Development of the Navy's COAMPS-TC

James D. Doyle, C. Amerault, S. Chen, J. Cummings[1], E. Hendricks[2], R. Hodur[3], T. Holt, H. Jin, Y. Jin, C.-S. Liou, M. Peng, K. Sashegyi, J. Schmidt

Naval Research Laboratory, Monterey, CA

[1]Naval Research Laboratory, Stennis, MS

[2]NRC, [3]SAIC, Monterey, CA

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ONR, PMW-120, NOAA

Typhoon Saomai (08W) and Tropical Storm Bopha (10W) 02Z 8 Aug 2006 (NASA MODIS)

Outline

- Background and COAMPS-TC description
- Real-time COAMPS-TC tests
  - T-PARC/TCS08 (2008)
  - Hurricane Forecast Improvement Project (HFIP) Demo (2009)
- Diagnosis and improvements to system
- New capabilities
  - Two-way air-sea coupled experiments
  - Adjoints
  - Ensemble techniques
- Summary and Future Research

COAMPS-TC
Background

- **COAMPS® has been the operational mesoscale model for the Navy since 1998 to support research and DoD operations.**
- **COAMPS-TC: New version of COAMPS® developed for tropical cyclone analysis and prediction:**
  - New 3D-Var TC analysis, synthetic observations for vortex initialization, improved microphysics, air-sea fluxes, and boundary layer (CBLAST)
  - Goal is to predict tropical cyclone *track, structure, intensity, ocean response*
- **COAMPS-TC demonstrated in real time in 2008-2009:**
  - T-PARC/TCS08 and Hurricane Forecast Improvement Project (HFIP) Demo
  - 45/15/5 km resolution (inner two moving nests)
- **Near-term objectives:**
  - Evaluate the skill of the COAMPS-TC predictions 2008-2009
  - Research to improve the prediction of TC track, structure, and intensity
  - Transition to Navy operations and HFIP multi-model ensemble
  - New insight into TC coupled processes, dynamics, and predictability

COAMPS-TC Overview

Current and Future Capabilities

Atmospheric Analysis

- **Complex Data Quality Control**
- **Relocation of TC in background**
- **Synthetic Observations:** TC vortex
- **NAVDAS 3DVAR:** u, v, T, q, TC option
- **Initialization:** Digital Filter Option
- **TC Balance Step:** (underway)

Ocean Analysis

- **Navy Coupled Ocean Data Assimilation** (NCODA) **System**
- **2D OI:** SST
- **3D MVOI:** T, S, SSH, Sea Ice, Currents
- **Complex Data Quality Control**
- **Initialization:** Stability check

Atmospheric Model

- **Numerics:** Nonhydrostatic, Scheme C, Moving Nests, Sigma-z, Flexible Lateral BCs
- **Physics:** PBL, Convection, Explicit Moist Physics, Radiation, Surface Layer
- **TC Tools:** Moving nests, dissipative heating, spray parameterization, shallow convection

Ocean Models

- **NRL Coastal Ocean Model** (NCOM)
- **Numerics:** Hydrostatic, Scheme C, Nested Grids, Hybrid Sigma/z
- **Physics:** Mellor-Yamada 2.5
- **Wave Models (WWIII and SWAN)**
- **Generalized Coupling Layer (ESMF)**

Atmospheric Ensembles

- **Initial Cond. Perturbation:** ET, EnKF
- **Physics Perturbations:** PBL, Convection…
- **Lateral BCs:** Global ensemble (NOGAPS)
- **Probabilistic Products:** Intensity, track…

Ocean Ensembles

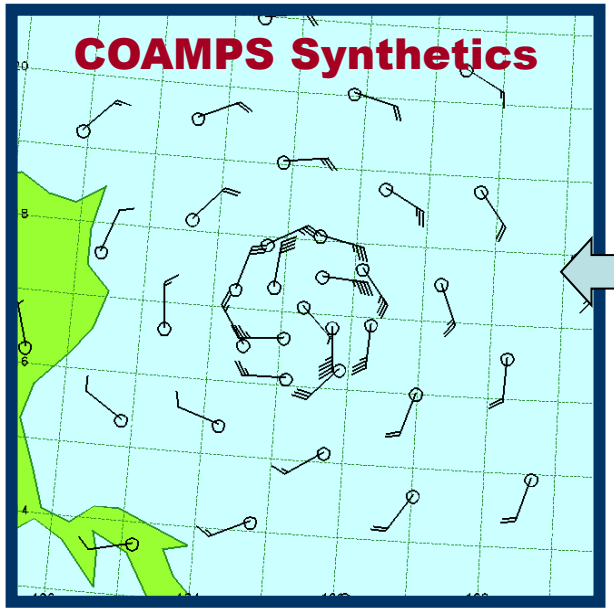
- **Initial Cond. Perturbation:** ET
- **Physics Perturbations:** PBL, Fluxes…
- **Lateral BCs:** NCOM
- **Probabilistic Products:** Mixed layer, OHC..

Tropical Cyclone Initialization

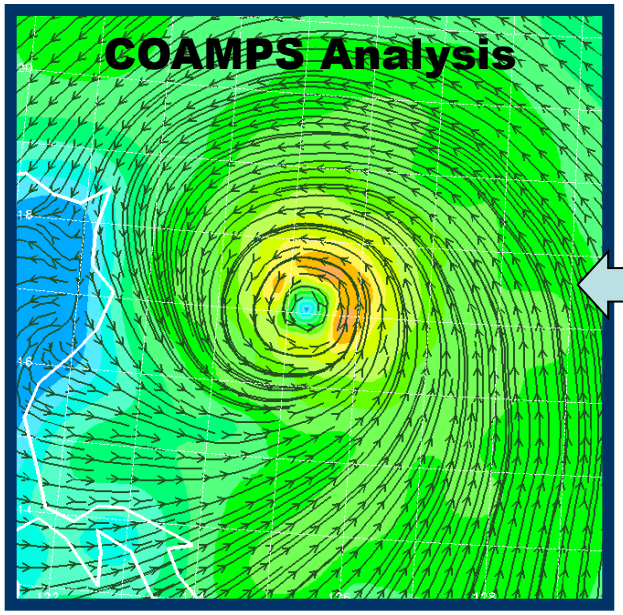
High-Resolution Synthetic Observations

Typhoon Sinlaku (15W) (0000 UTC 9 August 2008)

- Synthetic Observations:
  - Modified Rankine Vortex
  - JTWC / NHC Warning Message
  - NOGAPS truncated fields
- Blend Synthetics w/all other observations in 3DVAR



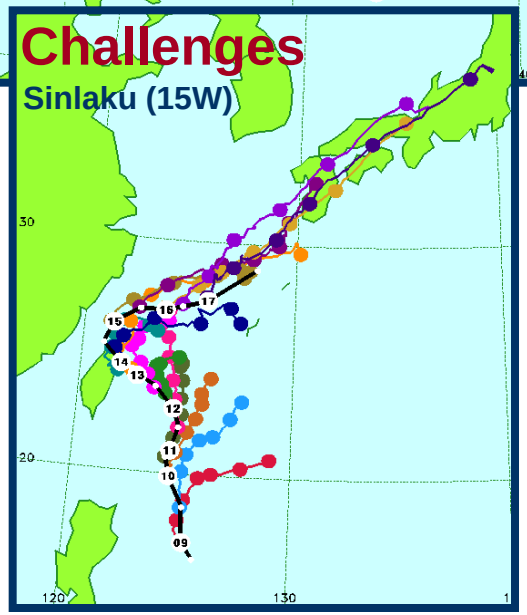
Synthetics to represent TC circulation



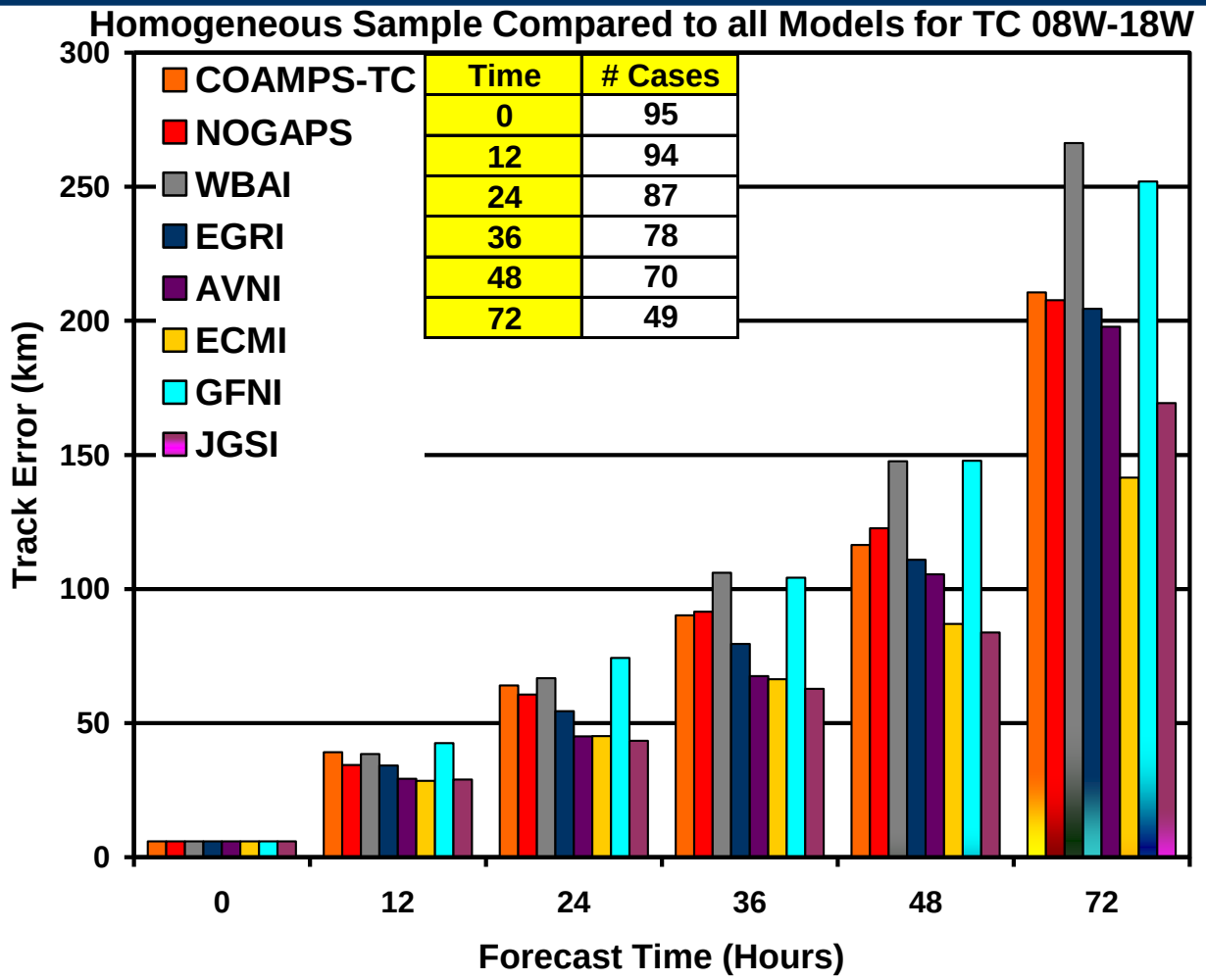
- Relocation of first guess (warm start)
- Improved TC representation with synthetics using 3DVAR

COAMPS-TC Track Forecasts for T-PARC/TCS08

Track Forecast Verification



Black line: Warning positions
Colored lines: COAMPS forecasts

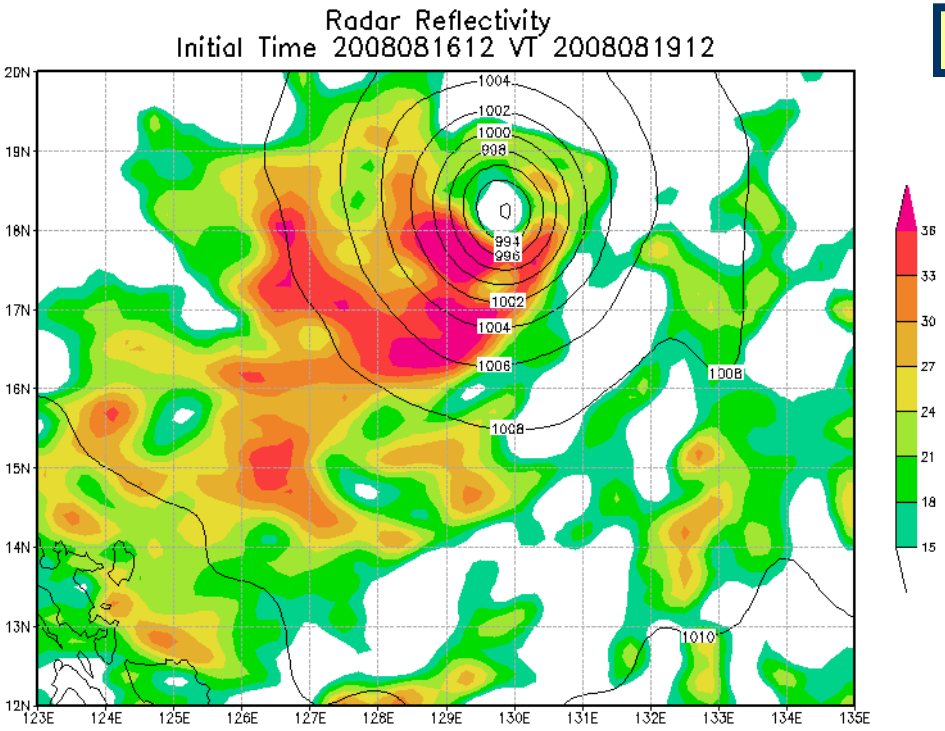


COAMPS-TC slightly underperforms in TC track early in the forecast, but does well at later forecast times outperforming GFDN and competitive with other models.

COAMPS-TC Structure Forecasts

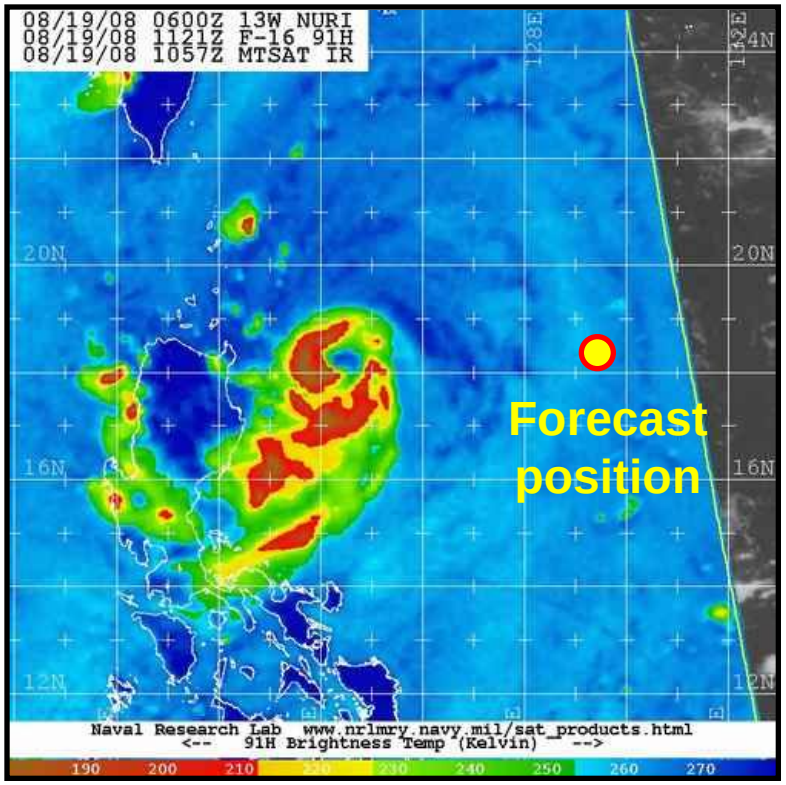
Structure Prediction of Typhoon Nuri

0000 UTC 26 September 2008 (72-h forecast)



COAMPS-TC Simulated Radar Reflectivity (72 h)

Microwave Satellite Imagery valid at 1121 UTC 19 Aug.



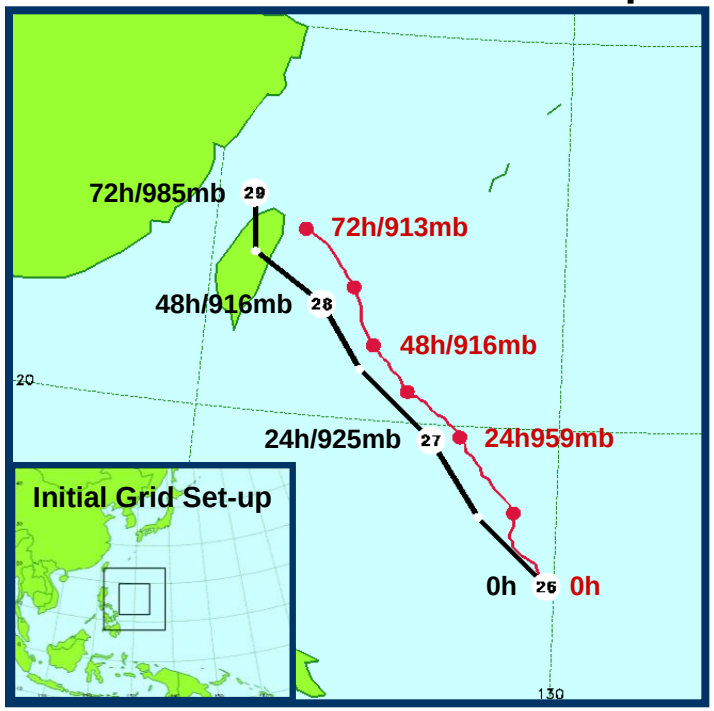
- **The 72-h forecast captures the distribution of the convection.**
- **Closed eye (radar) with heaviest convection on the south/southwest side.**
- **Precipitation over-forecast on western side of storm; track error at 72h.**

J. Hensley, P. Harr, R. Elsberry (NPS)

COAMPS-TC Intensity Forecasts

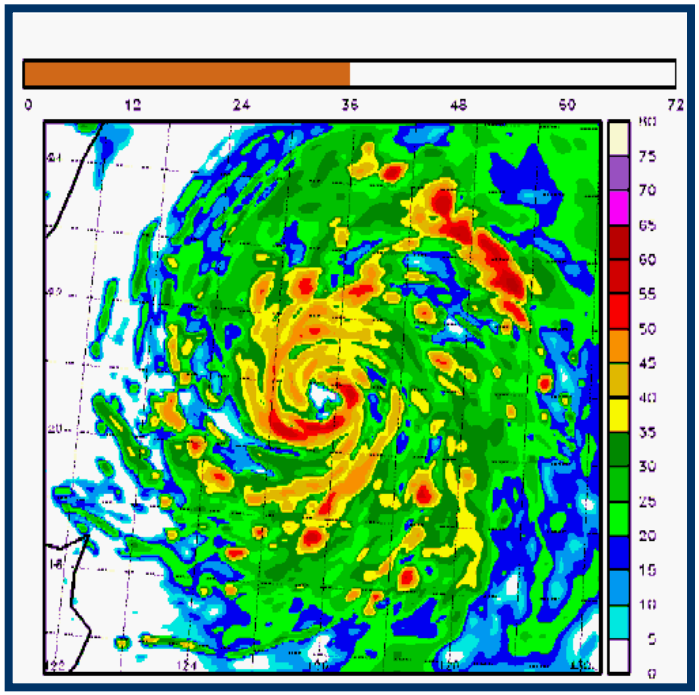
Prediction of Super Typhoon Jangmi

0000 UTC 26 September 2008 (72-h forecast)



COAMPS Forecast Track (red) and Official Warning Positions (black) plotted every 12 hours (dots)

Animation of COAMPS predicted radar reflectivity every 30 minutes on 5 km moving grid



- COAMPS-TC forecasted rapid intensification of Jangmi.
- Convection was spotty and disorganized early in forecasts.
- Overall, intensity forecasts were not as skillful as statistical models.

COAMPS-TC Improvements

Based on Analysis from T-PARC/TCS08

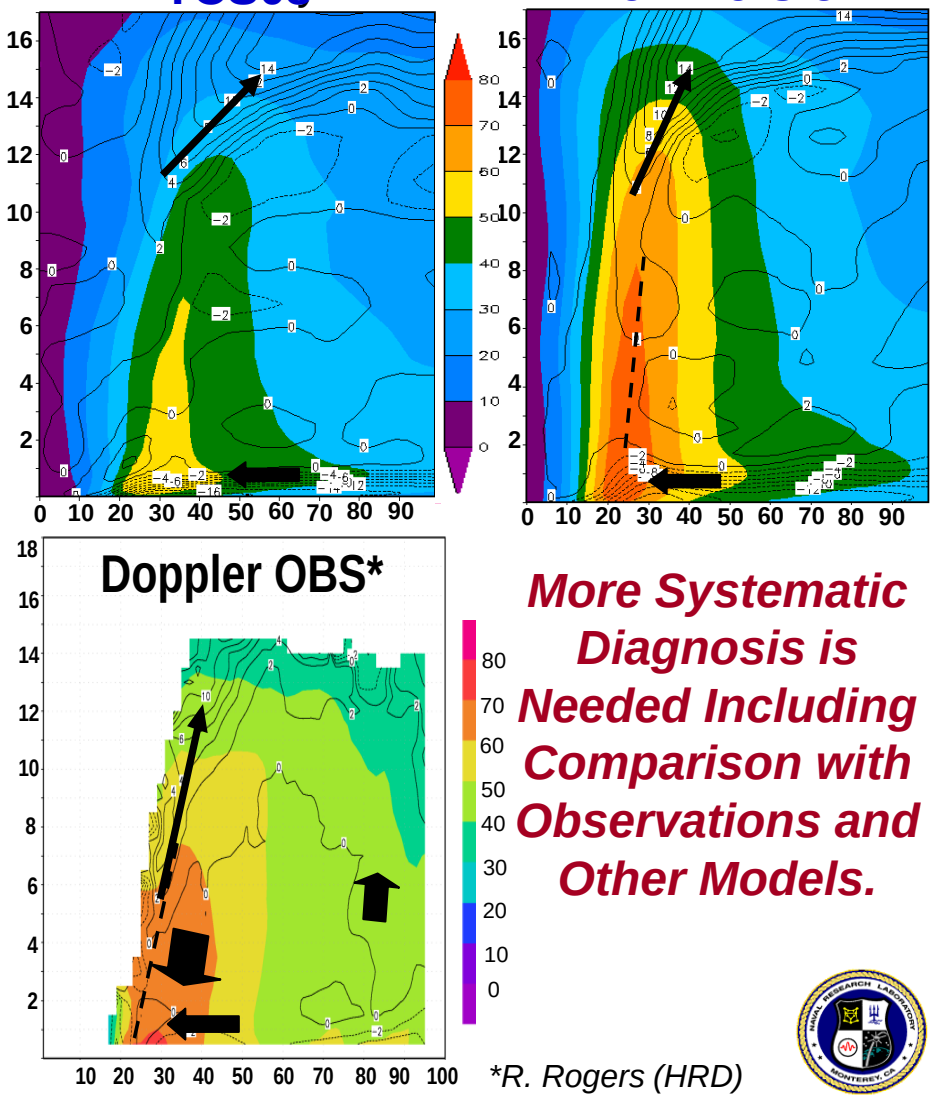
Azimuthally average tangential (shaded) and radial (contour) winds

Hurricane Katrina (72 h valid 00Z Aug 29 2005, Δx=3km)

New Version of COAMPS-TC

- *TCS08 Version*
  - *Basic TC 3D-VAR*
  - *Basic TC physics*
- *New Version*
  - *Additional synthetic observations*
  - *Improved 3D-VAR data assimilation*
  - *Bougeault type of mixing (PBL & above)*
  - *New sfc moisture transfer coefficient*
  - *New ice nucleation*
  - *New dissipative heating formulation*
  - *New sea spray parameterization*
  - *New shallow convection param.*

- **New COAMPS-TC**
  - **-Improves initial & forecast intensity**
  - **-Improves the convective structure**
  - **-Good agreement with Doppler obs.**



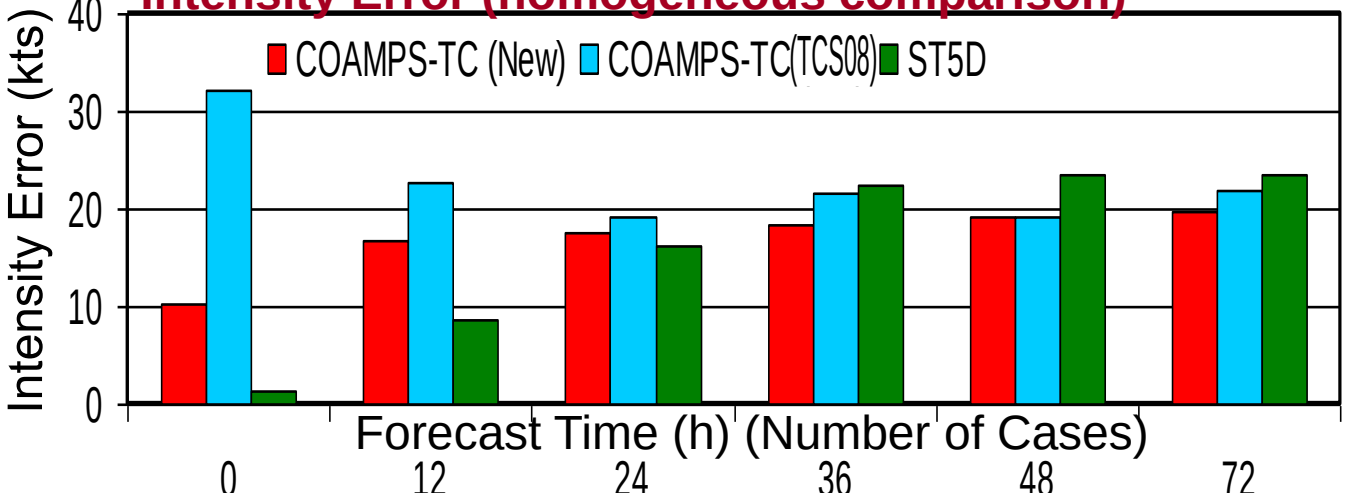
More Systematic Diagnosis is Needed Including Comparison with Observations and Other Models.

*R. Rogers (HRD)

COAMPS-TC W. Pacific Forecasts (2008)

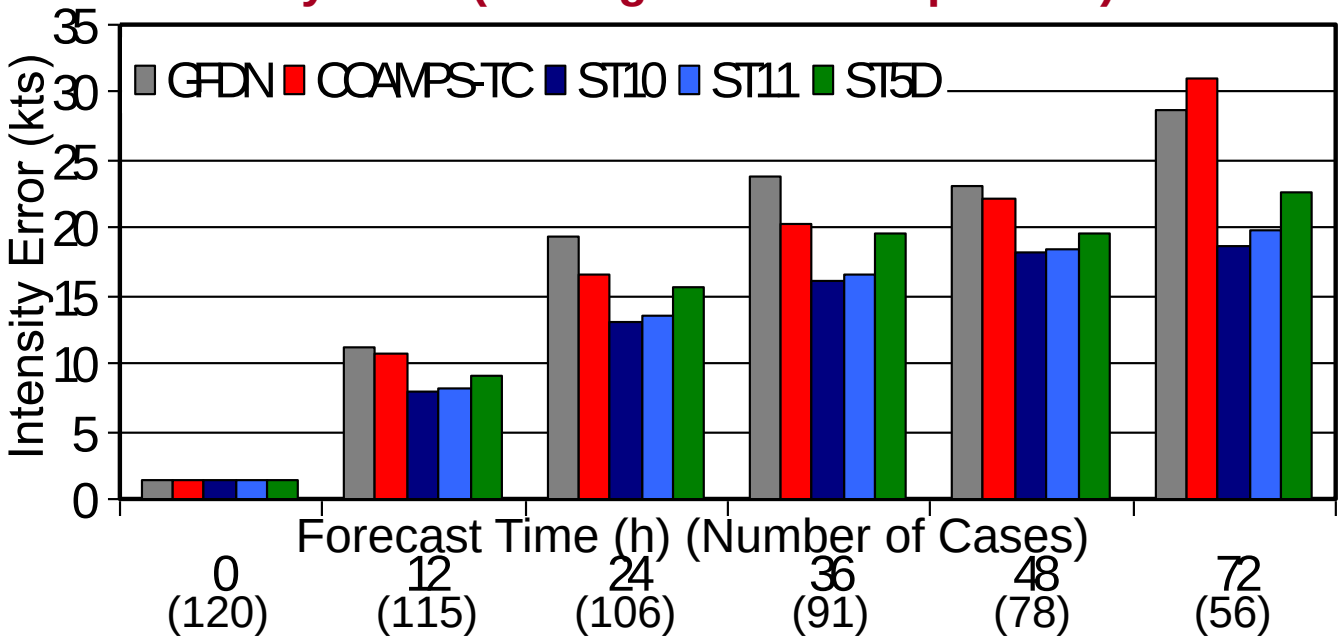
Improvements Following TCS08

Intensity Error (homogeneous comparison)



New Version of COAMPS-TC shows much improved TC intensity forecasts

Intensity Error (homogeneous comparison)

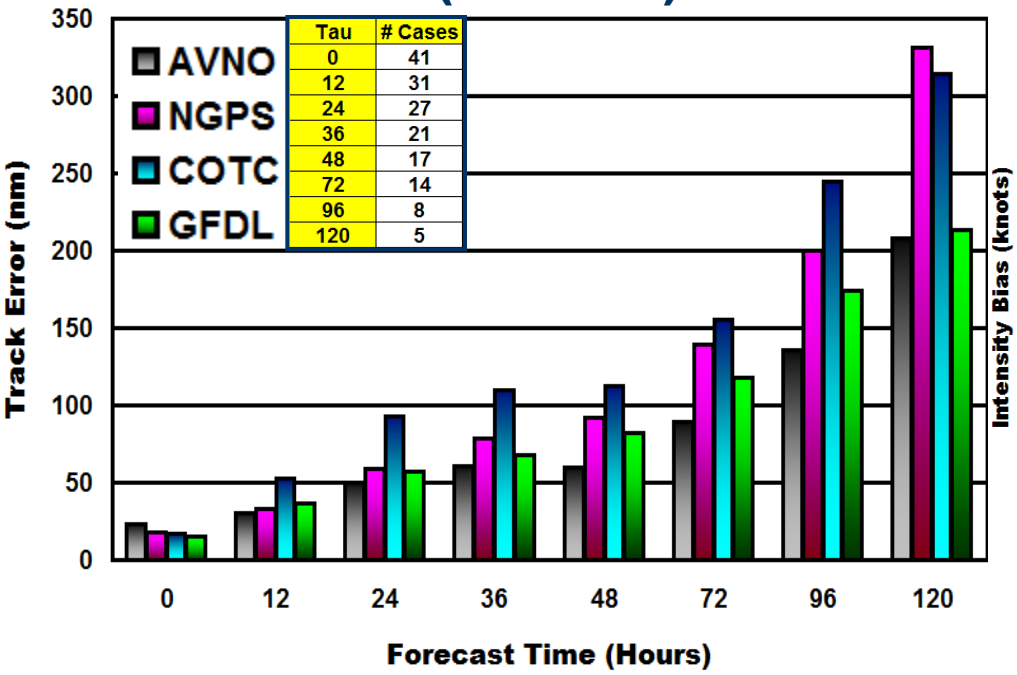


COAMPS-TC (new) intensity forecasts in W. Pacific for T-PARC/TCS08 are now similar to other skillful models. Similar improvement in Atlantic.

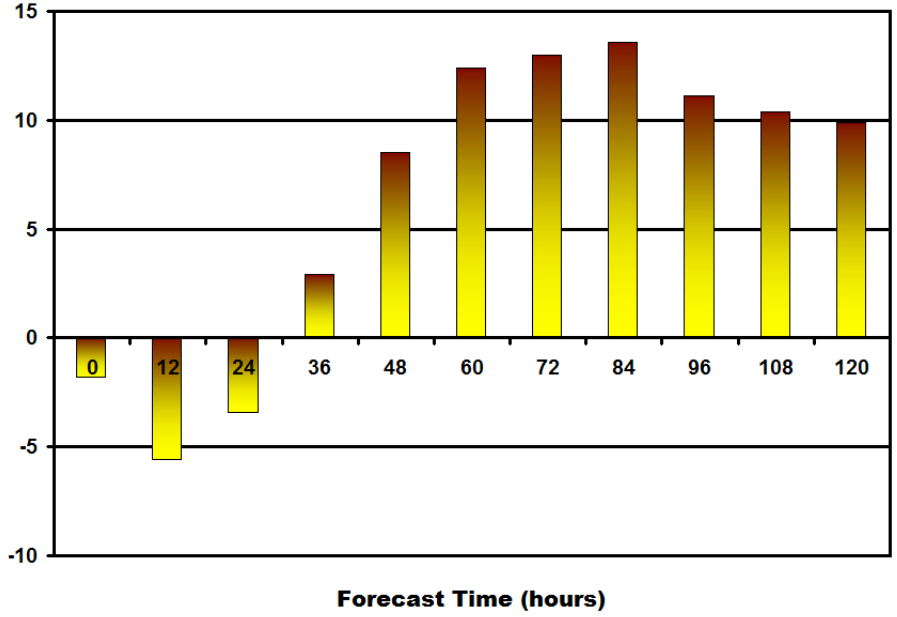
COAMPS-TC Atlantic Forecasts

Real-Time Forecasts for 2009 (HFIP)

Homogeneous Track Error (Atlantic)



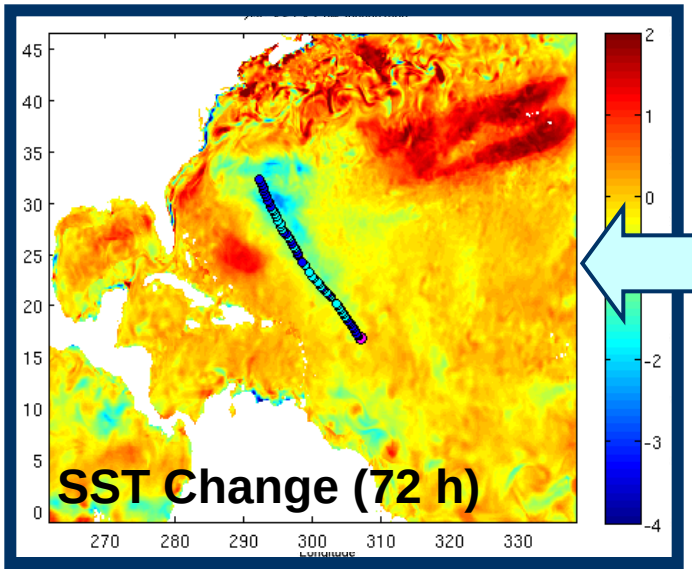
Storm Intensity Bias (Atlantic)



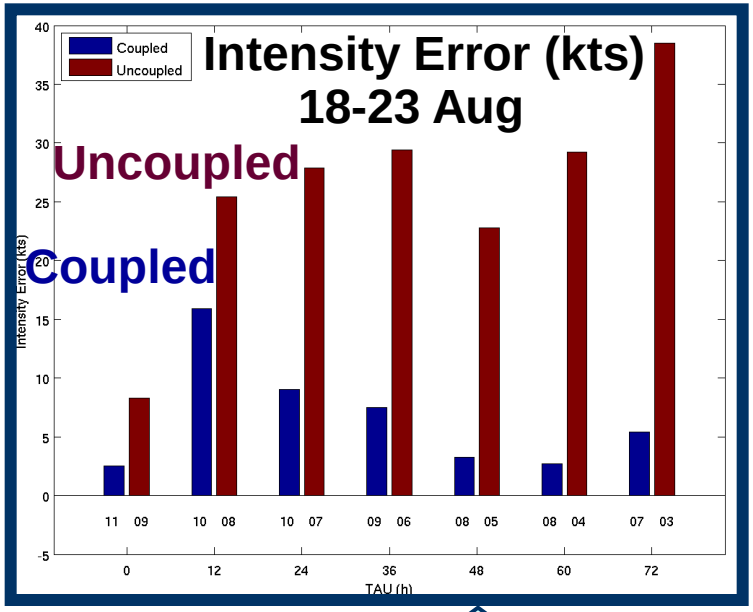
- Track forecasts in the Atlantic were poor, particularly for weak storms.
  - -Inadequacies of TC vortex initialization (especially weak storms).
- Systems initially weaken during first 12 h, then over-intensify.
  - -Intensity forecasts similar to GFDN through 48 h in WPAC.

COAMPS-TC Retrospective Forecasts

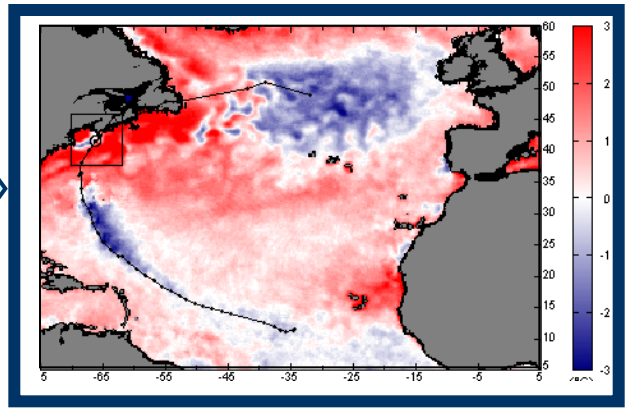
Coupled Air-Sea Prediction of Hurricane Bill (2009)



Animation of COAMPS-TC predicted SST, currents and 72-h SST change



Microwave Satellite Derived SST Shows 2-3 C Cool Wake Similar to the Coupled Model



Intensity Error Markedly Improved with Coupled Model

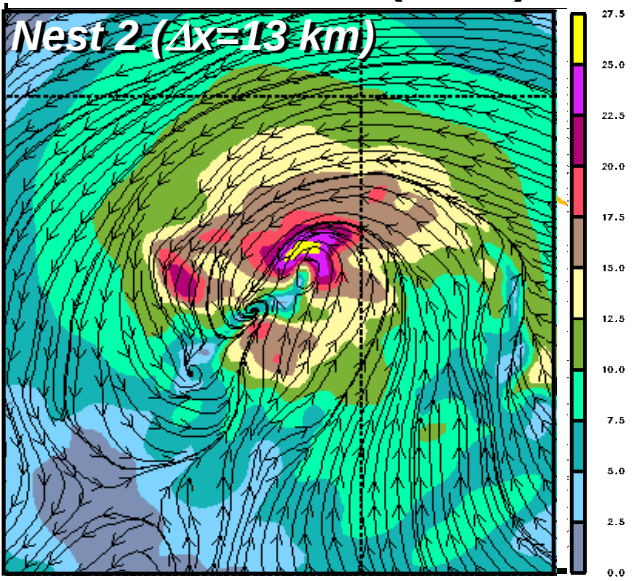
COAMPS-TC air-sea coupled forecasts alleviate an over-intensification bias as a result of SST cooling.

COAMPS-TC Adjoint during Genesis

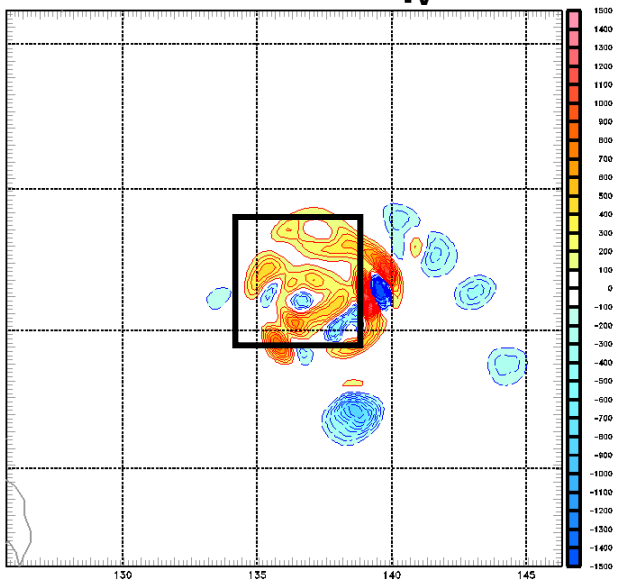
Quantifying Initial Condition Sensitivity for TY Nuri

- Adjoint allows for the mathematically rigorous calculation of forecast sensitivity of a response function to changes in initial state.
- COAMPS-TC adjoint includes full microphysics and nesting.

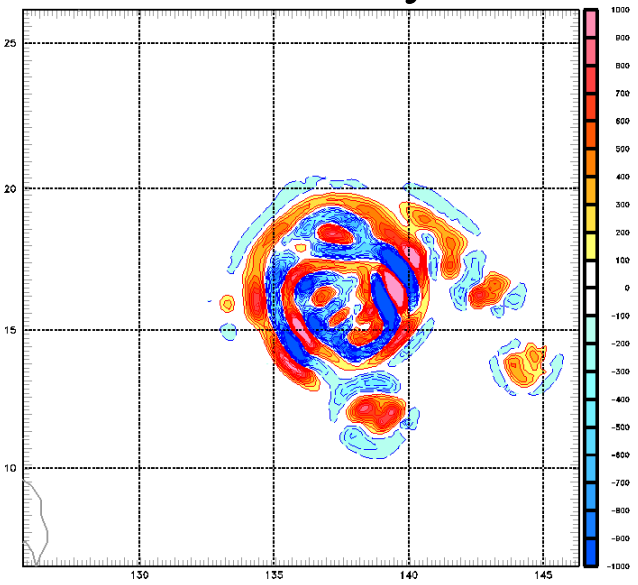
500-m Winds (m s^{-1})



500-m $\partial J/\partial q_v$



500-m $\partial J/\partial \zeta$

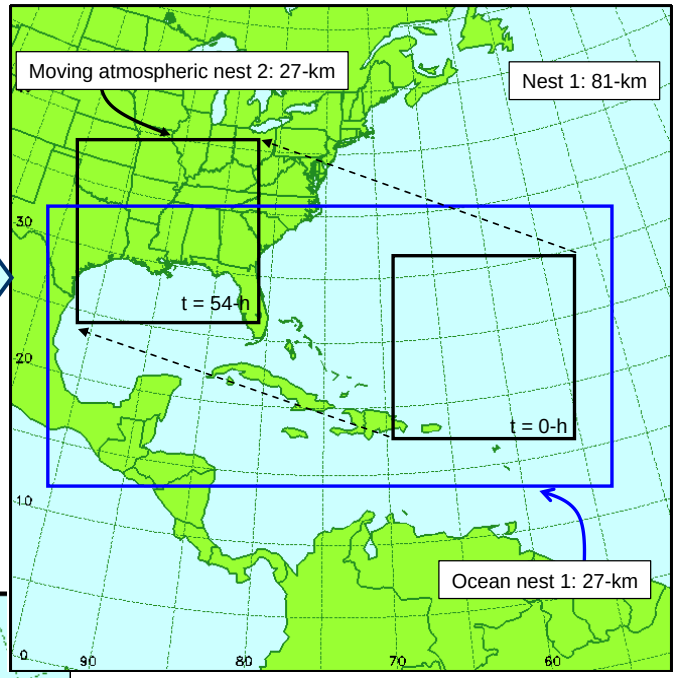


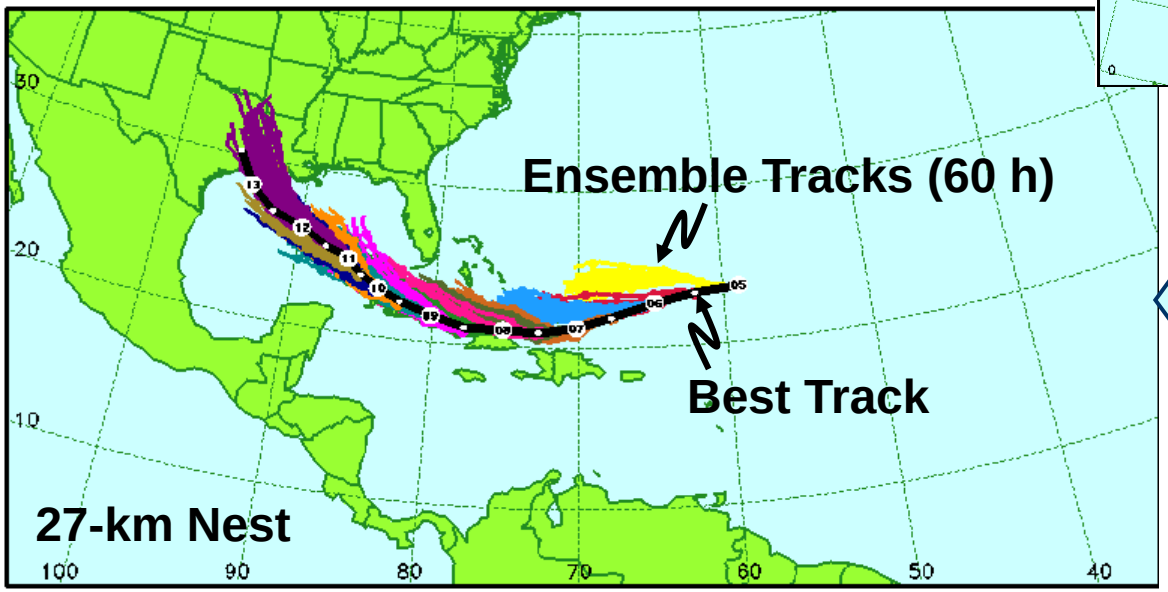
- **Sensitivity underscores importance of mid-level moistening for genesis.**
- **Spiral bands of ζ sensitivity (similar to Nolan and Farrell 1999).**
- **Evolved perturbations grow rapidly (30x growth in 9 h).**
- **Need to quantify predictability of TC lifecycle and characteristics.**

COAMPS-TC Ensembles

Coupled Air-Sea Ensembles of Hurricane Ike (2008)

- 29 member COAMPS-TC coupled ensemble forecasts of Hurricane Ike.
- Atmosphere: 81 km, 27 km
- Ocean: 27 km
- Perturbations: ET initial conditions, LBCs, ocean, model physics perturbations (cumulus, microphys., PBL, surface fluxes).





Coupled air-ocean ensembles provide probabilistic prediction of TC track, intensity, ocean response

Summary and Future Plans

- **High-resolution TC predictions for T-PARC & HFIP:**
  - COAMPS-TC Challenges:
    - TC vortex initialization, especially for weak and sheared storms
    - Organized convection and microphysics
    - Air-sea interaction in high-wind regime (uncertainties in sea spray etc.)
  - Promising results from air-ocean coupling: alleviates over-intensification
  - Improvements (physics & analysis) to COAMPS-TC based on real time fcsts
- **Future Research:**
  - Improvements to TC vortex initialization (EnKF and 4D-Var options)
  - Improvements in microphysics and convection in 3-5 km regime
  - 3-way coupled air-ocean-wave capability and coupled ensemble prediction
  - Quantify predictability of TC evolution (moist adjoint, EnKF)
  - Community collaborations through HFIP, NOPP, field projects (TCS08, ITOP…)
    - -Model diversity is important: Multi-model high-resolution ensembles
    - -Community-based diagnostics needed (obs., model intercomparison).

http://www.nrlmry.navy.mil/coamps-web/web/tc