A new tropical cyclone dynamic initialization technique using high temporal and spatial density atmospheric motion vectors and airborne field campaign data

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Background

- Initialization of tropical cyclones in numerical weather prediction (NWP) systems is a great challenge
  - Mass-wind field balance
  - Secondary circulation and heating
  - Asymmetries
- There can be large adjustments in structure and intensity in the first 24 hours if the initial vortex is not in balance
  - Spurious gravity waves
  - Spin-up (model and physics)
- Existing mesoscale NWP model TC initialization strategies
  - Bogus vortex, cold start from global analyses
  - 3DVAR or 4DVAR, possibly with synthetic observations
  - Ensemble Kalman Filter
  - Dynamic initialization
- Dynamic initialization allows vortex to have improved balance and physics spin-up at the initial time
  - Past work on dynamic initialization: Hoke and Anthes 1976, Fiorino and Warner 1981, Davidson and Puri 1992, Kurihara et al. 1993, Nguyen and Chen 2011, 2014, Hendricks et al. 2011, 2013

Objective

- A new dynamic initialization technique for multiply-nested tropical cyclone prediction models is developed
- This technique can utilize high temporal (10 minute) and spatial resolution atmospheric motion vectors (AMVs) and aircraft reconnaissance data (e.g., dropsondes, airborne radar)
- **Hypothesis:** The input of high-temporal and spatial representation of the 3D flow field in the TC and near-environment in this dynamic initialization framework will allow the numerical model to generate proper heating and asymmetries, yielding improved initial vortex balance, structure and intensity, which will ultimately lead to improved intensity and structure forecasts.

The Components

- **AMVs:** High temporal and spatial resolution from CIMSS

- **ONR TCI Data**: HIRAD and HDSS (advanced dropsonde system)

- **SAMURAI:** Spline Analysis at Mesocale Utilizing Reconnaissance Aircraft Instrumentation (Bell el al. 2012)
  - Highly accurate 3DVAR system blends the high-temporal resolution AMVs and TCI observations with the COAMPS-TC first guess

- **COAMPS-TC:** U.S. Navy tropical cyclone prediction system (Doyle et al. 2014)
  - Ingest increments from SAMURAI at high temporal frequency (10 minutes), perform dynamic initialization

Dynamic Initialization Technique

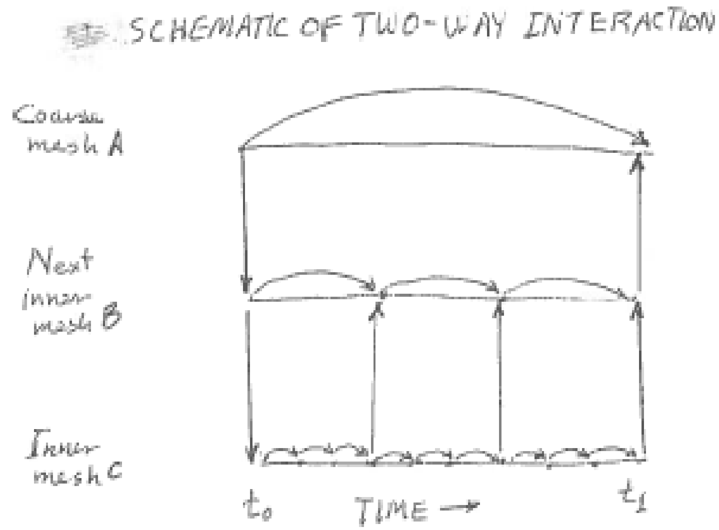
- SAMURAI analysis is prepared using COAMPS-TC background and AMVs

- Dynamic initialization is performed utilizing the SAMURAI increments for period of time, then real forecast is launched

- This quasi-continuous data assimilation allows for the vortex to adjust to the 10-minute forcing

  - 45-km grid, dt=90 sec
  - 15-km grid, dt=30 sec
  - 5-km grid, dt=10 sec

  - ***5-km grid will have 60 time steps to help remove imbalances and adjust to AMV/SAMURAI forcing***



$$\frac{\partial u}{\partial t} = F(u) + \propto (u_s - u_b)$$

$$\frac{\partial v}{\partial t} = F(v) + \propto (u_s - u_b)$$

(u_s-u_b) are the SAMURAI increments

Flow chart of Initialization (SCDI Scheme)

Future Integrated Version

COLD START INITIALIZATION OF **COAMPS-TC** (only first time)

At synoptic time 00Z, 06Z, 12Z, 18Z from GFS or NAVGEM. Initialize all 3 grids. Insert static balanced vortex matching TC vitals.

Perform 10-minute **COAMPS-TC** forecast at time t, send $\mathbf{u}_b$ to **SAMURAI**

Call **SAMURAI** to produce analysis increments ($\mathbf{u}_s$-$\mathbf{u}_b$) using background, and AMV and other observations (with known error characteristics).

Run **COAMPS-TC** with dynamic initialization to **SAMURAI** increments.

t=t+10 minutes

SAMURAI/COAMPS-TC/DI loop.

Run for 6-hours or other specified time while have high res AMVs and TCI observations

Execute real **COAMPS-TC**, no nudging

Currently using manual version where SAMURAI increments are produced offline using 6-h COAMPS-TC background

Proof of concept TCI case

Hurricane Joaquin, 1800 UTC October 04, 2015

15-min resolution AMVs, 6-h DI period

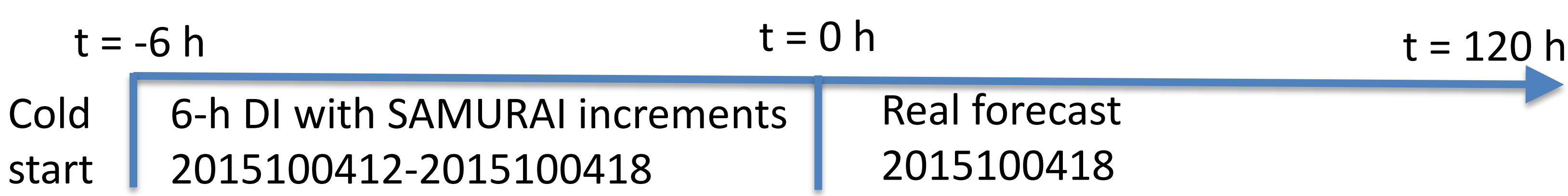
Proof-of-Concept

Hurricane Joaquin (2015)

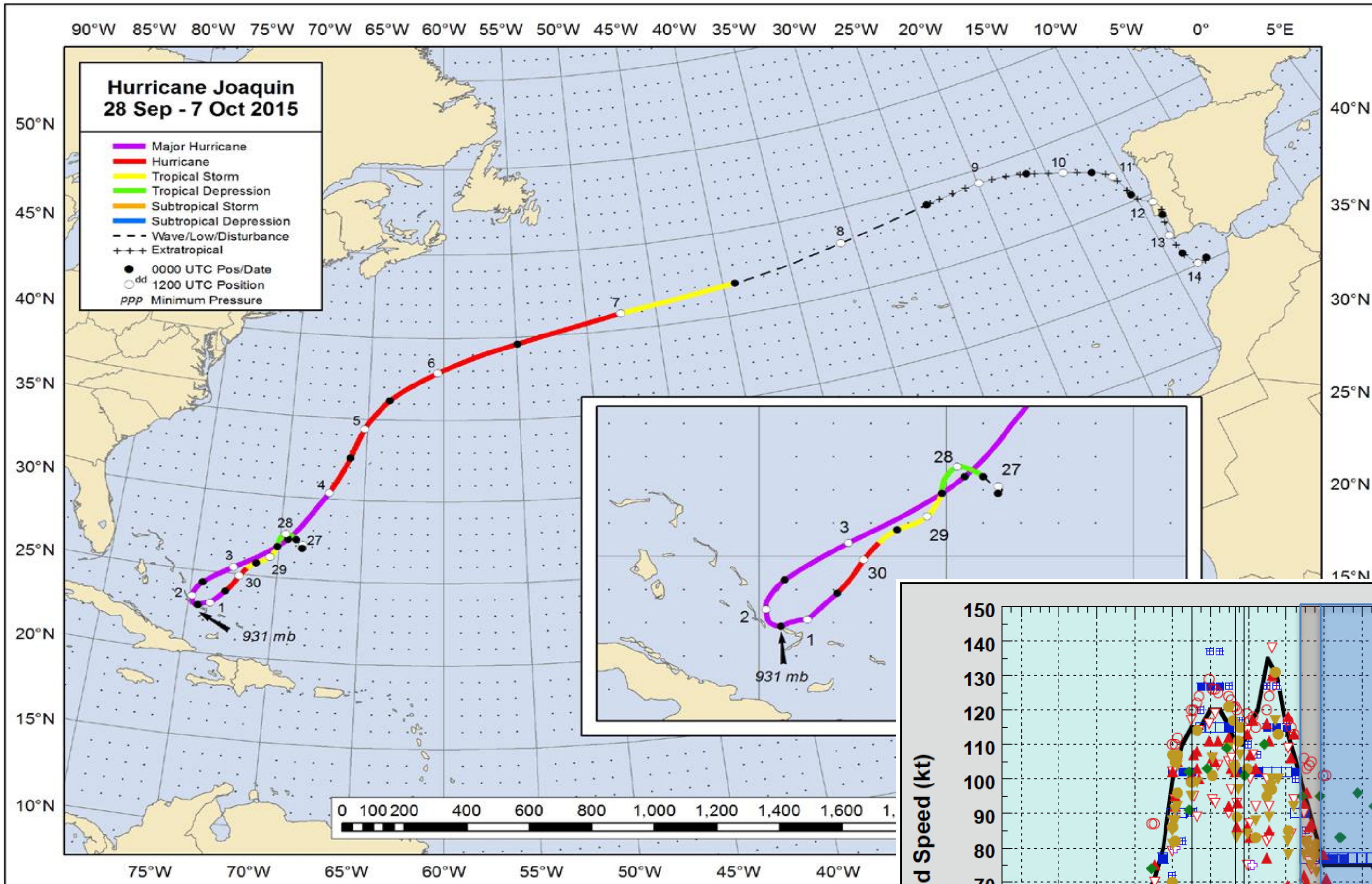
- Dynamic initialization using SAMURAI increments with 15-minute AMVs
  - 2015100412-2015100418

- Real forecast for 2015100418
  - Compare SAMURAI/COAMPS-TC/DI (**SCDI**) method to **CNTL** method in terms of track, intensity and structure

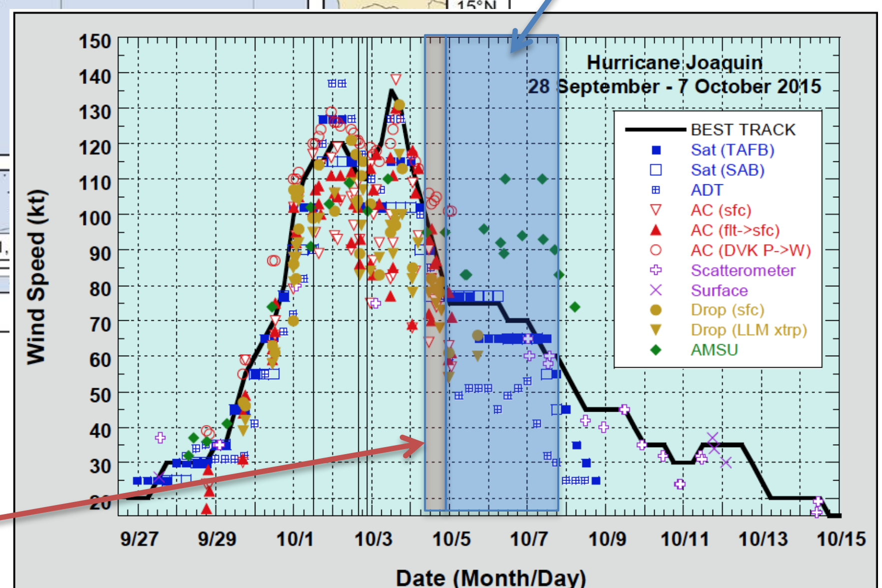
- Two forecasts to compare on 2015100418:
  - **CNTL:** standard COAMPS-TC initialization, bogus vortex, cold start with GFS global data
  - **SCDI**: SCDI scheme with SAMURAI increments on nest 3



Summary of Joaquin (2015)



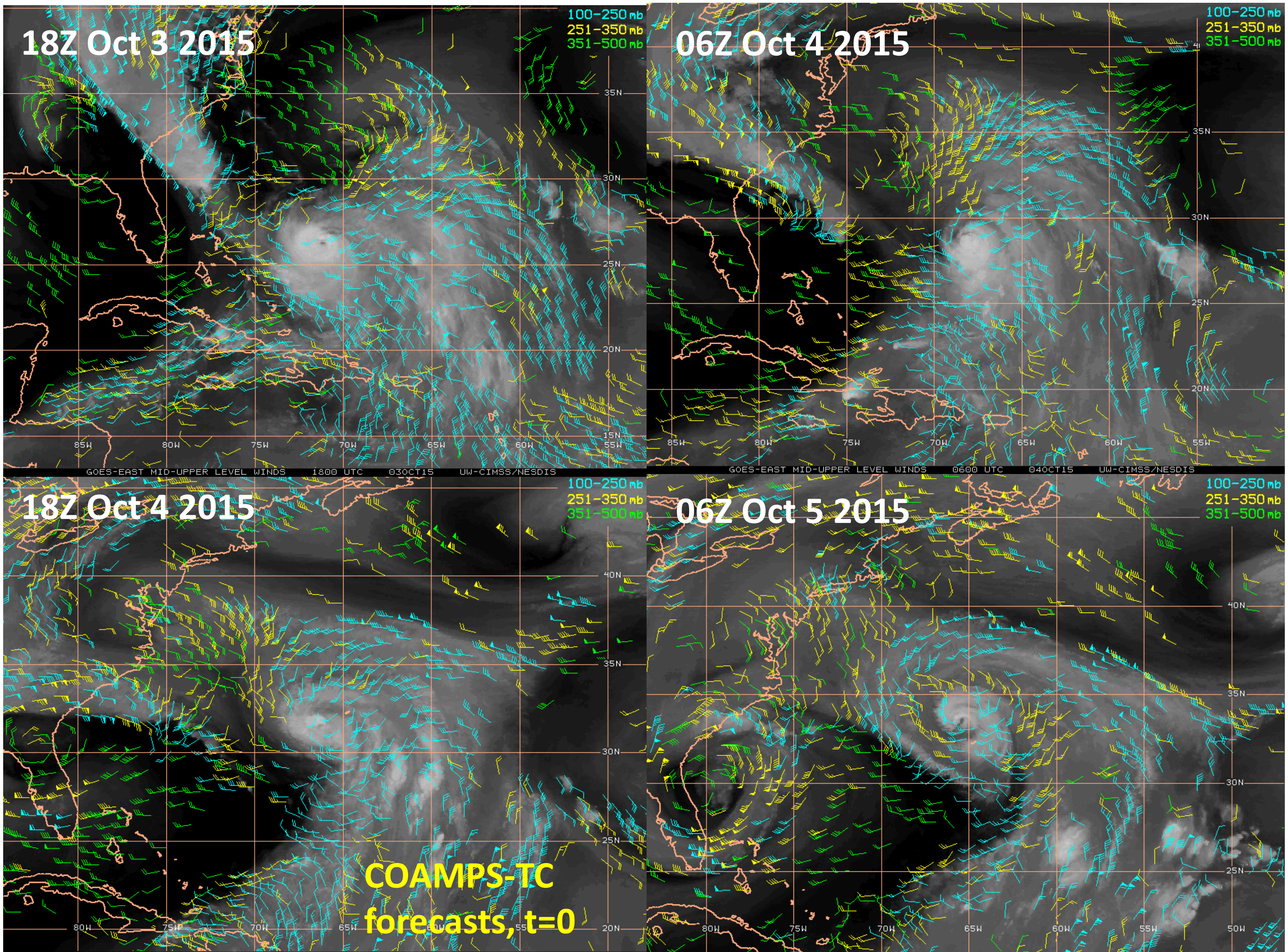
Figs. Courtesy National Hurricane Center



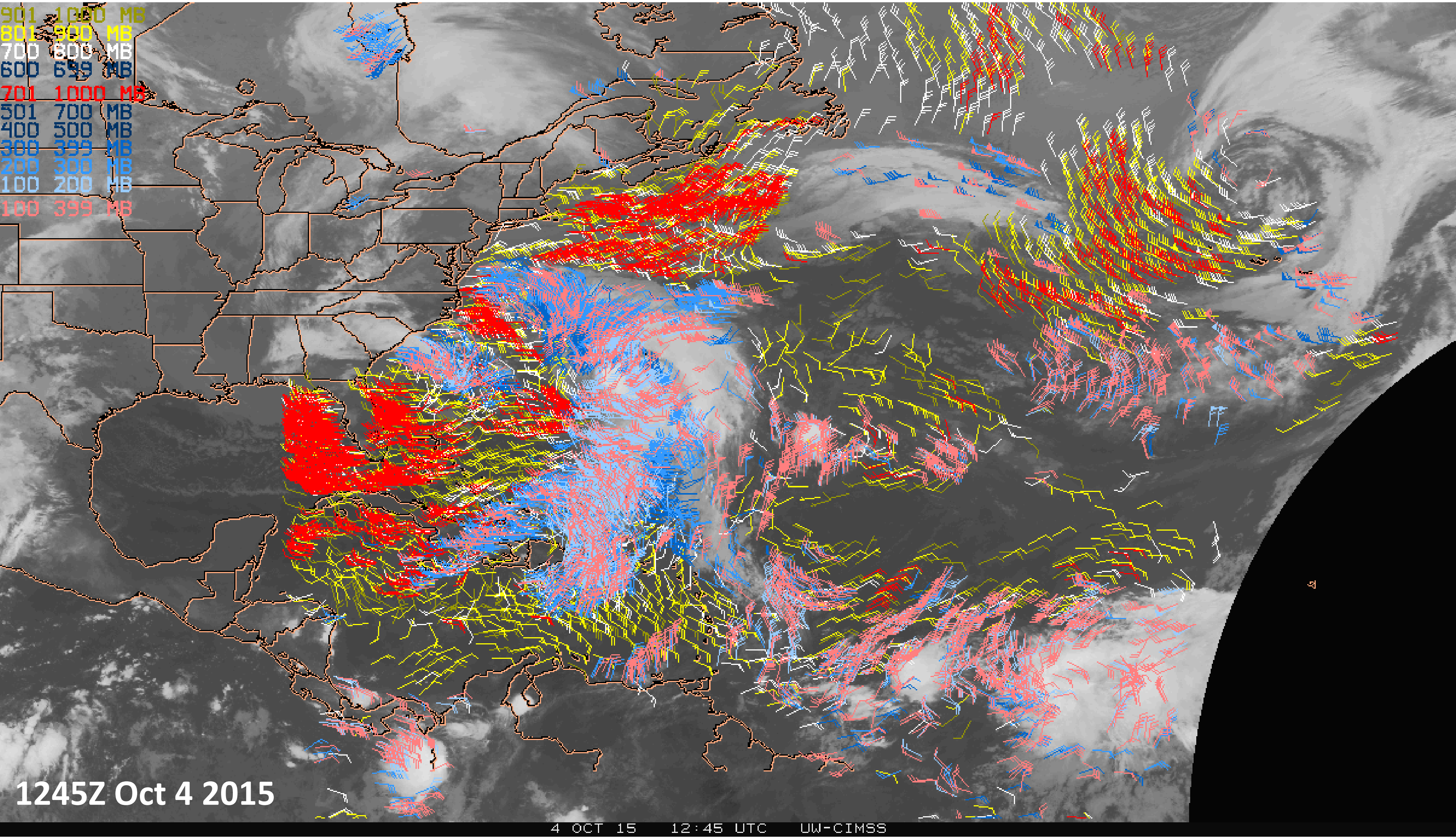
Real forecast

6-h dynamic initialization

Hourly Atmospheric Motion Vectors (AMVs)
Upper level evolution of Joaquin

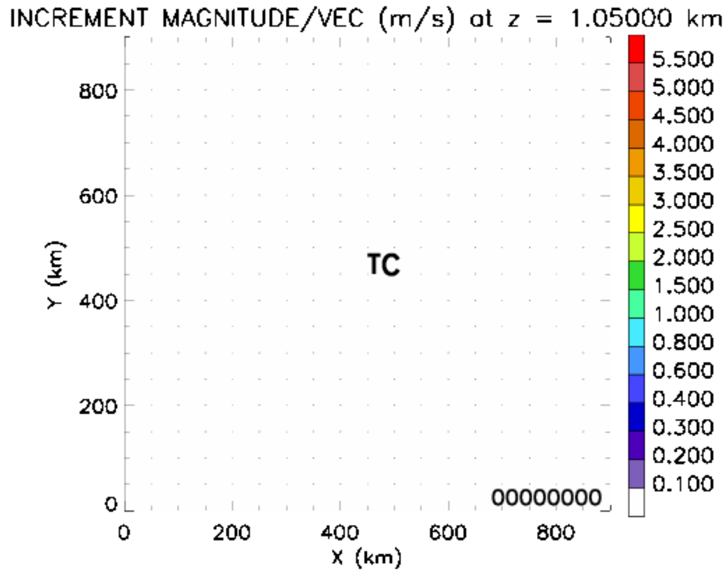


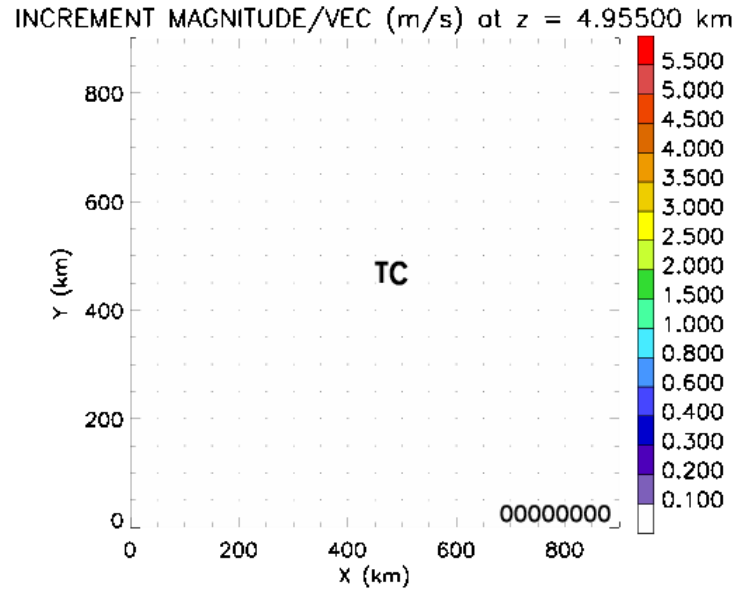
15-min Atmospheric Motion Vectors (AMVs) 2015100412-2015100418 (courtesy CIMSS)

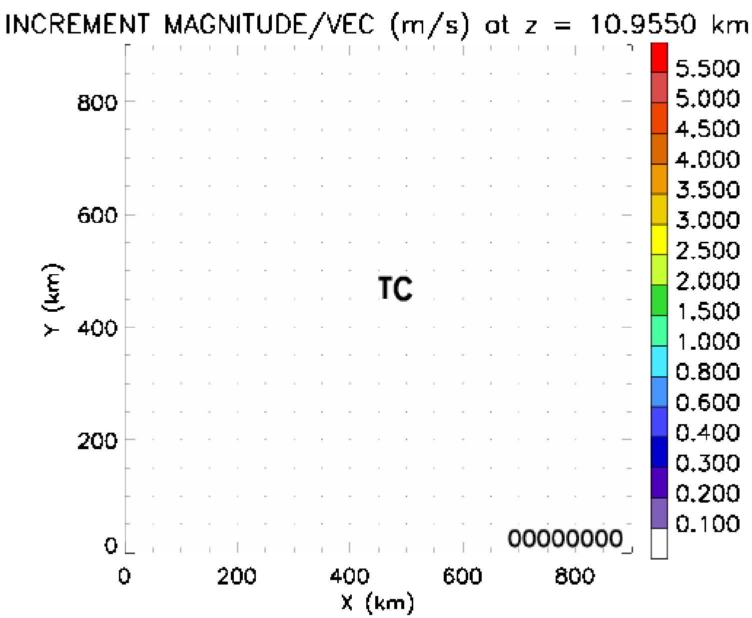


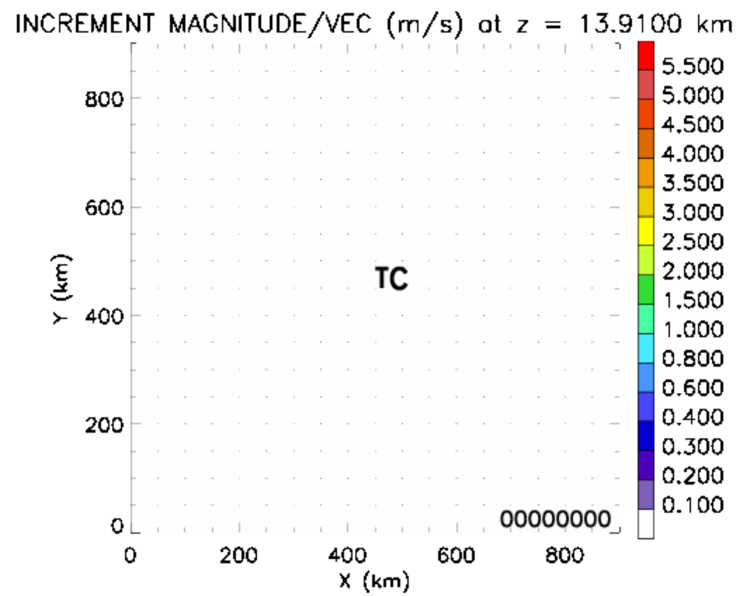
Initialization scheme fully utilizes high temporal and spatial resolution AMVs

SAMURAI increments – grid 3



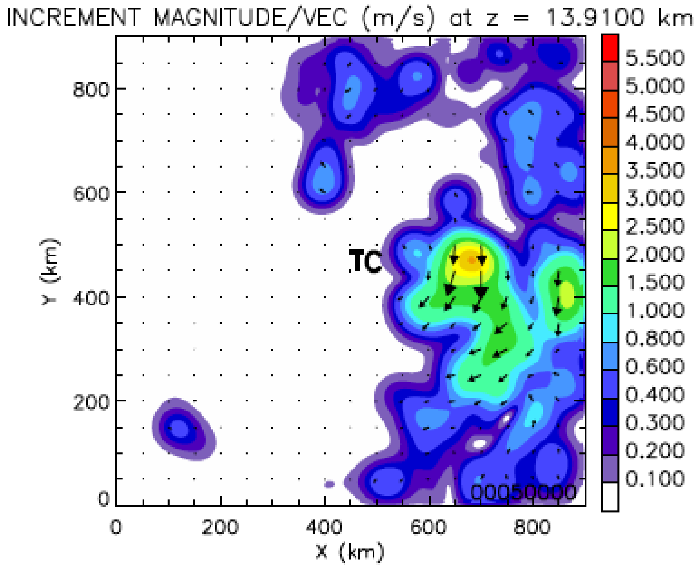


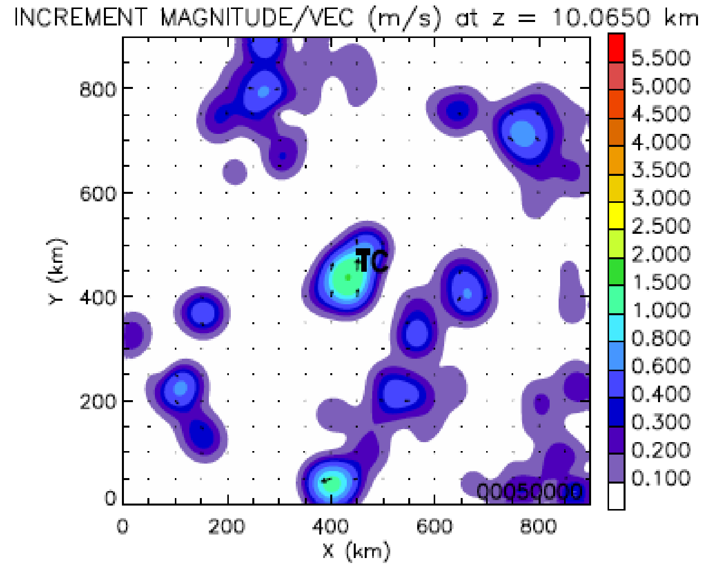


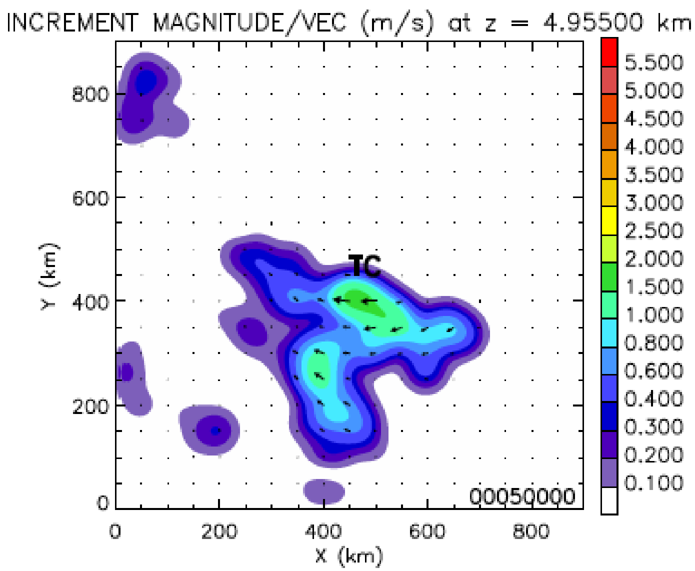


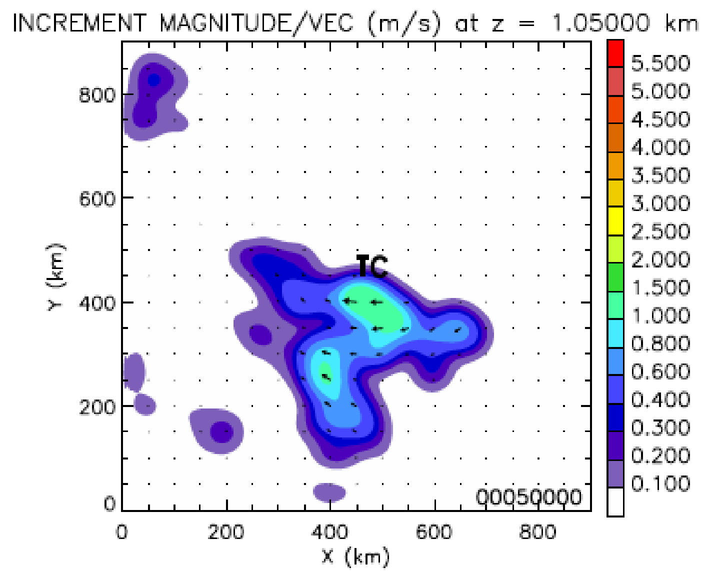
Analysis Increments

Valid 1700 UTC October 4



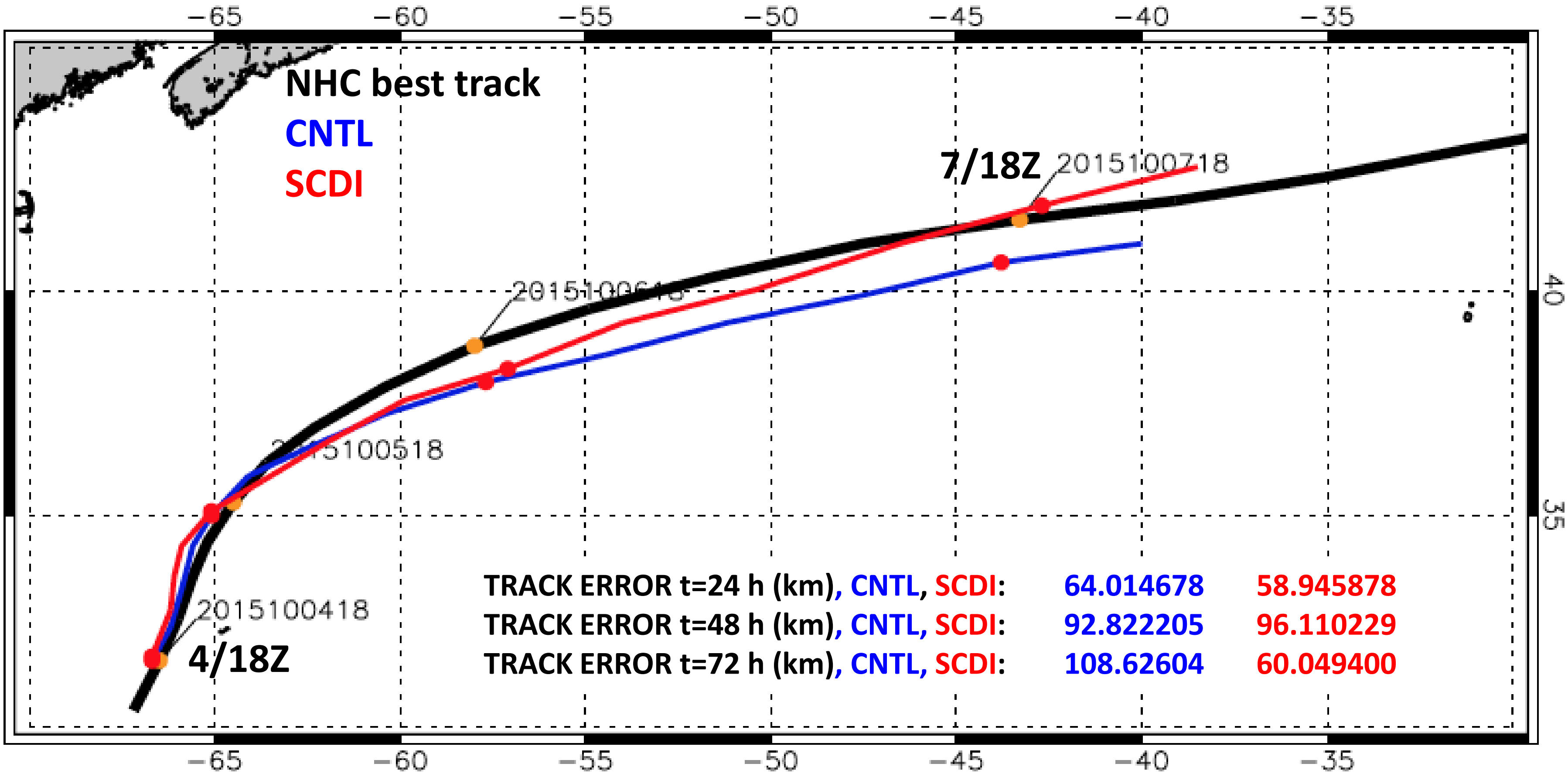






Comparison of SCDI and CNTL Track Forecasts

CNTL: standard COAMPS-TC initialization, bogus vortex, cold start with GFS global data
SCDI: SCDI scheme with SAMURAI increments on nest 3 only

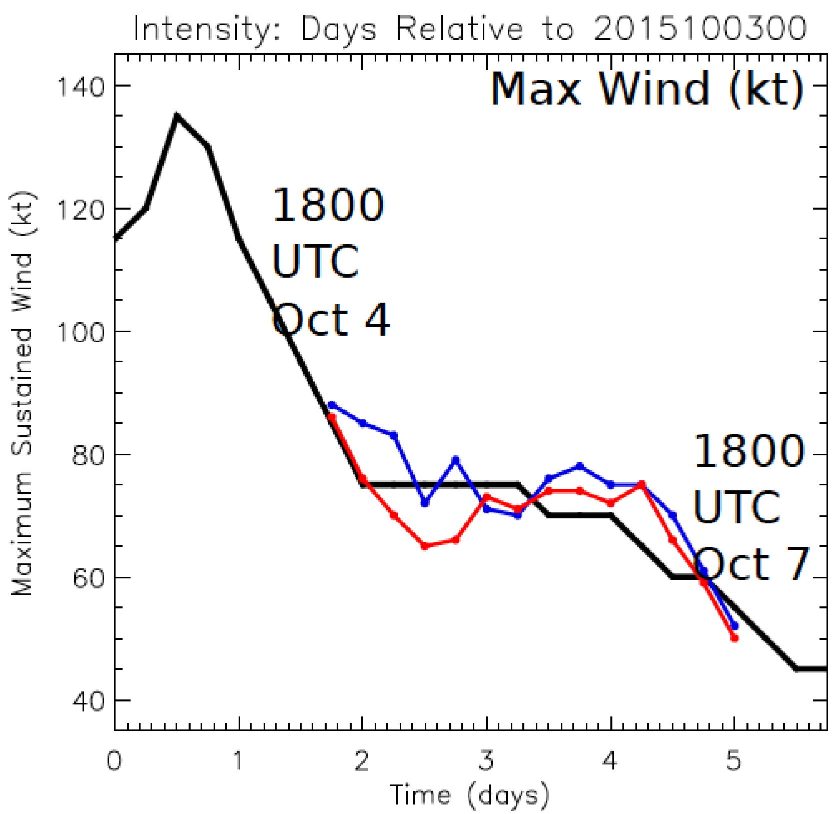


- Track errors are similar at t = 24, 48 h
- SCDI has 48 km lower track error at t = 72 h

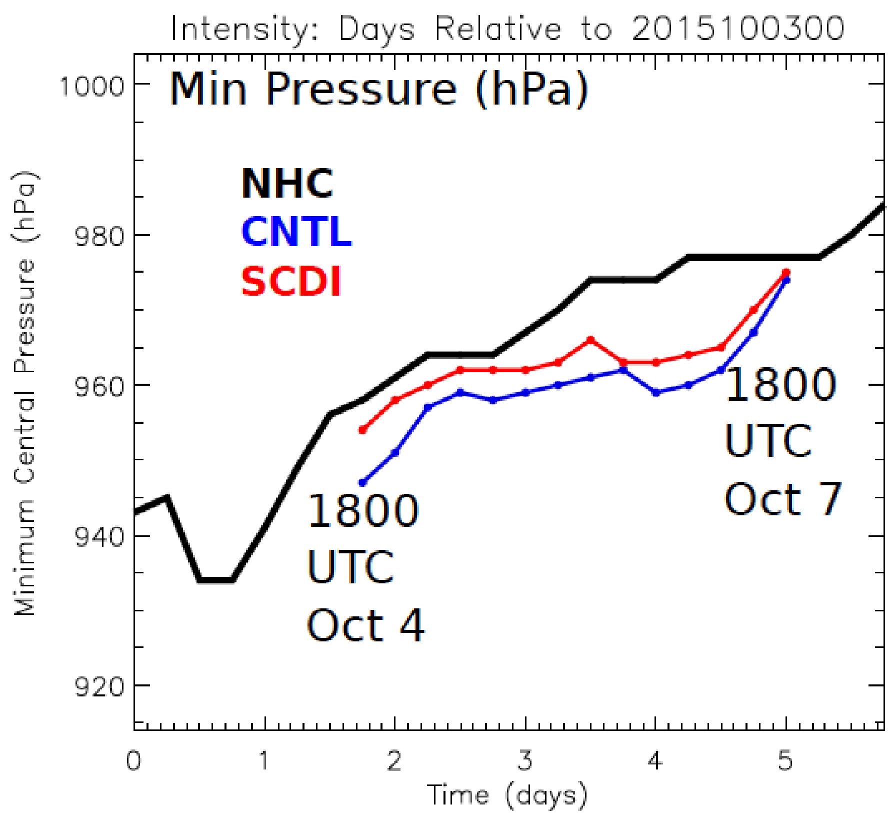
Comparison of SCDI and CNTL Intensity Forecasts

CNTL: **standard COAMPS-TC initialization, bogus vortex, cold start with GFS global data**
SCDI: SCDI scheme with SAMURAI increments on nest 3 only

VMAX (kt)



MSLP (hPa)

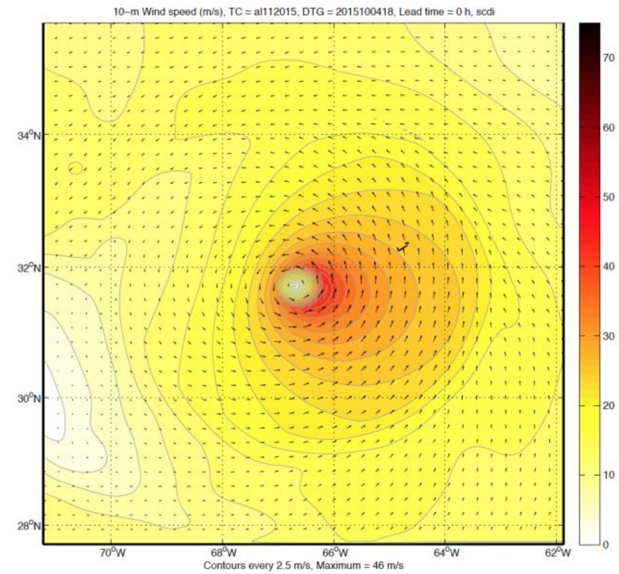


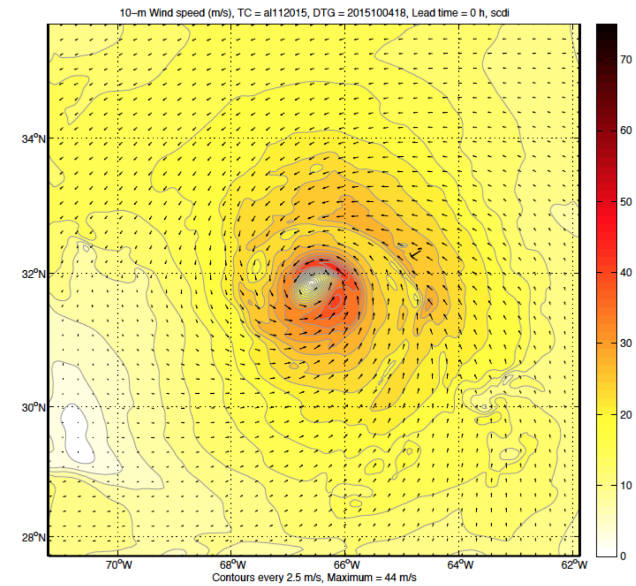
- SCDI scheme improves the MSLP prediction
- For VMAX, SCDI schemes have better initial weakening (t<12h), but weakens too much from t=12-36h

10-m wind speed (grid 3)

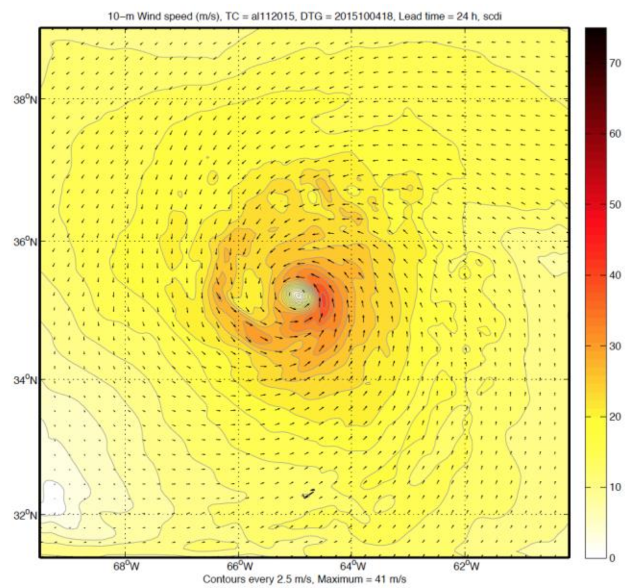
CNTL | **SCDI**

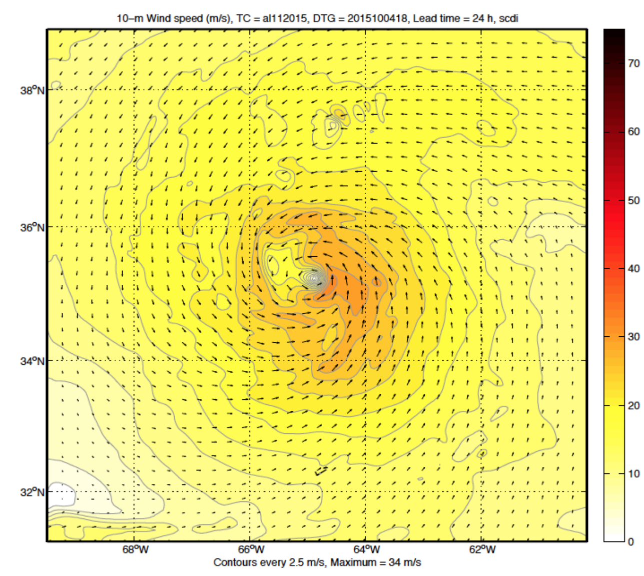
t = 0 h (valid at 1800 UTC Oct. 4)





t = 24 h (valid at 1800 UTC Oct. 5)

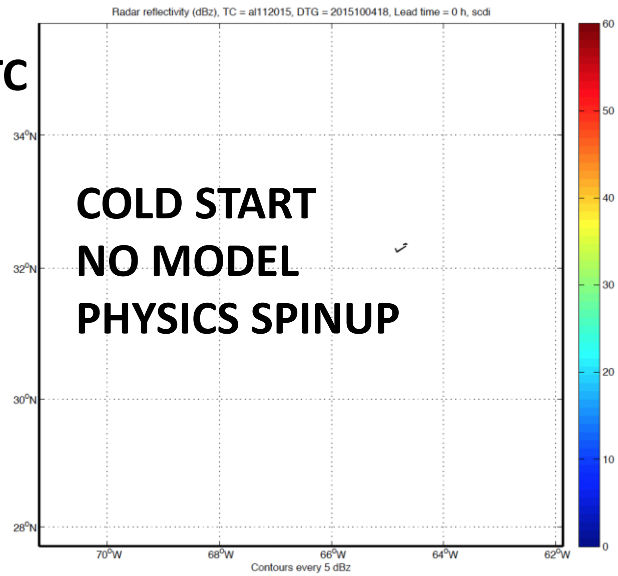




Simulated Radar Reflectivity (grid 3)

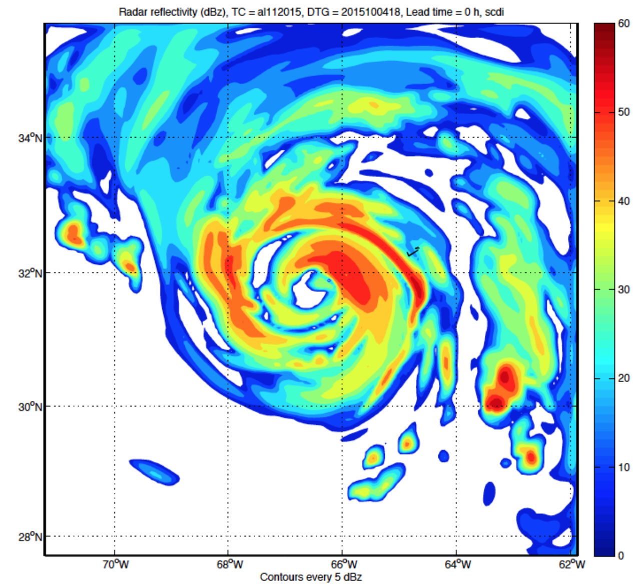
t = 0 h (valid at 1800 UTC Oct. 4)

CNTL



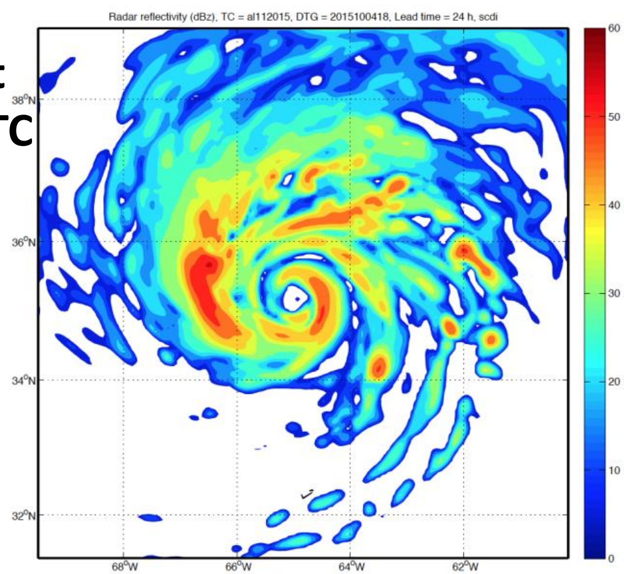
COLD START
NO MODEL
PHYSICS SPINUP

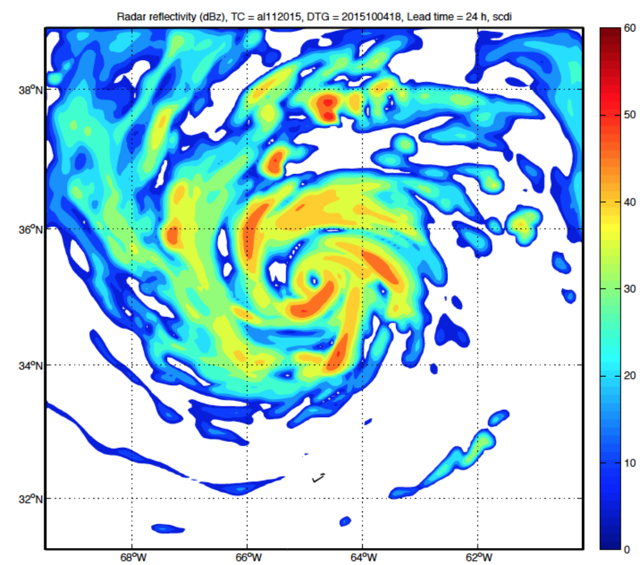
SCDI



SCDI scheme has model physics spin-up in the initial conditions

t = 24 h (valid at 1800 UTC Oct. 5)





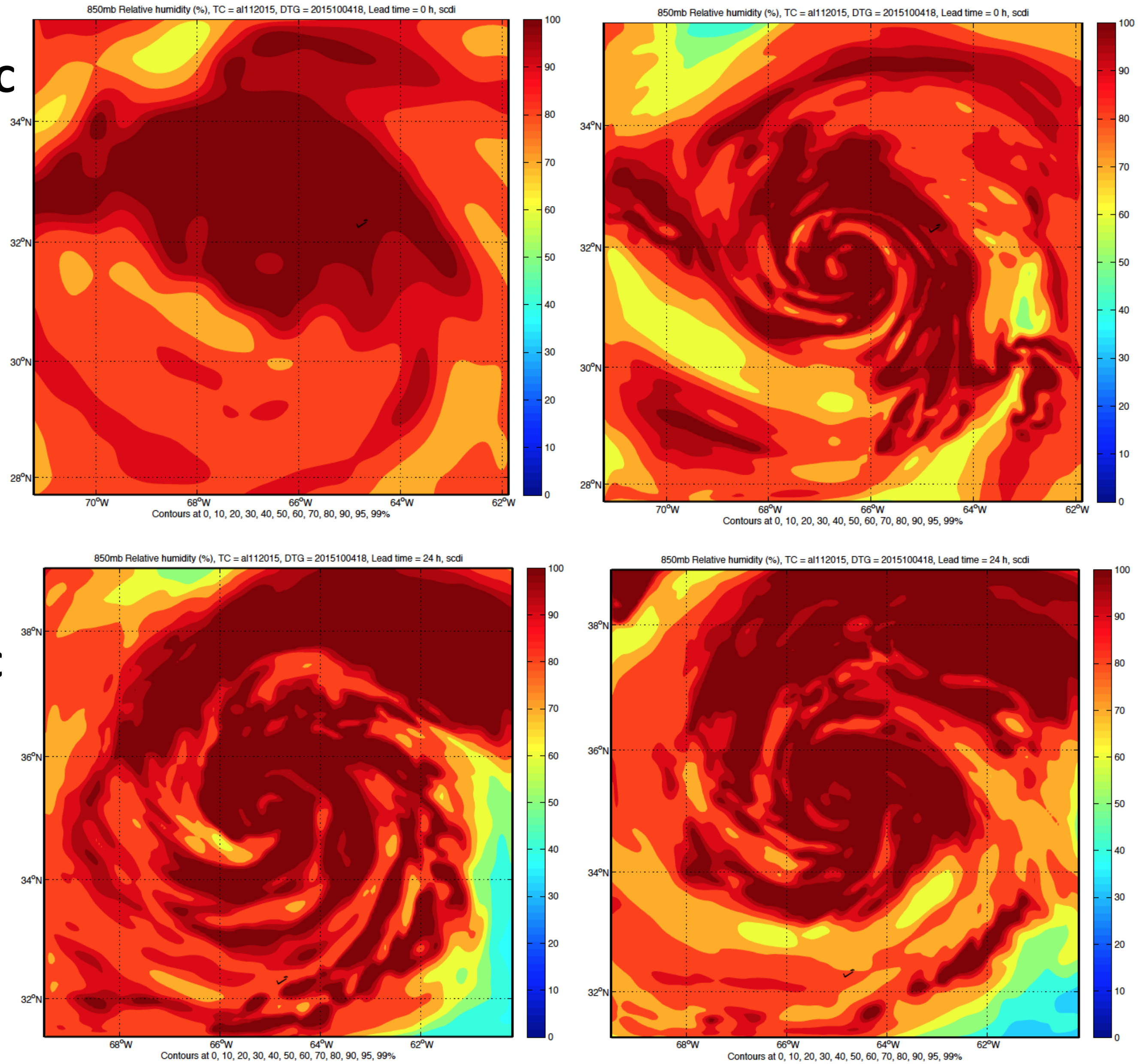
Produces a weaker vortex in time than CNTL

Relative humidity (grid 3)

t = 0 h (valid at 1800 UTC Oct. 4)

CNTL | **SCDI**

t = 24 h (valid at 1800 UTC Oct. 5)



SCDI scheme has moisture field more consistent with hurricane-like vortex at t=0 h.

Conclusions

- We have demonstrated a new dynamic initialization technique (SCDI) for the tropical cyclone prediction model COAMPS-TC that can fully utilize high temporal resolution AMVs (10 or 15 minutes) and airborne field campaign data

- A proof-of-concept of this technique was performed on Hurricane Joaquin (2015)

- The SCDI scheme has an improved intensity forecast in terms of MSLP, lower track error at t = 72 h, and model physics spin-up in the initial condition

- Future work:
  - Add HIRAD and HDSS data from ONR TCI experiment to the SAMURAI analysis for improved analysis and forecasts
  - Sensitivity to nudging coefficient, error characteristics, and dynamic initialization spin-up period
  - Perform simulations for other TCI cases

EXTRA SLIDES

Background

- Himawari-8 geostationary satellite has capability of continuous imagery (10-minutes) over the full disk (Advanced Himawari Imager)
  - New GOES-R satellites will have same capability (ABI)

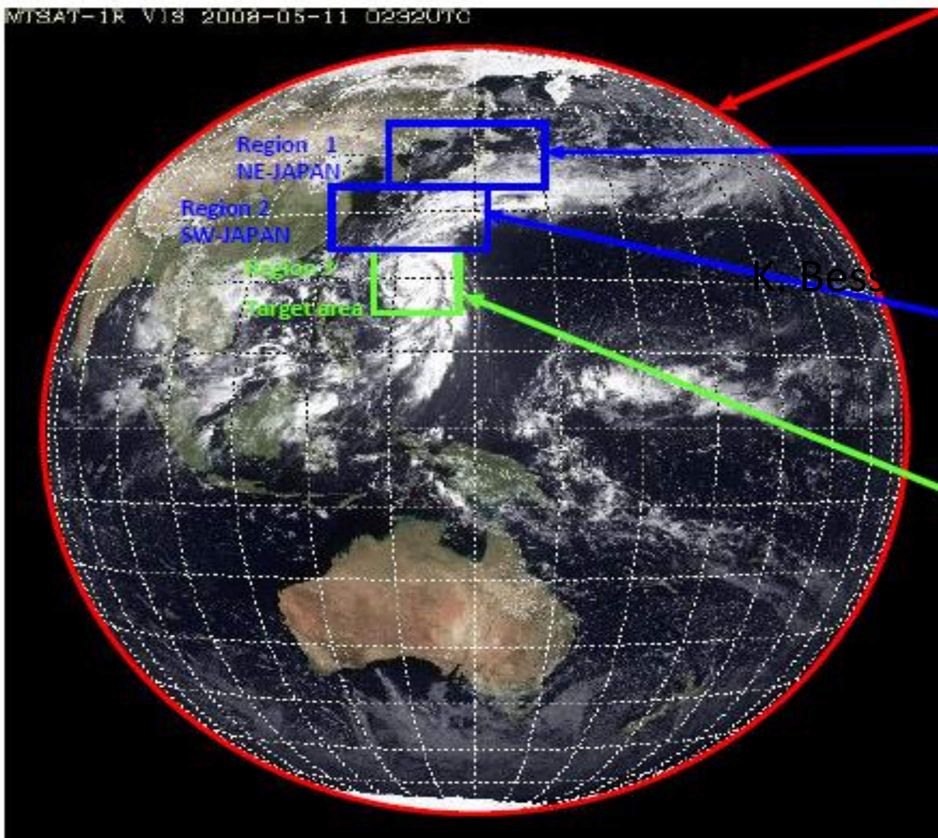
- This will allow for unprecedented observations of tropical cyclones

- However, current data assimilation systems are not capable of ingesting such high temporal observations (atmospheric motion vectors: AMVs)
  - Hourly AMVs are typically produced, and thinned to 100 km spacing in the horizontal

- An entirely new data assimilation and initialization strategy is required to utilize these observations

New Era in Environmental Satellites

AHI Observation Areas and Frequencies



Courtesy JMA, K. Bessho

Full disk
Interval : **10** minutes (6 times per hour)

Region 1 JAPAN (North-East)
Interval : **2.5** minutes (4 times in 10 min)
Dimension : EW x NS: 2000 x 1000 km

Region 2 JAPAN (South-West)
Interval : **2.5** minutes (4 times in 10 min)
Dimension : EW x NS: 2000 x 1000 km

Region 3 Target Area
Interval : **2.5** minutes (4 times in 10 min)
Dimension : EW x NS: 1000 x 1000 km

Frequency of observations will be drastically increased !!

NPS ENSEMBLE STORMS

Mary Jordan, Russ Elsberry, Eric Hendricks

NPS Ensemble Storms

- 2008-2014, ECMWF provided their 15- and 32-day vortex tracks and intensity forecasts directly to Dr. Russ Elsberry. In 2015, the ECMWF dataset was no longer available.
- In 2015, we modified our software to use the NCEP vortex track/intensity forecasts provided by the NCEP Cyclogenesis website (Mr. Tim Marchok).
  - Key feature: for each vortex location, variables were saved which describe the environment surrounding the vortex (such as vorticity).
- For TCI mission planning, we provided our ensemble storm tracks using the NCEP 16-day and ECMWF 15-day forecasts.
  - Our TCI forecasts did not leverage any of the environmental information.
- FY16 research focus: investigating how to use the environmental data.
  - Will it help identify false alarms?

Environmental Data with NCEP Vortex Tracks

- Hart (2003) Cyclone Phase Parameters
  - Parameter B – symmetry of the storm
  - Lower Thermal Wind 900-600 hPa
  - Upper Thermal Wind 600-300 hPa
  - MWR paper "A cyclone phase space derived from thermal wind and thermal asymmetry."
- Mean Relative Vorticity at 850 and 700 hPa
- Maximum Vorticity at 850 and 700 hPa
- Warm Core Check 500-300 hPa
- Maximum Wind Radii
- 34kt Radius from the vortex center for NE, NW, SE, SW quadrants
- Closed contour for Pressure
- Closed contour for Wind Speed

- Additional Features of NCEP track/intensity dataset:
  - Four models: ECMWF, GEFS, NAVGEM, Canadian (15/16-day forecasts)
  - Vortex tracks from deterministic model replaces the control (e.g., 50 or 20 members plus deterministic).

FY16 Accomplishments

- Re-ran our track/intensity software for mid-August – October 2015 for four models: GEFS, ECMWF, NAVGEM, Canadian
- Focus on four storms: Erika, Joaquin, Marty, Patricia
- For each storm and model:
  - Identified the ensemble storm forecast tracks which indicate possible genesis before NHC issues an invest.
  - Identified ensemble storms with match TCI storms in the invest, tropical depression, tropical storm, and hurricane phases.
  - Time series of mean relative vorticity, weighted mean vector motion (WMVM) pressure and wind speed, warm core check and the Hart cyclone phase parameters are compared with the Best Track timing of TD/TS/Hurricane phase.
  - Data processing was performed to prepare each storm's dataset for statistical analysis, such as:
    - Compare forecast track mean and spread with Best Track
    - Compare each model's performance for the four storms
    - Intercompare model performance

EXTRA SLIDES – NPS STORMS

Example of evaluation

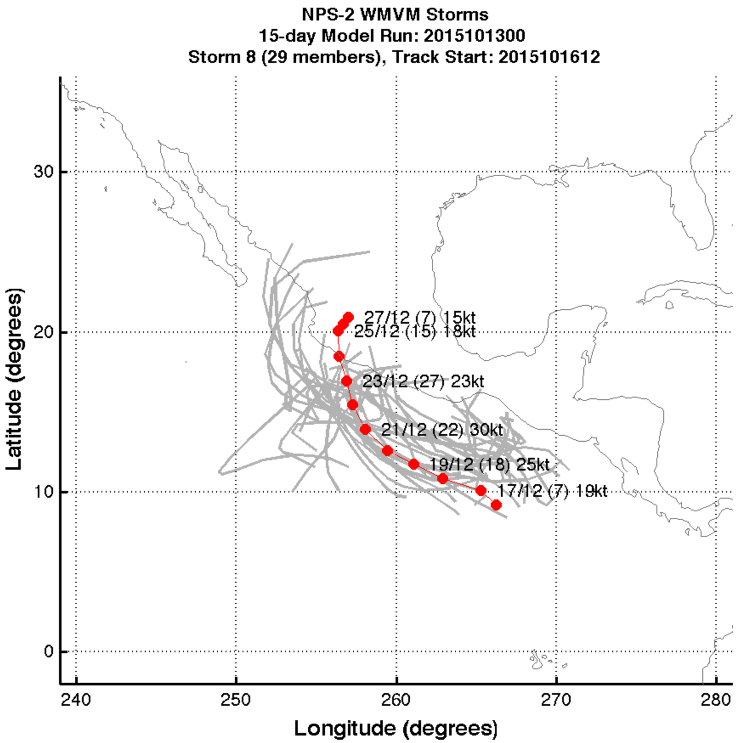
ECMWF model start 13/00 UTC (5 days prior to Invest)

(1) at 20/00, ensemble storm about 300 mi West of Best track location.

(2) Member tracks indicate landfall potential; high variability

(3) Weighted Mean Wind Speed indicates < 40 kt intensity throughout life of storm

(4) Warm Core parameters indicate large percentage of ensemble storm members are warm core

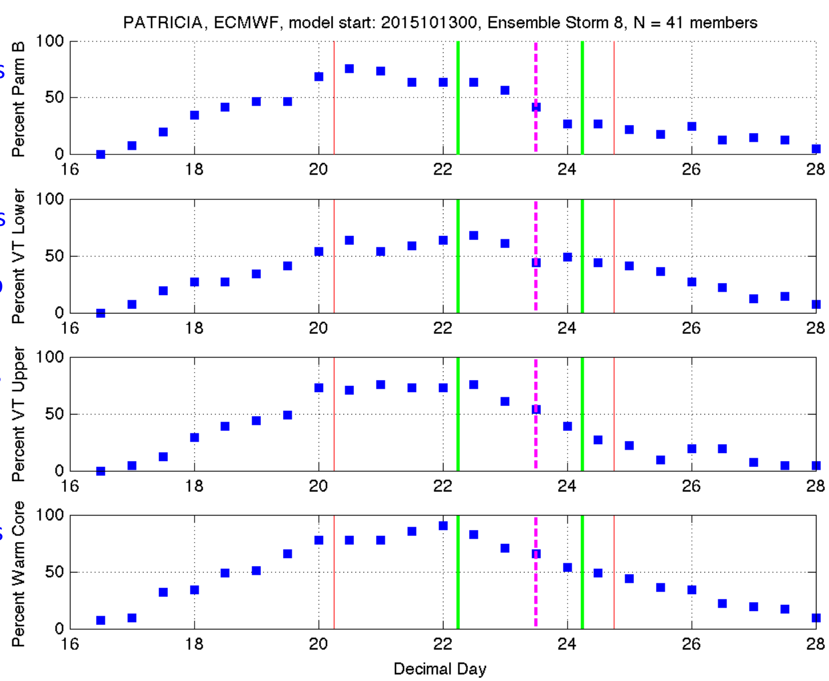


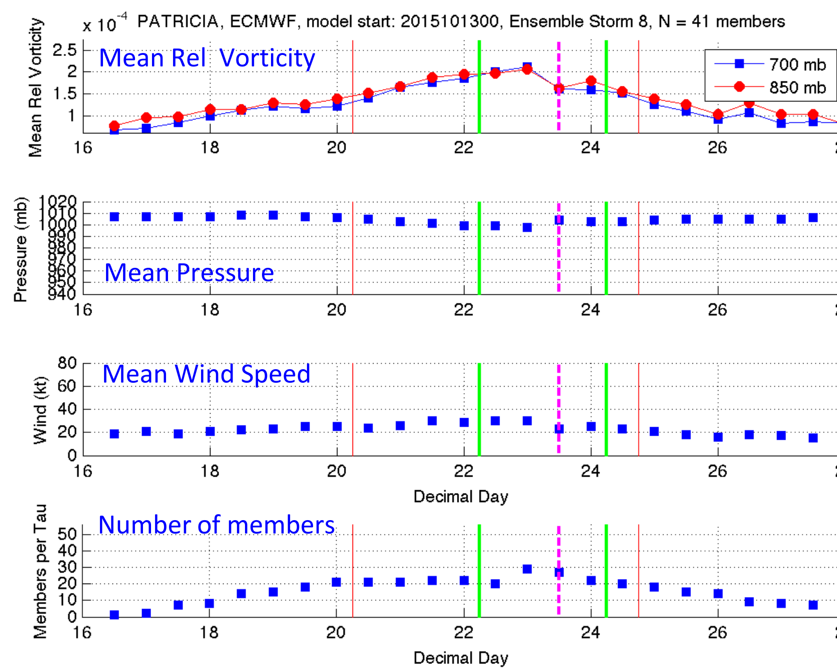
% members -10 <B < 10 symmetry

% members Warm core 900-600mb

% members Warm core 600-300mb

% members Warm core 500-300mb (Marchok)





FY15 Post-TCI Work

- Re-ran our track/intensity software for mid-August – October for four models: GEFS, ECMWF, NAVGEM, Canadian
- Estimated ensemble and deterministic resolution (need to verify with Tim Marchok)
  - Ensembles:
    - ECMWF: T639/L91 for 0-10 day, T319/L91 10-15 days
    - GEFS: T574/L64 for 0-192 hrs, T372/L64 192-384 hrs (~34 km, ~55 km)
    - NAVGEM: T239L50
    - Canadian: GEPS ver 4.0.0 ~50km resolution
  - Deterministic:
    - ECMWF: TL1279L137
    - GFS: T1534L64 0-10 days, T574/L64 10-16 days
    - NAVGEM: T425L60
    - Canadian: model grid spacing 0.35° x 0.23°