An Overview of COAMPS-TC Development and Real-Time Tests

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Super Typhoon Megi (15W) on 05Z 17 Oct 2010 (NASA MODIS)

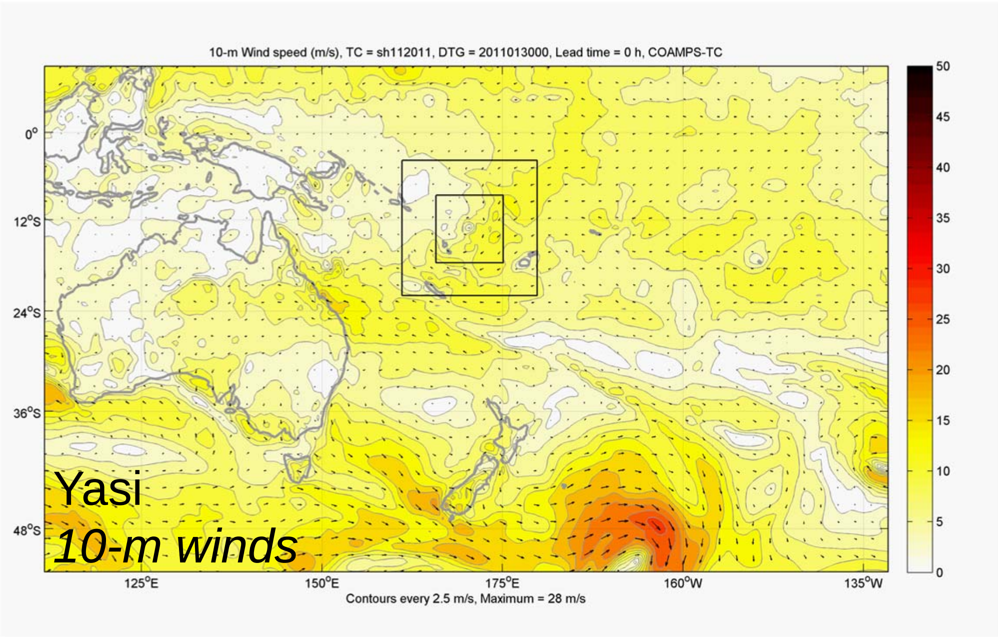
An Overview of COAMPS-TC Development and Real-Time Tests

Outline

- COAMPS-TC Analysis and Physics
- COAMPS-TC Stream 1.5 Demonstration
- Stream 2 Development and Real-Time Demo
- Summary

COAMPS-TC System Overview

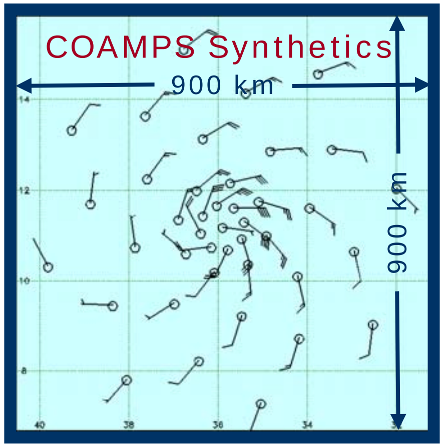
- Goal: **Significantly improve model forecasts of TC intensity, with sufficient fidelity to capture *rapid intensity changes*, *structure*, and *ocean response***
- Analysis: **Vortex relocation, synthetic observations, 3D-Var (NAVDAS)**
  Atmosphere: **Nonhydrostatic, moving nests, CBLAST fluxes, dissipative heating, shallow convection, spray parameterization option**
- Ocean: **3D-Var (NCODA), NCOM, SWAN, Wave Watch III options**
- Ensemble: **Coupled Ensemble Transform, Ensemble Kalman Filter**
- Configuration: **45-15-5 km, GFS or NOGAPS BCs, uncoupled or coupled**

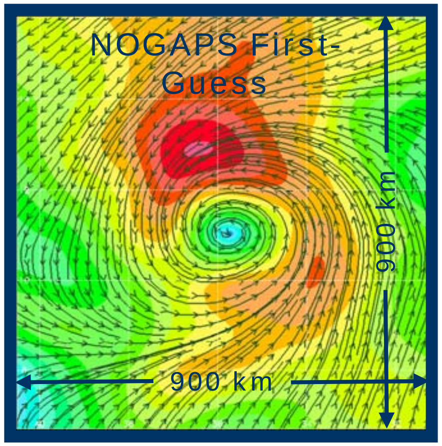


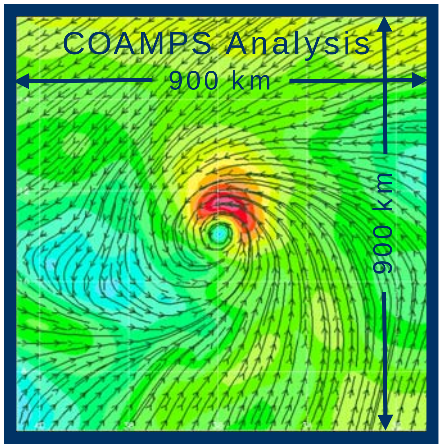
COAMPS-TC: **Analysis and Initialization of Tropical Cyclones**

Current Methodology

- Synthetic Observations:
  - **Based on warning messages from NHC or JTWC**
  - **41 "observations" for each TC with v_{max} < 45 kts (49 otherwise)**
  - **Synthetics specified at fixed radii**
  - **Modified Rankine vortex**
  - **u-, v-, T, z** (frictional turning near the surface)
  - **Observations generated from 1000 mb to 400 mb**
  - **Mean wind and previous storm motion included**
- NAVDAS:
  - **Synthetics treated as raobs**
  - **Relaxed geostrophic constraint within TC circulation**
  - **Reduced correlation lengths within TC circulation**
- Cold Start:
  - **First-guess fields: GFS (used for HFIP runs) or NOGAPS**
  - **Analysis is "contaminated" with global model circulation**
- Warm-Start (cycling):
  - **COAMPS-TC previous 6 h forecast used for first-guess**
  - **TC in COAMPS-TC 6 h forecast relocated to warning position**







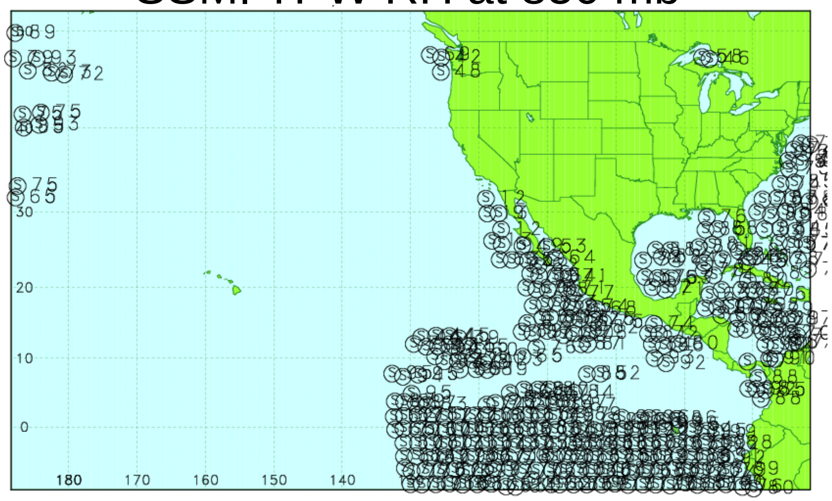
COAMPS-TC: Analysis Improvements

Assimilation of Total Precipitable Water

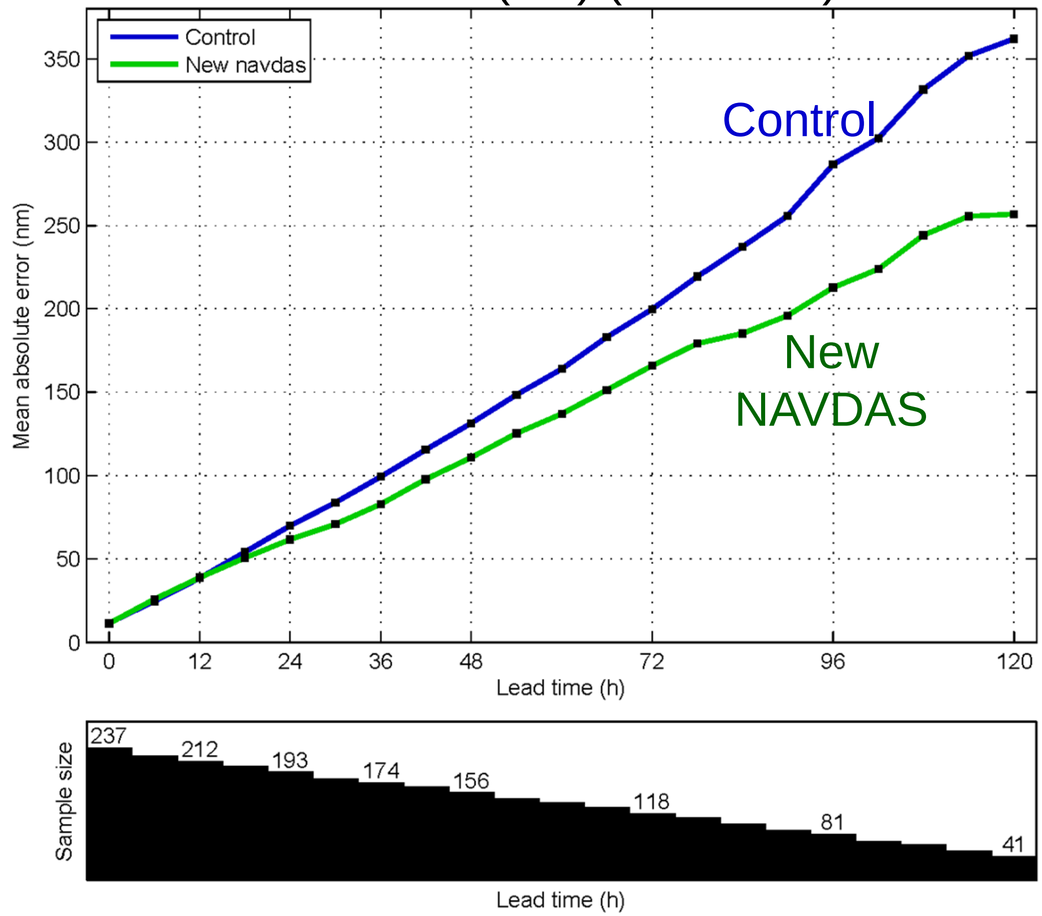
Additional Observations Assimilated

- SSM/I Total Precipitable Water (TPW)
- Additional satellite winds
- More scatterometer winds (averaging)

SSMI TPW RH at 850 mb



Track Error (nm) (E. Pacific)



- **Assimilation of additional satellite Observations (SSM/I TPW, Satellite Winds)**
- **Results in a Significant Improvement in the Track Skill**

COAMPS-TC Physical Parameterizations

Stream 1.5 and 2 Physics Options

Surface and Boundary Layer

- Modified Louis et al. (1982) COARE w CBLAST mods, sea spray option
- Land sfc.: **Force restore; NOAH option**
- TKE 1.5 (Bougeault): **Dissip. Heating**

Moist Physics

- Kain Fritsch (Dx>10km)
- Other options: **Emanuel, SAS, Kuo**
- Bulk microphysics (q_c, q_r, q_i, q_s, q_g) **Modified Lin (NRL); Thompson option**

Clouds, Radiation

- Cloud fraction: **Explicit type**
- Radiation: **Harshvardhan, Fu-Liou (2 & 4 stream) (TC default)**
- Shallow Convection: **Tiedke type**

Ocean Physics

- Mellor and Yamada (Level 2, 2.5)
- Grid-cell Re, Smagorinsky mixing
- WWIII, SWAN in testing
- Ocean only used in Stream 2 runs

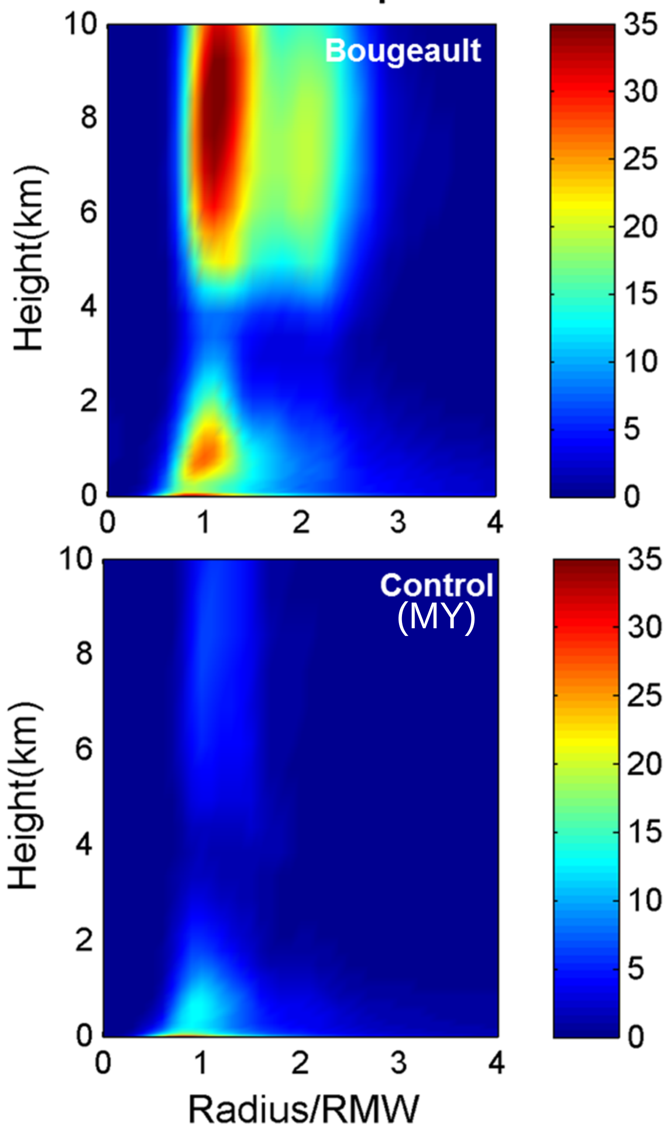
General Physics Development

- Physics Have an Origin in Non-TC Applications
- Nearly Every Parameterization has been Evaluated & Changed for TC Prediction, Particularly Microphysics, PBL, Surface Fluxes
- Efficiency is a Major Issue
- Code Complexity is a Major Issue

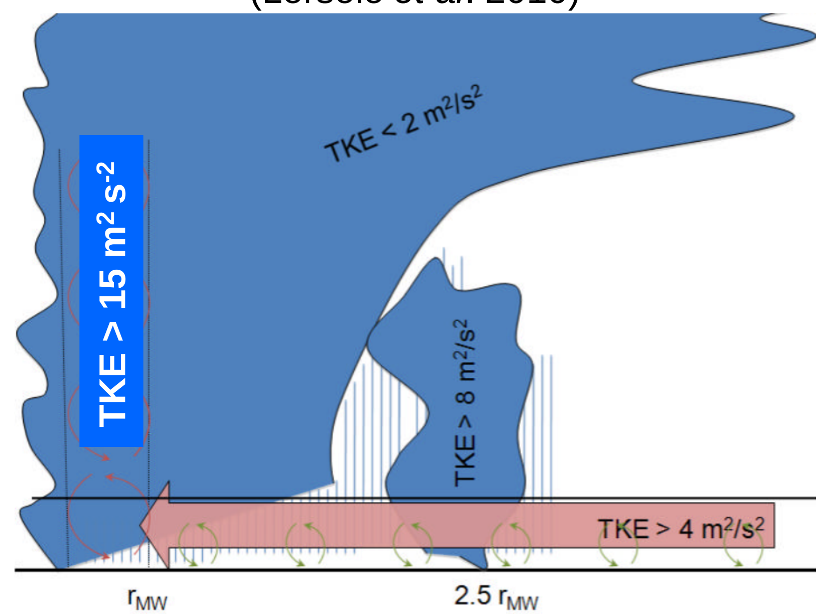
Mixing Length Formulation

Implementation of Bougeault Mixing Length

Simulated TKE profile



Observation-based schematic of TKE
(Lorsolo *et al*. 2010)

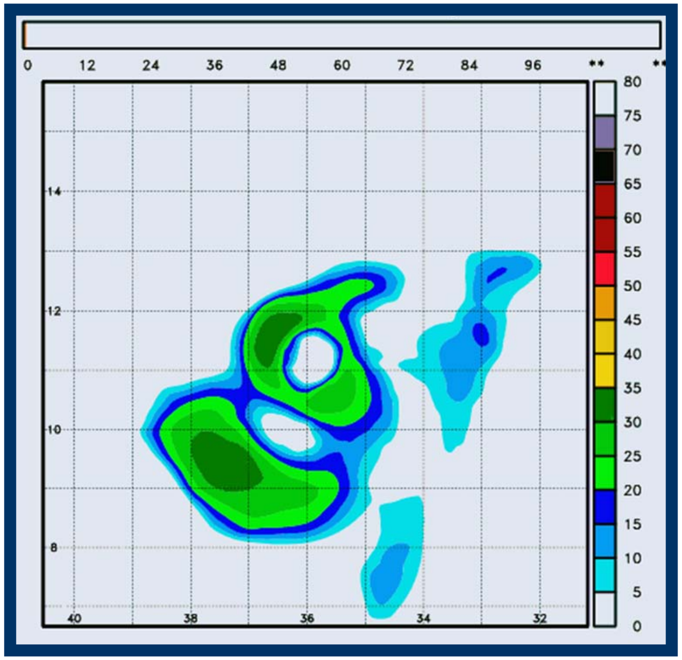


- **Bougeault mixing leads to much stronger turbulence intensity.**
- **Turbulence in deep convection is much stronger than in the BL.**
- **Dissipative heating is included (Jin et. al 2007, WAF)**

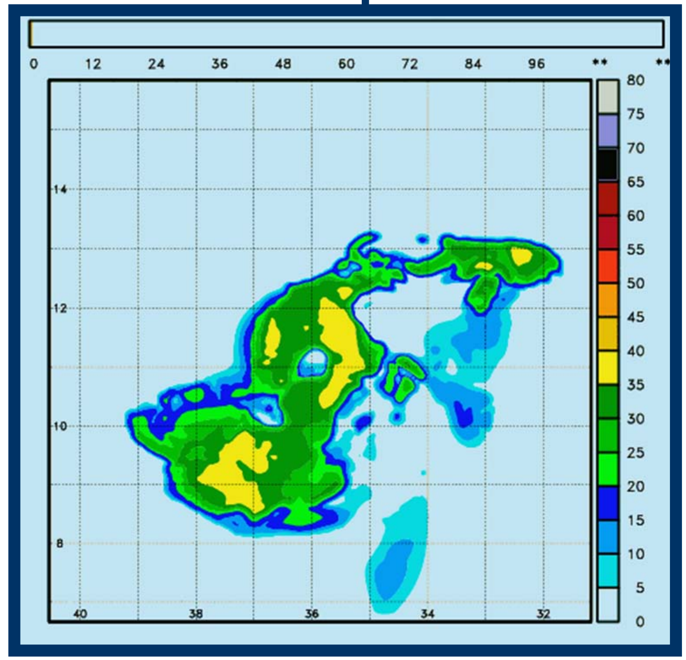
COAMPS-TC: Physics Improvements

New Formulation of In-Cloud Diffusion

Mellor-Yamada Level 2.5



M-Y with Klemp-Wilhelmson



Radar Reflectivity for TC Bill (2009081600)

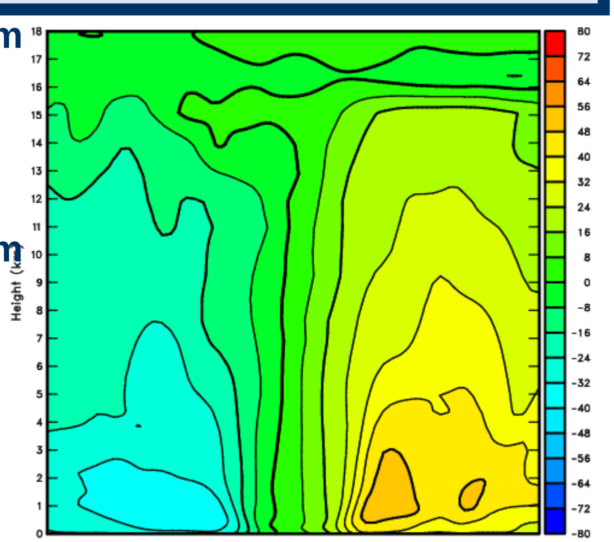
New Diffusion/PBL

- Quicker spin-up
- More banding
- Better intensity
- Thermodynamic structure better
- Tighter eye

18 km

10 km

0 km

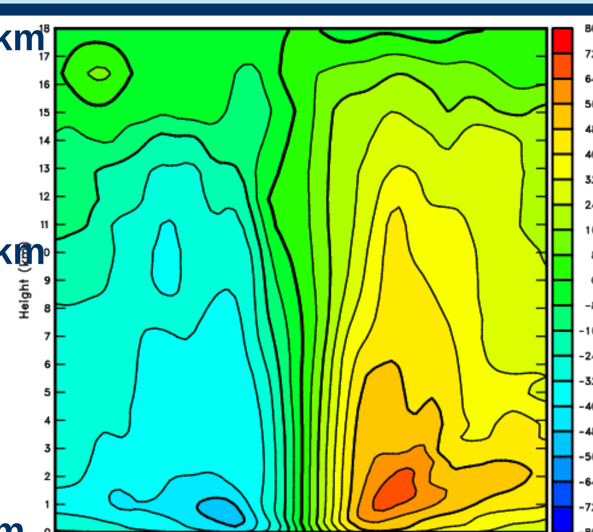


300 km

18 km

10 km

0 km



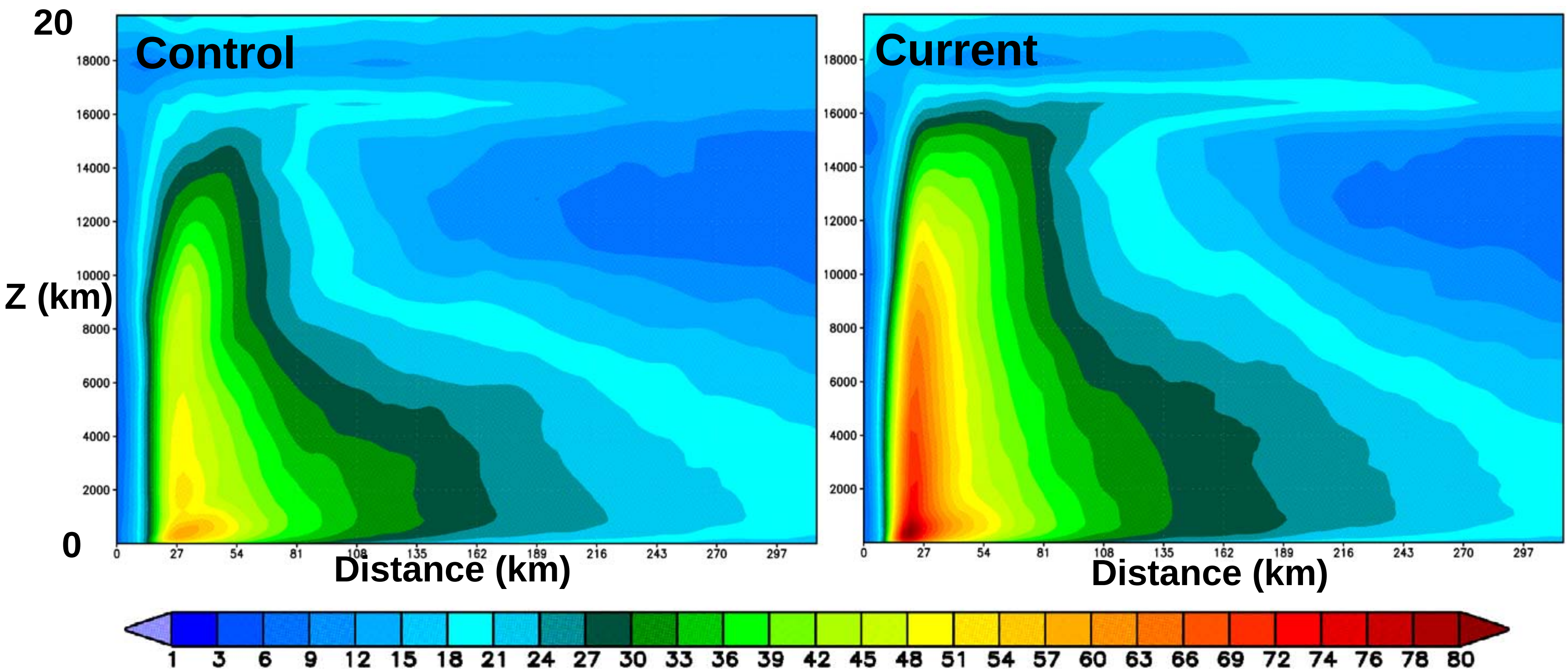
300 km

Azimuthal Wind Component at 72 h

COAMPS - TC

Ice Microphysics Representation: Hurricane Katrina Tests

Azimuthally Averaged Wind Speed (m s^{-1})



Current ice nucleation microphysics helps organize the inner core structure with a reduction in the upper-level cloud ice (positive bias in control).

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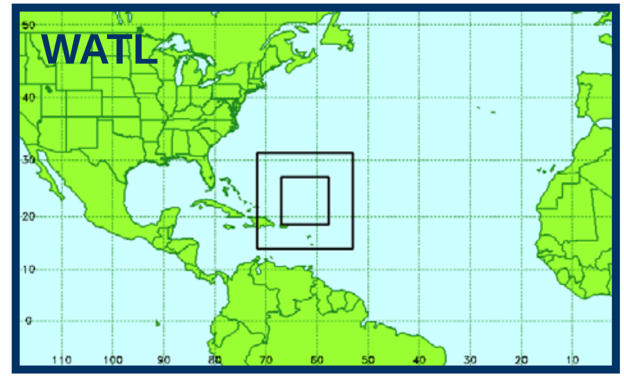
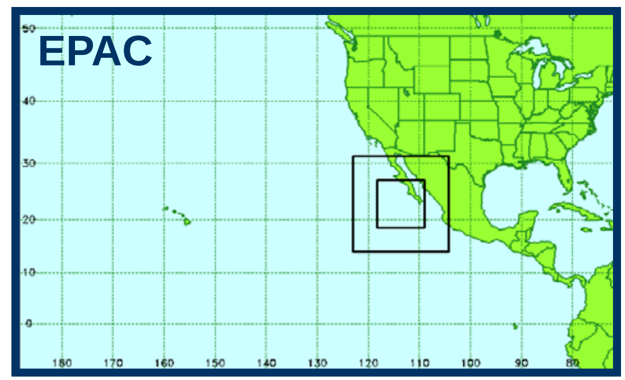
Mode of Operations for Running COAMPS-TC during HFIP 2010-2011

- **45/15/5 km grids for WATL, EPAC, WPAC basins**
- **45 km grid fixed for all storms**
- **Inner 2 grids move with the TC**
- **Runs automatically submitted using observed TC location/intensity at +0420 (every 6h)**
- **Forecasts run to 120 hours**
- **GFS used for IC** (cold starts only) **and LBC**
- **First run for each TC is a cold start, 6 h warm start for each subsequent run**
- **Output from each run posted on NRL web site; http://www.nrlmry.navy.mil/coamps-web/web/tc Forecasts sent to DTC and JTWC**
- **Real Time for WATL, EPAC, WPAC basins**

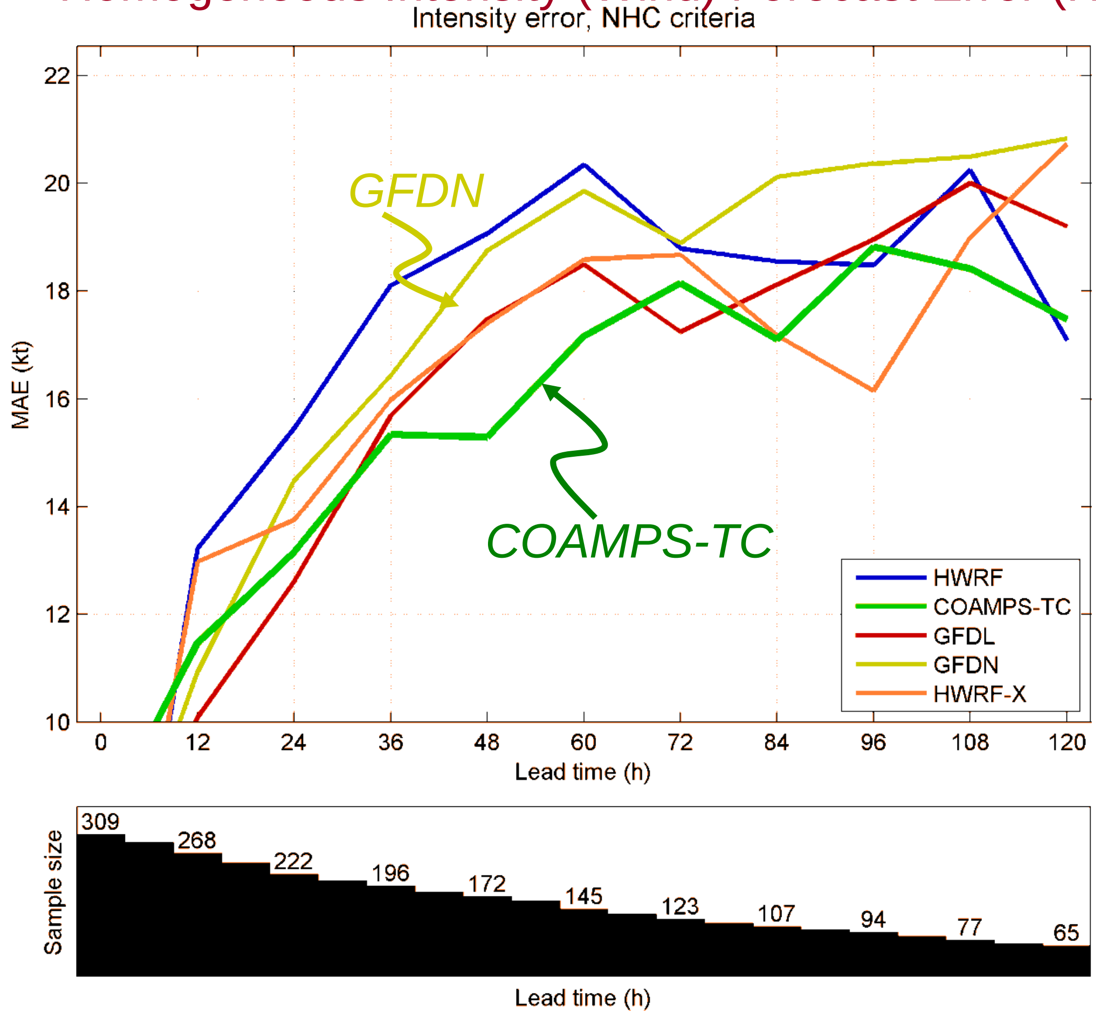




COAMPS-TC

2010 Real-Time HFIP W. Atlantic Forecasts

Homogeneous Intensity (Wind) Forecast Error (Kts)

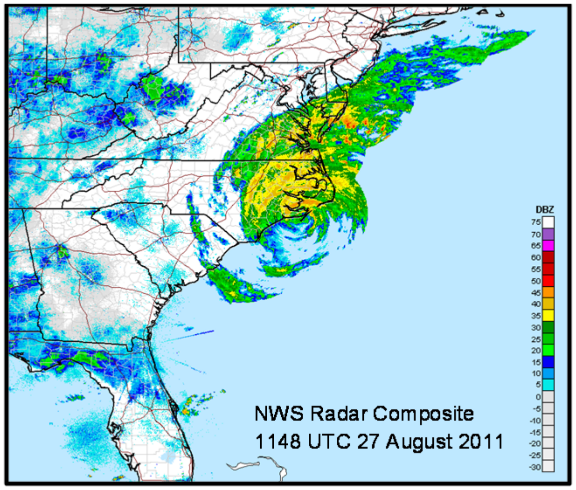


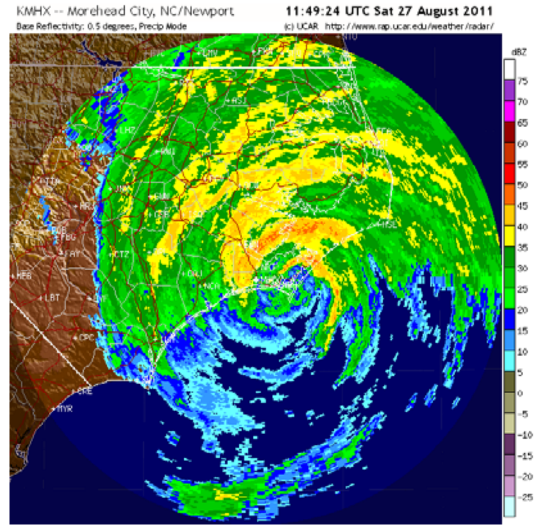
COAMPS-TC Exhibited Promise for Intensity Forecasts in WATL (top model in 30-66h period) and Improvement over GFDN.

COAMPS-TC 2011 HFIP Stream 1.5

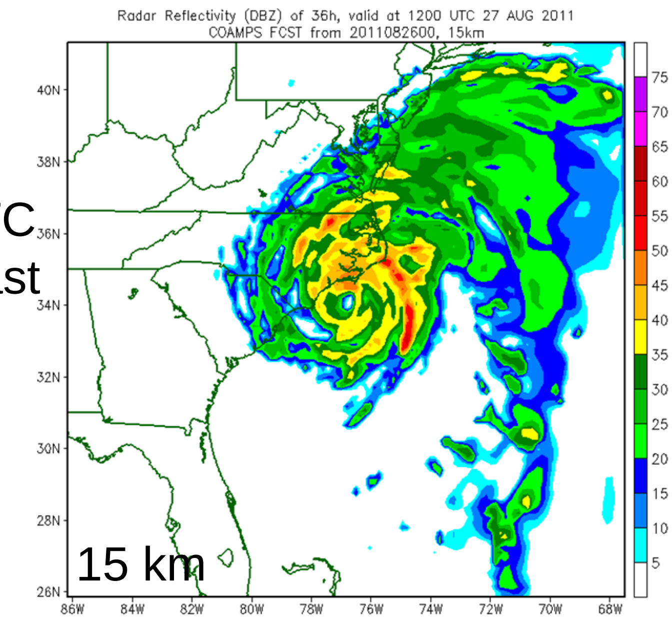
Irene Forecast Evaluation

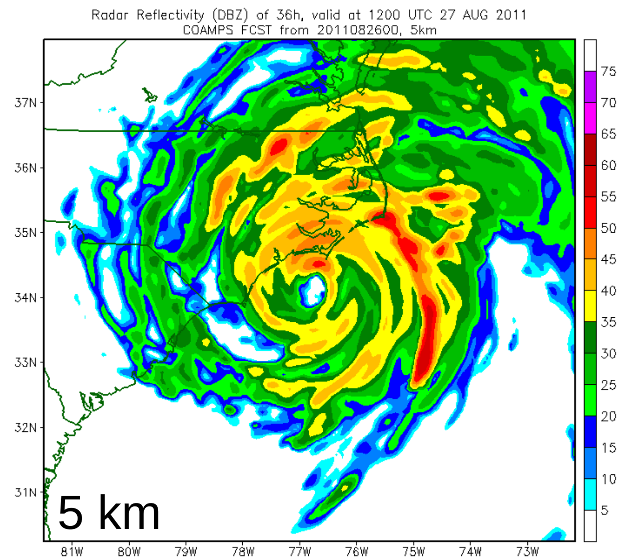
NWS Radar





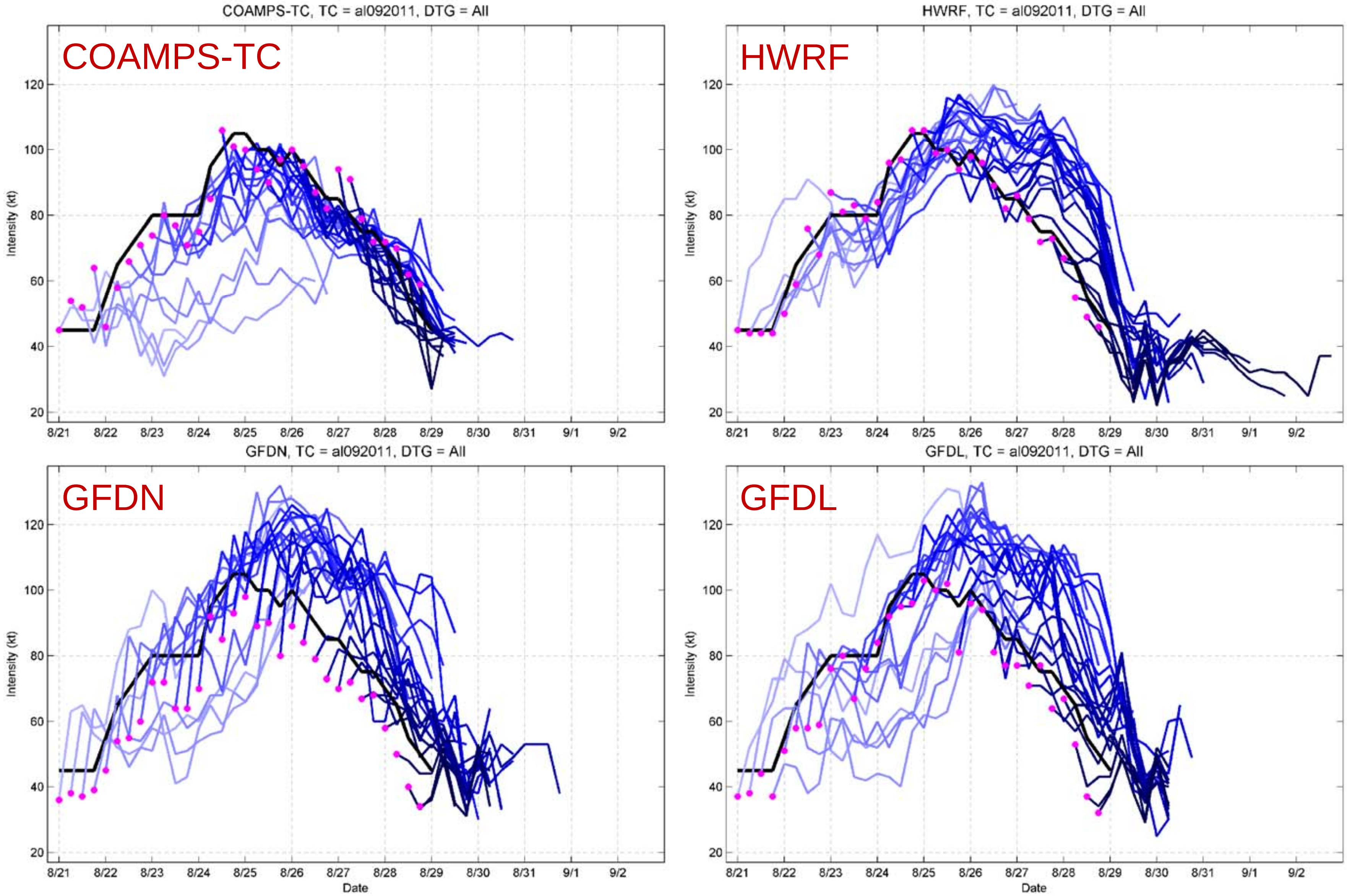
COAMPS-TC 36-h Forecast





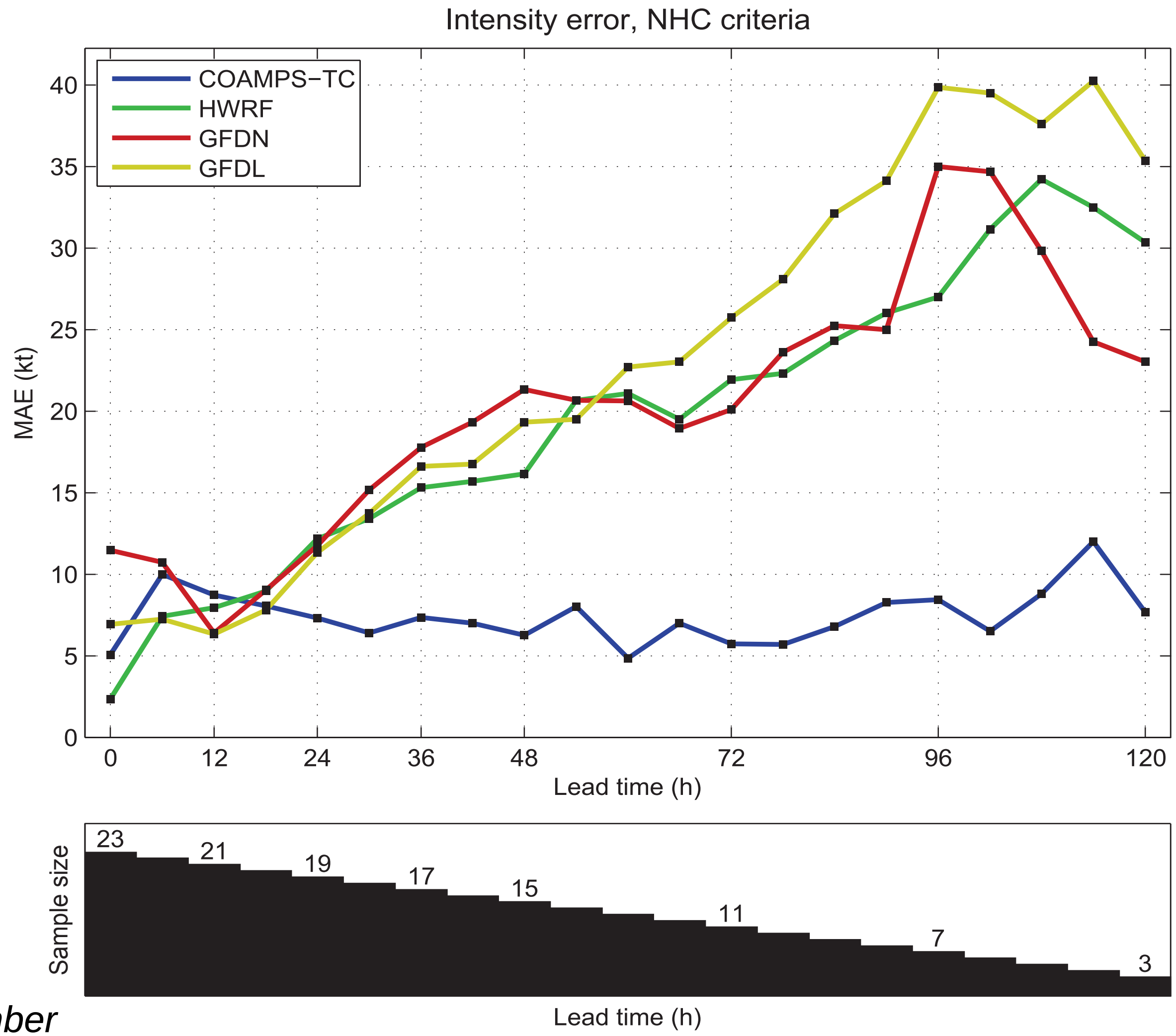
COAMPS-TC Captured Irene's Precipitation Structure Quite Well.

COAMPS-TC
Irene Intensity Statistics



COAMPS-TC 2011 HFIP Stream 1.5

Irene Intensity Errors (kt)

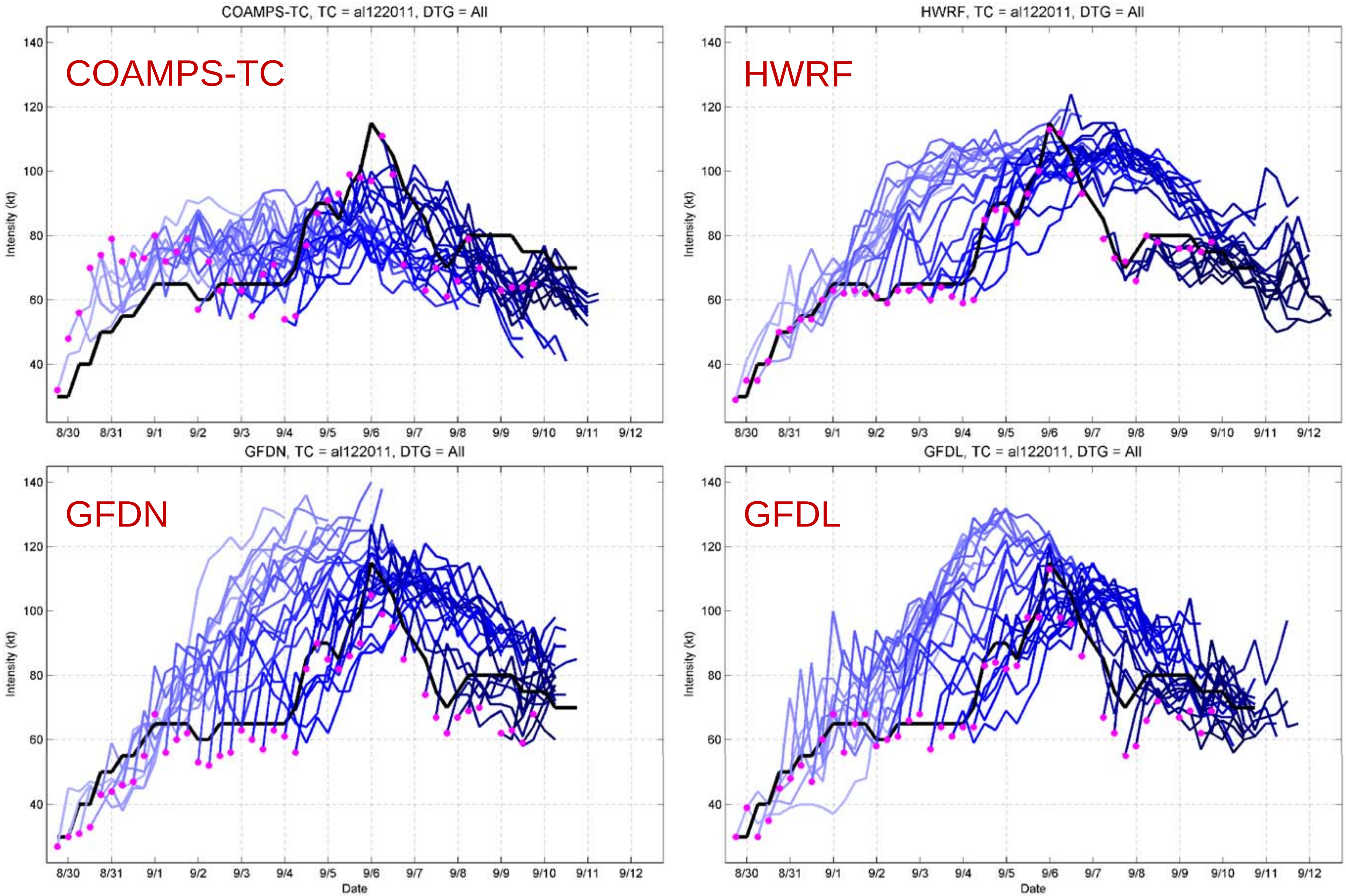


After 00Z 23 September
No interpolation to account for late model fields

COAMPS-TC Performed Very Well for Irene. Tests are Underway to Understand the Performance Better.

COAMPS-TC

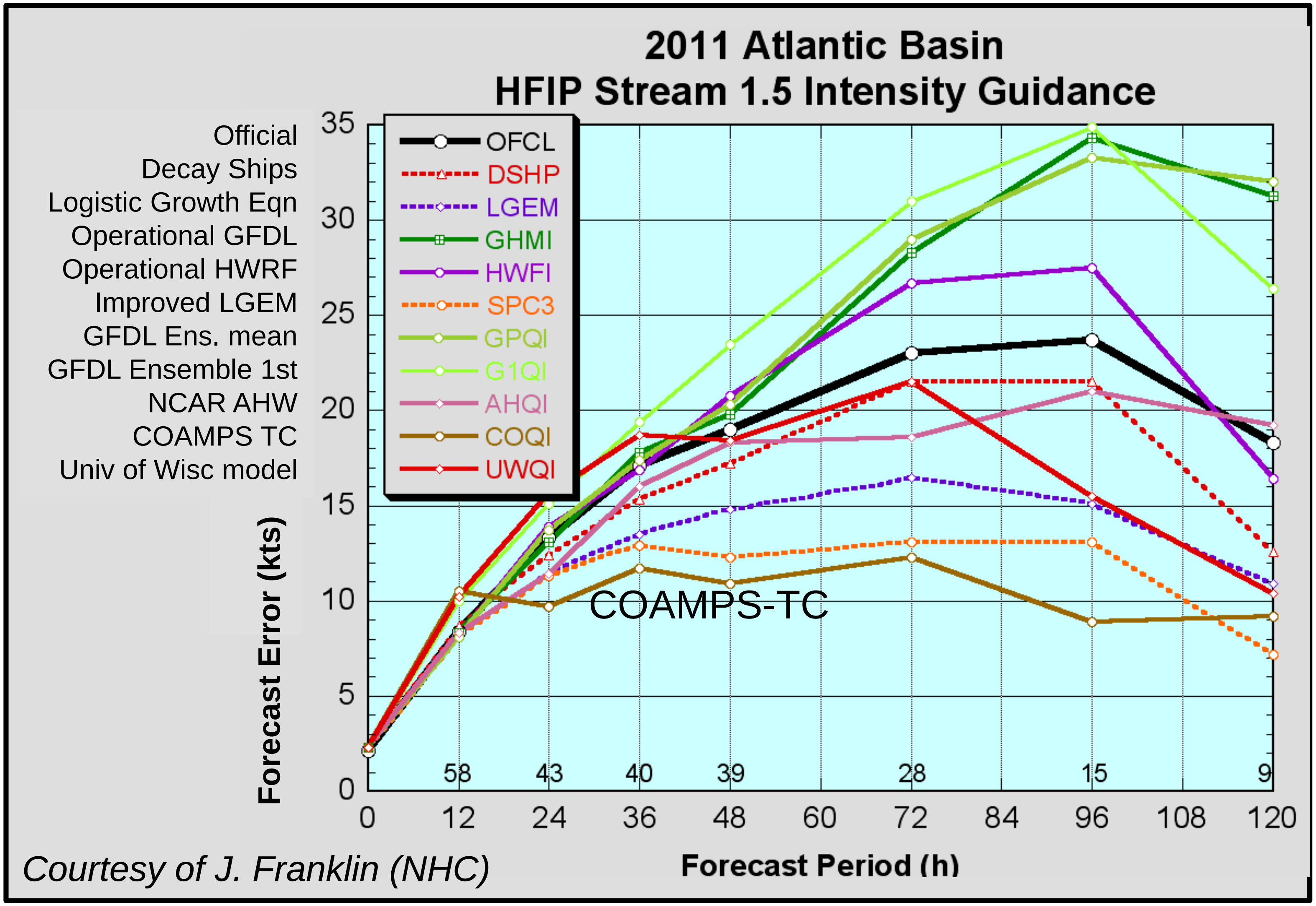
Katia Intensity Statistics



No interpolation to account for late model fields

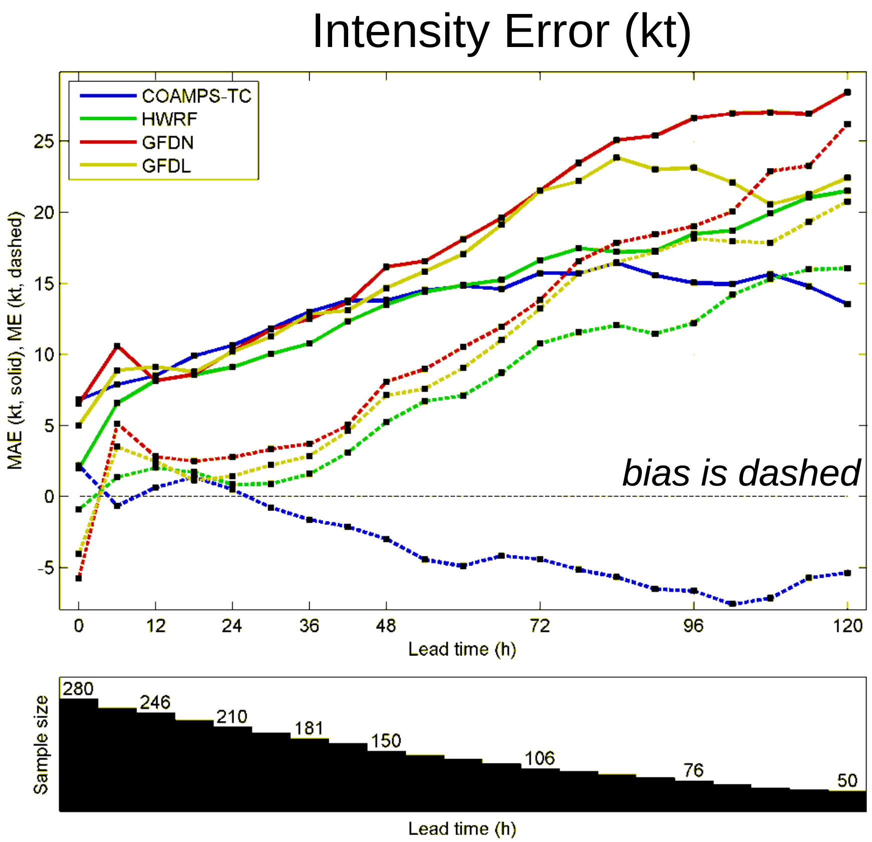
COAMPS-TC

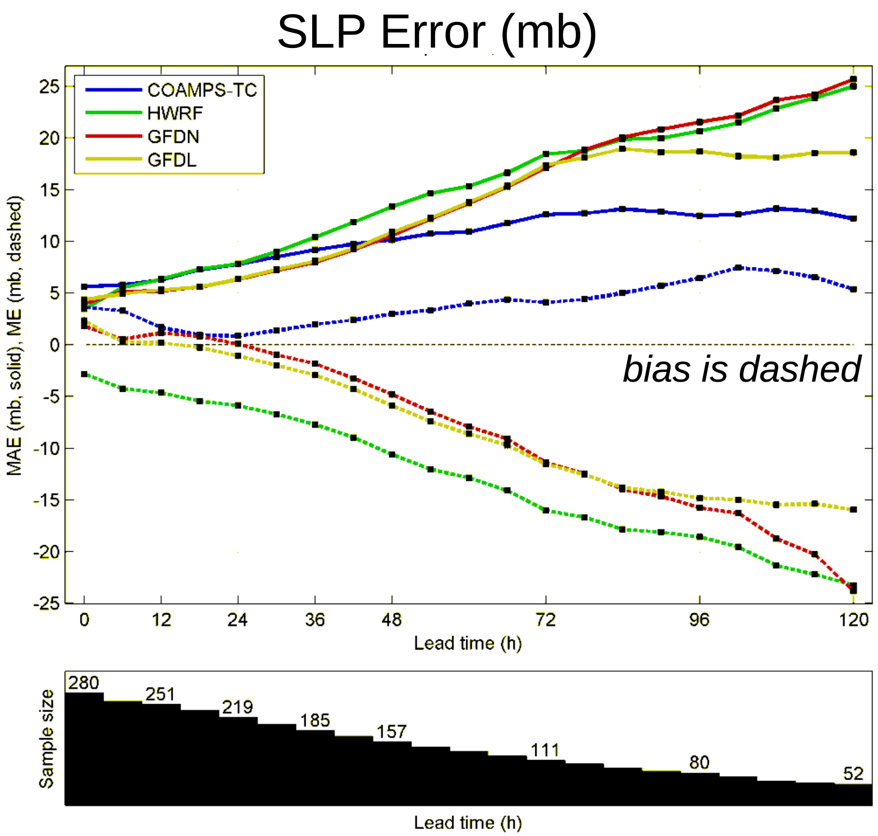
2011 W. Atlantic Intensity Statistics (thru 20 Sep)



COAMPS-TC

2011 W. Atlantic Intensity Statistics (thru 7 Oct.)



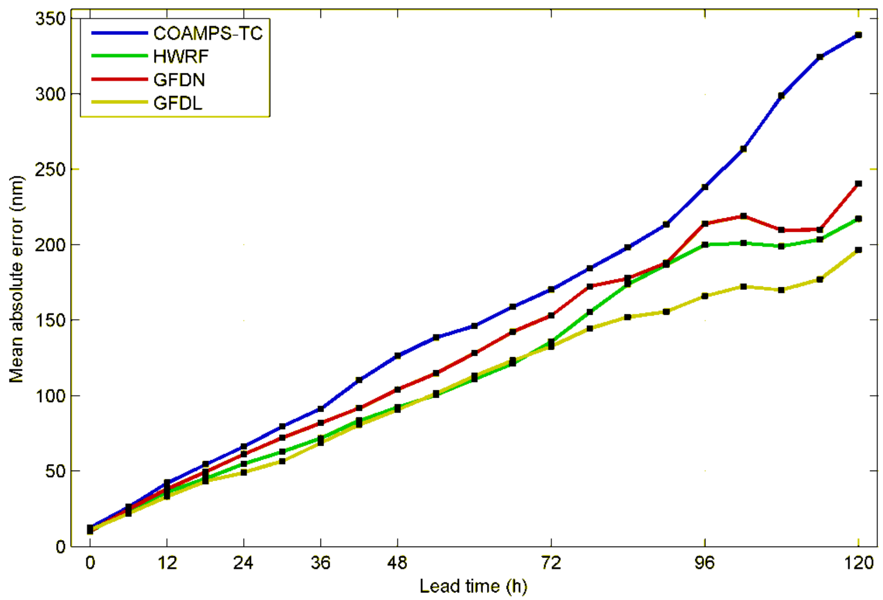


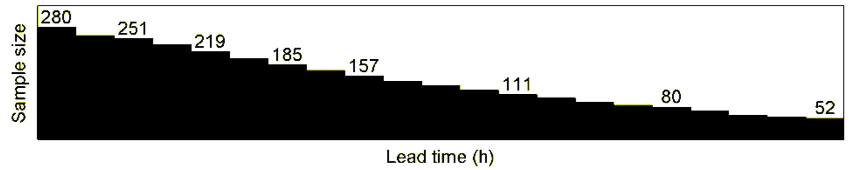
Intensity verification of other operational models (more samples) shows COAMPS-TC performs similar to 48 h and improved beyond that.

COAMPS-TC

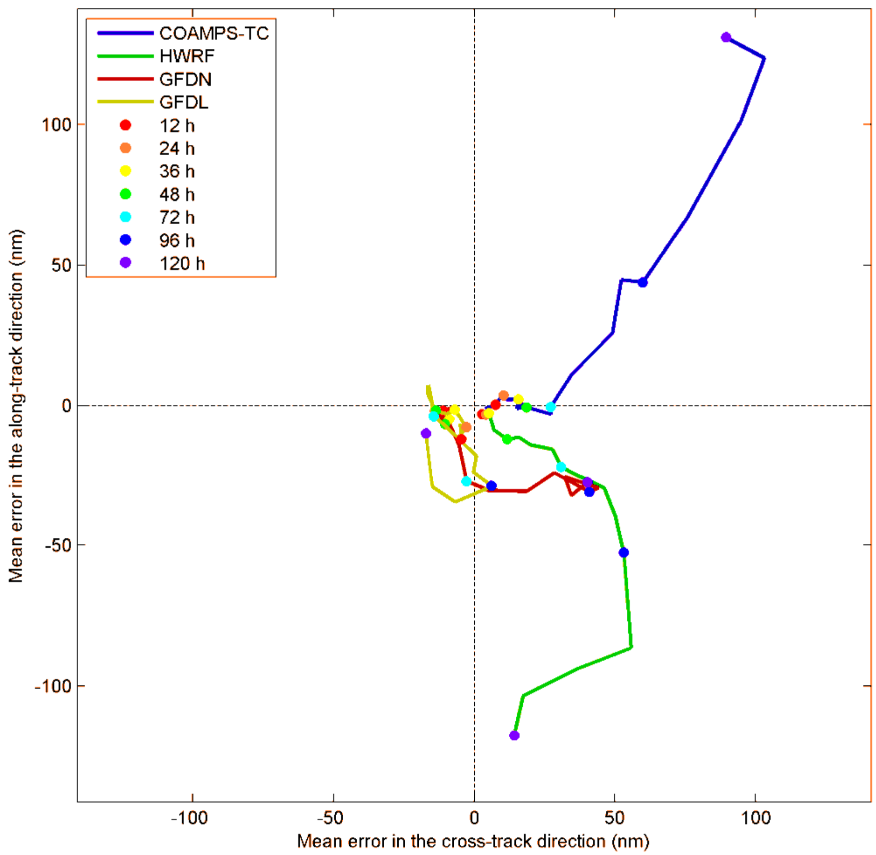
2011 W. Atlantic Track Statistics (thru 10/7/11)

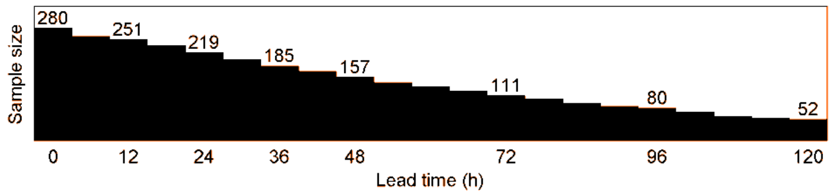
Track Error (nm)





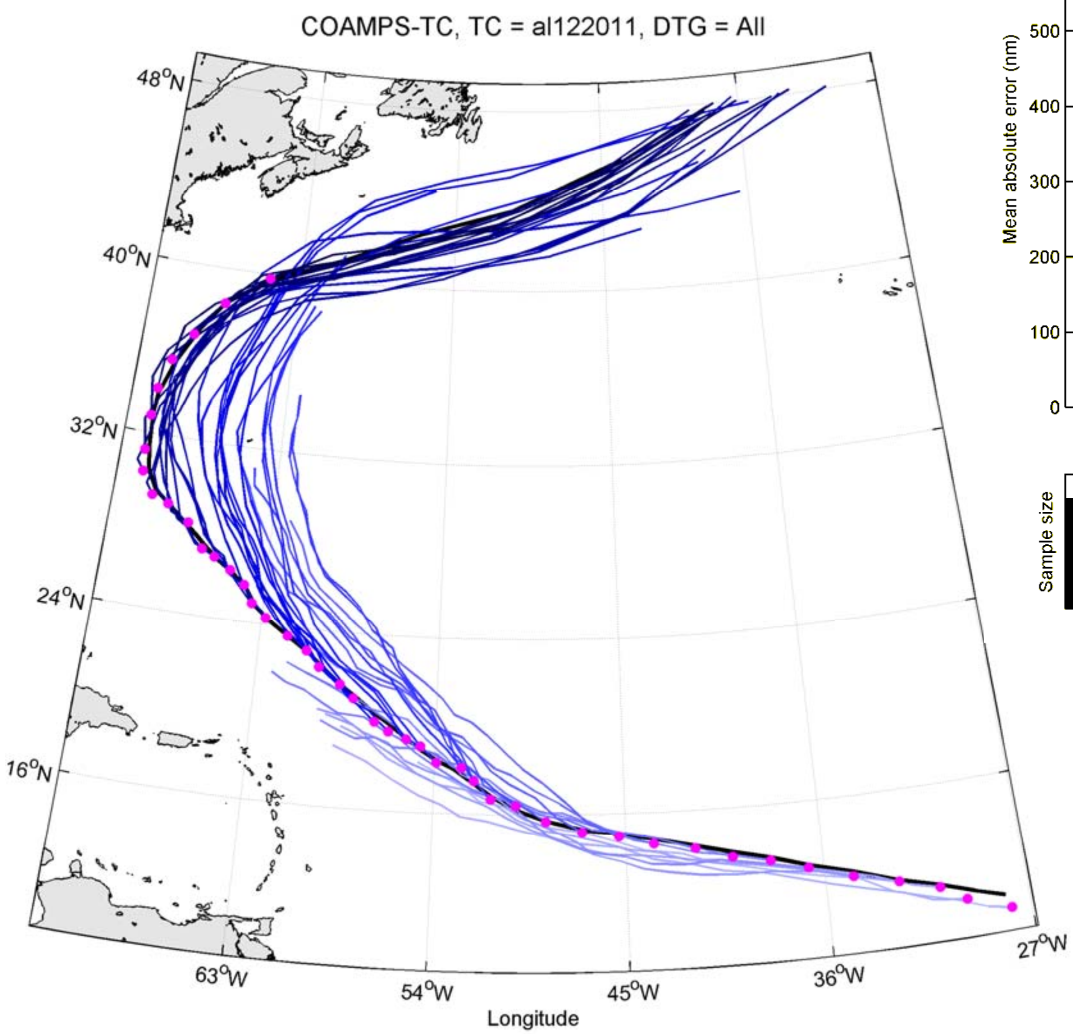
Storm Relative Directional Decomposition

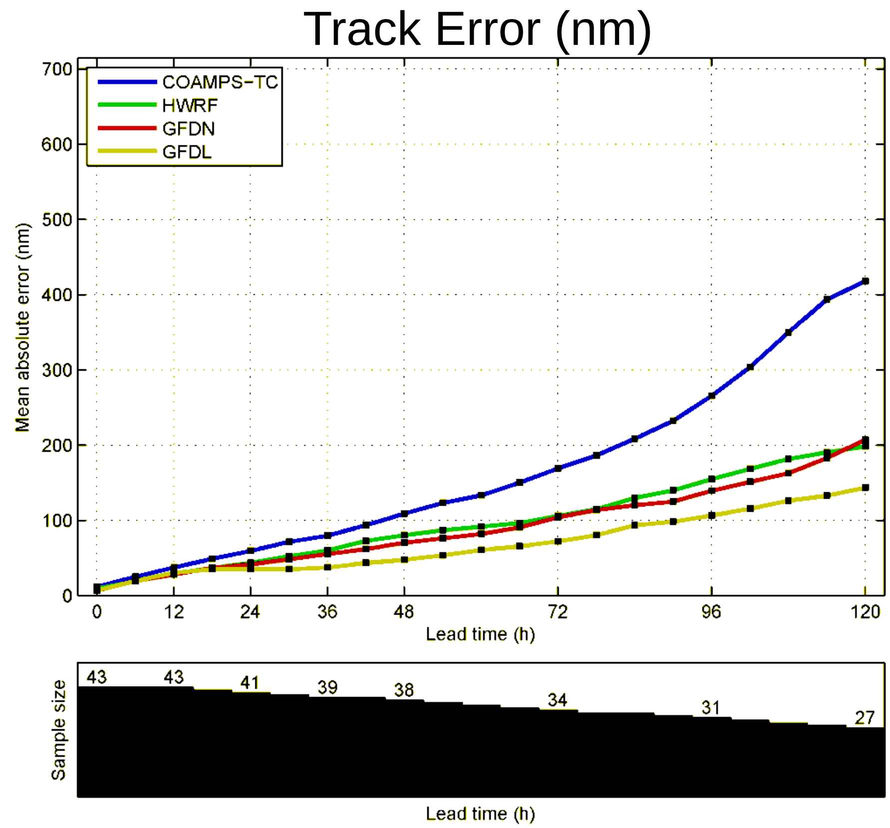




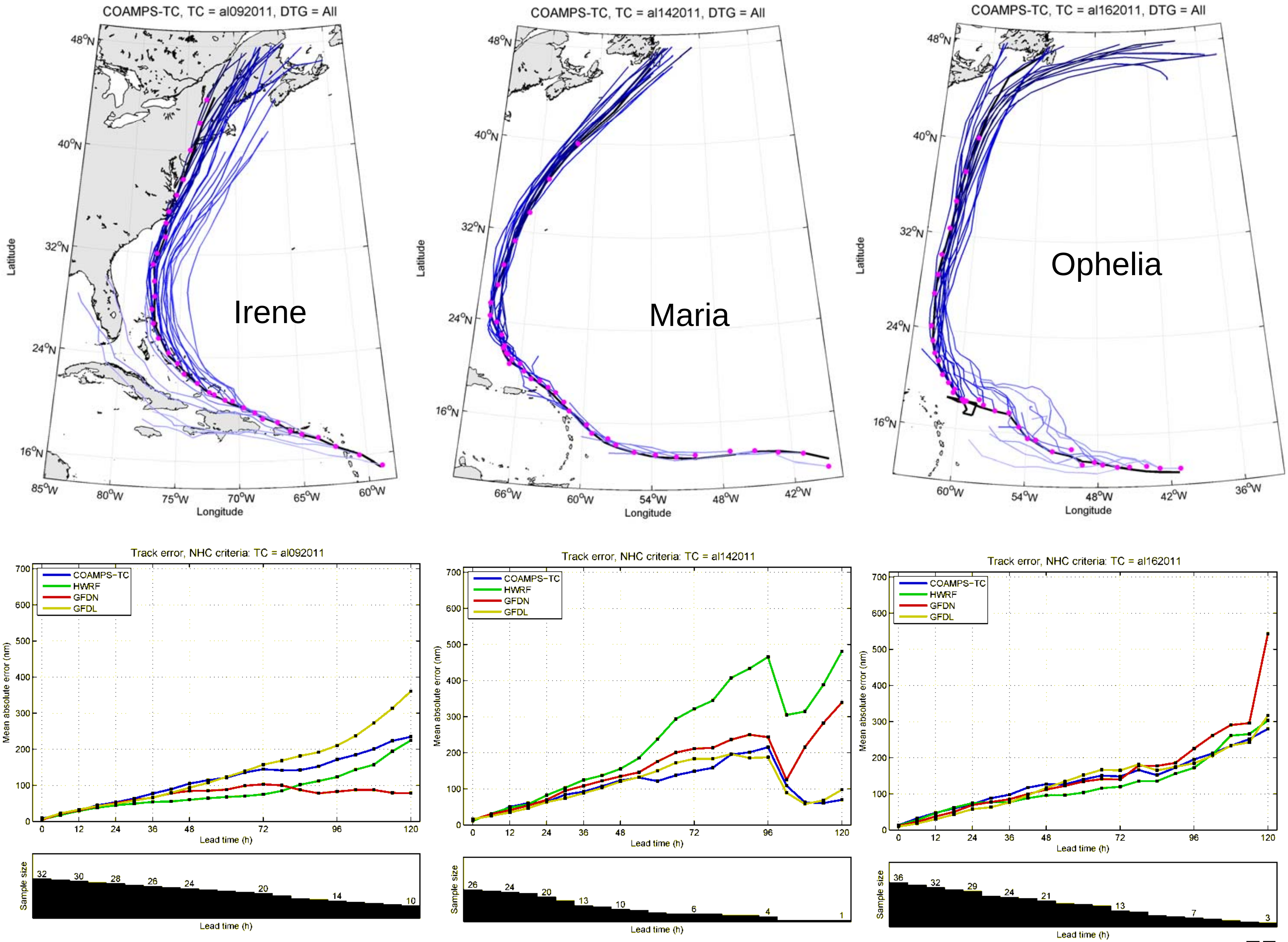
COAMPS-TC Shows Some Track Forecast Deficiencies in W. Atlantic Basin.

COAMPS-TC
Katia Track Statistics





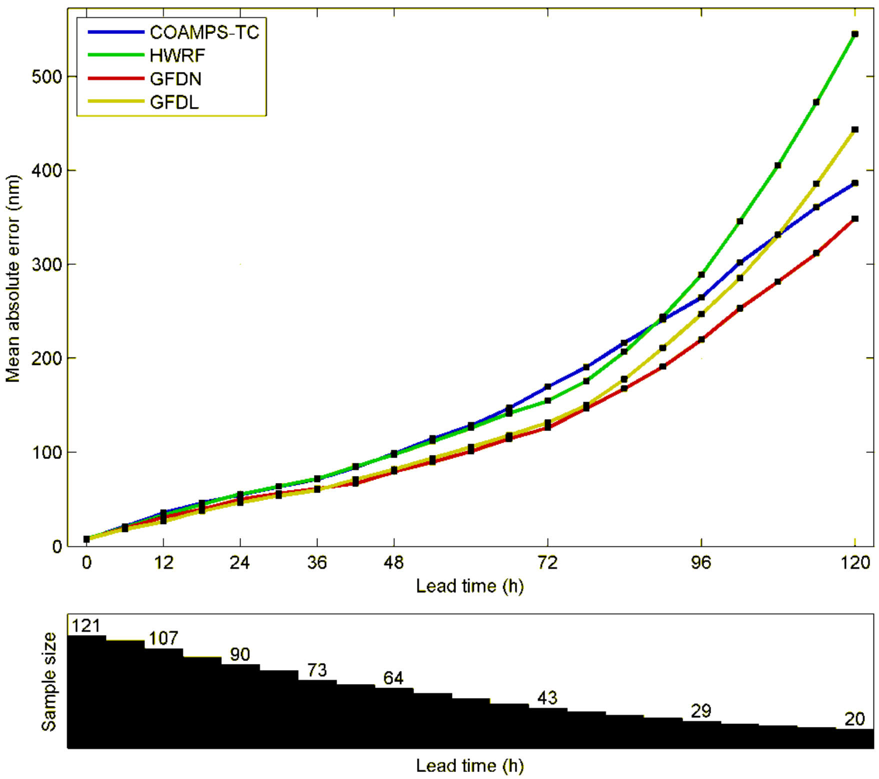
Track of Katia was poorly forecasted, particularly during recurvature.


COAMPS-TC, TC = al092011, DTG = All
Irene
COAMPS-TC, TC = al142011, DTG = All
Maria
COAMPS-TC, TC = al162011, DTG = All
Ophelia
Latitude
Longitude
Track error, NHC criteria: TC = al092011
Track error, NHC criteria: TC = al142011
Track error, NHC criteria: TC = al162011
COAMPS-TC
HWRF
GFDN
GFDL
Mean absolute error (nm)
Lead time (h)
Sample size

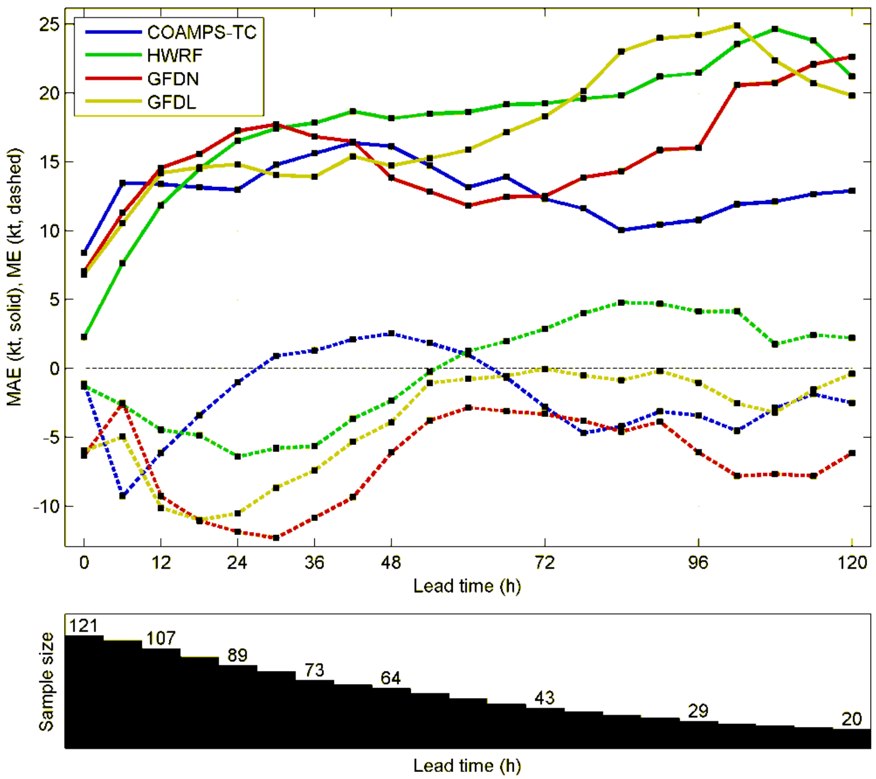
COAMPS-TC

Eastern Pacific Basin (through 10/7/2011)

Track Error (nm)



Intensity Error (kt)



COAMPS-TC Track Error in E. Pacific is Comparable to Other Models.
Intensity Error for COAMPS-TC is Reasonably Good after 18 h.

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COAMPS-TC Ensembles

Data Assimilation Background

Serial EnKF (DART)

- Two-way interactive DA – highest resolution nest defines the innovation
- Observations: Surface/ship stations, cloud-track winds, aircraft data, dropsondes, radiosondes, SSMI/S and WindSat TPW
- Distance based localization, multiplicative based inflation

80-member ensemble for DA

- 6-hr update cycle
- GFS-EnKF lateral boundary conditions
- GFS-EnKF fields interpolated to COAMPS grid for the initial ensemble

45-15-5 km 2-way interactive nests for each storm

- Atlantic, EastPac, and WestPac
- 15 and 5 km nest follows storm independently for each member
- Nest relocated to ensemble mean position for DA

COAMPS-TC Ensembles
Forecast System Background

10-members (option to run 20-members)

- 120-h lead time twice daily (00 and 12 UTC)
- GFS-EnKF lateral boundary conditions

Perturbations

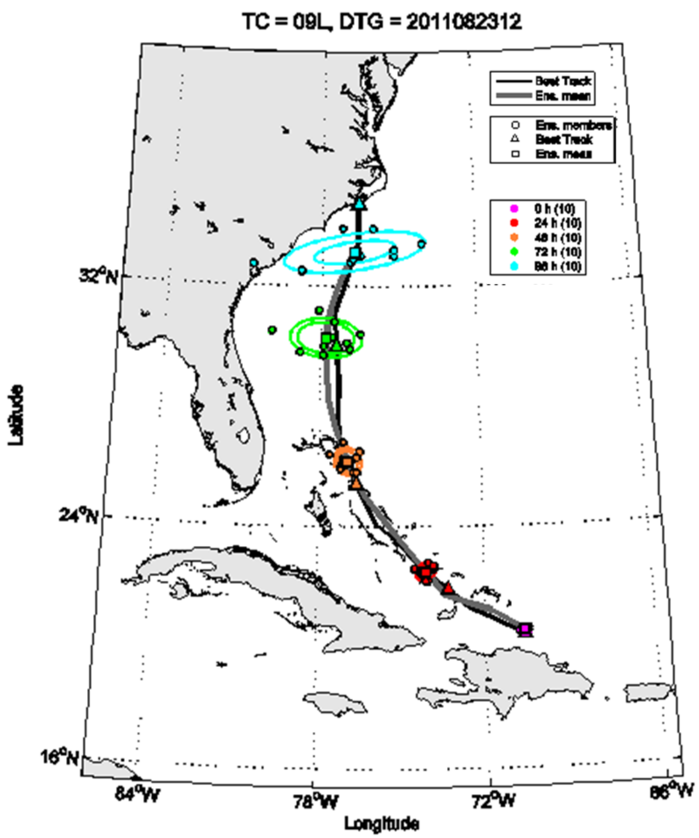
- IC perturbations from members 1-10 of the DA ensemble
- No perturbations to model parameterizations

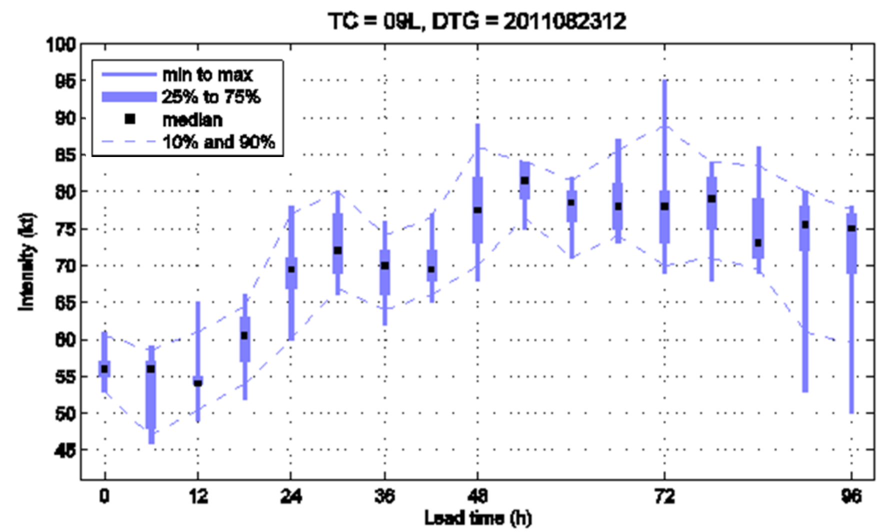
Graphics output to web

- Summary plots for intensity, size, and track
- 15 and 15 km mesh graphics computed in storm relative coordinate
- **http://www.nrlmry.navy.mil/coamps-web/web/ens?&spg=1**

COAMPS-TC Ensembles
Irene Probabilistic Products

10 Member 5-km Resolution Ensemble System (COAMPS-TC DART)





TC position from individual ensemble members every 24 h and ellipses that encompass the 1/3 and 2/3 ensemble distributions.

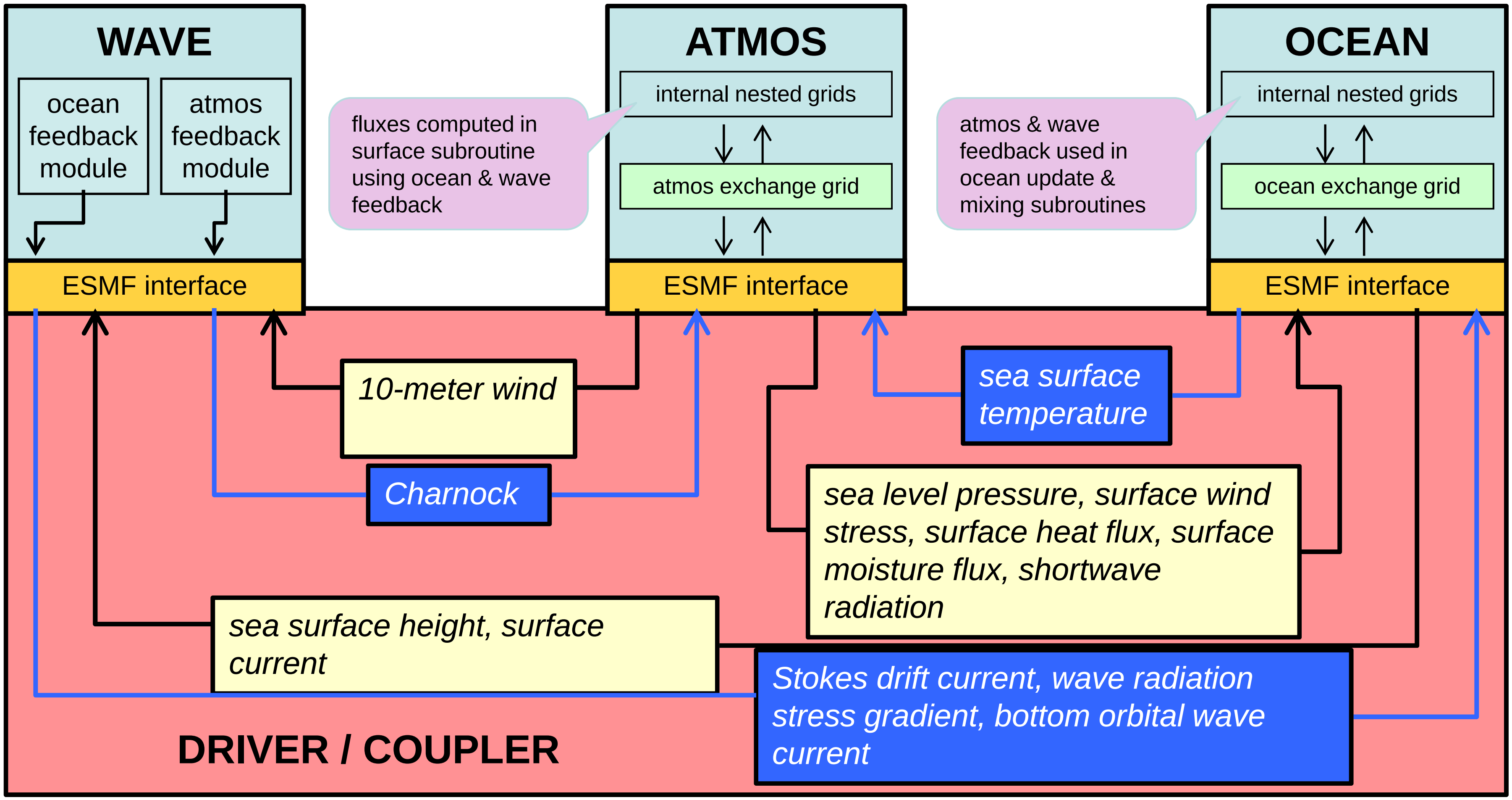
Median, minimum, maximum, and 10% and 90% distributions are shown

COAMPS-TC Ensemble System is a new capability demonstrated in real time.

Coupled COAMPS-TC

Air-Sea Interface Physics

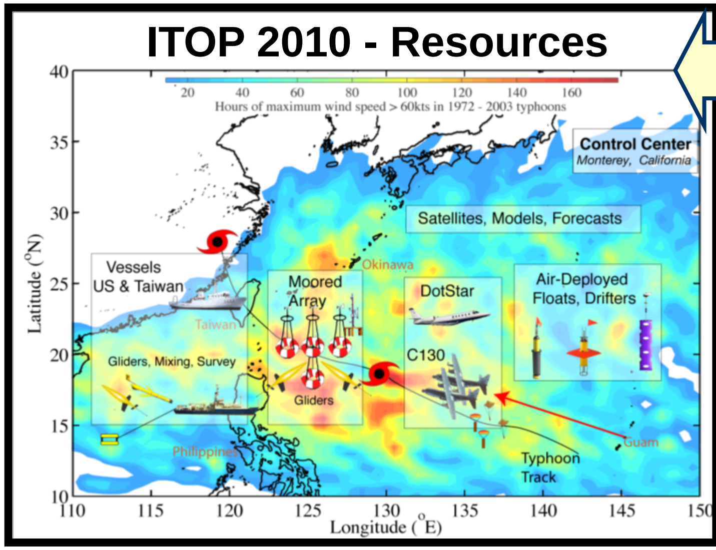
Earth System Modeling Framework (ESMF)



COAMPS contains a community based (ESMF) coupler to facilitate flexible and generalized exchange between components

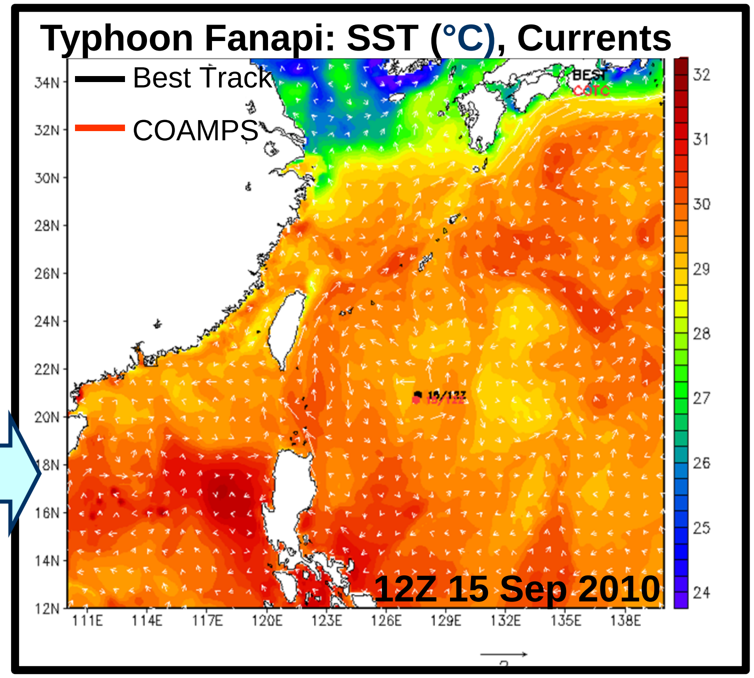
COAMPS-TC: ITOP

Impact of Typhoons on the Ocean in Pacific

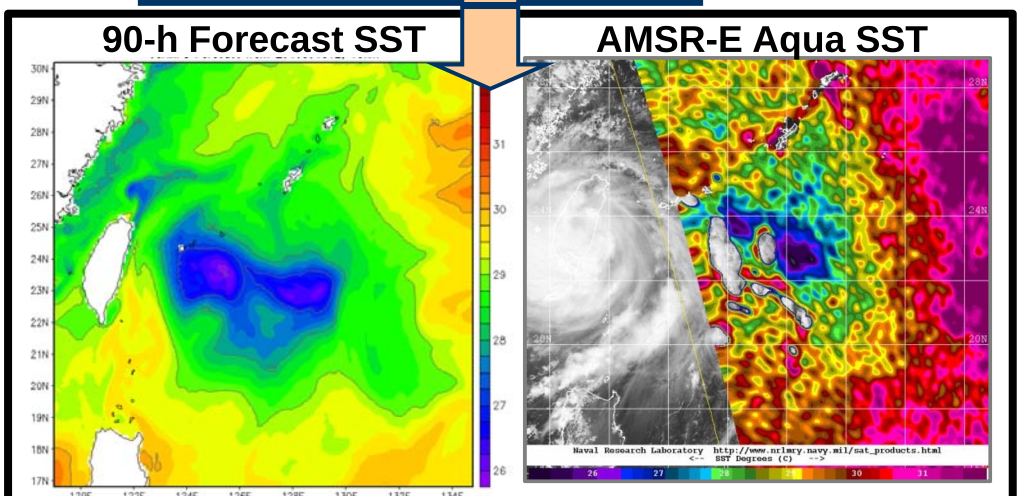


ONR Sponsored ITOP in W. Pacific

Air-Ocean Coupling in Real–Time COAMPS-TC Predicts SST Wake of 2-4˚C



Satellite Derived SST Shows 2-4°C Wake Similar to Coupled Model

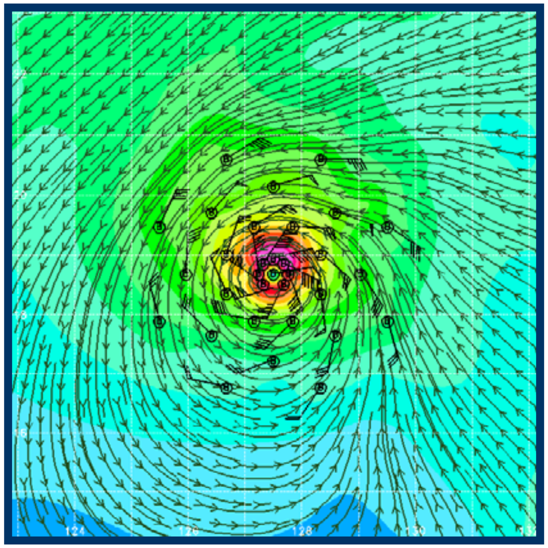


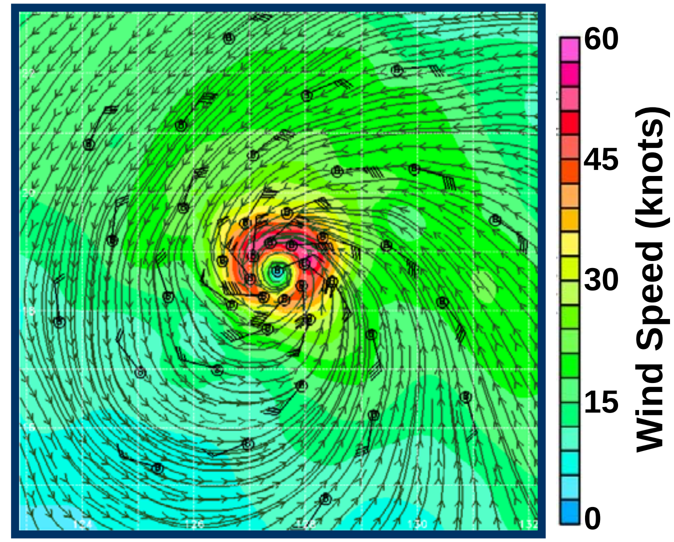
- **COAMPS-TC coupled tested in real time during ITOP in 2010 in WPAC**
- **COAMPS-TC coupled (air-ocean) capability is being tested in real time for WATL in 2011 (Stream 2)**
- **ITOP is an excellent dataset to evaluate the coupled system**

COAMPS-TC: Analysis Improvements

New Synthetic Observations

The current methodology places synthetic observations at fixed radial locations, out to 4°-6° away from the TC center

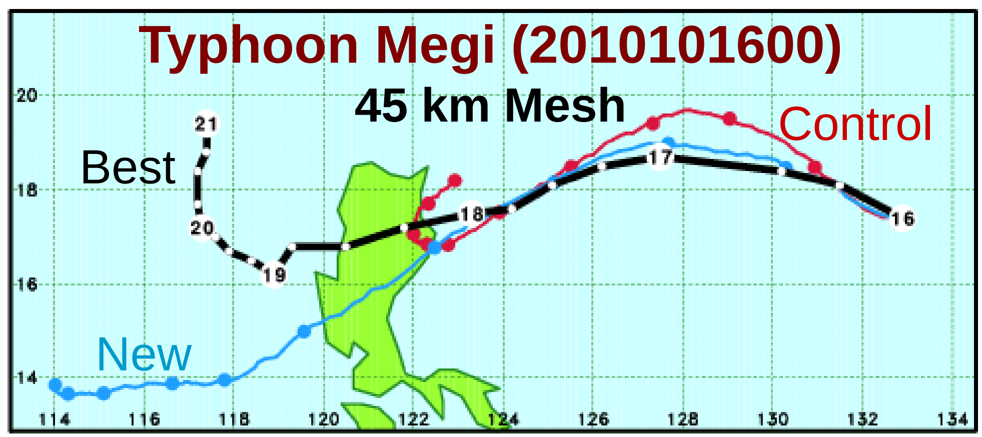




The new methodology dynamically places observations at the radius of maximum winds out to the radius of the 34-knot wind

<u>New Synthetics</u>

- **Represent the size and structure of TC better.**
- **Track is improved (~15%) over 50+ cases.**

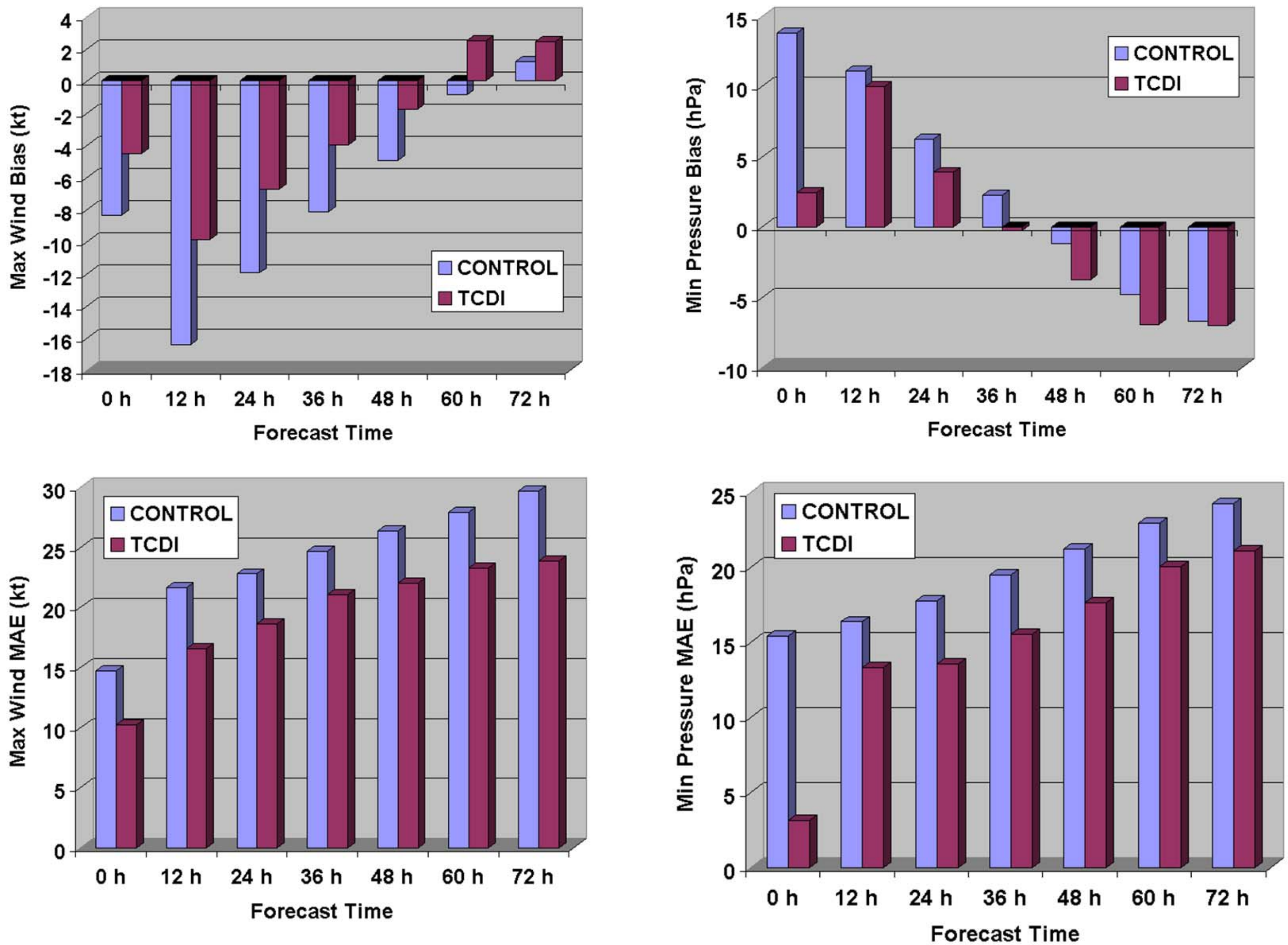


Tropical Cyclone Dynamical Initialization (TCDI)

Verification of TC Intensity

11 Tropical Cyclones from 2008/2009 in WPAC/WATL

Time	Cases
0 h	112
12 h	112
24 h	111
36 h	109
48 h	106
60 h	104
72 h	97

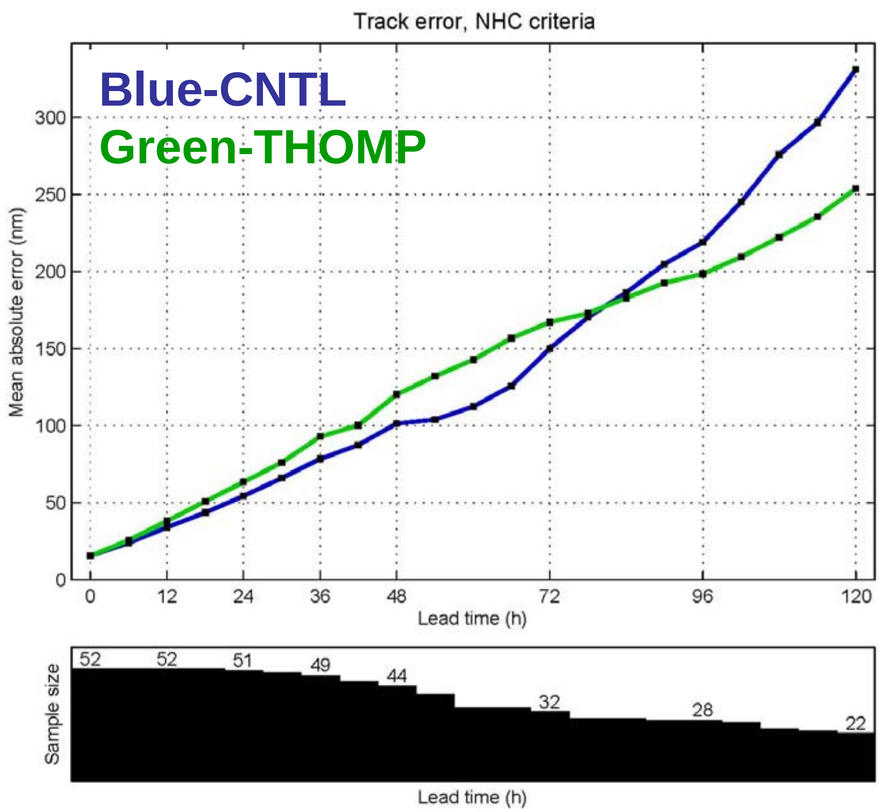


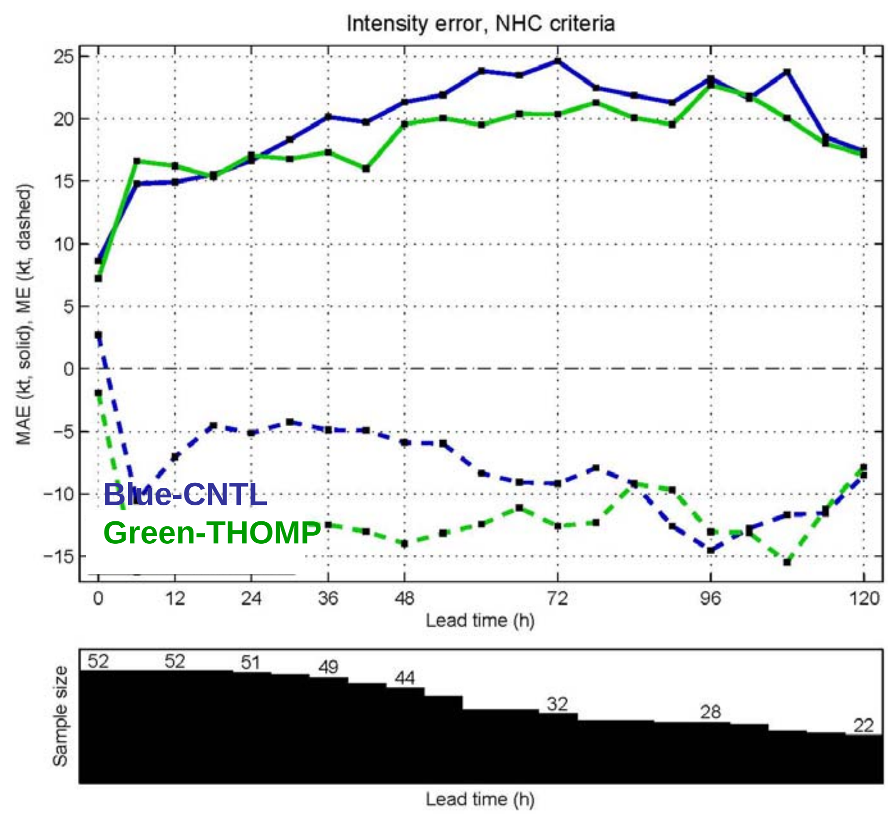
TCDI improves the intensity forecasts

COAMPS-TC: Physics Improvements

Evaluation of the Thompson Microphysics Scheme

- **Thompson (2008) V3.3** implemented in COAMPS-TC:
- two-moment for cloud ice and rain
- single-moment for cloud water, snow, and graupel
- prescribed number of cloud droplets (100 cm^{-3})

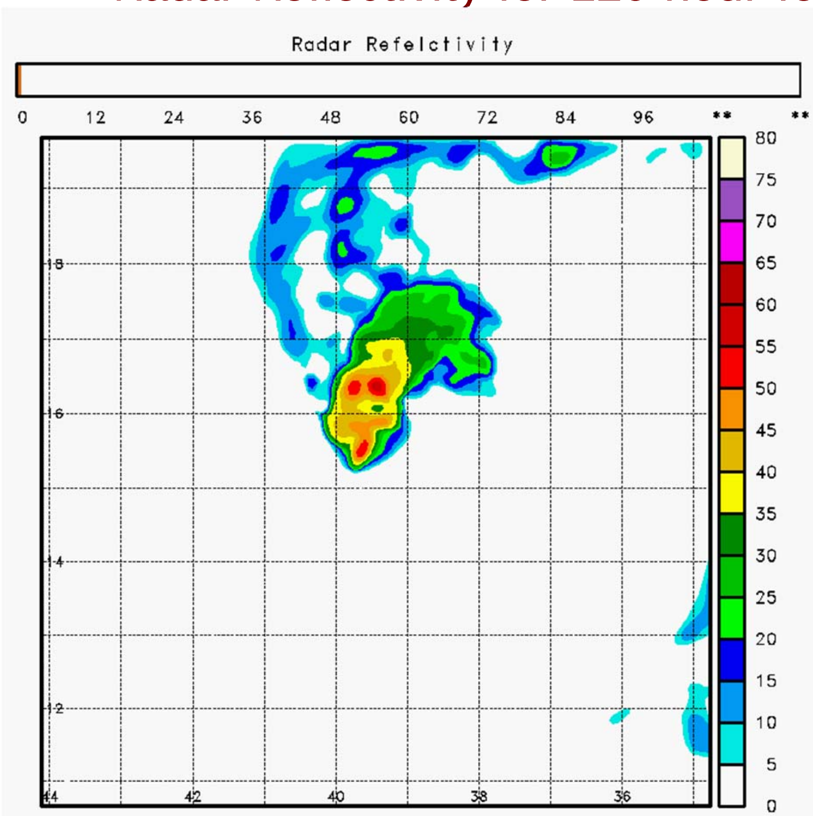




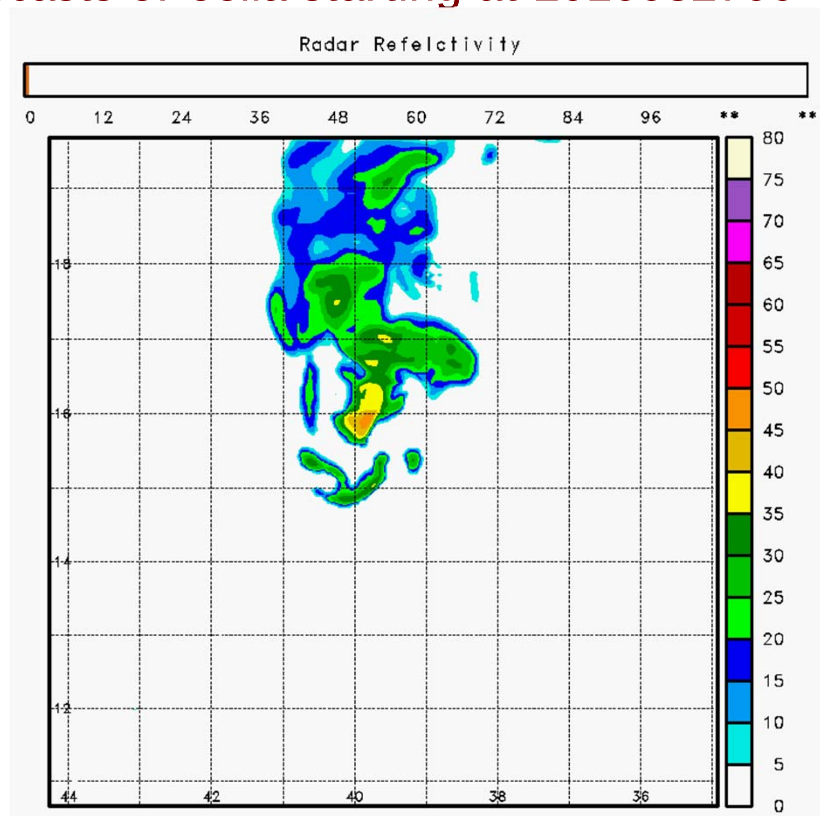
COAMPS-TC: Physics Improvements

Convection during Spin-Up of TC

Radar Reflectivity for 120 hour forecasts of Celia starting at 2010082700



Explicit microphysics



New Microphysics Mixing and New Cumulus (SAS)

- **Improvements to the Microphysics Mixing and New SAS Produces more Organized Convection During Intensification**
- **However, Intensity is Over-Predicted with SAS.**

COAMPS-TC
Summary and Challenges

- Real-time tests in 2011 using improved COAMPS-TC
  - **WATL, EPAC, WPAC, IO: Collaborate w/ NHC, JTWC**
- Promising COAMPS-TC Intensity Predictions
  - **Performed well in 2010 and 2011; Some excellent results in 2011**
  - **Transition to FNMOC in FY12: Validation Test Panel (underway)**
- HFIP Stream 2 Tests and Development
  - **Ensembles: Possibility of HFIP multi-model ensemble of ensembles**
  - **Fully Coupled System: Community ESMF air-sea interface for ocean & waves**
  - **New Physics: Emphasis on microphysics, PBL, fluxes (joint develop. possible)**
- Challenges and Issues
  - **Vortex-scale DA:** **EnKF, 4D-Var, coupled DA (all underway at NRL)**
  - **TC Physics:** **Cloud microphysics, subgrid-scale convection, PBL**
  - **Air-Sea Coupling:** **Air-sea-wave coupled physics and interfaces**
  - **Probabilistic Pred.:** **Opportunities for a multi-model ensemble system**