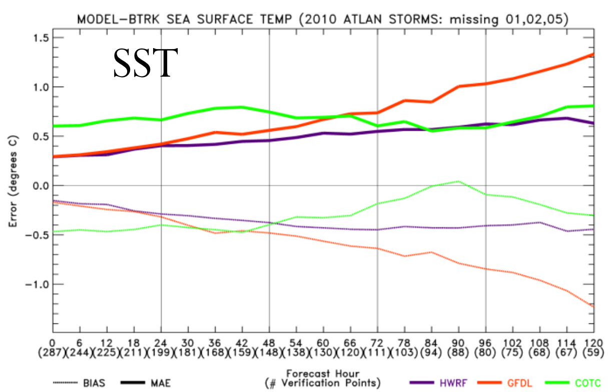
Model Inter-comparison of Large-Scale Parameter Errors HWRF, GFDL, COAMPS-TC

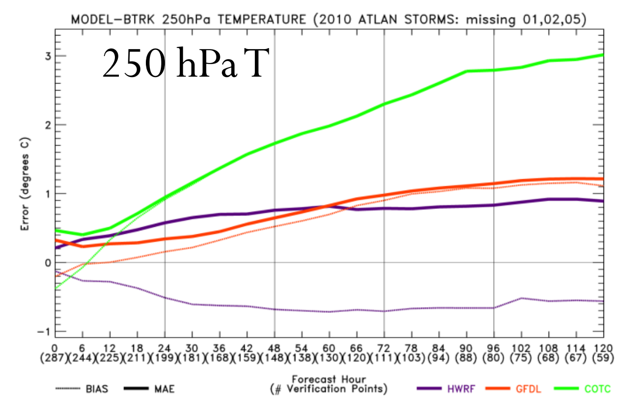






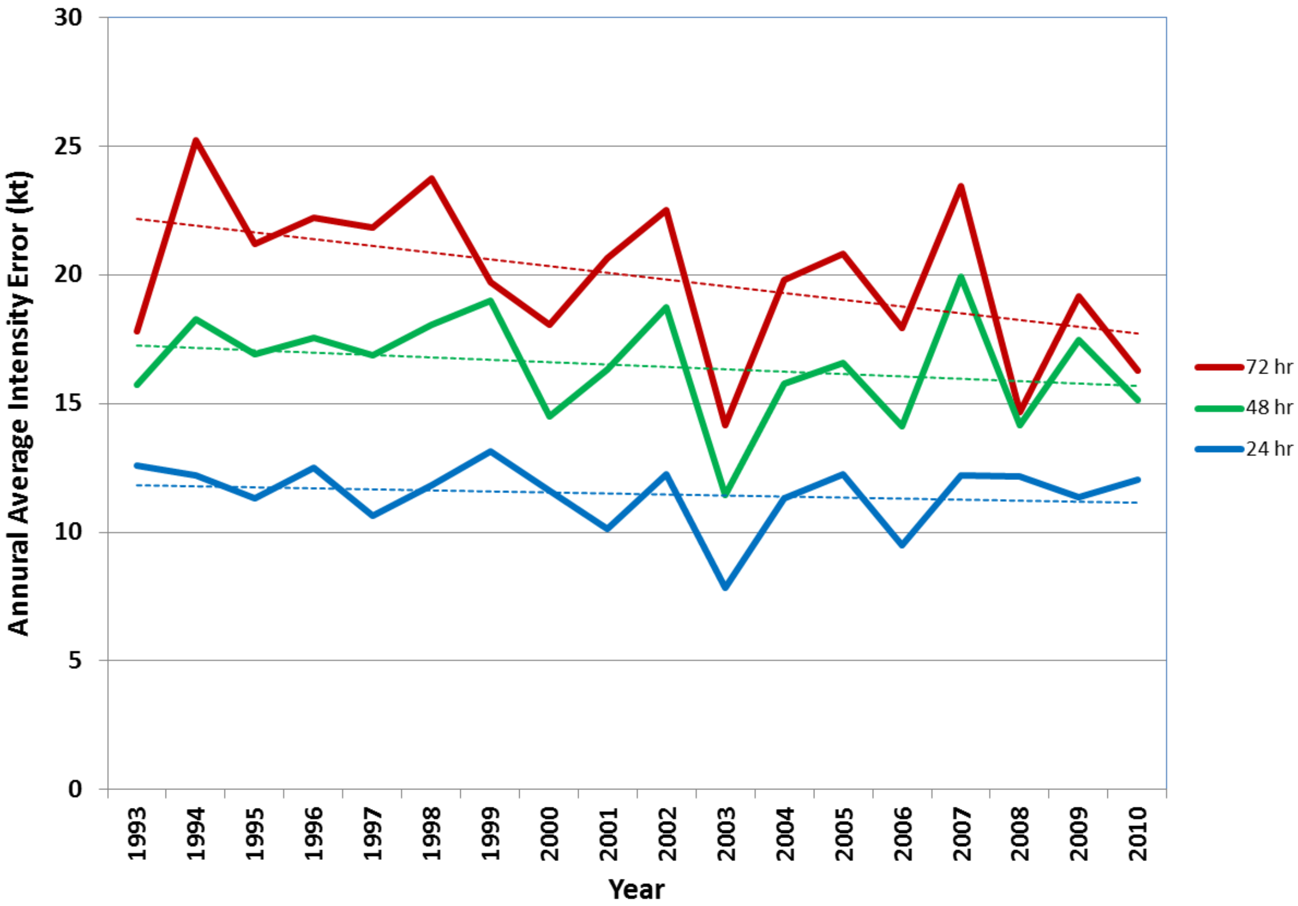






Ground "truth": Working best track, GFS analyses, Reynolds SST analyses

Statistical-Dynamical Intensity Model Forecast Error Trend



SHIPS 1993-1999, D-SHIPS 2000-2005, LGEM 2006-2010

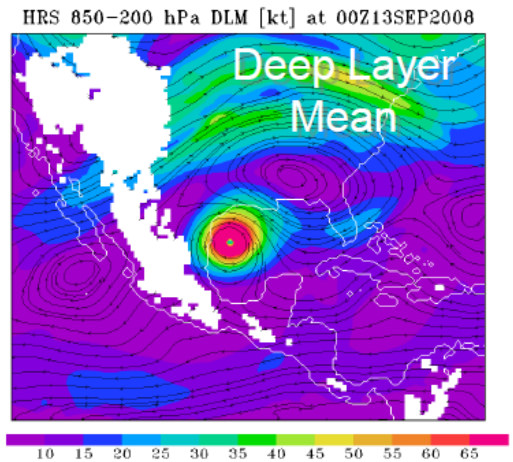
18 Year Improvements of 6%, 10% and 20% at 24, 48 and 72 hr

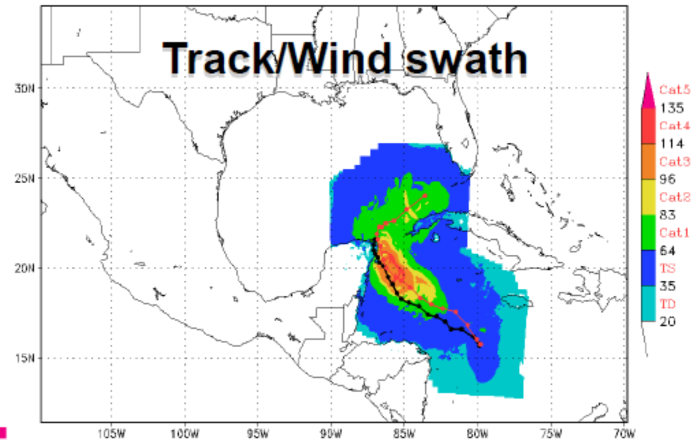
AOML/HRD Diapost

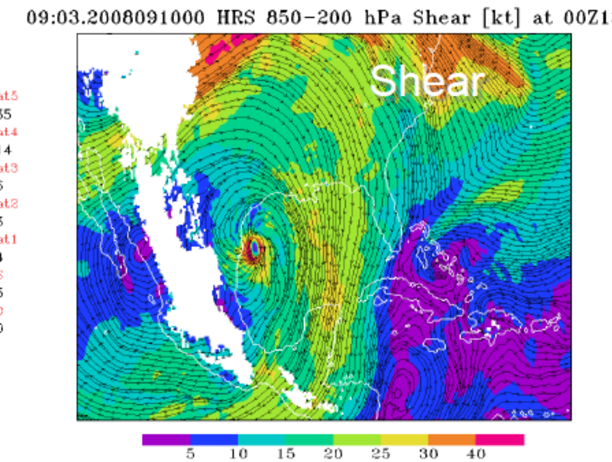
- One code, one executable all available within WRF framework (WRF application program interface)
- Orders of magnitude faster than NMM-wrfpost (at 9 km takes <5 minutes for processing 3-h WRF output for 5 day forecast)
- Provides binary/flat file data, GrADS control files compatible with GrADS. Also ASCII track information.
- Grib files produced via HFIP output module.
- Can be linked to official tracker via output module.
- Horizontal: Native rotated lat/lon (minimum loss in information) and standard lat/lon and Cylindrical projection for inner core
- Vertical: Native hybrid, standard pressure and height
- Wind swaths, Deep-layer mean, Shear and other hurricane/environment specific variables
- Inner core details: Hovmöller diagrams

Thiago, AOML

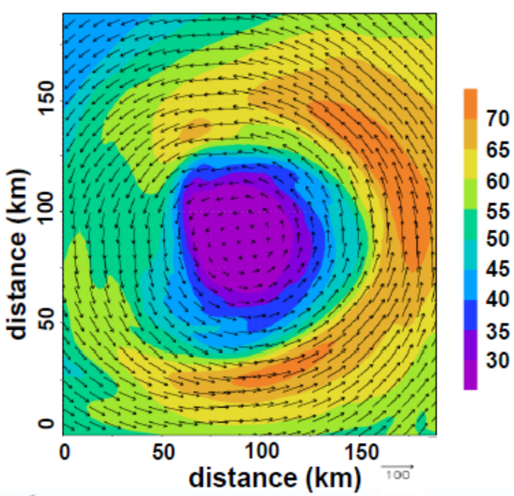
Environmental Scale

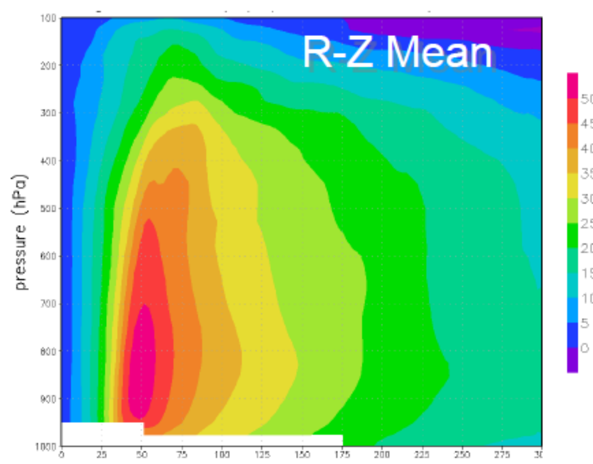


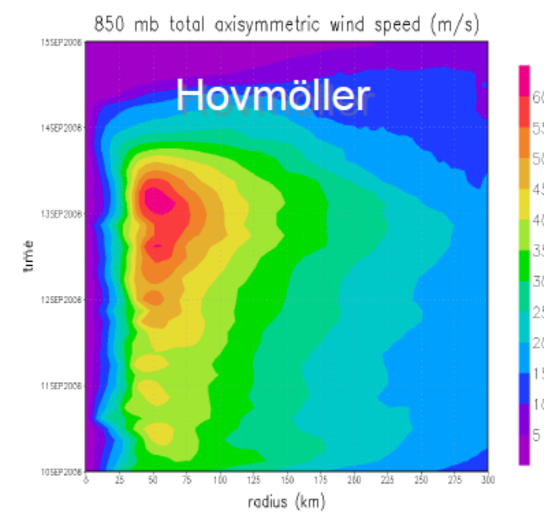




Vortex Scale







Thiago, AOML

Developmental Testbed Center

Summary

- Hurricane model diagnostics are needed because of the complexity of these prediction systems
- Extract model parameters in the context of a conceptual or theoretical framework
- Diagnostics serve multiple purposes
  - Forecast model improvements
  - Inter-model comparisons
  - Comparisons with observations
  - Improved physical understanding of hurricane processes
- Diagnostic procedures are scale-dependent
- Several hurricane model diagnostic routines under development
  - Possible support by the DTC under HFIP