The performance of the WAM4.5 based on a revised formulation of the whitecapping dissipation and on limiting the drag coefficient in hurricane type wind forcing

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MOTIVATION

- **To improve the performance of the Canadian Meteorological Centre (CMC) ocean wave model WAM4.5 for extreme storm events such as hurricanes**

METHODOLOGY

- **Use of one-way coupled model system:**
  - ***Blended CHC (Canadian Hurricane Centre) parametric hurricane model and CMC GEM (*Global Environmental Multiscale) *model winds are created using the HURSWIM technique***
  - ***Blended and unblended winds generated are used to drive an improved and enhanced WAM4.5***

- **Assessment of the performance of WAM4.5 for hurricanes Juan and Wilma**

SUMMARY of CONCLUSIONS

- **Study indicates:**
  - **Blending of CHC parametric hurricane wind model winds and CMC GEM model forecast winds produces more realistic, intense and compact wind and wave systems**
  - **The blended wind statistics in excess of 10 m/s are slightly better than the corresponding unblended wind statistics**
  - **WAM4.5 generated wave parameters based on blended winds show general improvements over those based on unblended winds.**
  - **Enhanced WAM4.5 produces C_D and u_* which show a tendency for saturation for wind speeds in excess of about 25 ms^{-1} in agreement with the results of Donelan et al. (2004) and Powell et al. (2003). The results also indicate that C_D capping may not be necessary**

Outline

- The Wave Model WAM4.5
- Generation of hurricane winds
  - CHC parametric hurricane wind models
  - One-way coupled model system
- WAM 4.5 wind forcing
  - Unblended CMC GEM model winds
  - Blended CHC hurricane model and CMC GEM model winds
- Results of wave simulations of hurricanes Juan and Wilma
  - With unblended and blended winds
  - With and without revised formulation of whitecapping dissipation
  - With and without drag coefficient capping
- A look to the future

WAM Cycle-4.5 (WAM4.5)

- **An update of WAM Cycle-4 (WAM4)**
  - **Operational implementation**
    - **Northwest Atlantic and Northeast Pacific with grid resolution of 0.5^{o}**
    - **Great Lakes with grid resolution of 0.05^{o}**
- **Improvements**
  - ***Parallelization***
  - ***Inclusion of linear wave growth source term***
  - ***Inclusion of depth-induced wave breaking source term***
  - ***Numerics adjustments:***
    - ***Maximum wave-induced stress =< 5.0 and u_*^2 m^2s^{-2}***
    - ***U_{10min} = 1.0 m/s; u_{*min} = 0.01 m/s → $C_{Dmin} = 10^{-4}$***
    - ***$Z_{0min} = 1.0 \times 10^{-7}$ m***

WAM4.5 (cont'd)

- **Enhancements**
  - ***Revised formulation of whitecapping dissipation source term S_{ds} as described in Bidlot et al.(2005)***
  - ***Other small and necessary adjustments:***
    - ***Mean windsea frequency replaces the mean frequency of the total sea in the prognostic cut-off frequency equation and in Hersbach-Janssen limiter***
    - ***Hersbach-Janssen limiter is reduced by a factor of 0.6***
    - ***In the Charnock parameter equation the constant 0.01 is replaced by 0.0095***

WAM4.5 (cont'd)

- **Enhancements (Cont'd)**
  - ***The total stress in look-up table:***
    - *Now expressed in terms of U_{10} and SQRT(τ_w) instead of U_{10} and τ_w*
    - *Maximum U_{10} increases from 50 m/s to 70 m/s*
    - *The table size is now 200 x 200 instead of 100 x 100*

- ***Constraint on u_* through capping of drag coefficient, C_D***
  - C_{Dcap} *= 0.0036 (Jensen et al., 2006)*
  - $u_* = MIN(u_* , sqrt(C_{Dcap} * U_{10}^2))$

Generation of Hurricane Winds

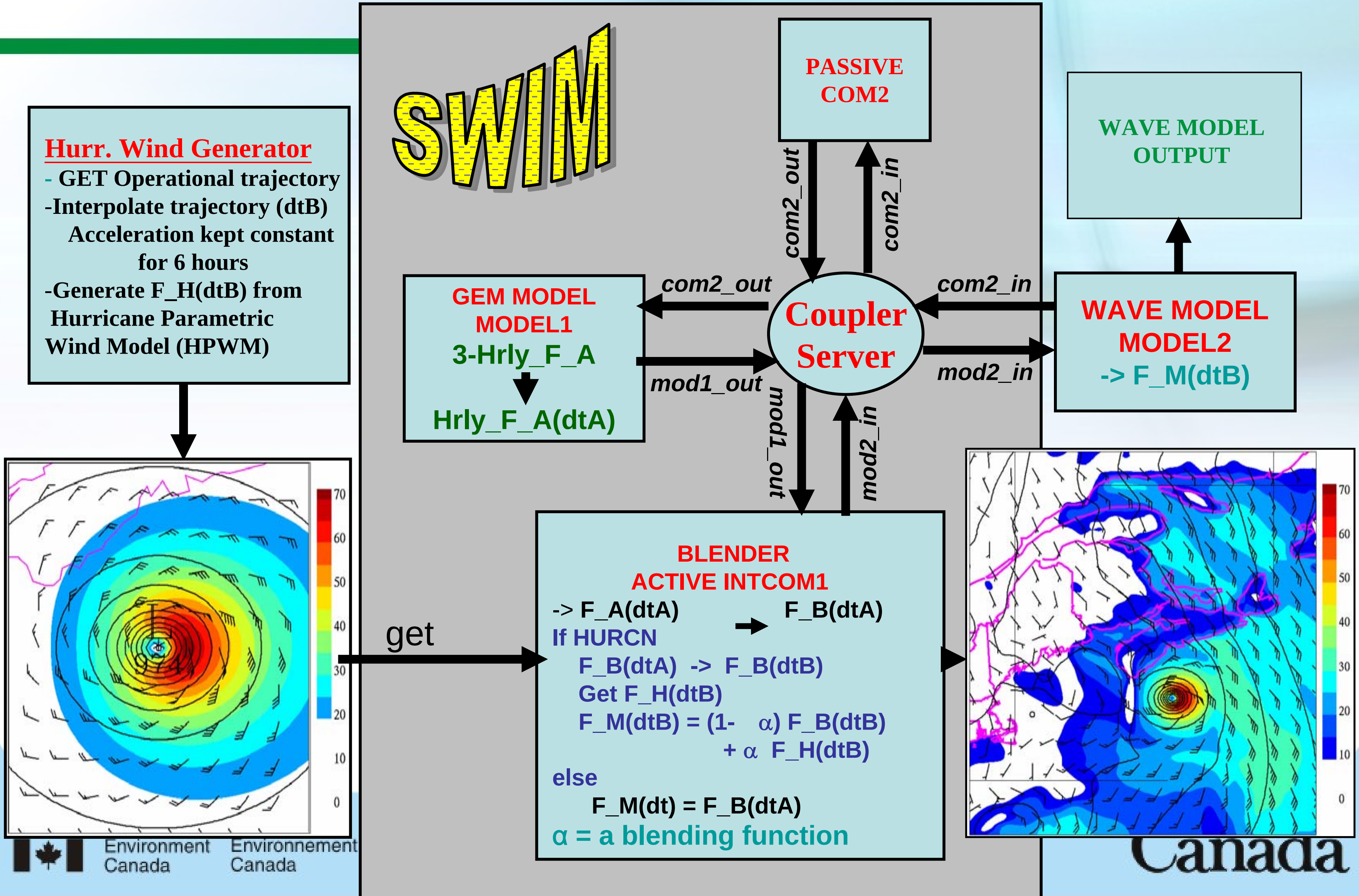
- The operational GEM model have often shown weaknesses in representing and predicting wind and pressure fields associated with hurricanes

- To improve the accuracy of the surface fields in the shorter term for input to a wave model, the Surface Wind Interpolator and Modifier (SWIM) technique is used to blend hurricane parametric model wind and pressure fields based on the CHC trajectory forecasts into the operational GEM model surface fields

- The hurricane parametric wind model used in this study is called the SLOSH wind model (see Jelesnianski et al. 1992; Phadke, 2003; Houston and Powell, 1994)

ONE-WAY COUPLED MODEL SYSTEM

INTCOM1 = Interpolator/Communicator *COM2 = Communicator*



WAM4.5 Wind Forcing

- The WAM4.5 uses the winds produced by HURSWIM on a coarse grid with a resolution of 0.5^o covering the oceanic area 25^{o}N – 70^{o}N and 82^{o}W – 0^{o}W

- The WAM4.5 is driven by both blended and unblended winds produced by HURSWIM to simulate the waves in hurricanes Juan (25-30 September 2003) and Wilma (24-28 October 2005)

Simulations of Hurricanes Wilma and Juan

- **Denote:**
  - ***H = Hurricane blending***
  - ***C = Drag coefficient capping***
  - ***R = Revised formulation of S_{ds}***
  - ***N = No***

- ***WAM4.5 runs based on blended winds are defined as:***
  - **H-NC-NR or NCNR**
  - **H-NC-R or NCR**
  - **H-C-R or CR**

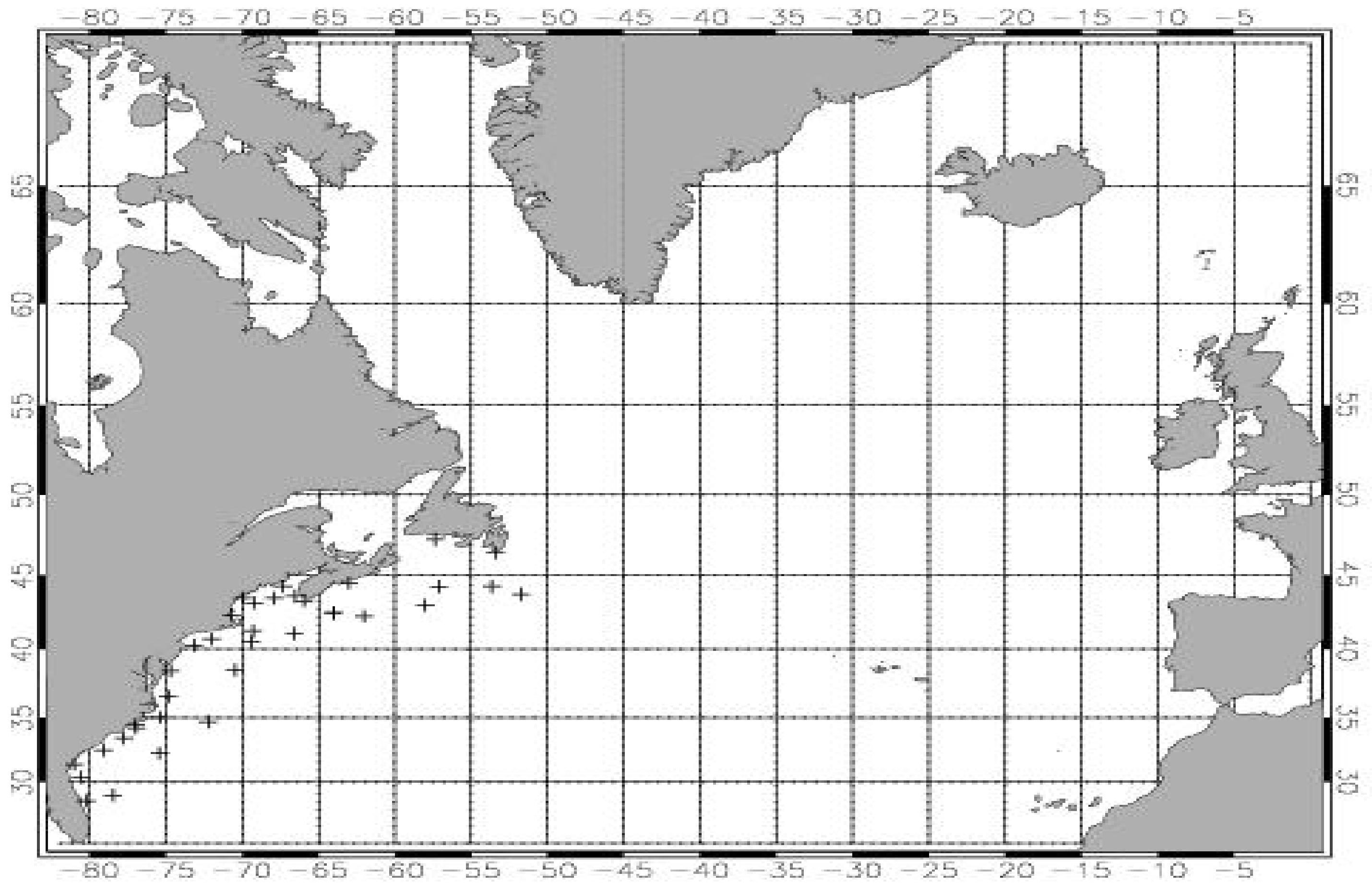
- ***WAM4.5 run based on unblended wind is defined as:***
  - **NH-NC-NR or NHNCNR**

- **C_{Dcap} = 0.0036 (Jensen et al., 2006)**

- **Validation buoys**
  - **Wilma: 25 buoys**
  - **Juan: 23 buoys**

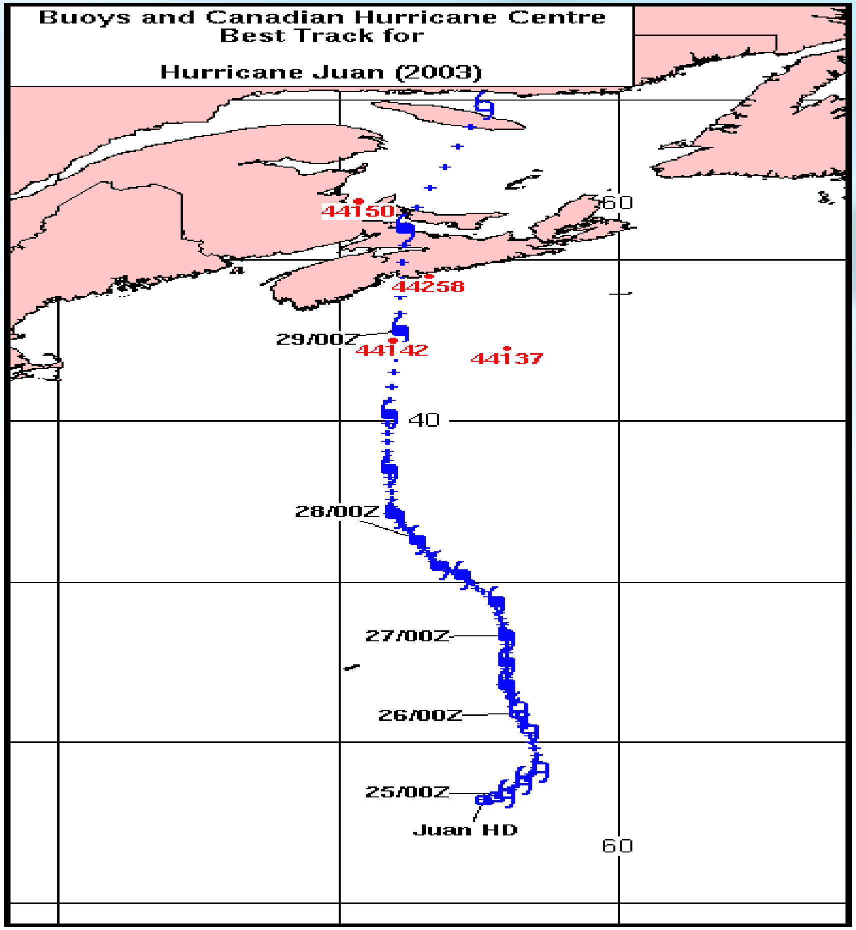
WAM4.5 Grid Area

MEDS and NDBC Validation Buoy Locations



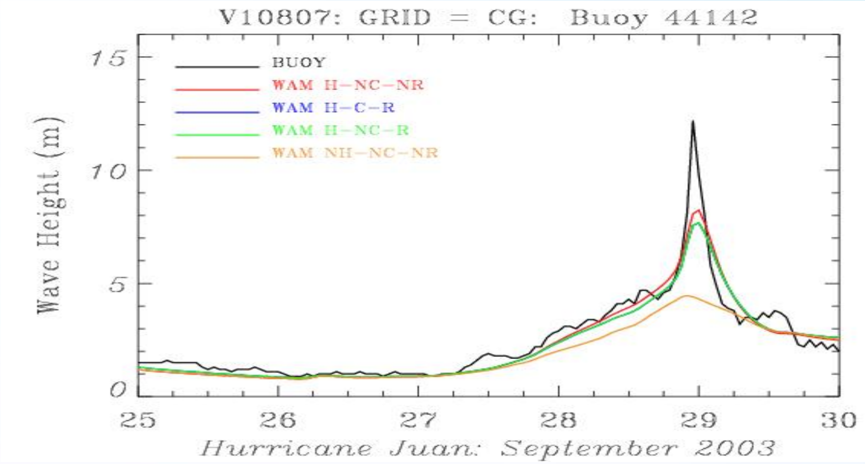
Hurricane Juan

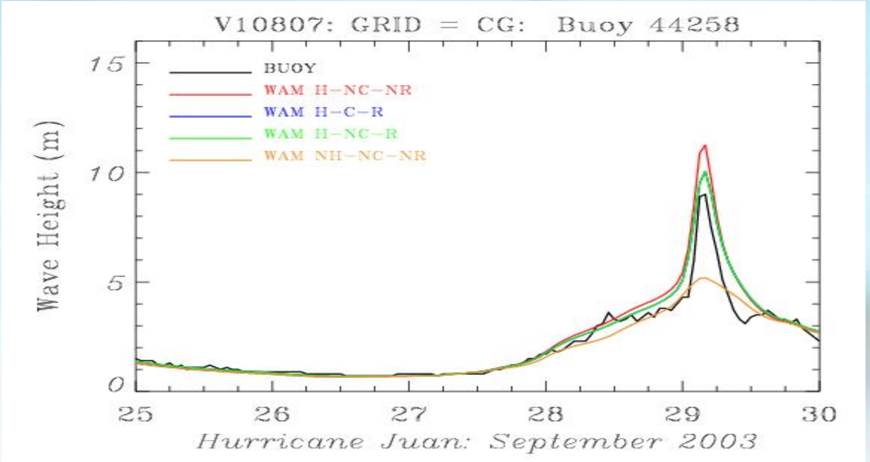
(00Z/25 – 00Z/30 Sep 2003)

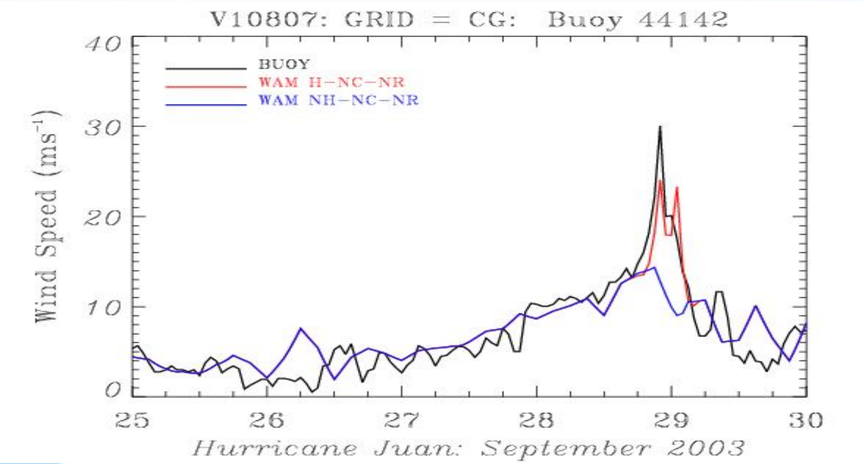


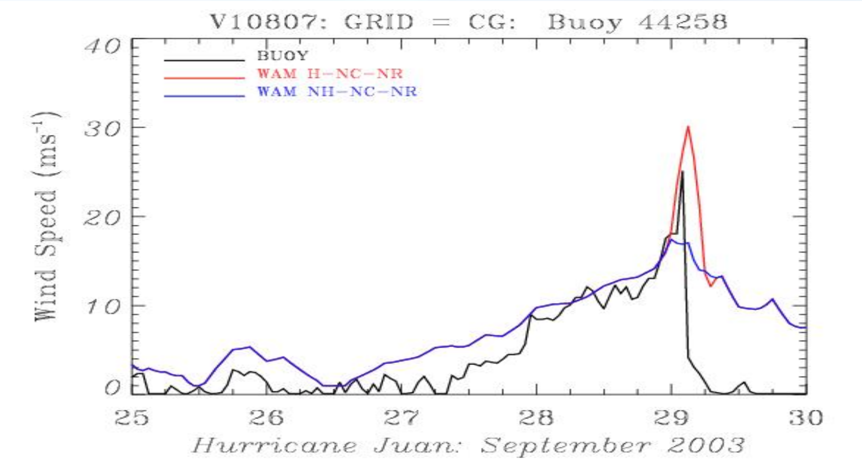
JUAN: SWH and Wind Speed Time Series

Legend: H-NC-NR: Hurricane blending, no C_d capping and no S_{ds} reformulation
H-C-R: Hurricane blending, C_d capping and S_{ds} reformulation
H-NC-R: Hurricane blending, no C_d capping and S_{ds} reformulation
NH-NC-NR: No hurricane blending, no C_d capping and no S_{ds} reformulation







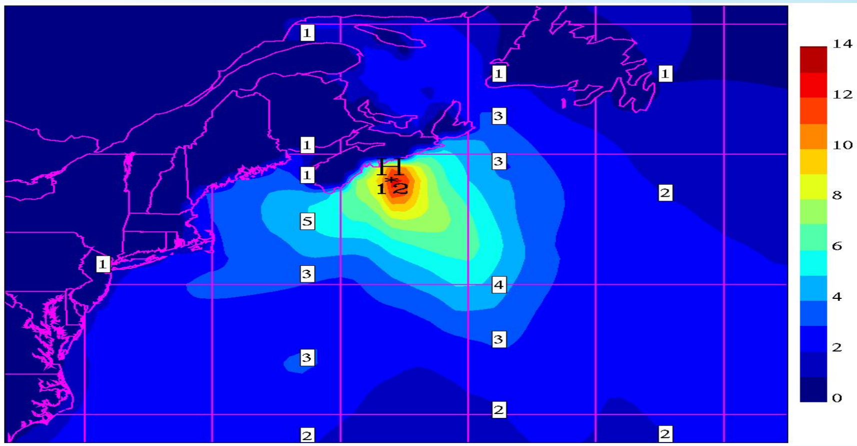


JUAN: SWH (m) Snapshots of Hurricane vs. No Hurricane Blending

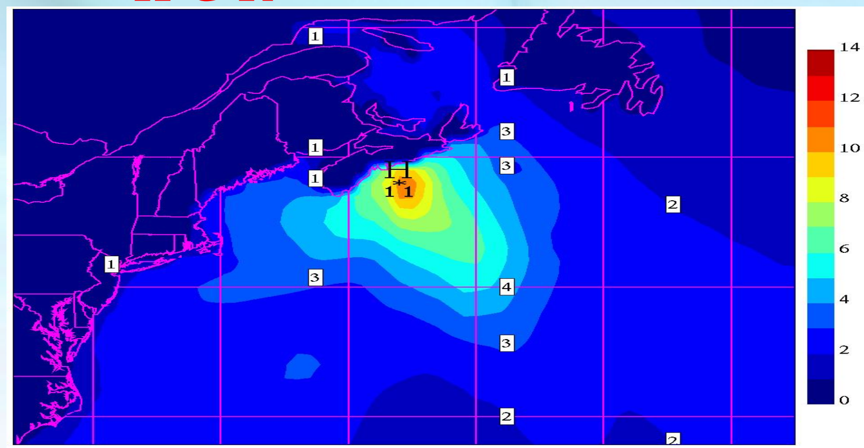
Valid 0300 UTC 29 September 2003

Buoy 44258 obs: SWH = 8.9 m

H-NC-NR



H-C-R



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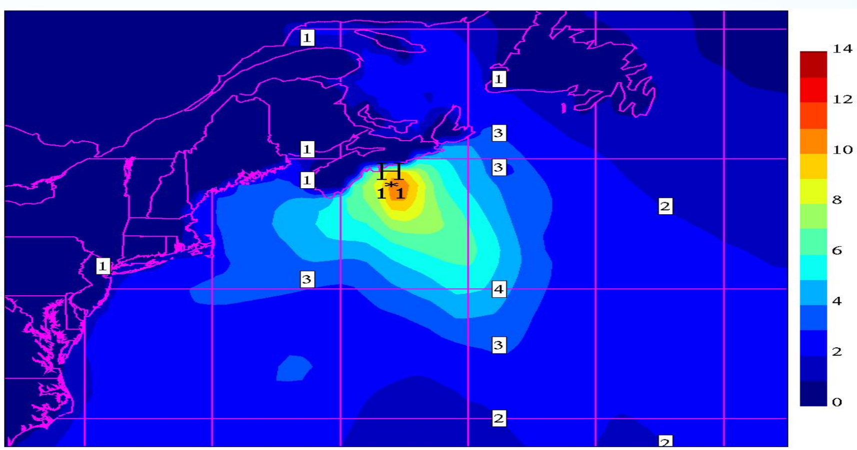
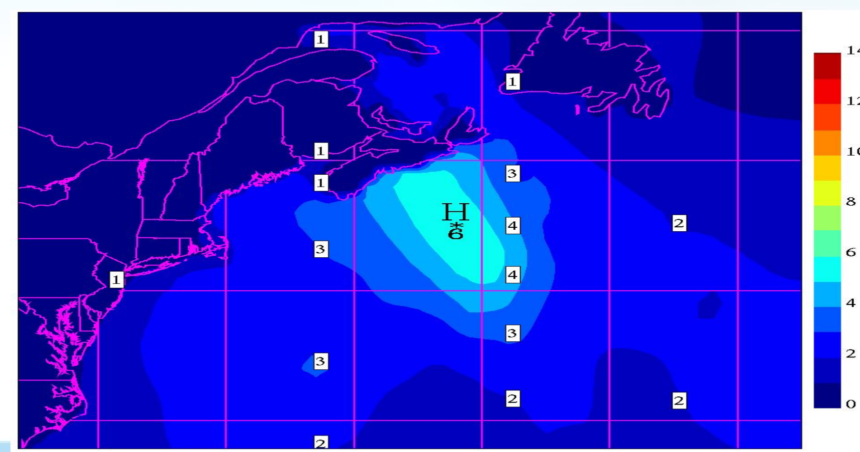


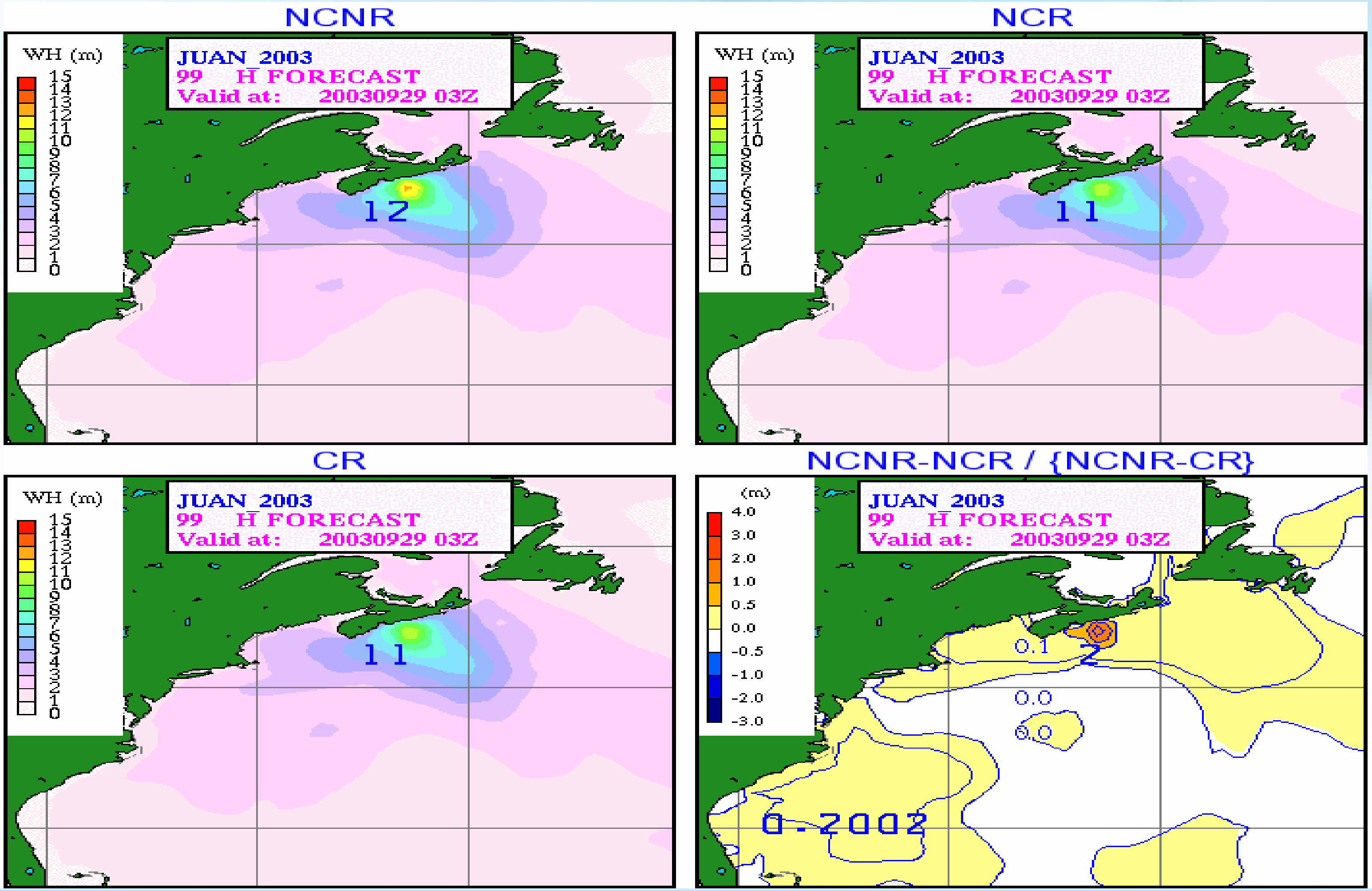
NH-NC-NR



JUAN: SWH Snapshots Based on Blended Winds

Lwr. Rt.. Pan: SWH differences of NCNR-NCR (col scale) and NCNR-CR (blue lines)

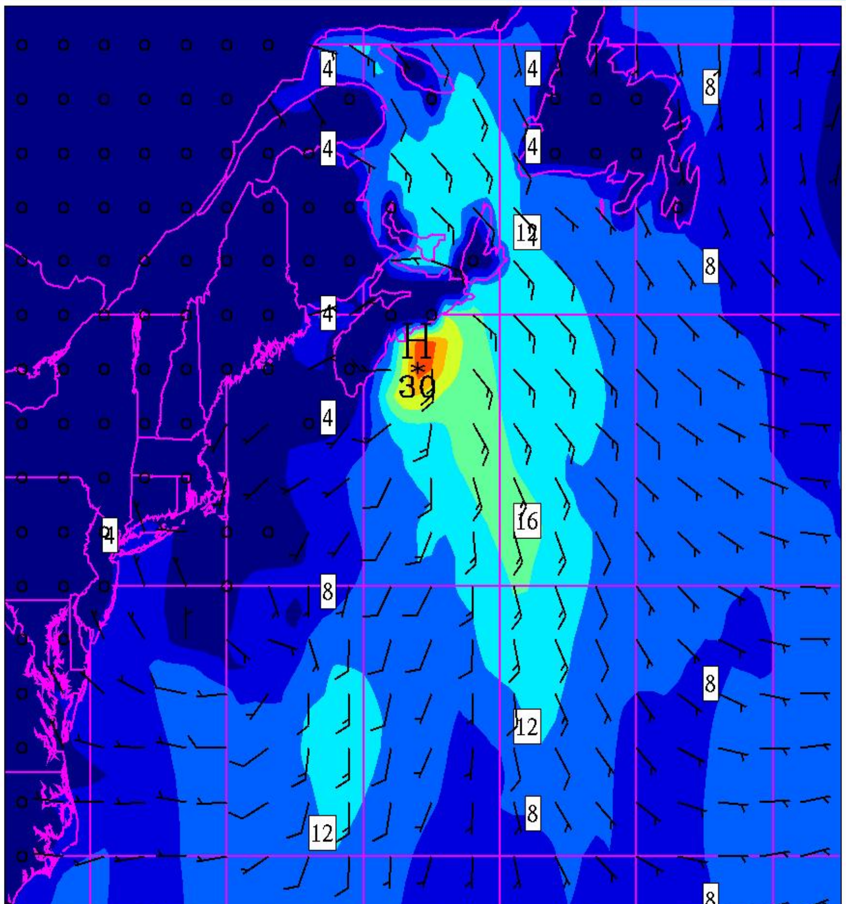
Valid 0300 UTC 29 September 2003



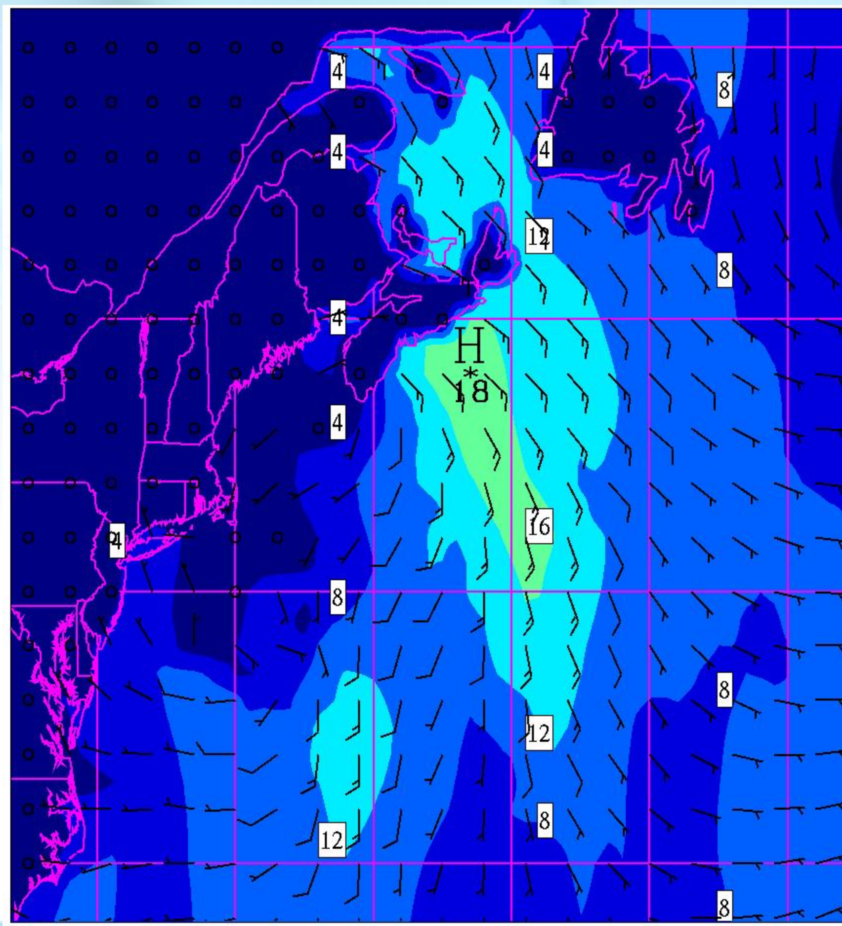
JUAN: Winds (ms^{-1}) Snapshots of Hurricane vs. No Hurricane Blending

Valid 0300 UTC 29 September 2003

Hurricane blending



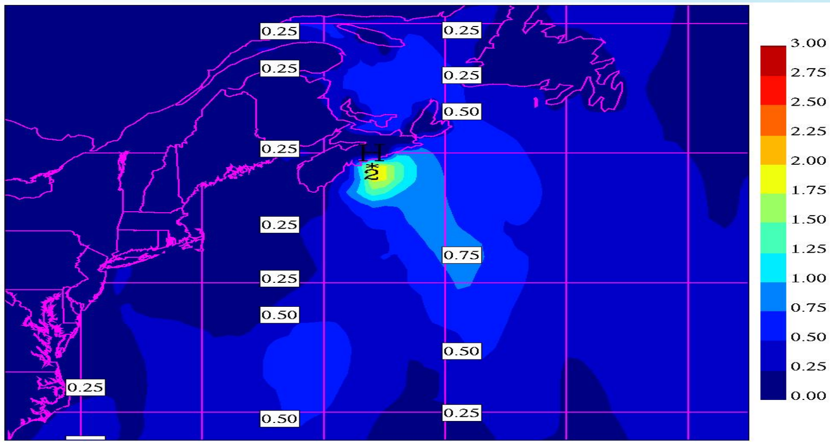
No hurricane blending



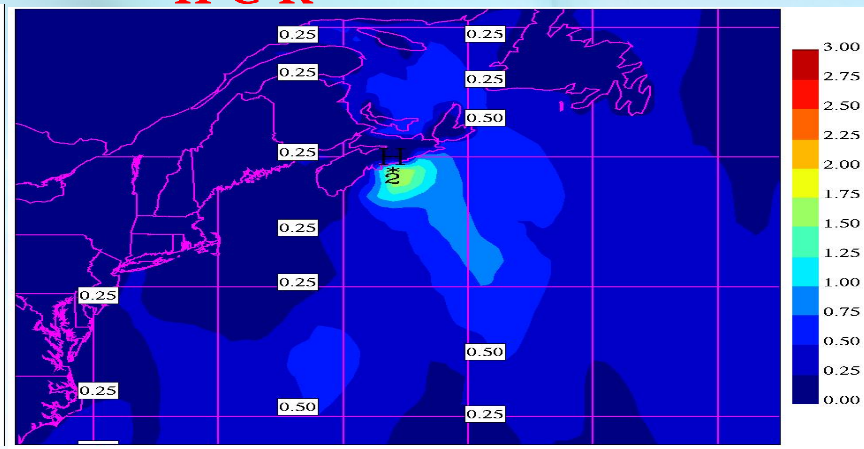
JUAN: u_* (ms^{-1}) Snapshots of Hurricane vs. No Hurricane Blending

Valid 0300 UTC 29 September 2003

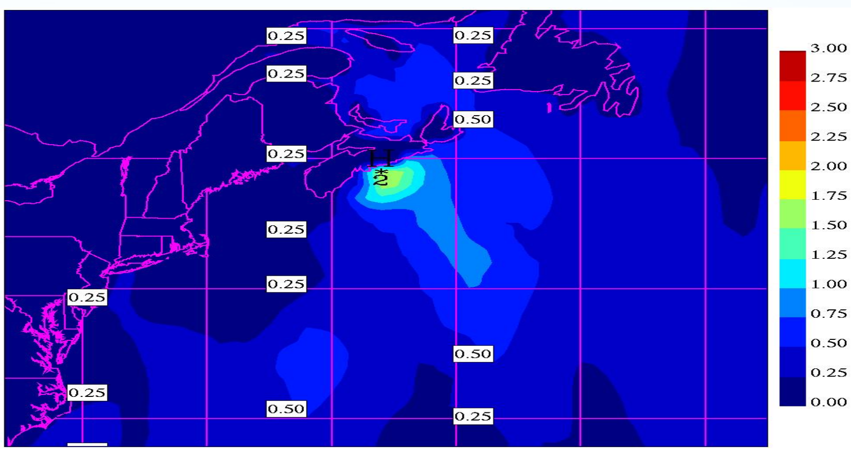
H-NC-NR



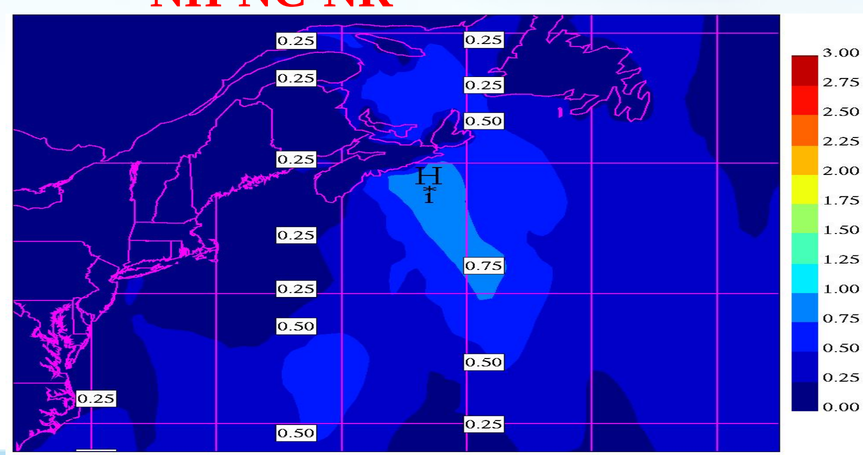
H-C-R



H-NC-R



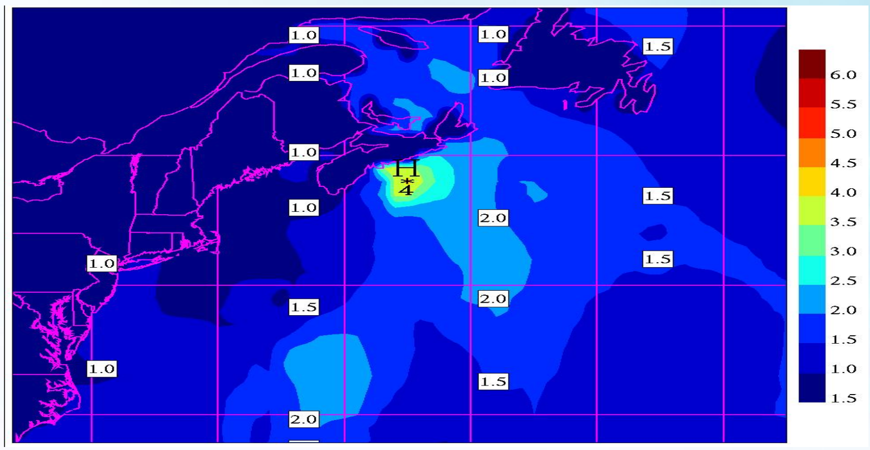
NH-NC-NR



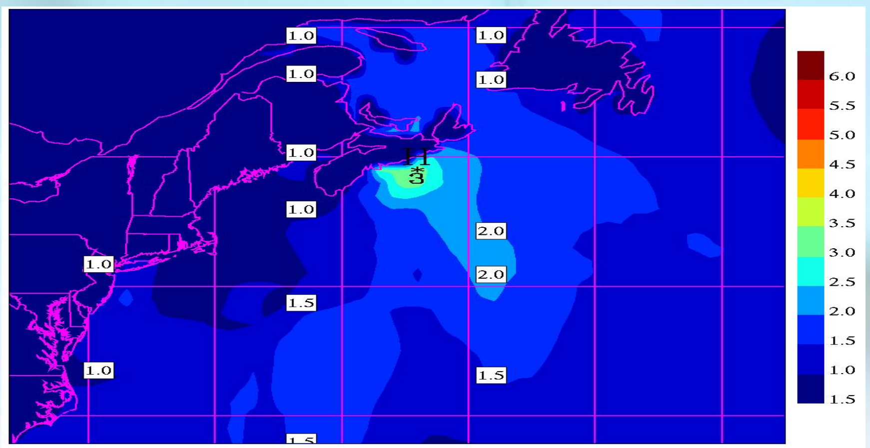
JUAN: C_D (x 10^{-3}) Snapshots Hurricane vs. No Hurricane Blending

Valid 0300 UTC 29 September 2003

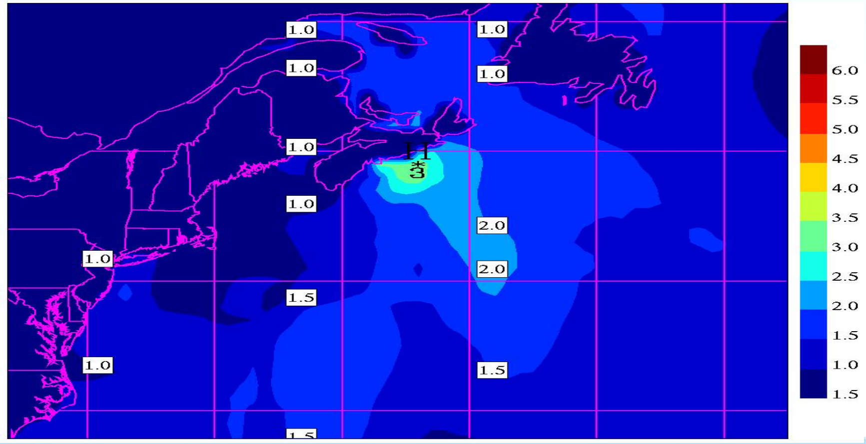
H-NC-NR



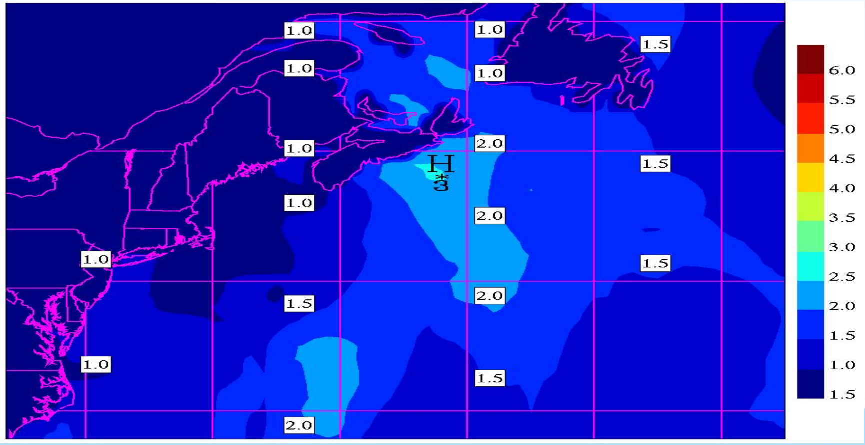
H-C-R



H-NC-R



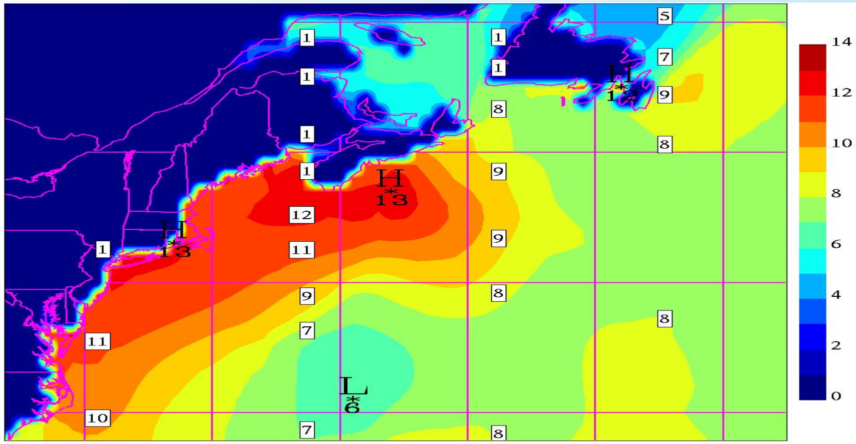
NH-NC-NR



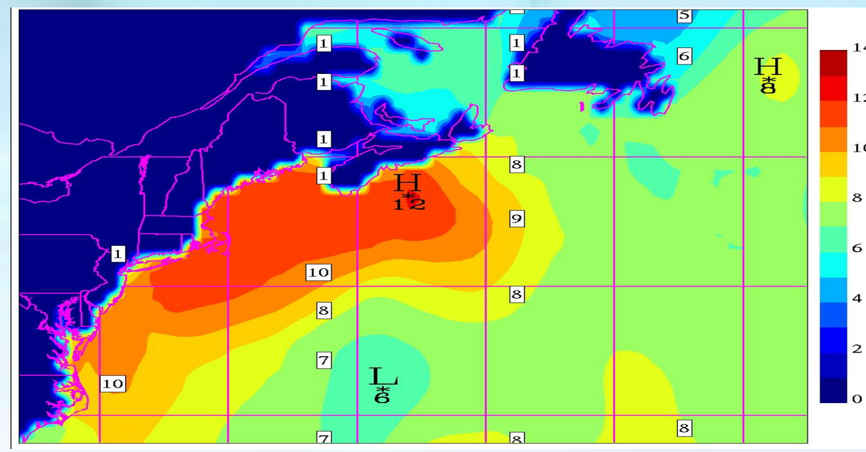
JUAN: Mean Period (s) Snapshots of Hurricane vs. No Hurricane Blending

Valid 0300 UTC 29 September 2003

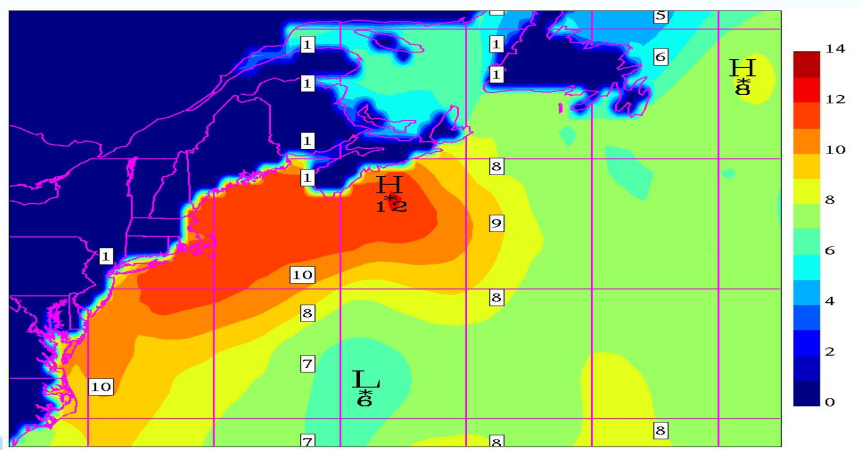
H-NC-NR



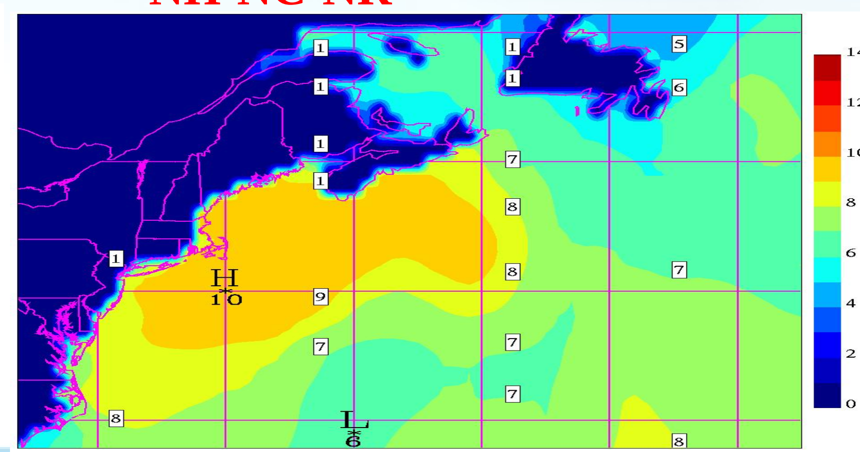
H-C-R



H-NC-R

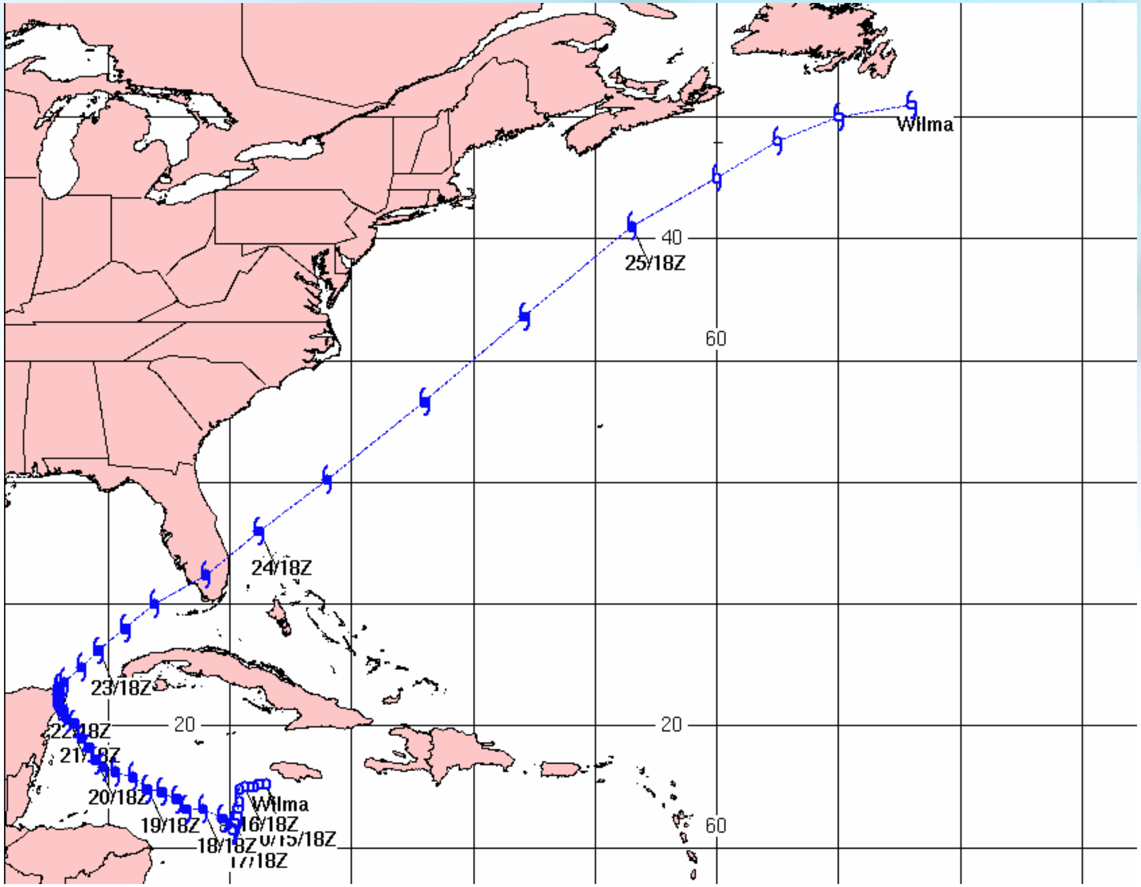


NH-NC-NR



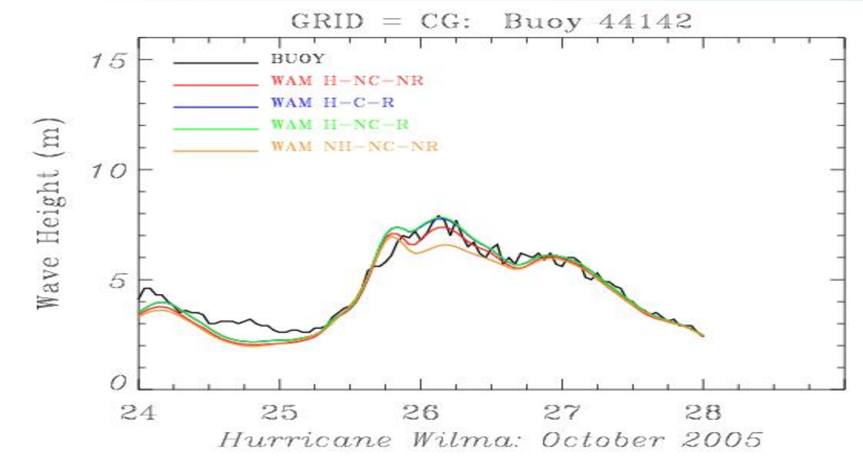
Hurricane Wilma

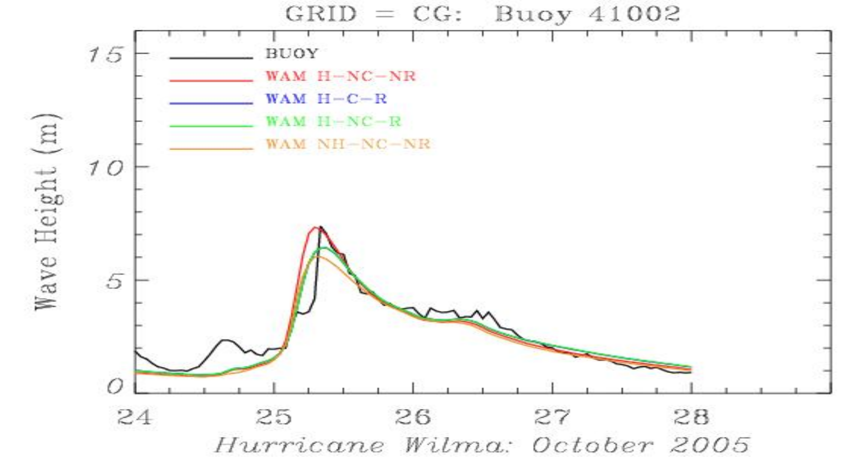
(00Z/24 – 00Z/28 Oct 2005)

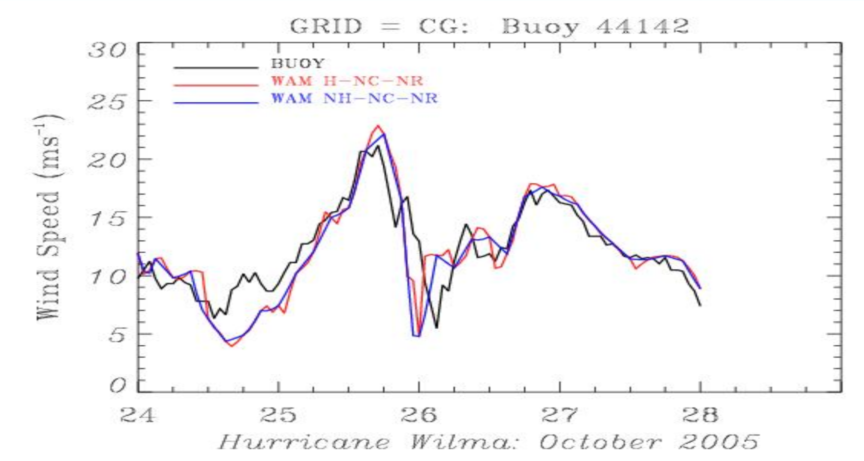


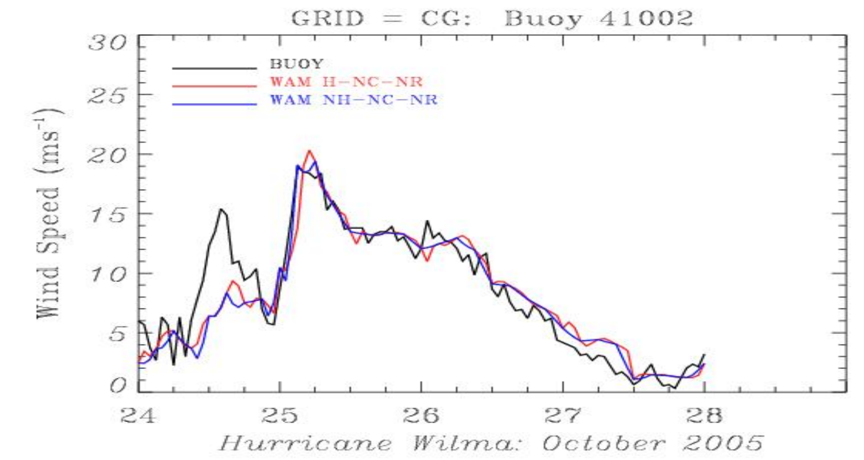
WILMA: SWH and Wind Speed Time Series

Legend: As in JUAN





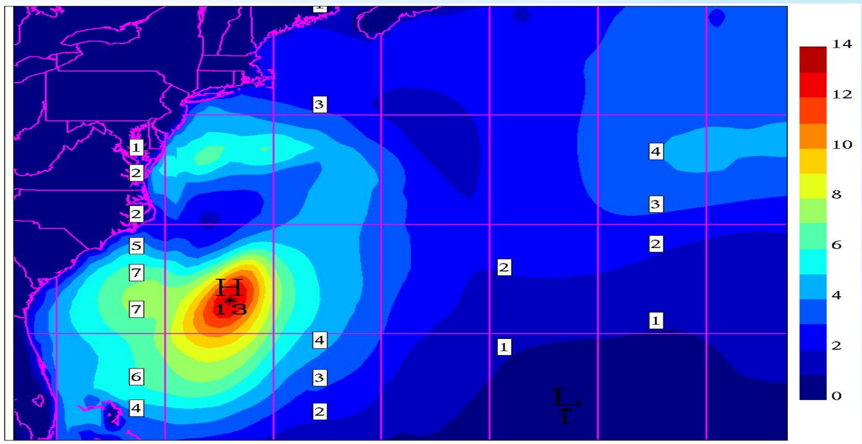




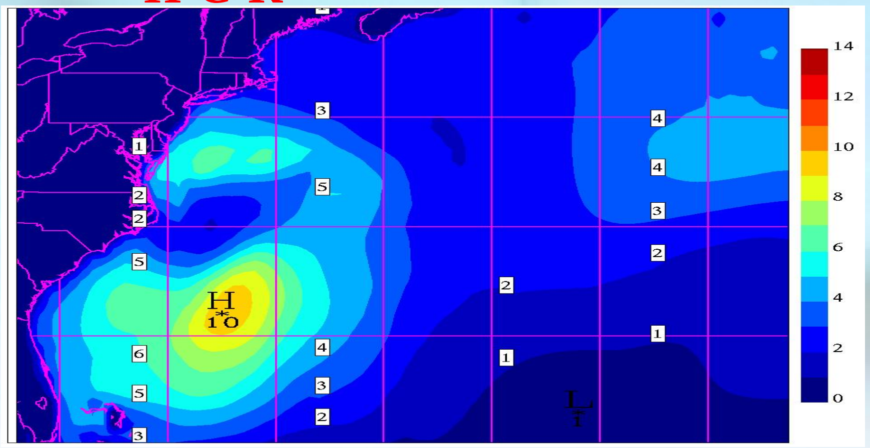
WILMA: SWH (m) Snapshots of Hurricane vs. No Hurricane Blending

Valid 0600 UTC 25 October 2005

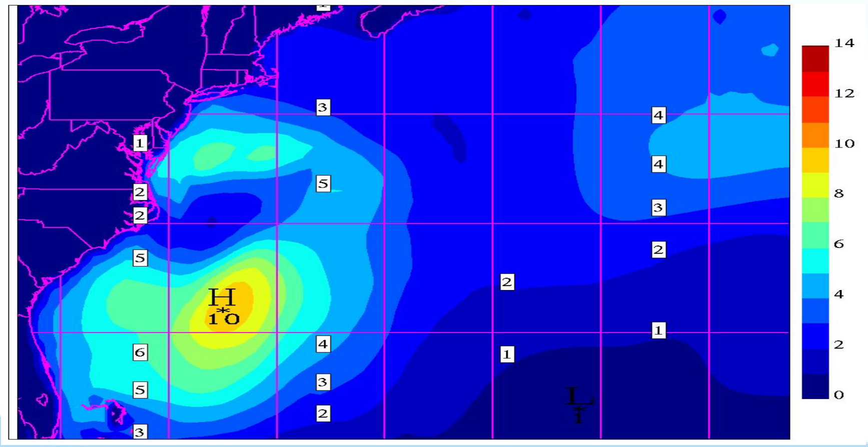
H-NC-NR



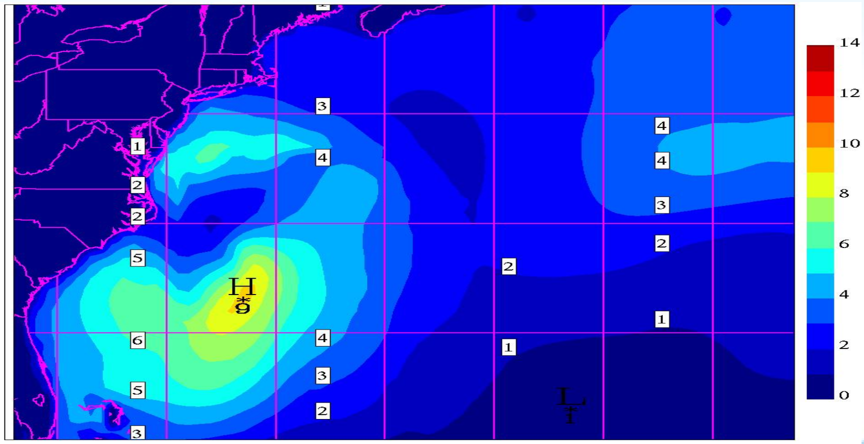
H-C-R



H-NC-R



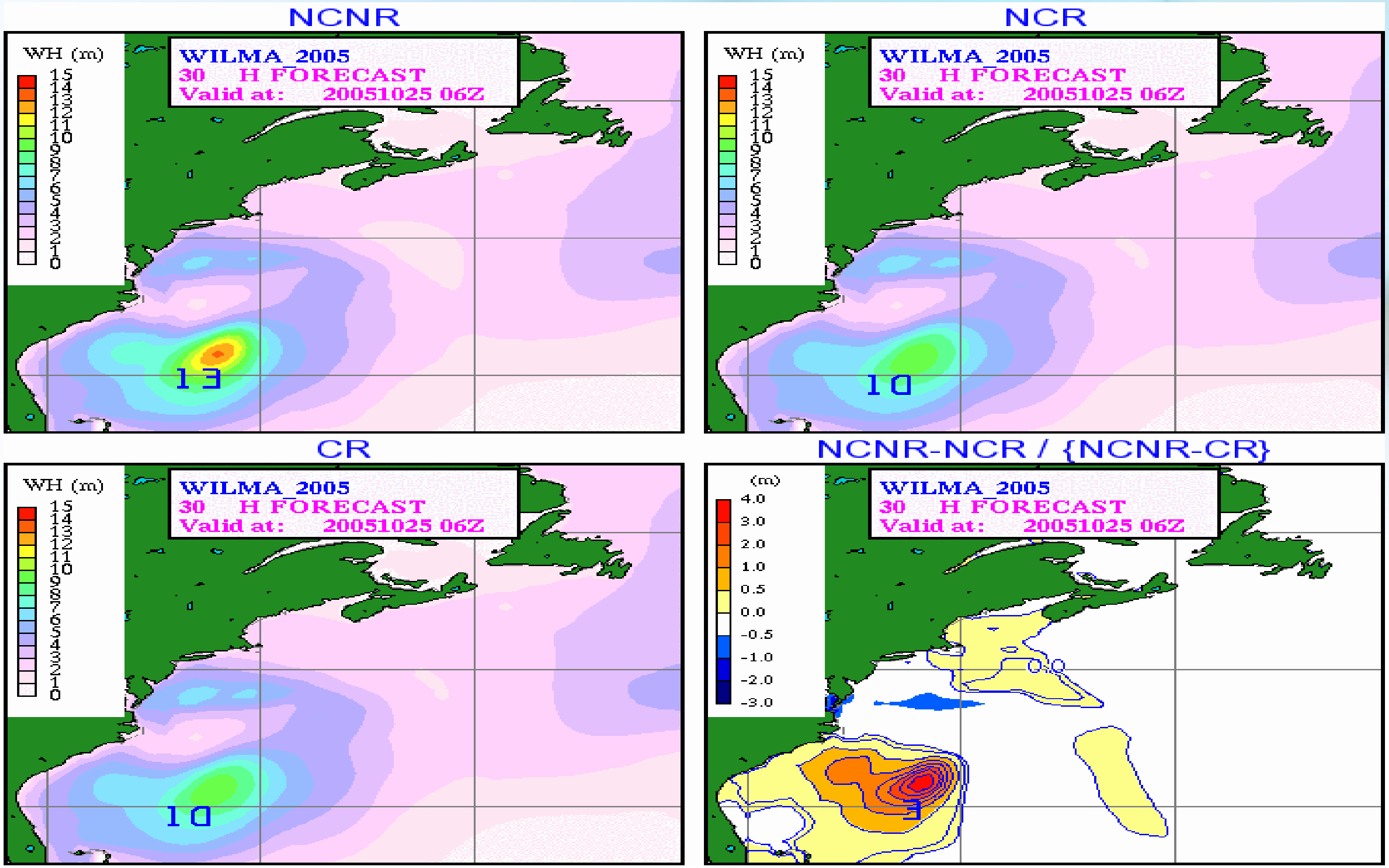
NH-NC-NR



WILMA: SWH Snapshots based on blended winds

Lwr. Rt.. Pan: SWH differences of **NCNR-NCR (col scale) and NCNR-CR (blue lines)**

Valid 0600 UTC 25 October 2005



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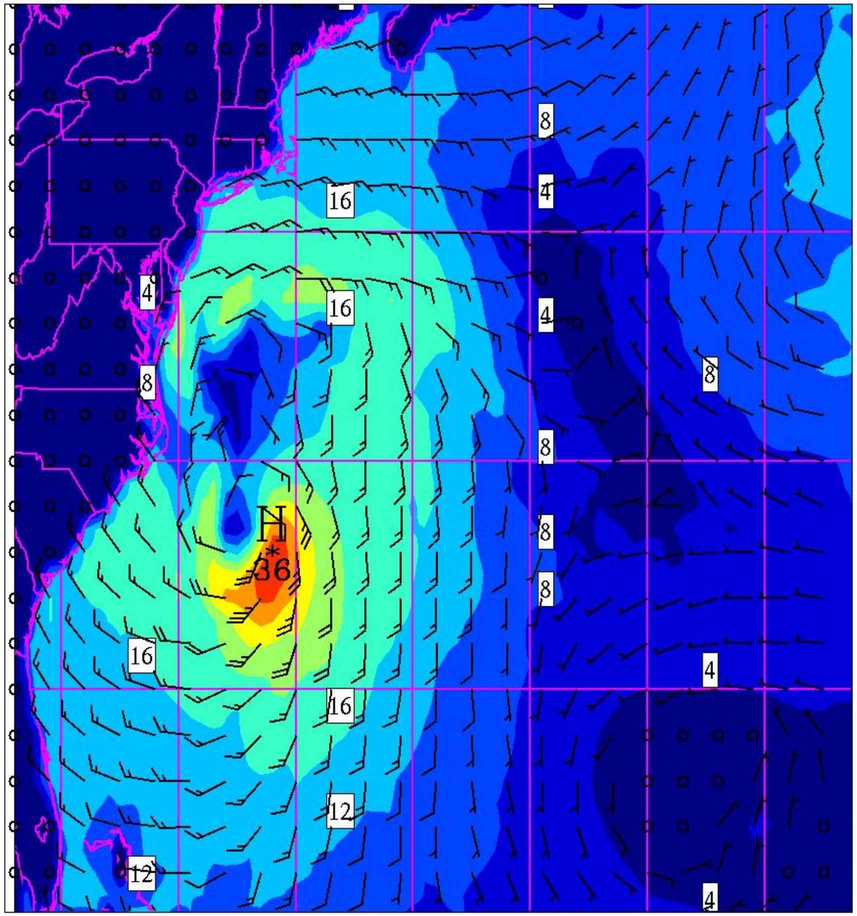
Canada

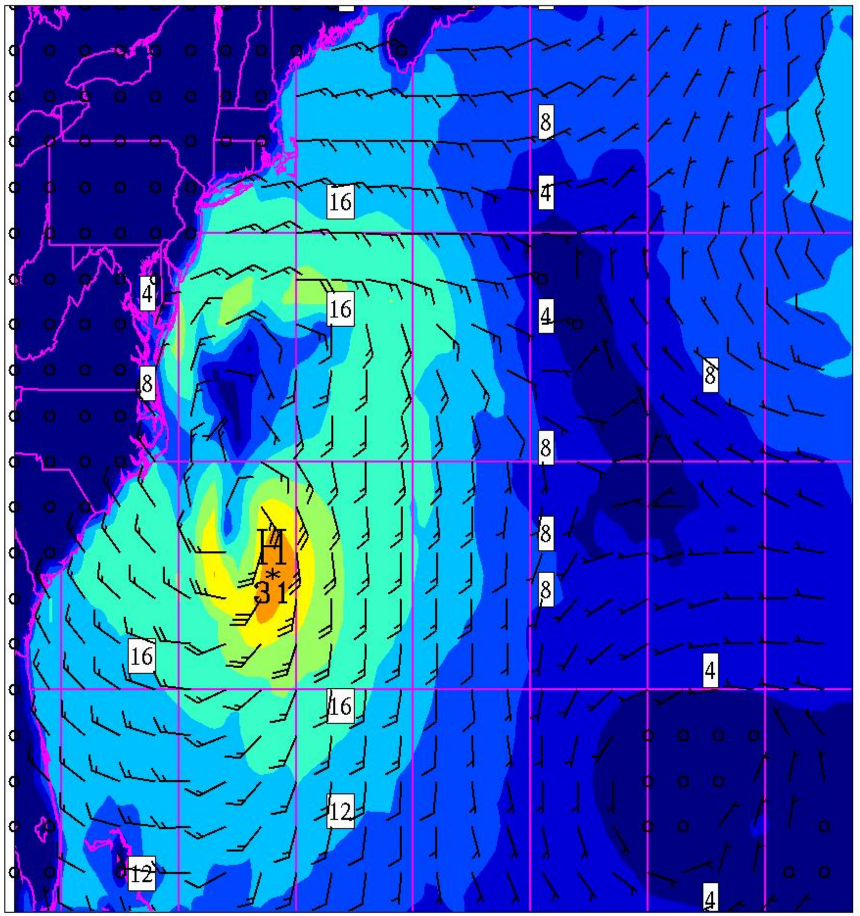
WILMA: Wind (ms^{-1}) Snapshots of Hurricane vs. No Hurricane Blending

Valid 0600 UTC 25 October 2005

Hurricane



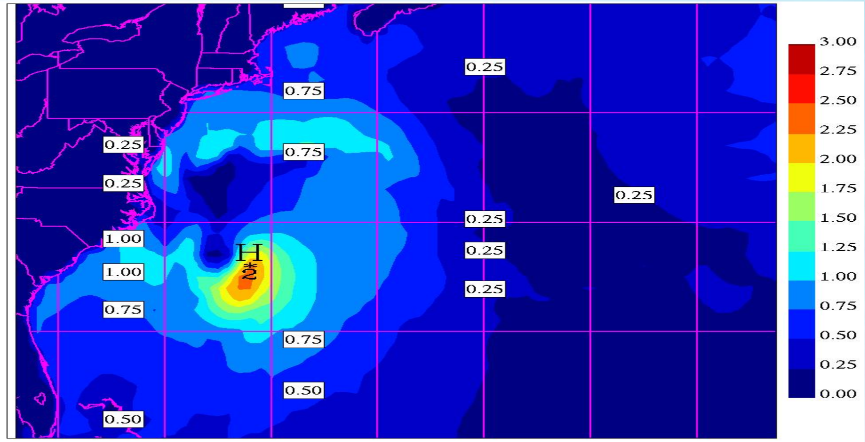
No Hurricane



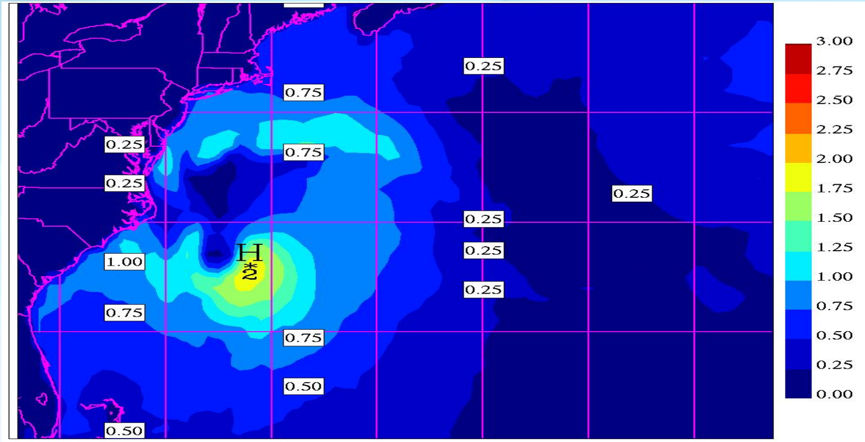
WILMA: u_* (ms^{-1}) Snapshots of Hurricane vs. No Hurricane Blending

Valid 0600 UTC 25 October 2005

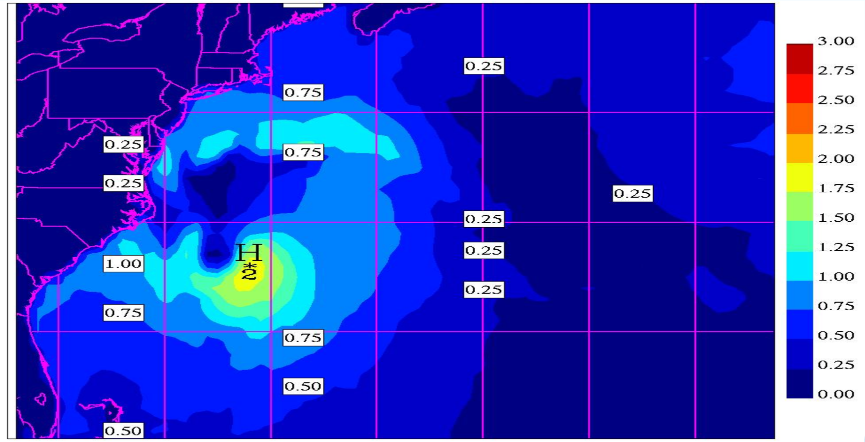
H-NC-NR



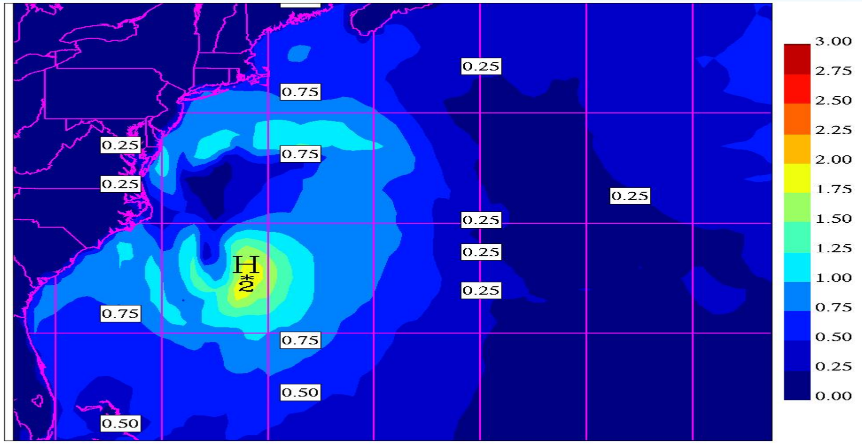
H-C-R



H-NC-R

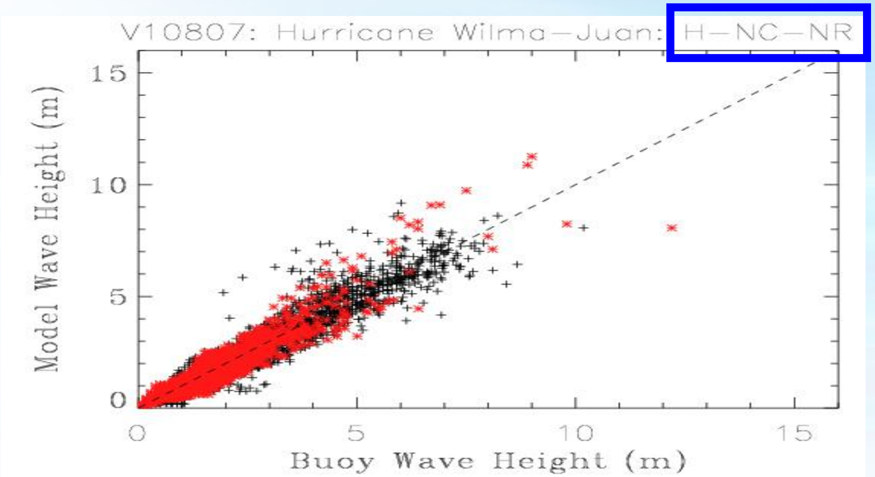


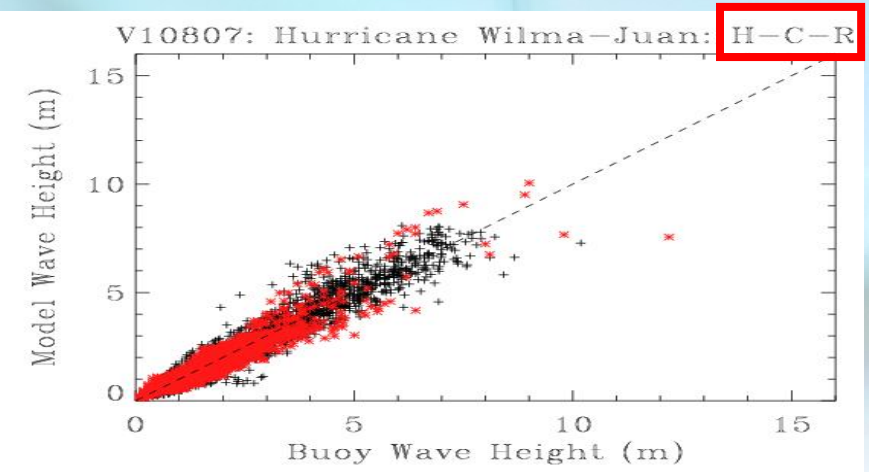
NH-NC-NR

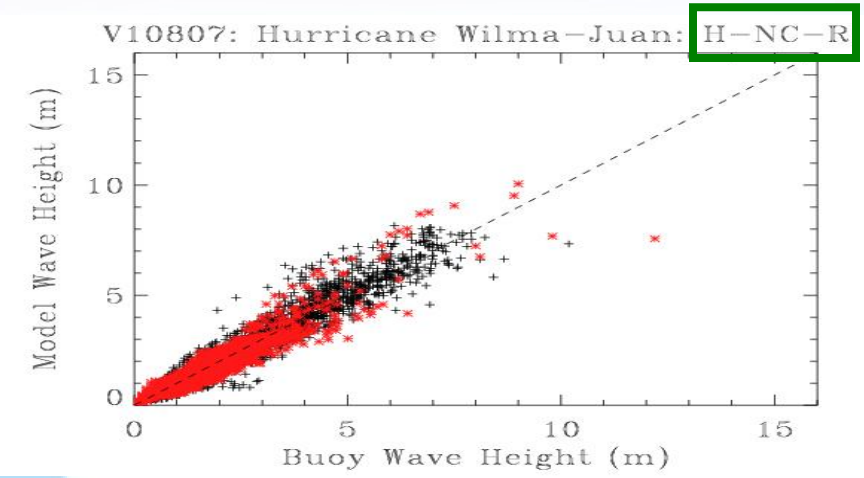


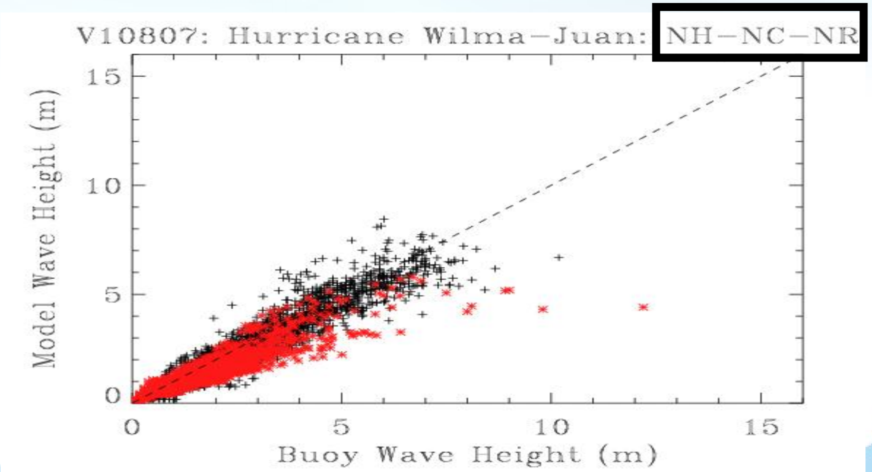
SWH Scatter Plots of Wilma (black) and Juan (red)

Legend: As in time series plots



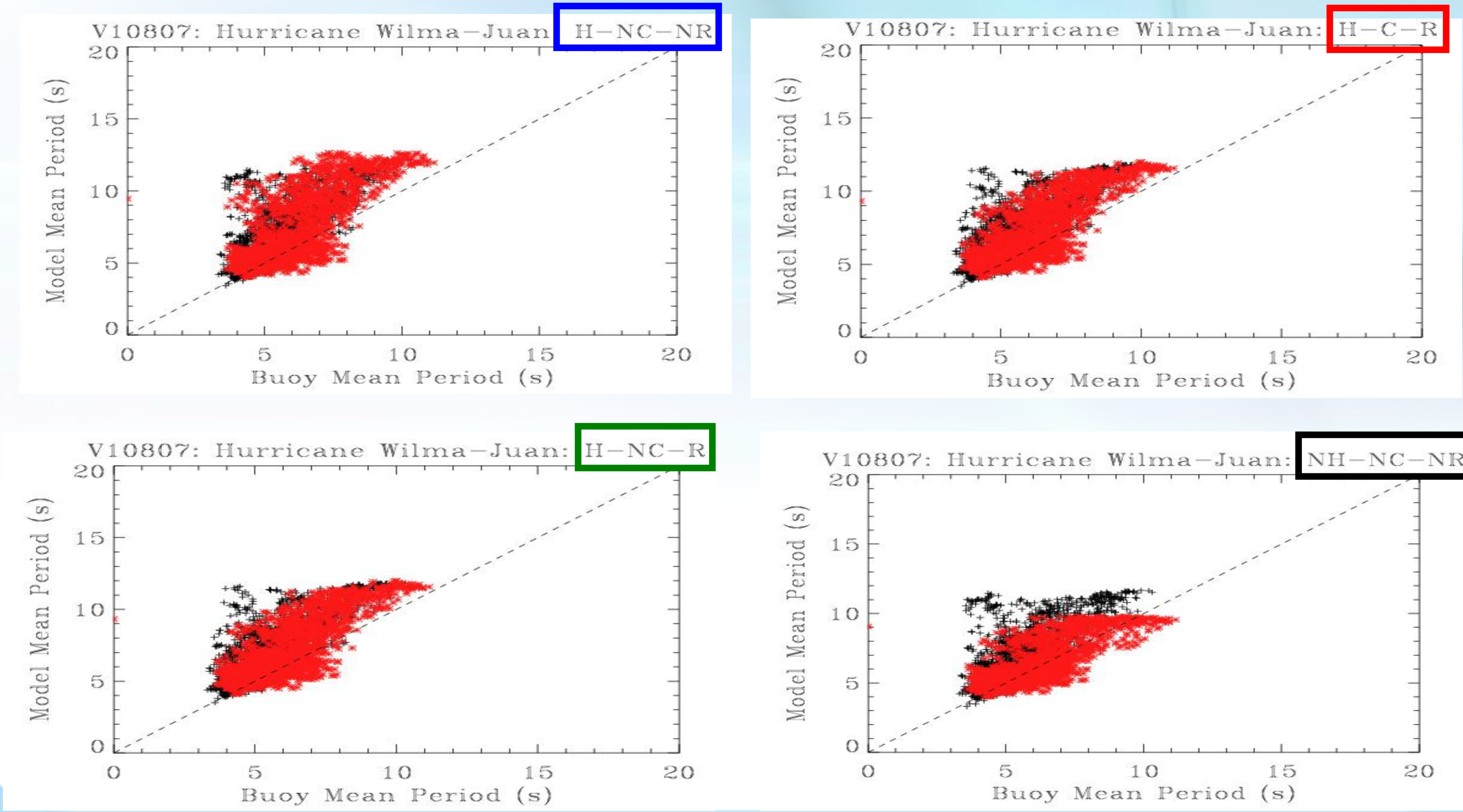






Mean Period Scatter Plots of Wilma (black) and Juan (red)

Legend: As in time series plots

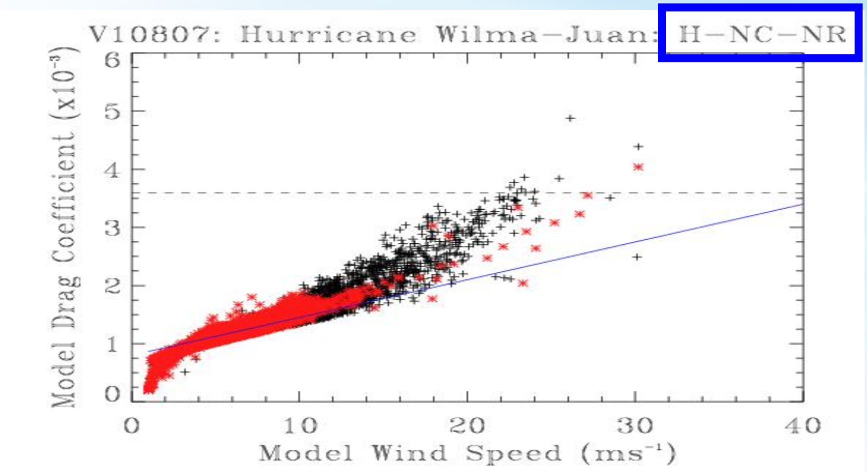


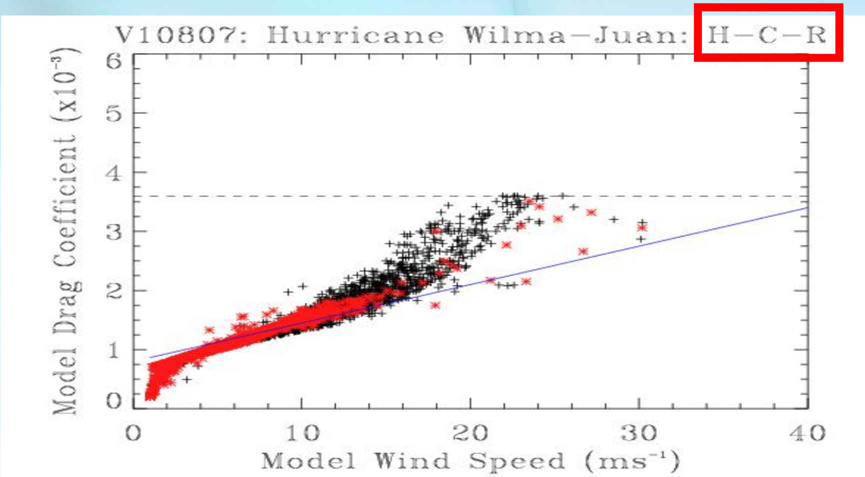
C_D Scatter Plots of Wilma (black) and Juan (red)

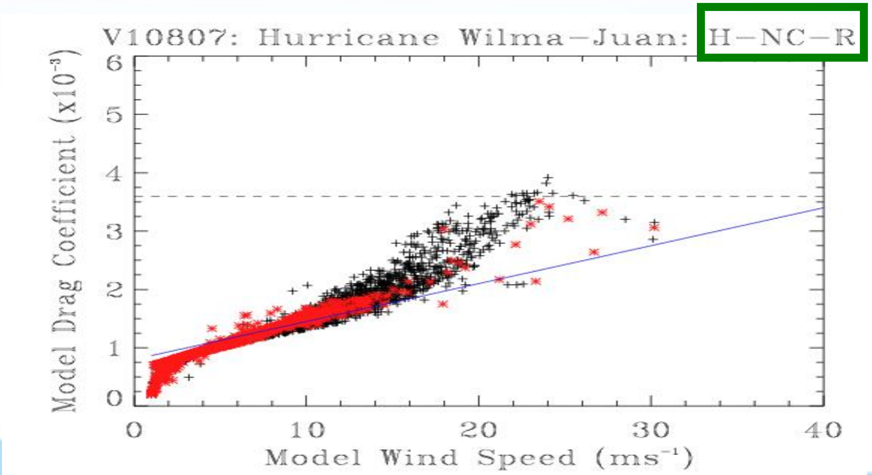
Legend: As in time series plots

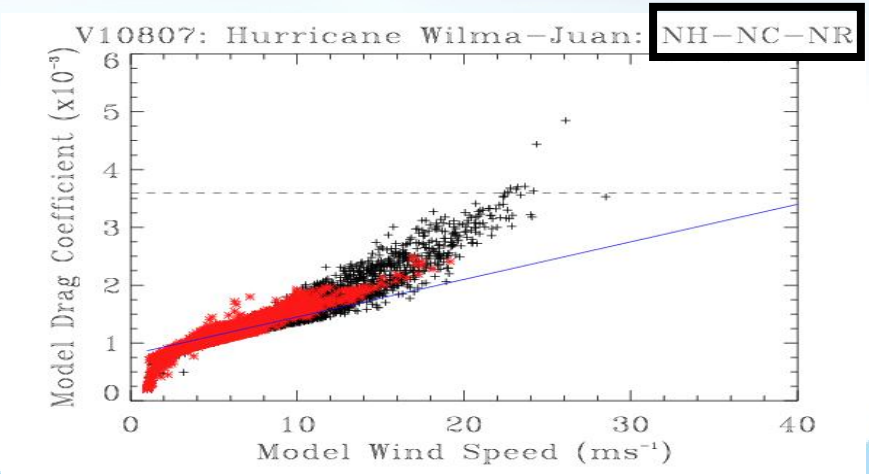
Blue line: $C_d = (0.80 + 0.065U_{10})10^{-3}$

Donelan et al. (2004): C_{dcap}=0.0028 at 33 ms^{-1}; Powell et al. (2003): C_{dcap} = 0.0026 at 35 ms^{-1}



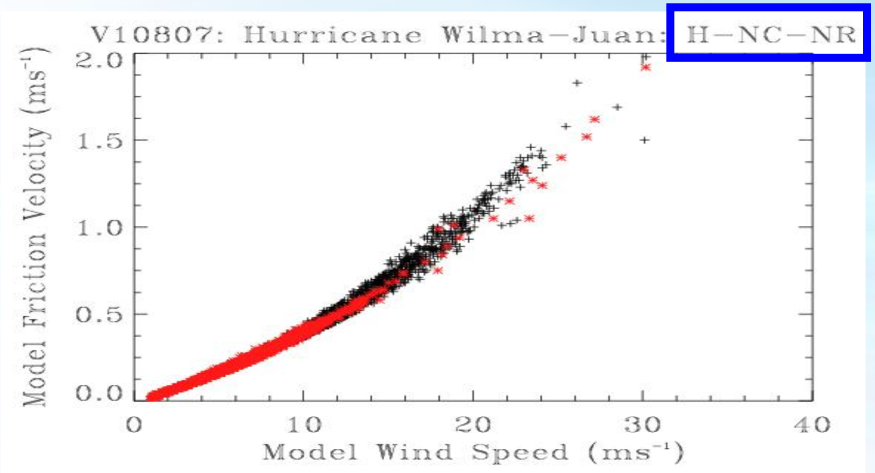


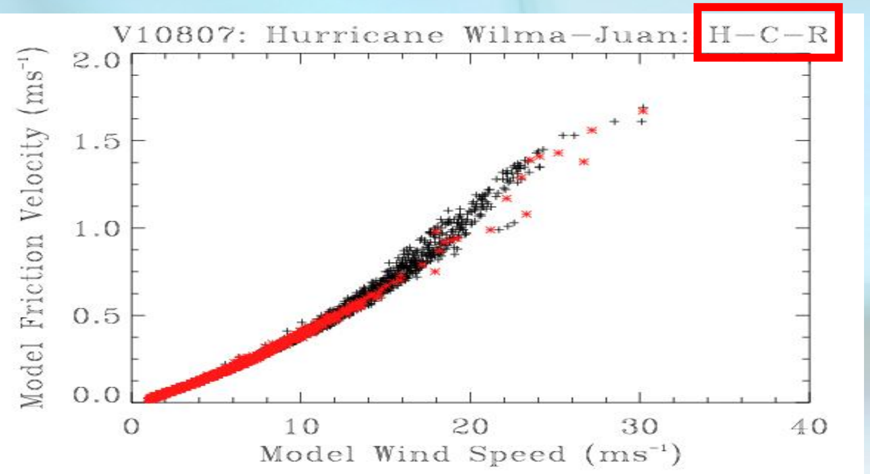


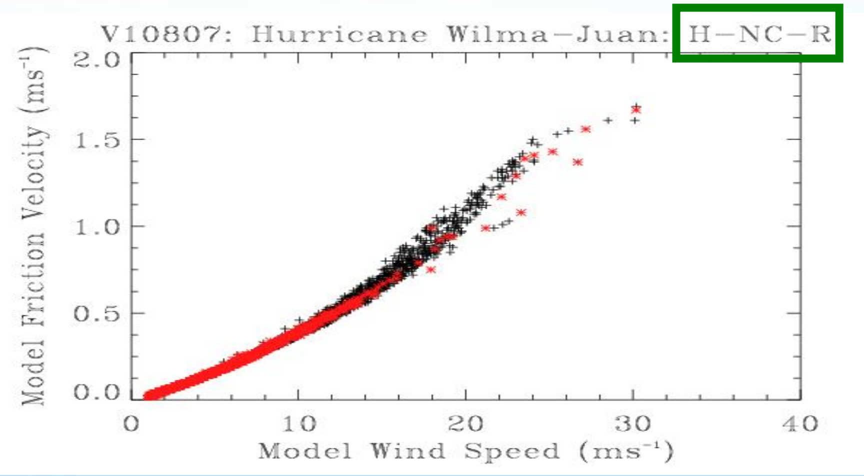


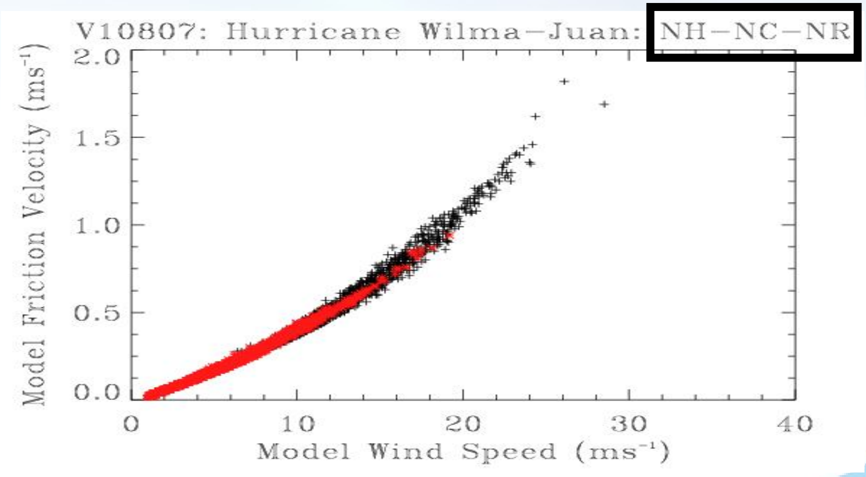
u_* Scatter Plots of Wilma (black) and Juan (red)

Legend: As in time series plots









WILMA and JUAN WAVE STATISTICS

WAVE HEIGHT STATISTICS (m)				
Statistical Parameters	H-C-R	H-NC-R	H-NC-NR	NH-NC-NR
Buoy Mean	2.110	2.110	2.110	2.110
Model mean	2.055	2.059	2.016	1.875
Bias	-0.053	-0.050	-0.094	-0.234
Rmse	0.432	0.434	0.468	0.535
Stddev	0. 428	0.431	0.458	0.481
SI (Stddev/Model Mean)	0.203	0.204	0.217	0.228
r	0.964	0.964	0.959	0.949
ac	0.964	0.964	0.957	0.937
rv	0.920	0.919	0.906	0.877
s	1.003	1.005	0.991	0.915
a	-0.091	-0.094	-0.117	-0.055
b	1.018	1.021	1.011	0.915
N (No. of obs.)	5197	5197	5197	5197

SI = Scatter Index (*(Stddev/Model Mean)*
r = linear correlation coefficient
ac = anomaly correlation
rv = reduction of variance
s = symmetric slope
a = intercept of linear regression line
b = slope of linear regression line

WILMA and JUAN WAVE STATISTICS (cont'd)

WAVE MEAN PERIOD STATISTICS (s)				
Statistical Parameters	H-C-R	H-NC-R	H-NC-NR	NH-NC-NR
Buoy Mean	5.976	5.976	5.976	5.976
Model mean	7.336	7.343	7.432	6.910
Bias	1.360	1.367	1.456	0.934
Rmse	1.922	1.931	2.178	1.717
Stddev	1.357	1.364	1.620	1.441
SI	0.227	0.228	0.271	0.241
r	0.740	0.739	0.702	0.638
ac	0.614	0.612	0.591	0.569
rv	-0.735	-0.853	-1.357	-0.465
s	1.239	1.240	1.265	1.164
a	1.050	1.056	0.736	1.958
b	1.052	1.052	1.120	0.829
N (No. of obs.)	3913	3913	3913	3913

WILMA and JUAN WIND STATISTICS

WIND SPEED STATISTICS (>= 10.0 m/s)		
Statistical Parameters	**Blended**	**Unblended**
Buoy Mean	**13.925**	**13.925**
Model mean	**13.093**	**12.880**
Bias	**-0.832**	**-1.045**
Rmse	**2.297**	**2.385**
Stddev	**2.141**	**2.144**
SI (Stddev/Model Mean)	**0.154**	**0.154**
r	**0.830**	**0.807**
ac	**0.811**	**0.775**
rv	**0.478**	**0.437**
s	**0.955**	**0.936**
a	**-0.836**	**0.171**
b	**1.000**	**0.913**
N (No. of obs.)	**1437**	**1437**

CONCLUSIONS

- The blending of the wind field based on CHC parametric hurricane wind model with the CMC regional GEM model forecast wind field using the HURSWIM technique in a one-wave coupled system produces more realistic wind and wave fields reflecting the presence of more intense and compact wind and wave systems

- The blended wind statistics in excess of 10 m/s are slightly better than the corresponding unblended wind statistics

- WAM4.5 driven by blended winds produces significant wave heights that show improvement over those based on unblended winds.

- For WAM4.5 driven by blended hurricane winds only:

  - WAM4.5 enhancements make the extreme hurricane waves more realistic and give better agreement between model and observations when compared with no enhancements. C_D and u_* show a tendency for saturation for wind speeds in excess of about 25 ms^{-1} in agreement with Donelan et al. (2004) and Powell et al. (2003). The results based on C_D capping and WAM4.5 enhancements are almost identical to those based on WAM4.5 enhancements only

A LOOK TO THE FUTURE

- **Further enhancements to wave model**
  - **Inclusion of variable currents/ bathymetry/ice coverage and thickness**
  - **Inclusion of other bottom friction and depth-induced wave breaking source term options**
  - **Inclusion of alternatives to the DIA for nonlinear wave-wave interactions**

- **Ensemble wave forecasts**
  - **CMC already runs a 20-member + 1 control (degraded global GEM model) ensemble wind forecast system**
  - **Implementation of a global version of WAM4.5 driven by ensemble of wind forecasts in experimental mode**
  - **Expected output: probabilistic wave forecasts up to at least 10 days. This includes probability of exceedence for specific extreme waves to give more quantitative estimates of risk to marine structures and operations.**

- **Coupling and nesting**
  - **Two-way coupling of WAM4.5 and the operational GEM model**
  - **Operational implementation of one-way coupling of WAM4.5 and the CHC parametric wind model (HURSWIM)**
  - **Operational implementation of nested versions of WAM4.5 in nearshore applications in the Northwest Atlantic, Northeast Pacific and Gulf of St. Lawrence**

Thank you!