Dynamical Initialization of Tropical Cyclones and Predictability Issues using COAMPS-TC

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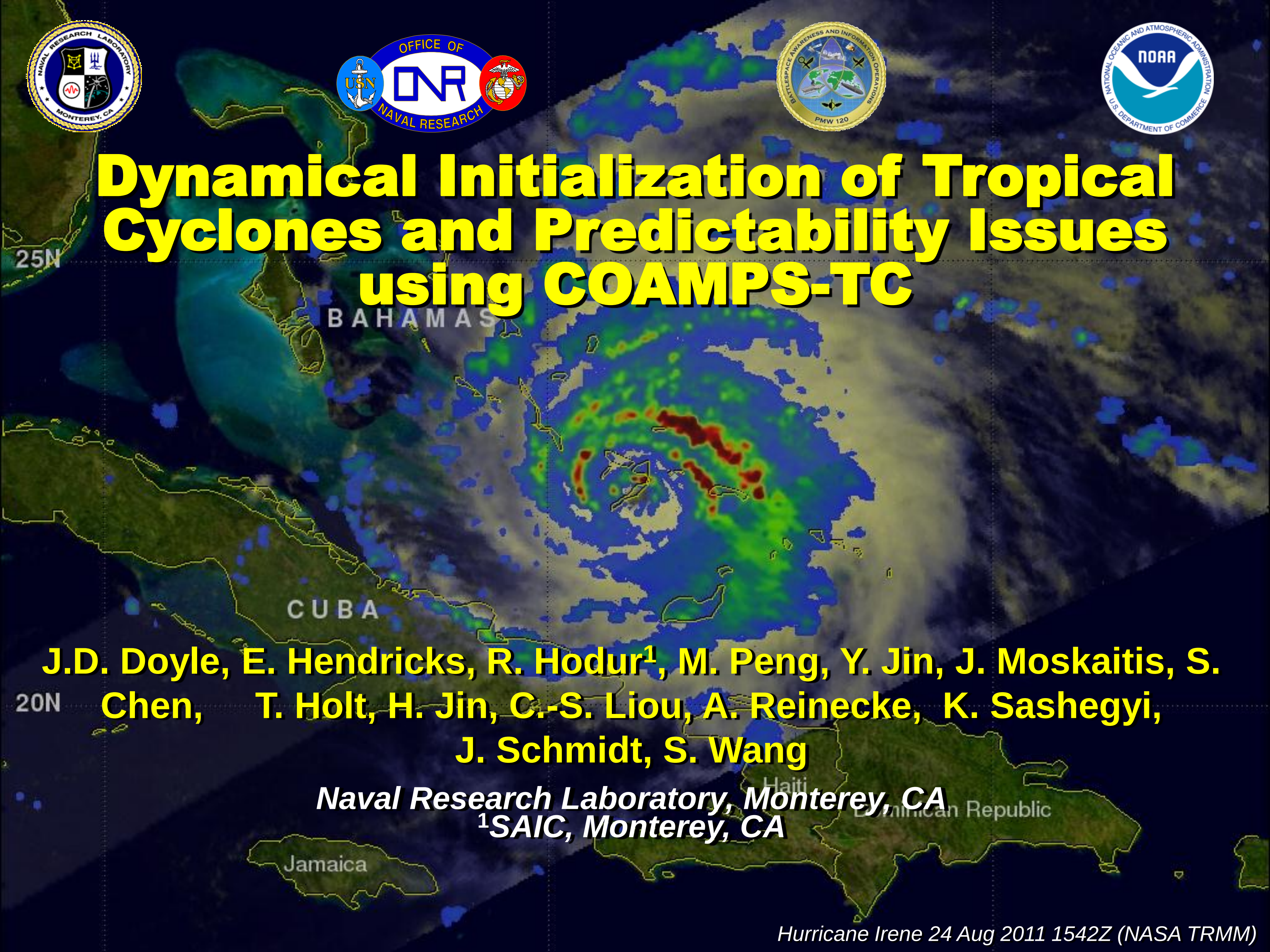
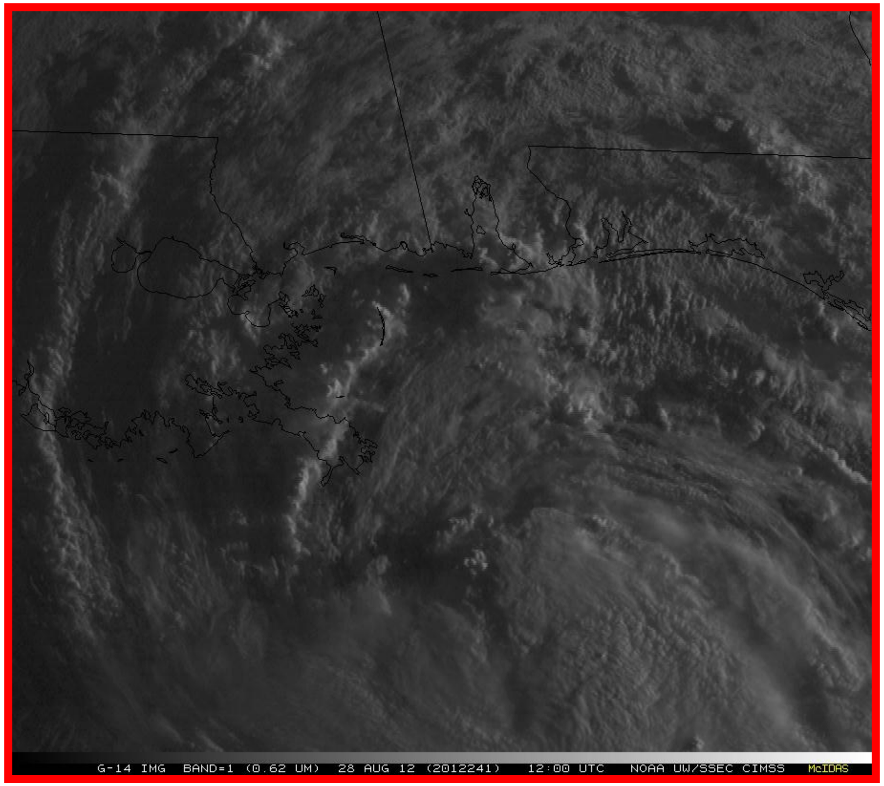


Hurricane Irene 24 Aug 2011 1542Z (NASA TRMM)

Motivation

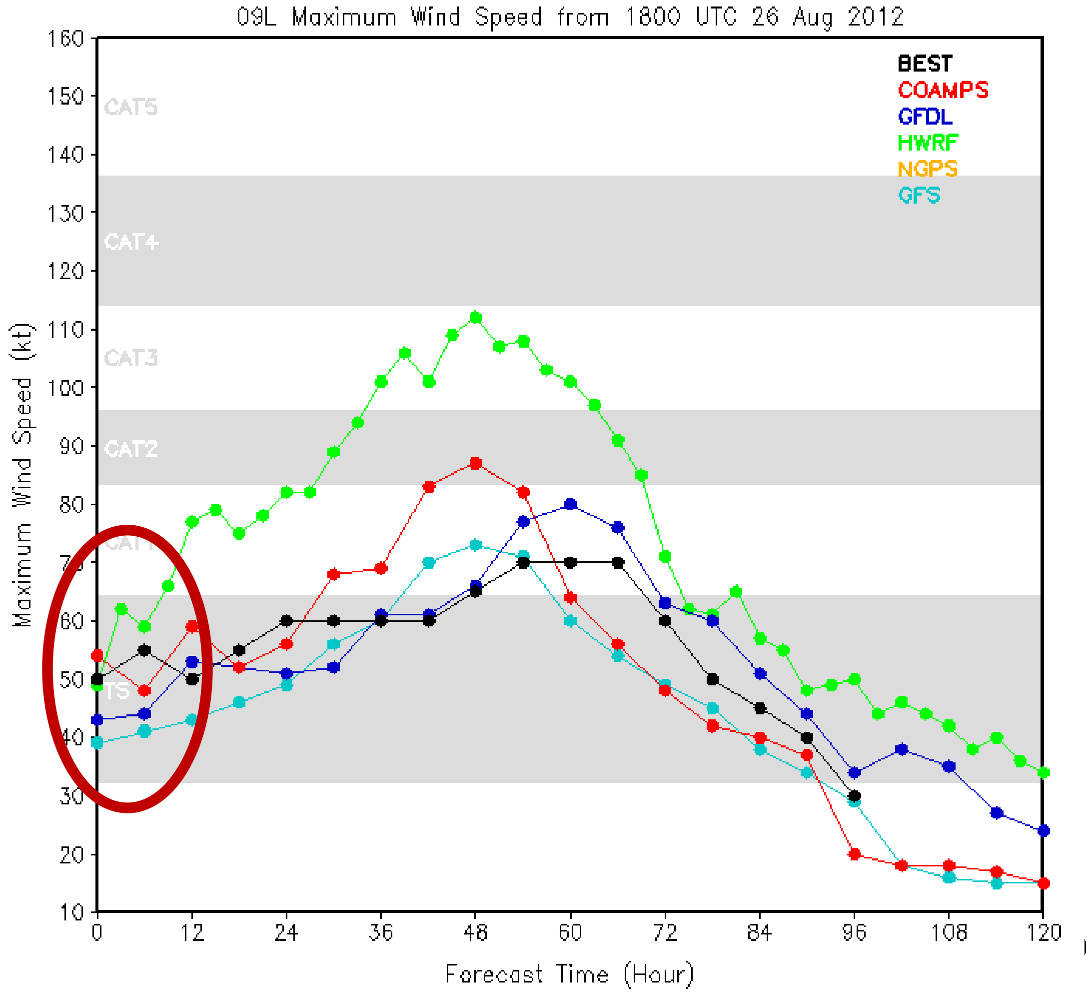
Statement of the Problem

- Models cannot predict reliably the tropical cyclone intensity or structure; large analysis innovations occur.
- Observations within storm are often difficult to use [cloudy radiances, dropsondes (storm relative, drift), surface, synthetic..]
- Conventional DA approaches suffer from balance/spin-up issues when innovations are large.
- Methods such as dynamical initialization may help some of these issues.



GOES-14 1-min rapid scan visible imagery of Tropical Storm Isaac (2012) Intensity: 976 mb, 60 kt (courtesy Chris Velden)

W. Atlantic Intensity Error
2010 and 2011

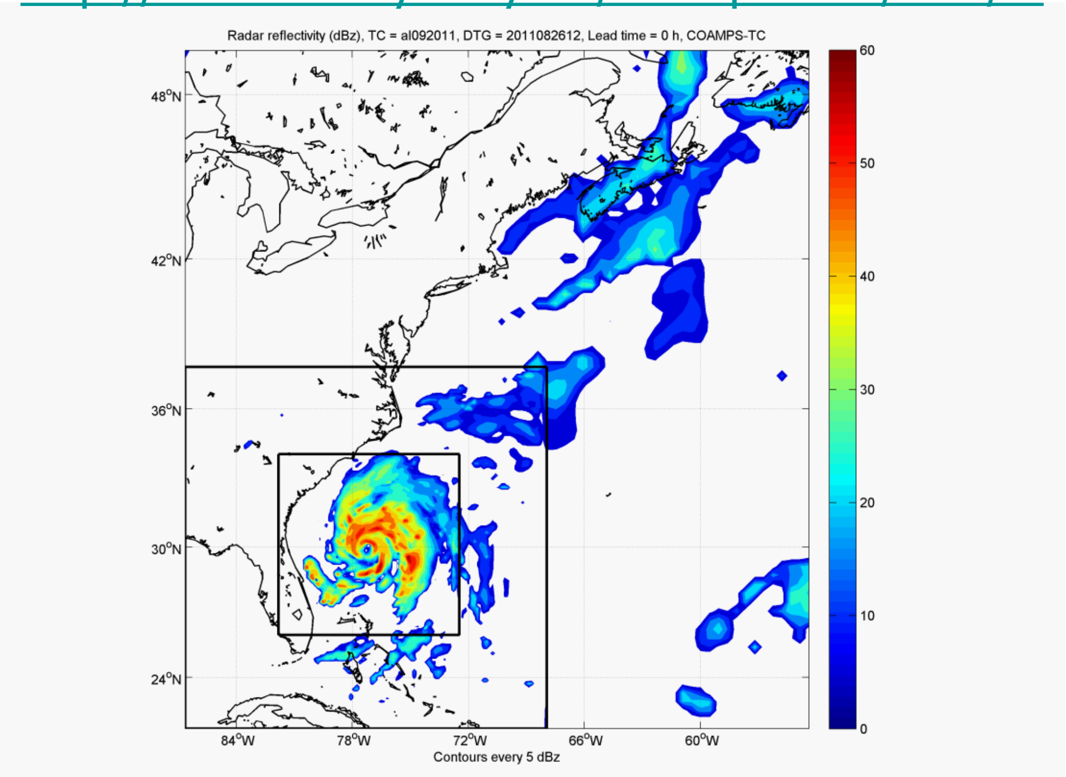


- COAMPS-TC intensity forecasts verified well, particularly beyond 30 h.
- Less skillful in the first 24 h of forecast.
- Spin down / spin up is a big issue for most (or all) models.

COAMPS-TC System Overview

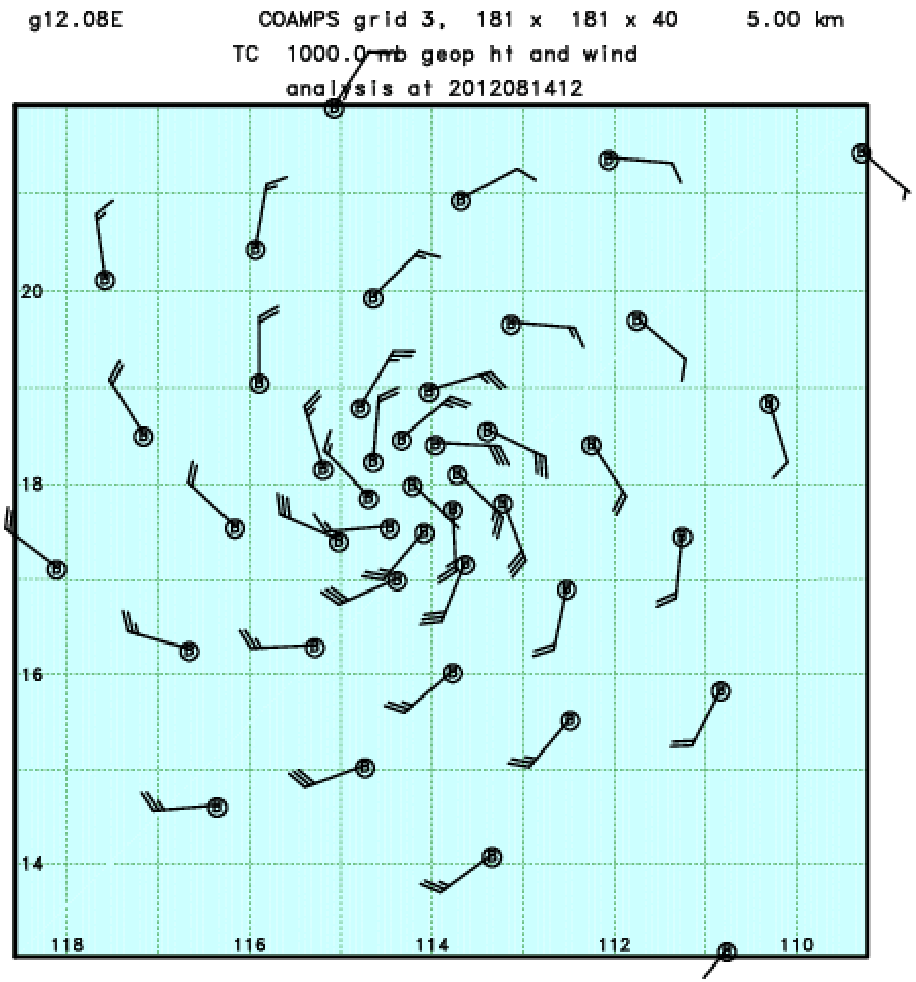
- **Analysis:** Synthetic observations, 3D-Var (NAVDAS), Dynamic Init.
- **Atmosphere:** Nonhydrostatic, moving nests, CBLAST fluxes, dissipative heating, NRL_PBL, NRL microphysics, shallow/deep conv.
- **Ocean:** 3D-Var (NCODA), NCOM, SWAN, Wave Watch III options
- **Ensemble:** COAMPS-TC EnKF DART, Coupled Ensemble Transform
- **Real-Time:** 45-15-5 km, GFS/NOGAPS BCs, cycling DA, uncoupled/coupled

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



Overview of Synthetic Observations

Analysis of Synthetics with 3D-Var

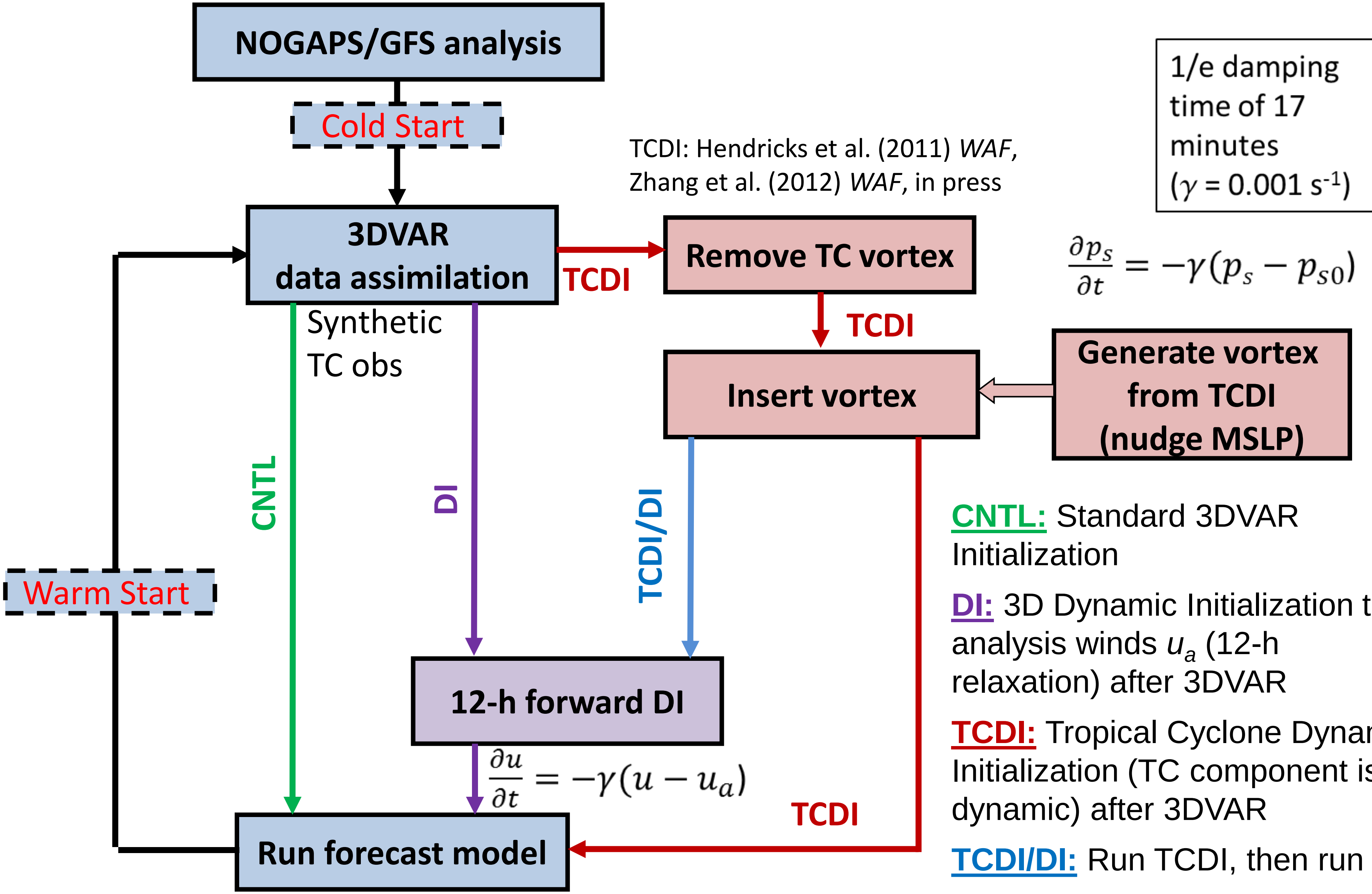


- Modified Rankine vortex based on estimated intensity/structure
- 1000-400 hPa, 6 degree radius, typically 49 observations
- U,V,T,H (T and H from balance equations)
- Boundary layer adjustment (wind reduction and inward turning)
- Vertical decay (warm core)
- Blend TC synthetics with all other observations in 3DVar (NAVDAS)

Liou and Sashegyi (2011), Nat. Hazards

TC Dynamical Initialization

TCDI, DI, TCDI/DI



CNTL: Standard 3DVAR Initialization

DI: 3D Dynamic Initialization to analysis winds u_a (12-h relaxation) after 3DVAR

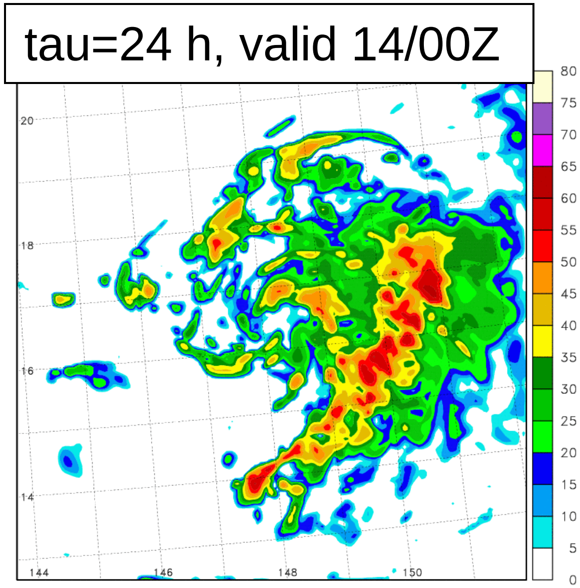
TCDI: Tropical Cyclone Dynamic Initialization (TC component is dynamic) after 3DVAR

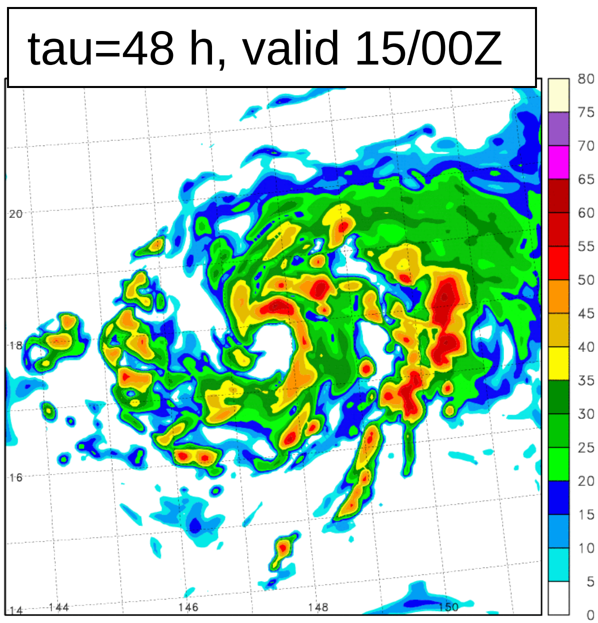
TCDI/DI: Run TCDI, then run DI

TC Dynamical Initialization

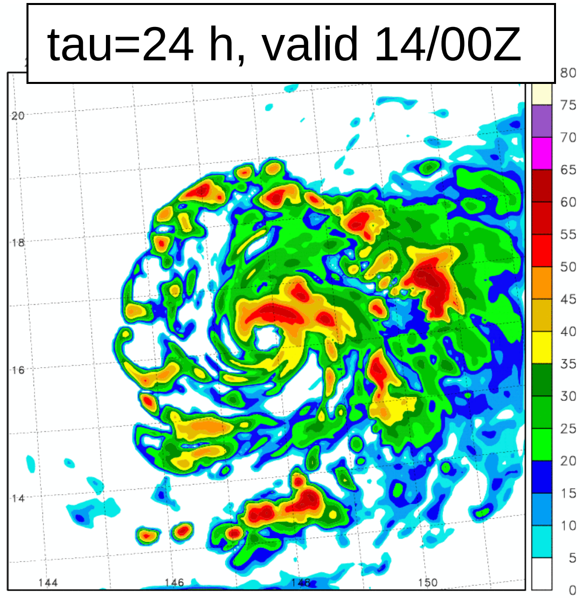
TCDI for Choi-Wan (2009)

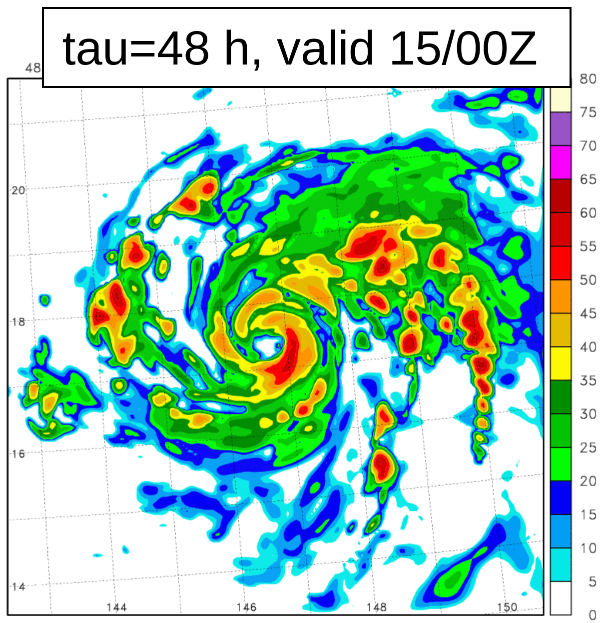
Control





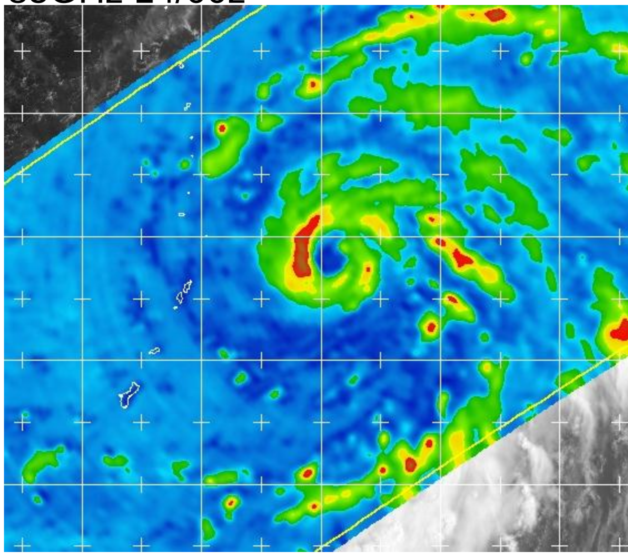
With TCDI



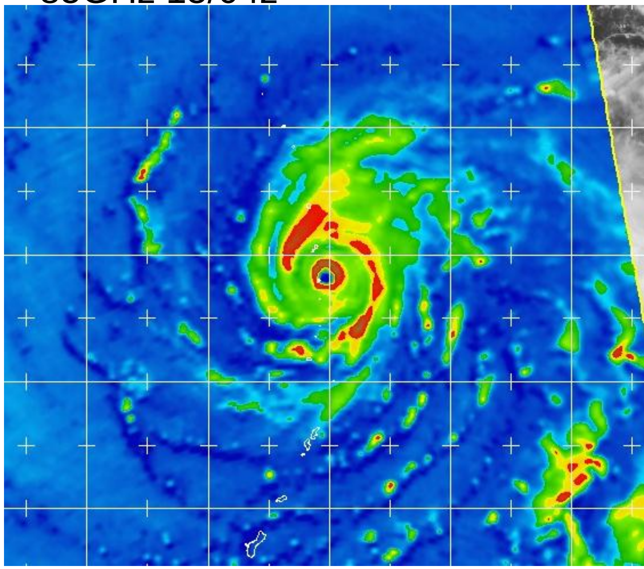


OBSERVATIONS

85GHz 14/00z



85GHz 15/04z

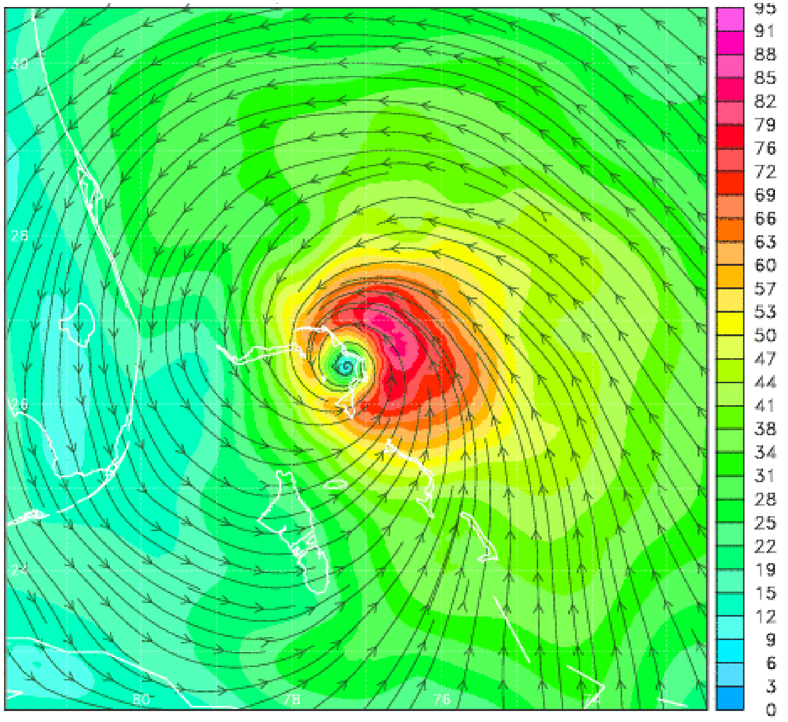


TC Dynamical Initialization

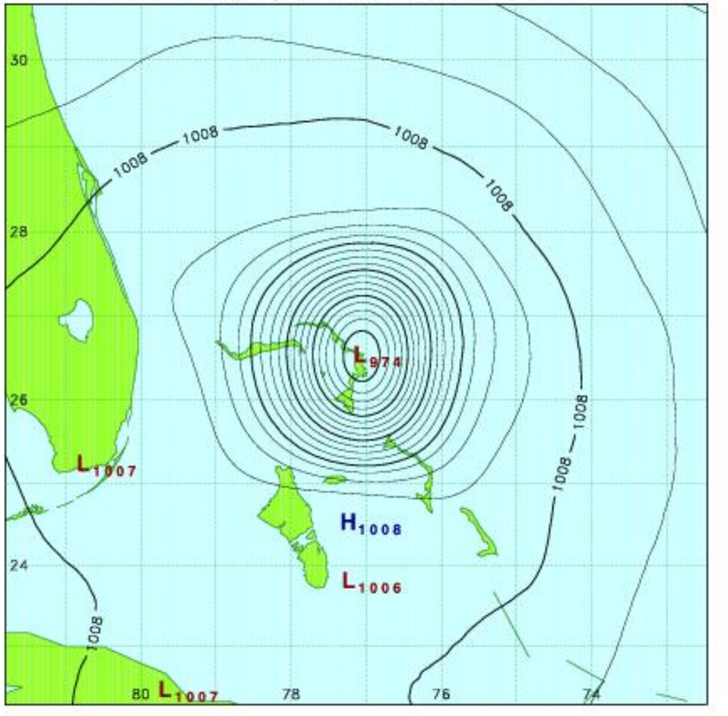
DI (Dynamical Initialization)

Hurricane Irene (09L) (2011082518)

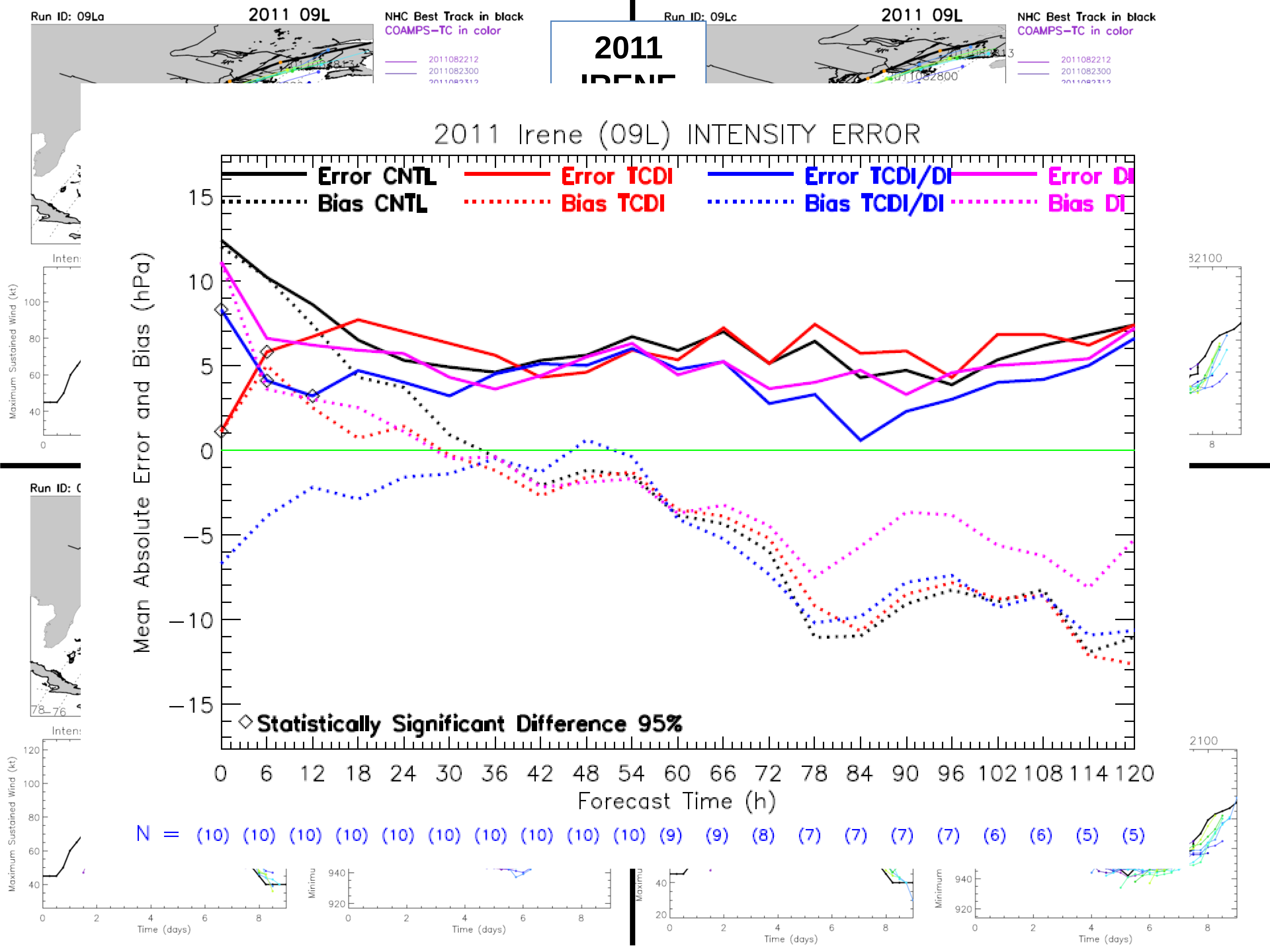
10-m Winds (kt)



Sea Level Pressure (hPa)

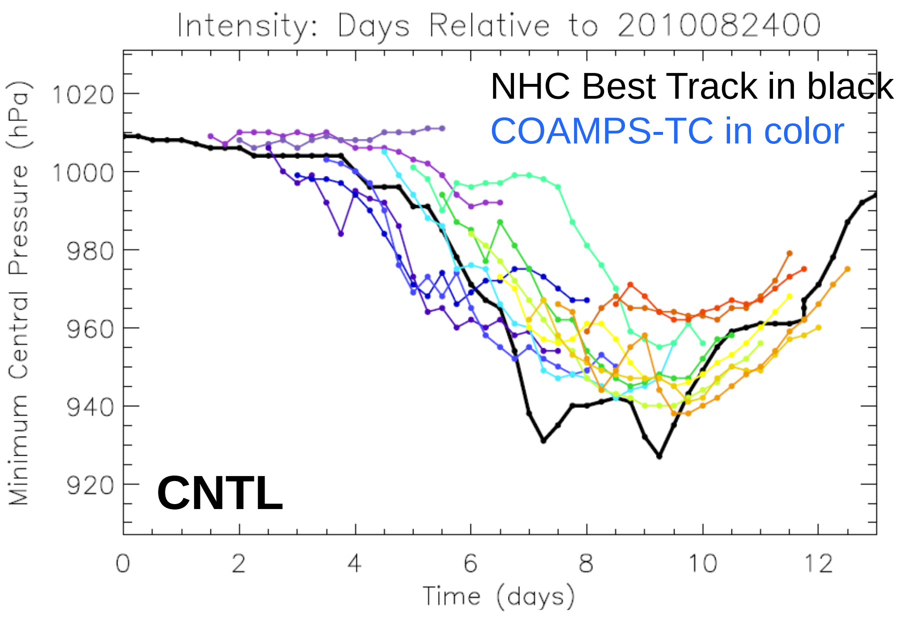


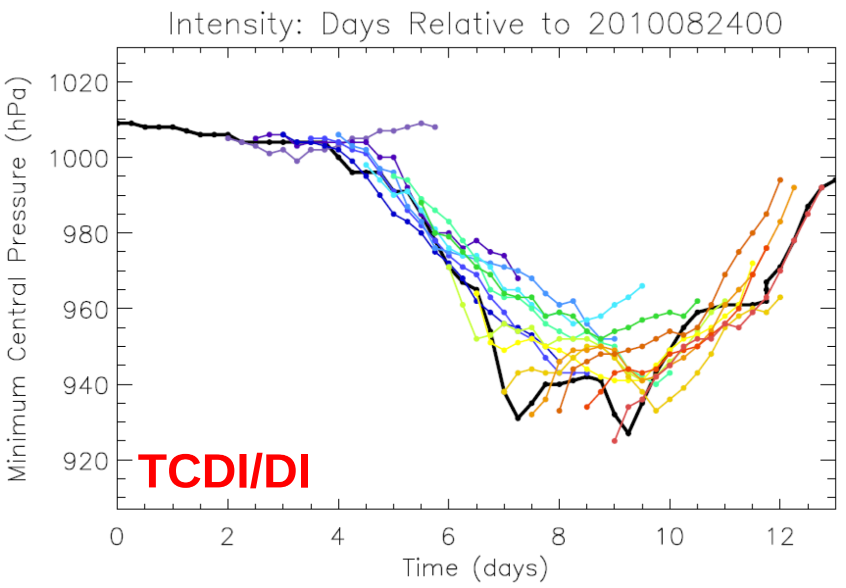
- **During DI, the horizontal momentum is held quasi-steady.**
- **3DVAR is not able to produce gradient balanced vortex, rapid adjustment to winds during DI.**
- **Benefits of DI: balance adjustment, physics spin-up**

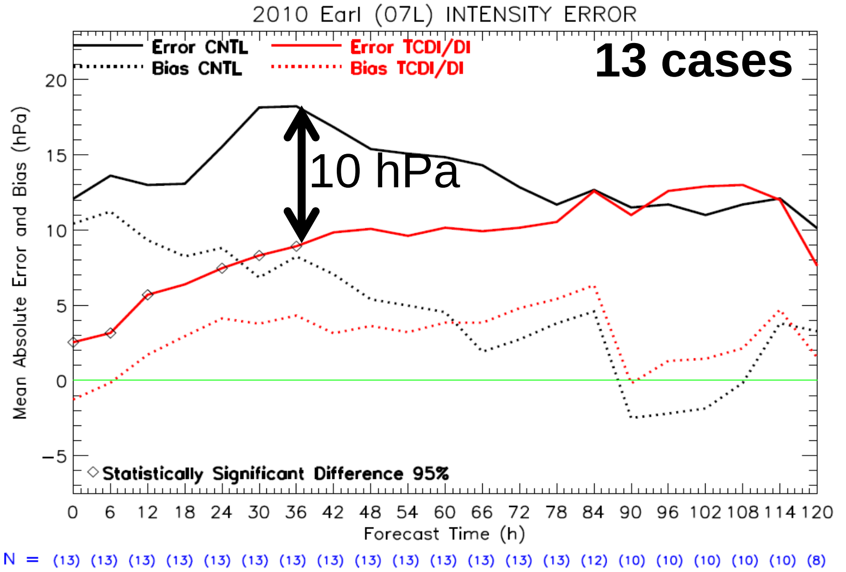


Run ID: 09La
2011 09L
NHC Best Track in black
COAMPS–TC in color
Run ID: 09Lc
2011 09L
NHC Best Track in black
COAMPS–TC in color
2011
2011 Irene (09L) INTENSITY ERROR
Error CNTL
Bias CNTL
Error TCDI
Bias TCDI
Error TCDI/DI
Bias TCDI/DI
Error DI
Bias DI
Mean Absolute Error and Bias (hPa)
Statistically Significant Difference 95%
Forecast Time (h)
N = (10) (10) (10) (10) (10) (10) (10) (10) (10) (10) (9) (9) (8) (7) (7) (7) (7) (6) (6) (5) (5)
Maximum Sustained Wind (kt)
Time (days)

TC Dynamical Initialization: 07L Earl (2010)







Significant intensity error reductions for Earl by using TCDI/DI

TC Dynamical Initialization

Track Error (nm): Homogeneous Comparison

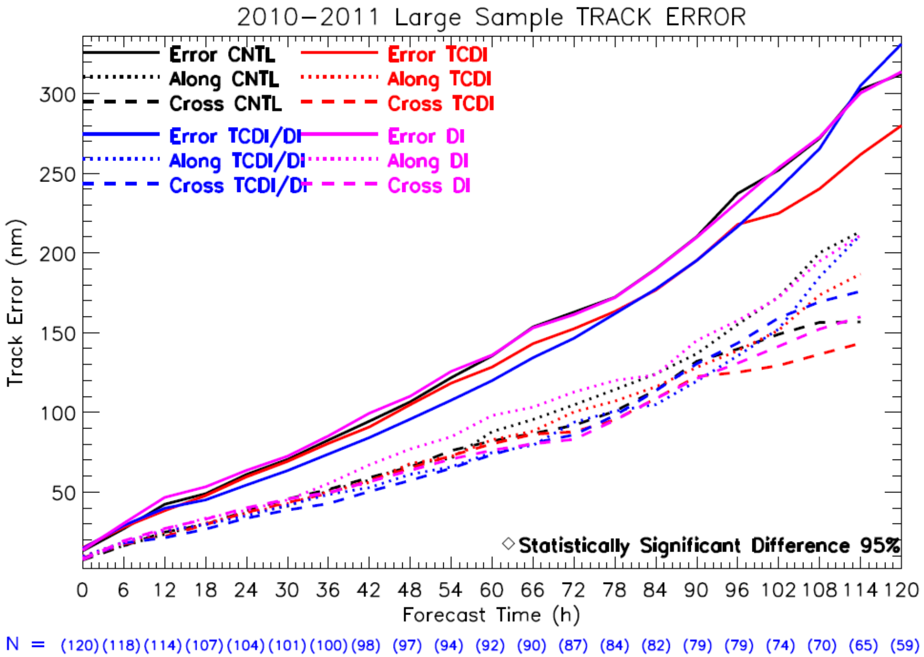
Years: 2010-2011

Atlantic Storms: Danielle, Earl, Igor, Irene, Katia, Maria, Rina, Julia

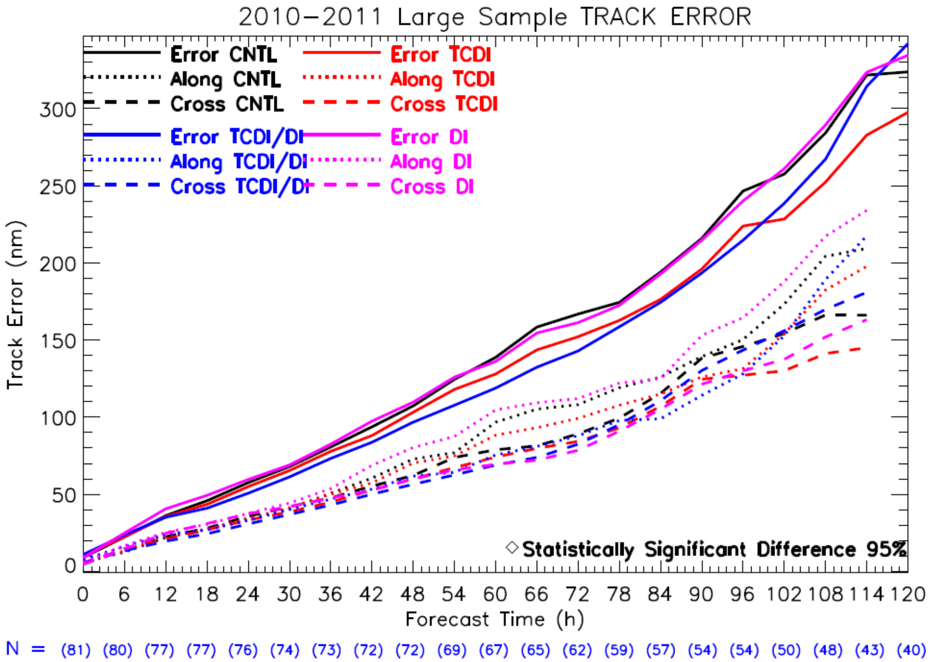
Western North Pacific storms: Chaba, Fanapi, Ma-On

Cases: 120

ALL Cases



STRONG Initial intensity < 990



TCDI/DI (blue curve) has lower track error for ALL cases (relative to control) and for strong storms ($psfc_0$ < 990 hPa)

TC Dynamical Initialization

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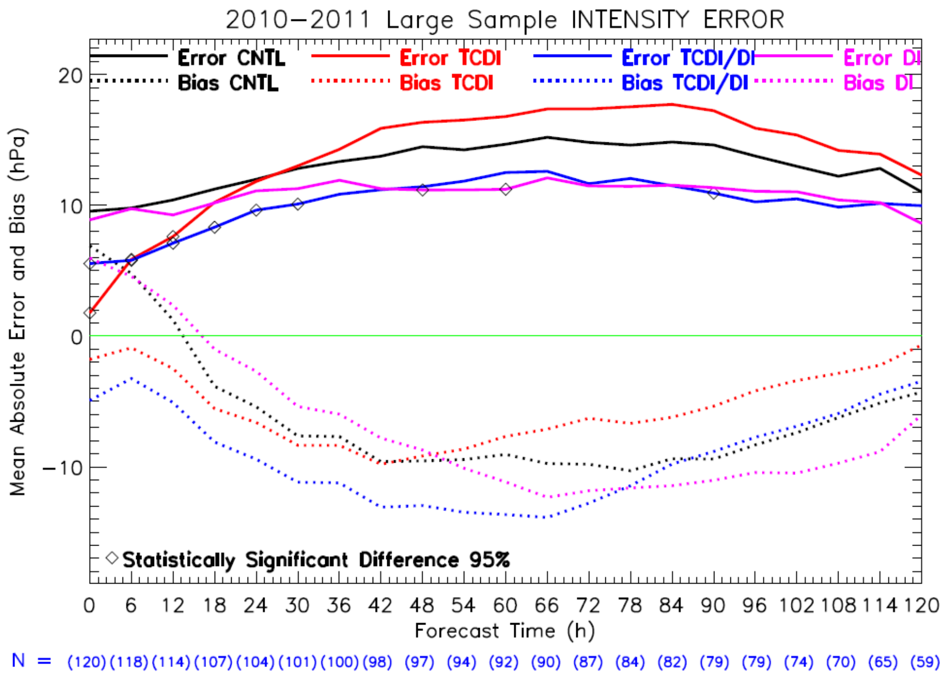
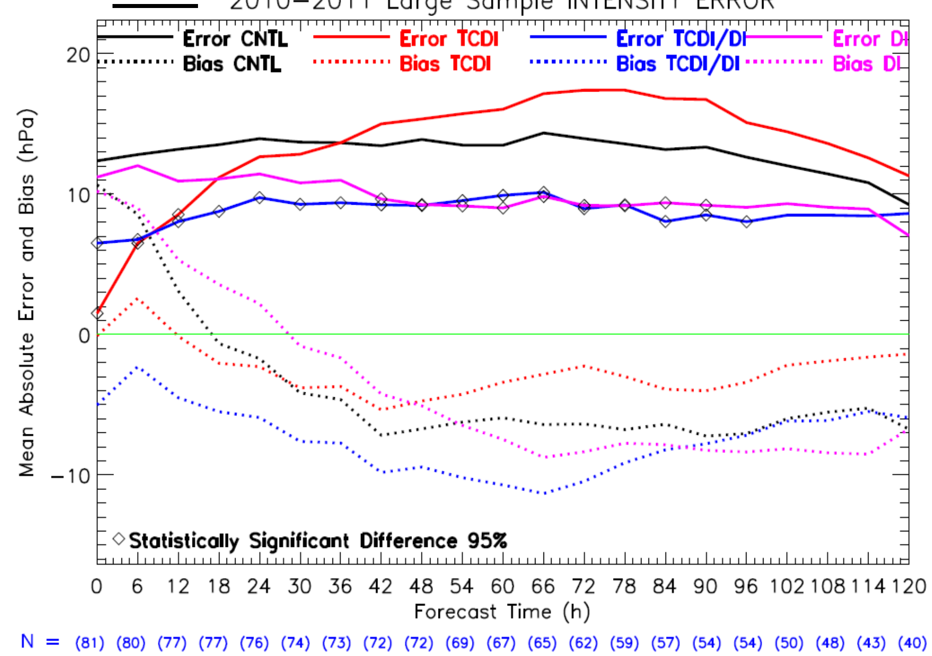


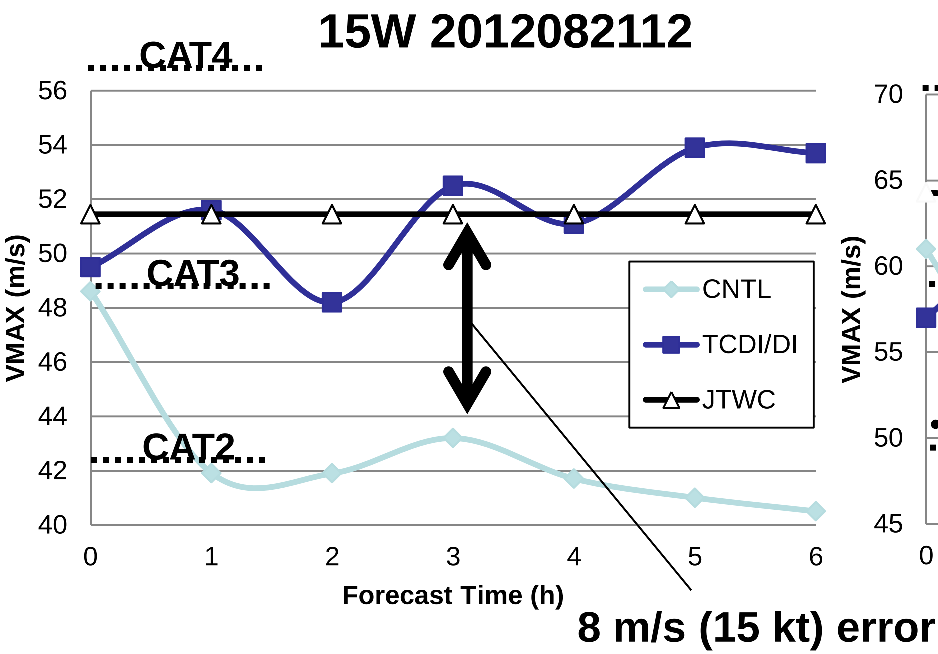
STRONG Initial intensity < 990 hPa

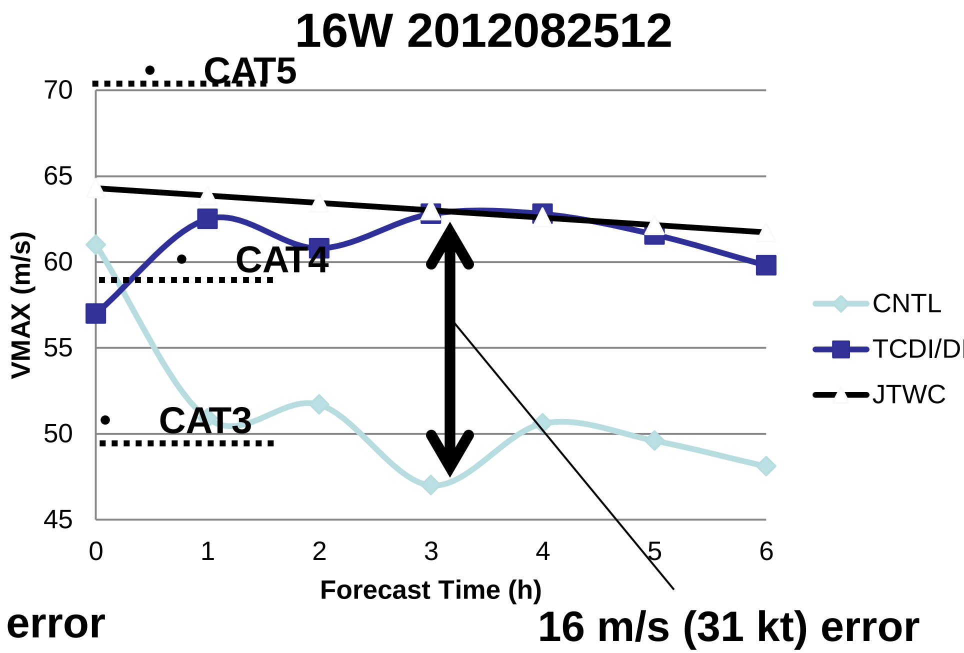


TCDI/DI (blue curve) has lower track error for ALL cases (relative to control) and especially for strong storms ($psfc_0$ < 990 hPa)

TC Dynamical Initialization

Real-Time Parallel Runs: 15W (Tembin) and 16W (Bolaven)

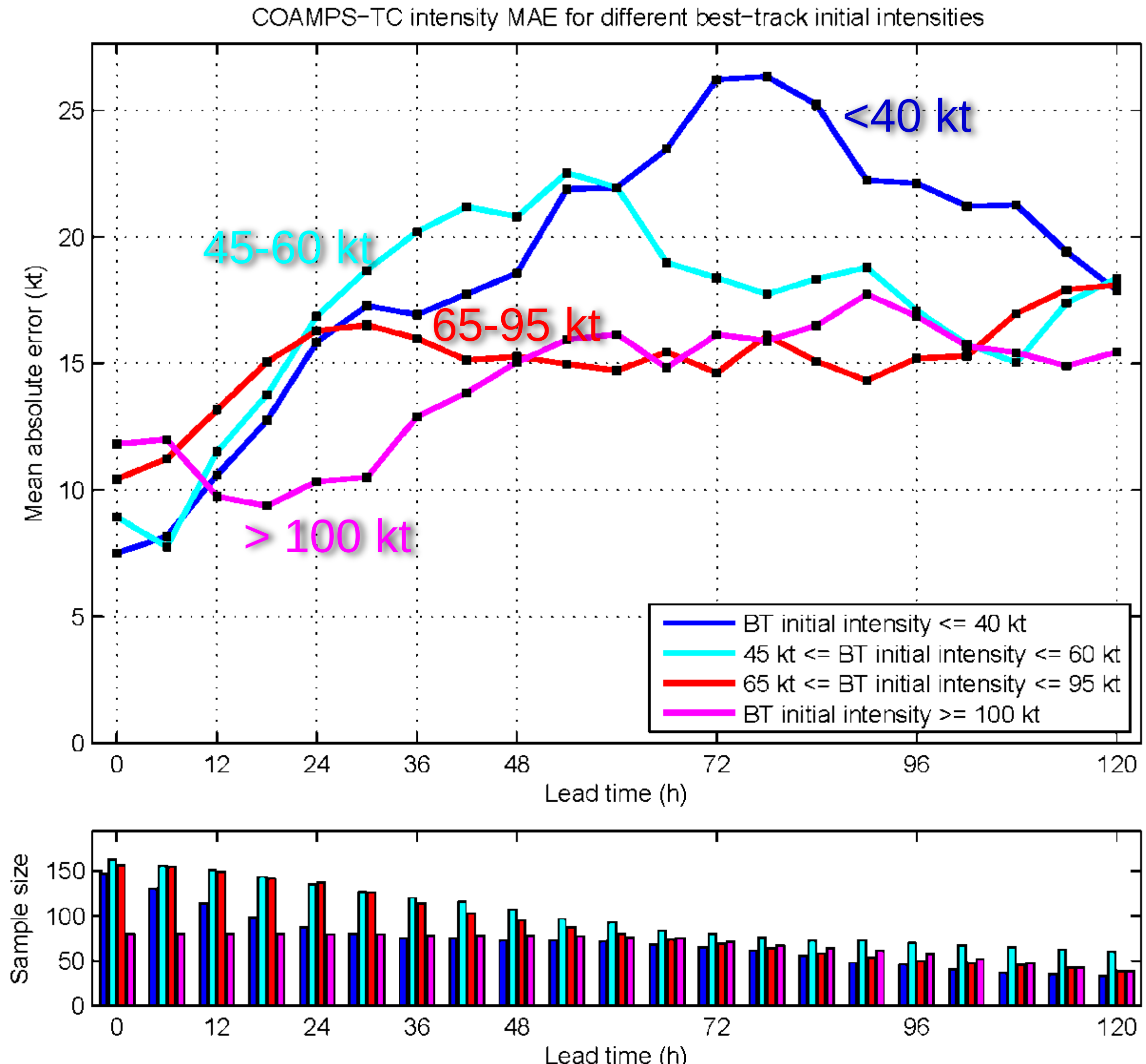




- TCDI/DI tested in parallel in real-time in 2012
- Marked improvement in spin-down issue for intense cyclones

Intensity Predictability Aspects

COAMPS-TC Intensity Skill (2008-2010 W. Atlantic)

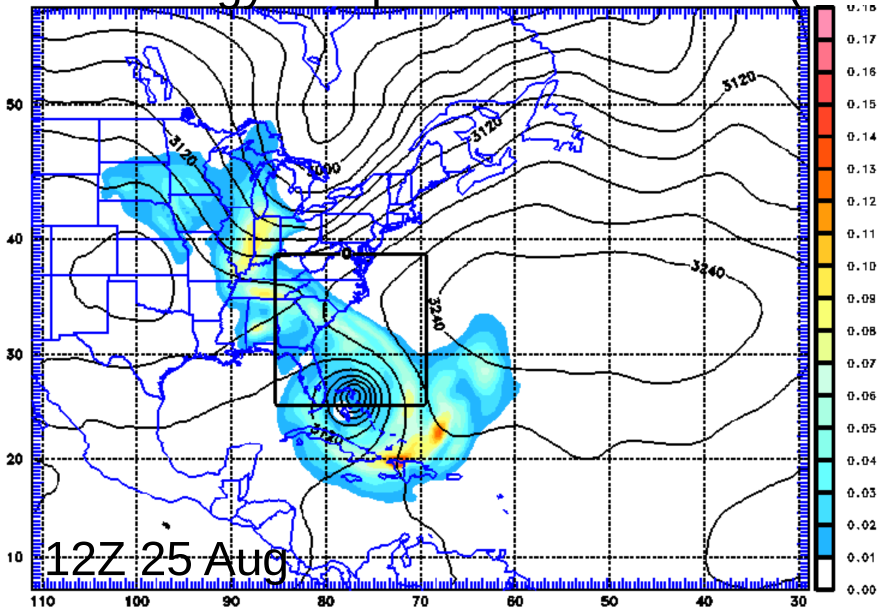


Weak storms (at the initial time) have larger intensity and track errors.

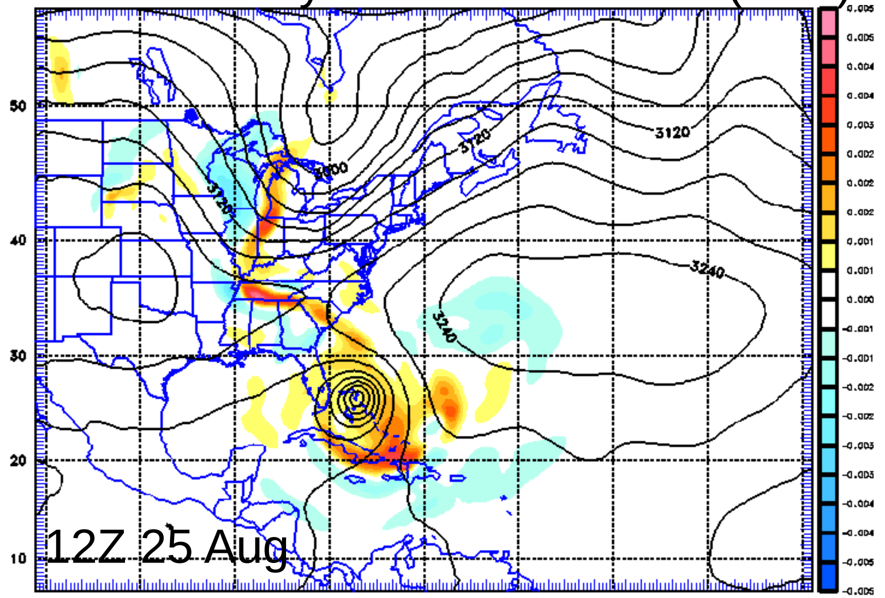
Predictability Aspects
Adjoint Sensitivity

Adjoint allows for the mathematically rigorous calculation of forecast sensitivity of a response function to changes in initial state

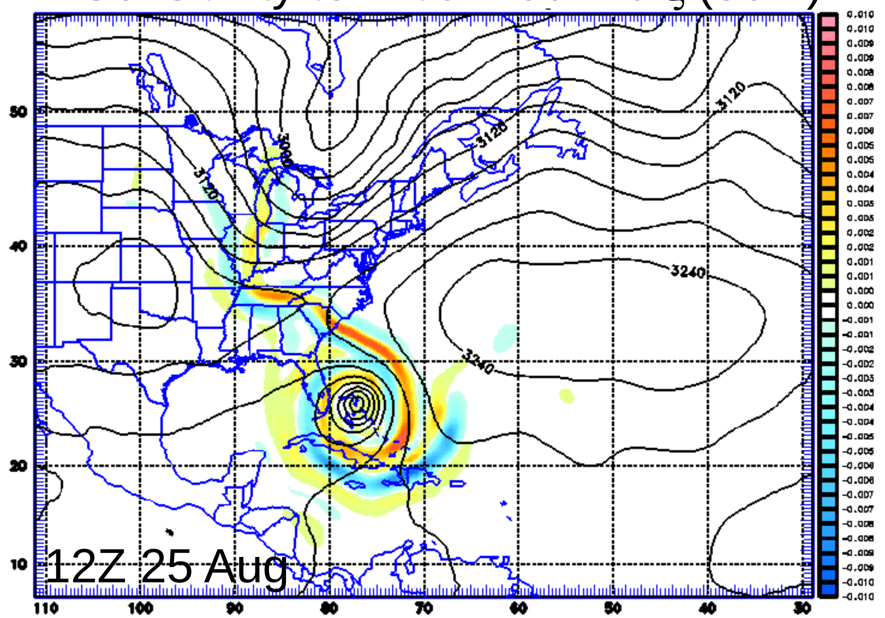
Total Energy of Optimal Perturbation (36 h)



Sensitivity to Initial 700 mb θ (36 h)



Sensitivity to Initial 700 mb ζ (36 h)

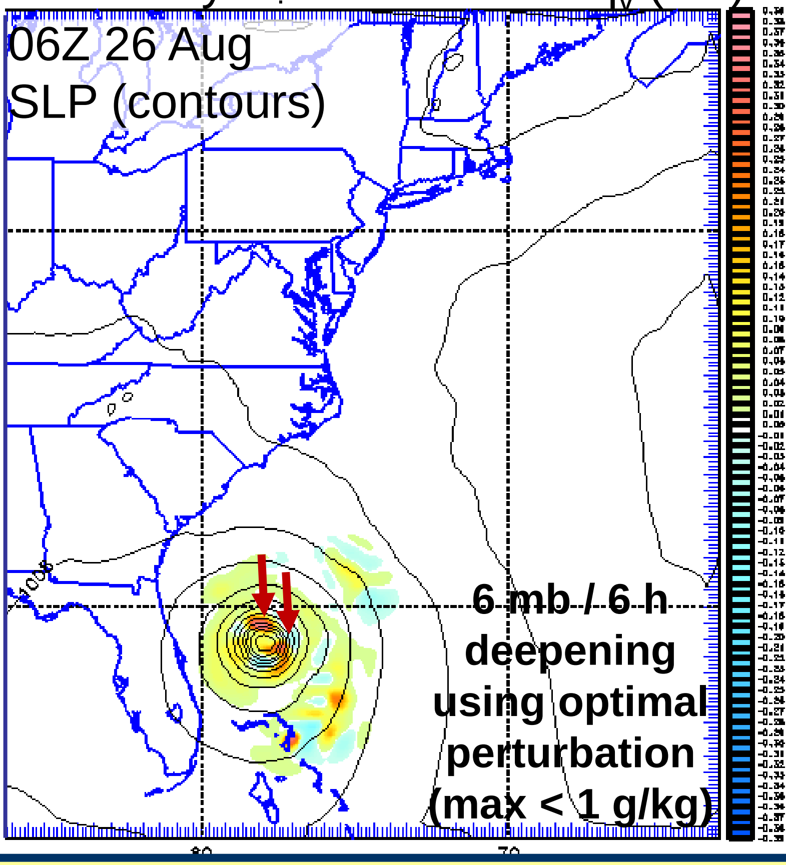


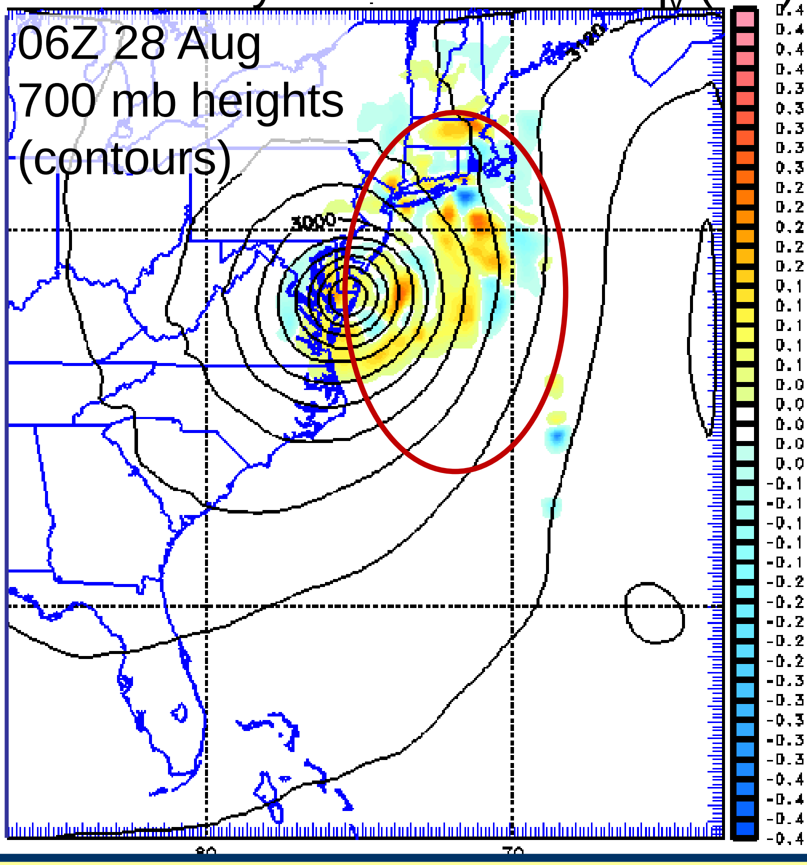
- Moist trajectory and dry adjoint (45 km).
- Sensitivity maxima around the storm and near mid-tropospheric shortwave.
- Stronger sensitivity to θ than winds.
- Enhanced sensitivity to outer ζ structure.

Predictability Aspects

Moist Adjoint Sensitivity

Adjoint sensitivity calculations for higher-resolution (15 km) with moisture (includes cloud microphysics)



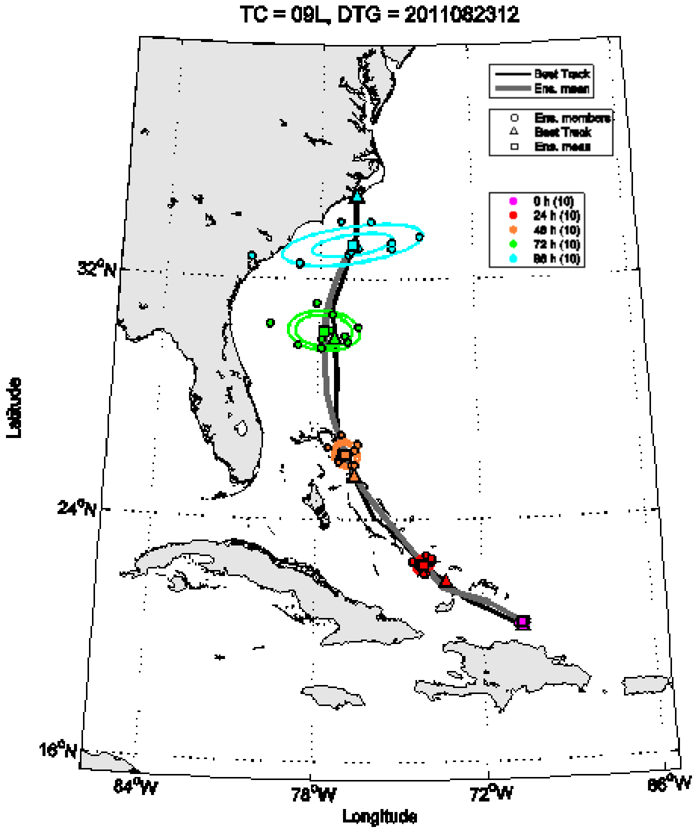


- Low-level moisture sensitivity 5-10x greater than winds and 2x greater than θ.
- Most sensitive region is in the inner core.
- Sensitivity tests show intensification is very sensitive to the moisture observations.
- During ET transition, moisture sensitivity expands and sensitivity max in eastern flank.

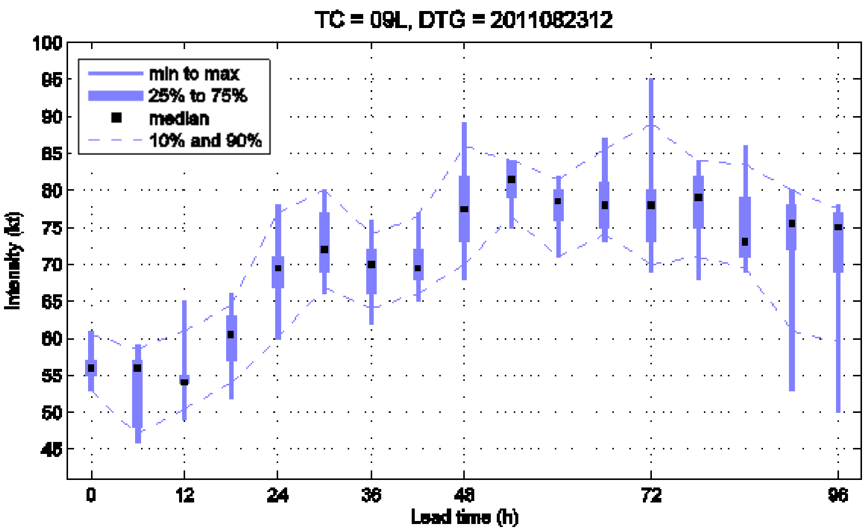
Predictability Aspects

Irene Ensemble (EnKF) 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.



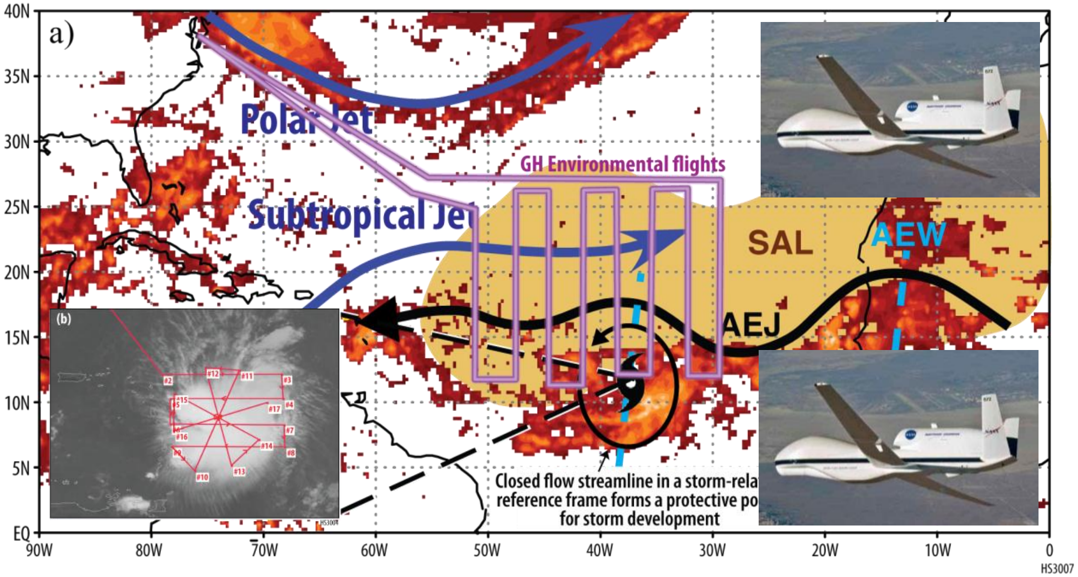
Median, minimum, maximum, and 10% and 90% distributions are shown

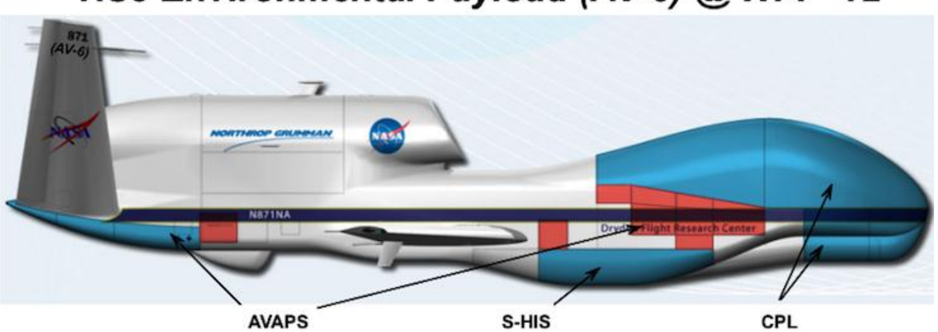
- **COAMPS-TC Ensemble System (using DART) run in real time (5 km) for EnKF DA (80 members) and 5 day forecasts (10 members) (in support of HFIP).**
- **Significant uncertainty in the intensity.**

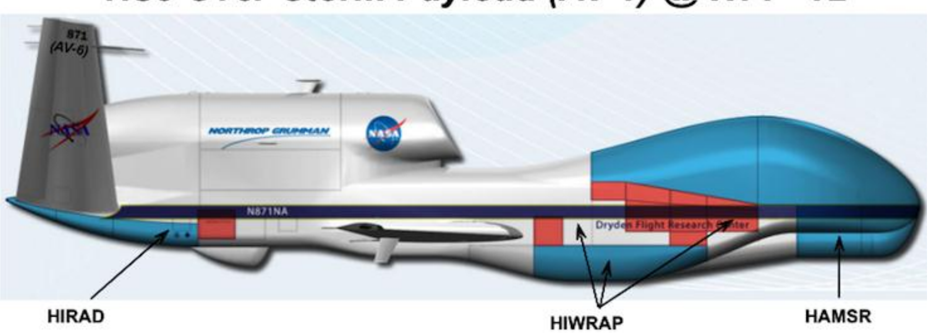
Hurricane Severe Storm Sentinel (HS3)
NASA Field Campaign (2012-2014)

NASA field campaign to observe inner core and environment of TC's to address questions regarding formation and intensity change

- 2 Global Hawks will sample environment and over storm
- NRL will focus on hurricane outflow characteristics, dynamics, and predictability
- First field phase Sep-Oct '12







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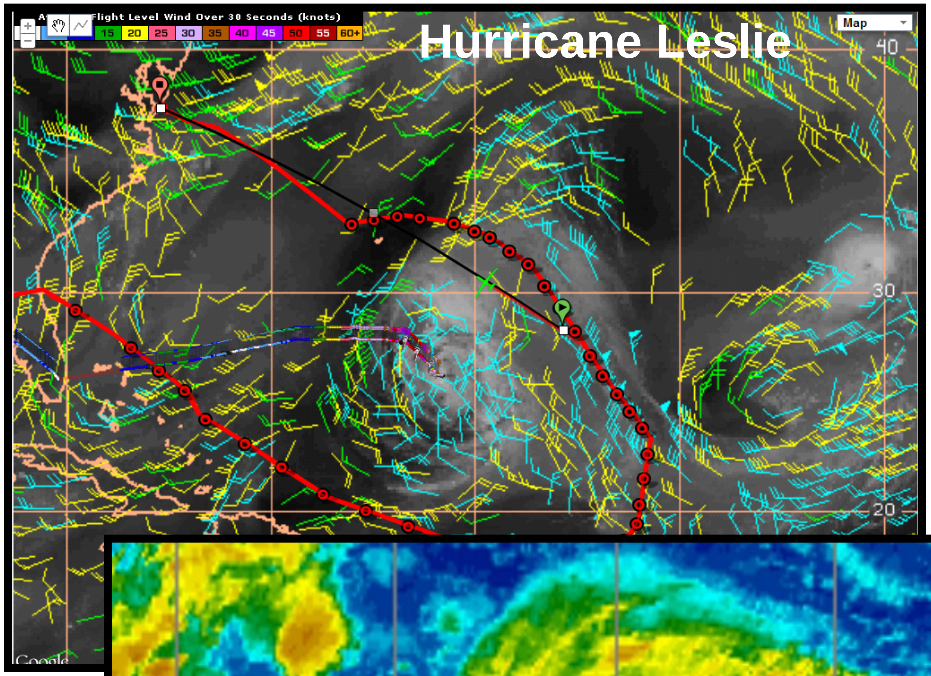
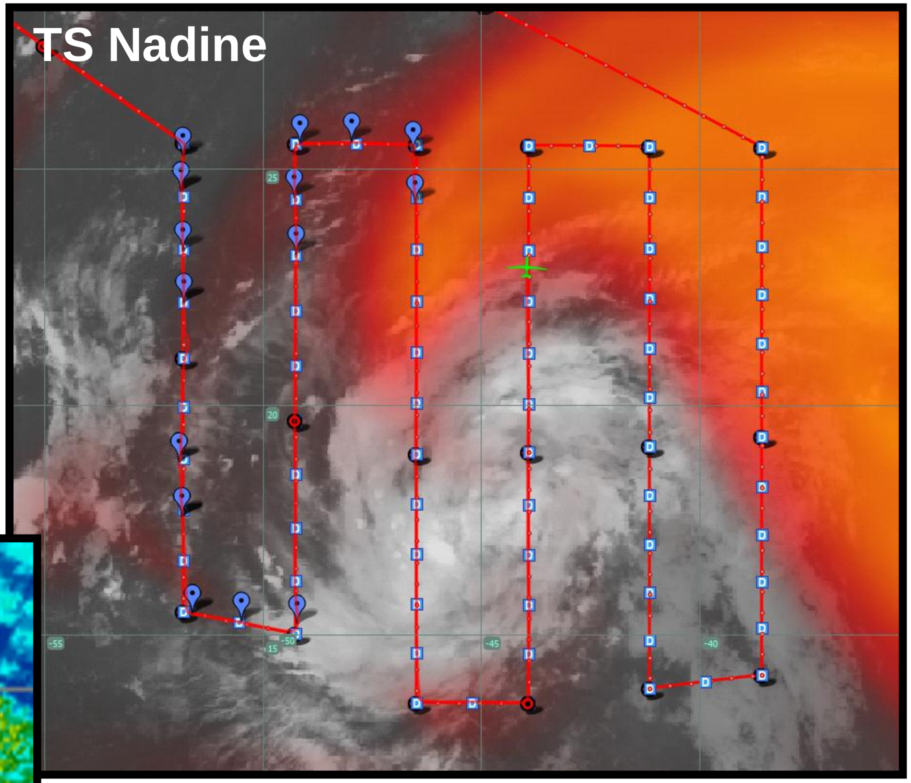
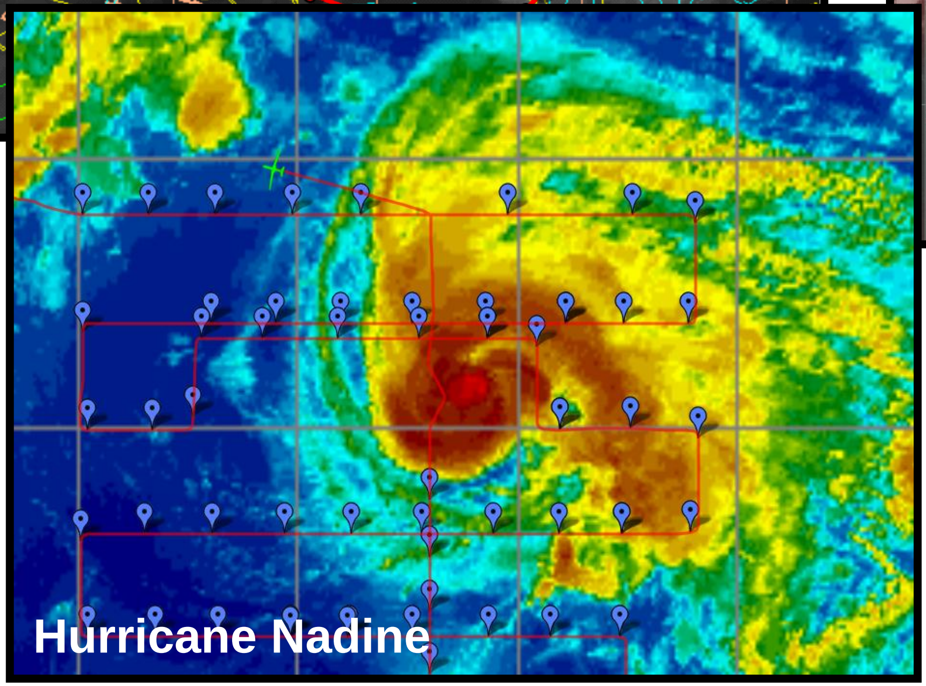






- Ferry mission and 2 science missions so far.
- Excellent datasets for data impact, initialization, and predictability studies.
- Missions sampled outflow.

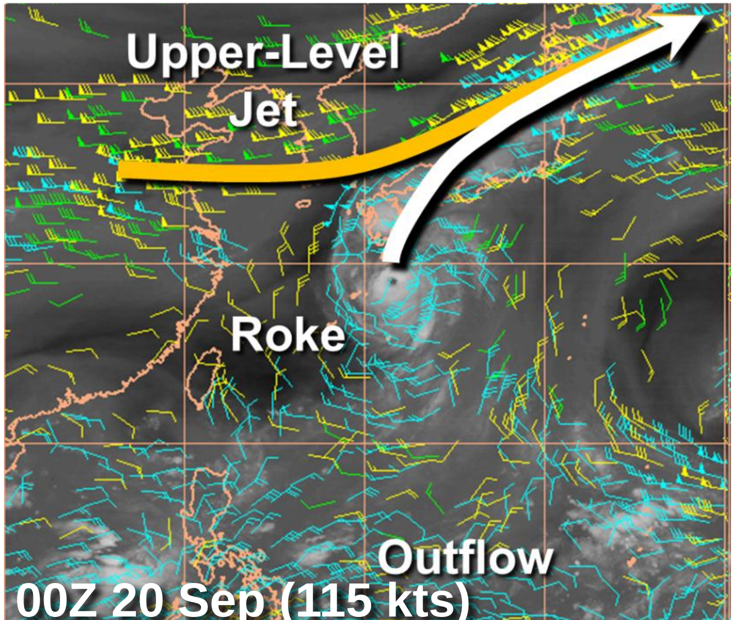
TC Initialization and Predictability Issues
Summary and Challenges

➢ Dynamical Initialization
- Most TC models suffer from spin-up and spin-down issues early in the forecasts, which adversely impact the short term intensity skill (and track).
- Several DI methods for COAMPS-TC have been developed.
- Balanced vortex (from look-up table) and a newtonian relaxation step results in large improvements to the intensity (and track).
- DI is a natural framework to include satellite derived heating rates (future).

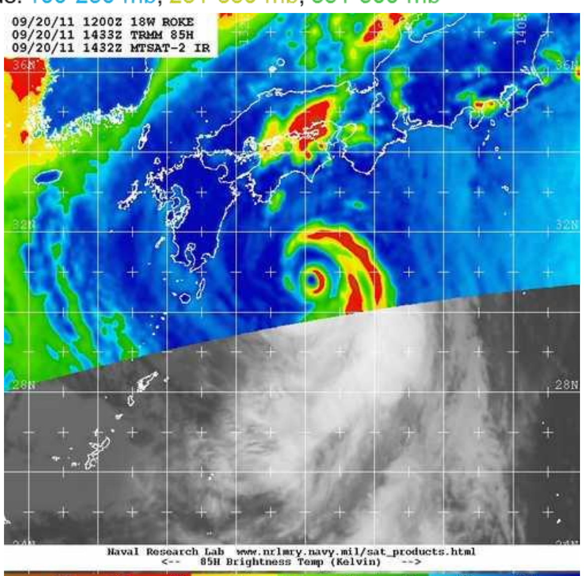
➢ Predictability
- Track & intensity are poor for weak storms.
- Adjoint results underscore the multi-scale nature of TC prediction and large sensitivity to initial moisture distribution (intensity targeted observations?).
- Multi-model high-resolution ensemble (HFIP) is a promising direction.

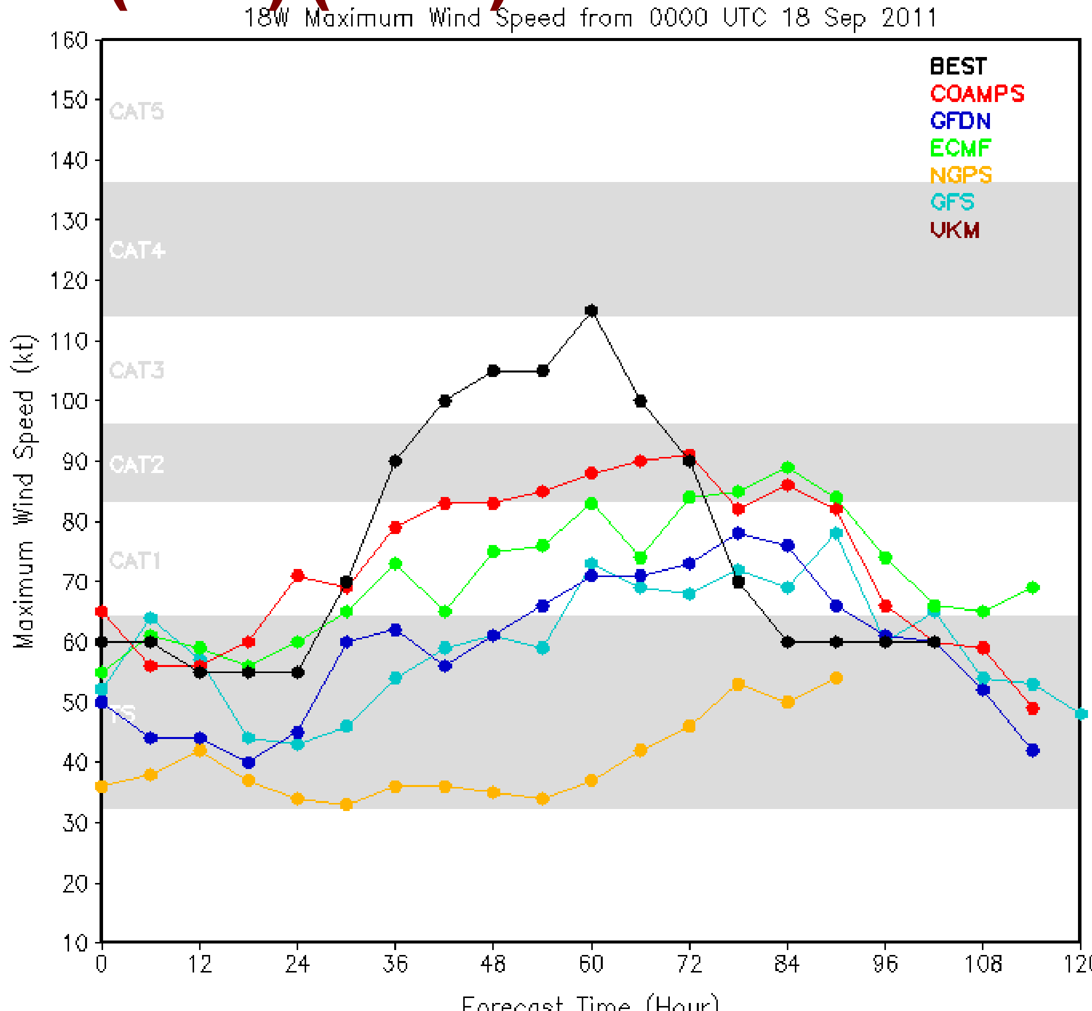
➢ Challenges and Issues
- Roles of the environment and internal processes need to be understand.
- Need to quantify TC predictability for intensity (RI, scale interactions etc.).
- Role of the outflow (link to environment) needs to be considered.
- Model calibration based on few metrics (e.g., max wind) may lead to unbiased forecasts, but with large errors (poor RI, similar to statistical models).

Predictability Aspects: Rapid Intensification
Roke (18W) (2011)



Winds: 100-250 mb, 251-350 mb, 351-500 mb





- •TY Roke remained weak for days, underwent rapid intensification (RI), and threatened Tokyo.
- •Models failed to capture RI.
- •Outflow merged with upper jet during RI.
- •A focus of NASA HS3 will be on outflow interactions