Improved tropical cyclone initialization for NCEP operations through direct assimilation of storm information

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TC Initialization at NCEP

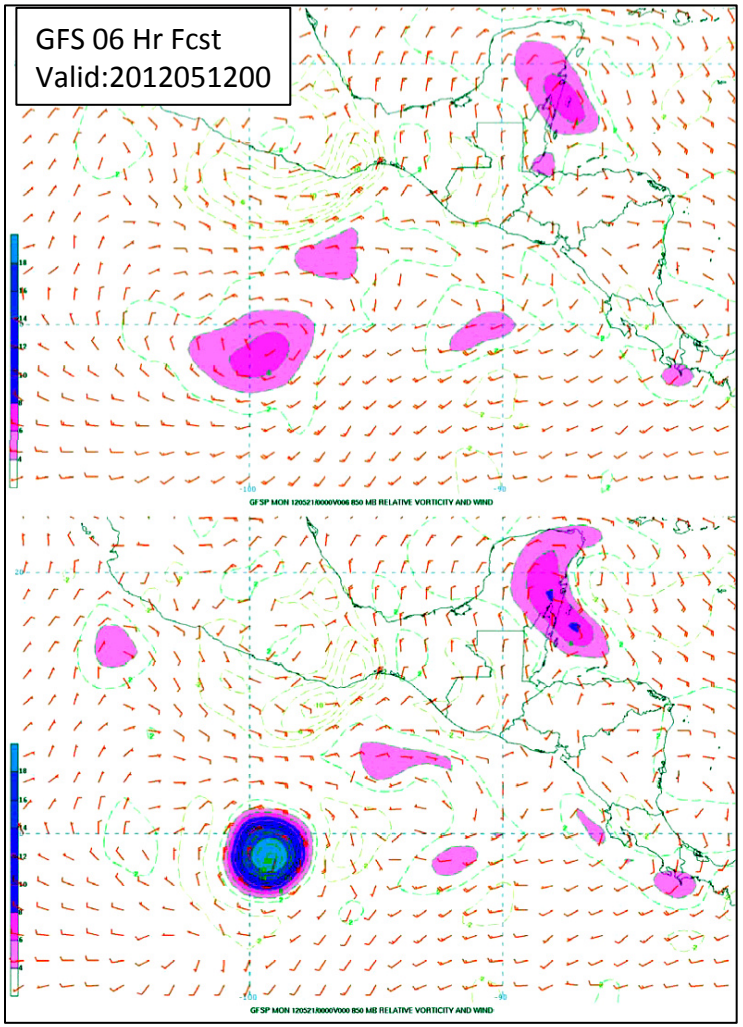
- For the operational GFS / GDAS, there is always some component from outside of the actual assimilation of real observations involved:

1. "Tracker" is run on GDAS forecast
   a. If storm found in forecast/background, ***mechanical relocation*** of vortex
   b. If not found, ***bogus observations*** are generated (winds are assimilated)

2. Advisory minimum sea-level pressure observations are then assimilated with other observations regardless of (1)

Example of Bogus Wind Assimilation

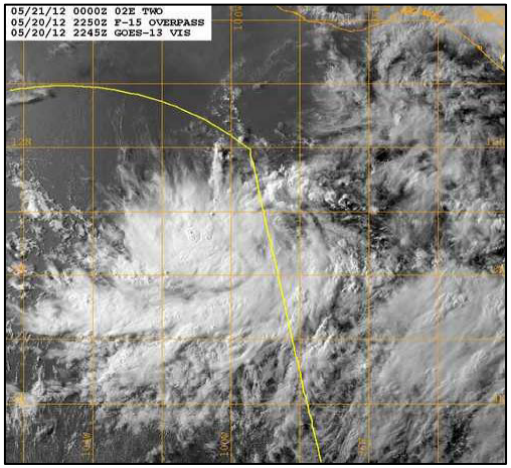
Generally rare in operations, Occurs mainly in genesis situation



Automated tracker "failed" to find coherent vortex to relocate

This can happen because:

- Distance from observation too large
- Too much tilt
- Parameters used to find position misaligned
- Nothing there



For Bud, tracker "failed" and resultant analysis had radically different vortex due to assimilation of bogus winds (and advisory minSLP)

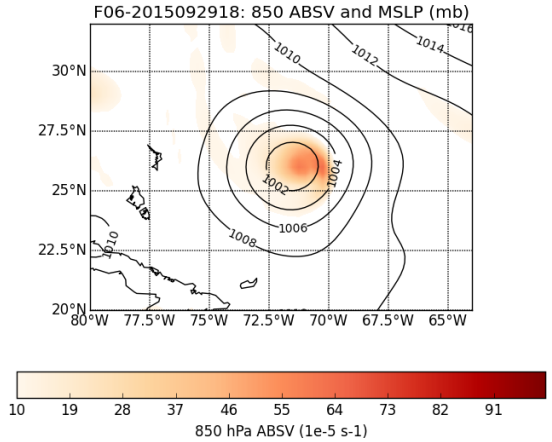
How does Mechanical Relocation Work?

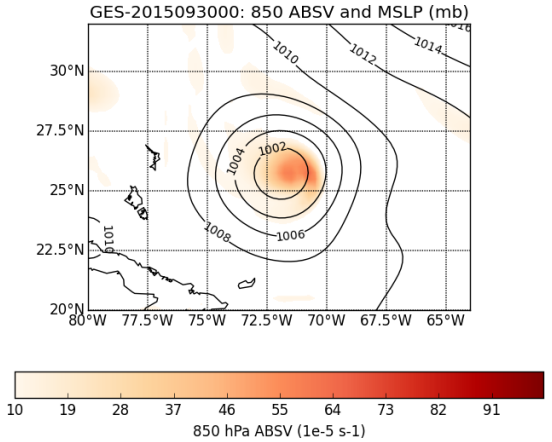
- Locate tropical cyclone vortex in short forecast/background
  - Automated tracker on post-processed regular grid (grib files)
  - Abort process if storm center over major land mass, if terrain >500m, or if relocation distance is too large
- Separate vortex from "environment" (GFDL Filter)
- Move vortex to advisory position
  - This then serves as background for assimilation
- Assimilate observations including advisory minSLP

Impact of Relocation on Joaquin (2015093000)

Move Storm SW by ~0.5 degrees

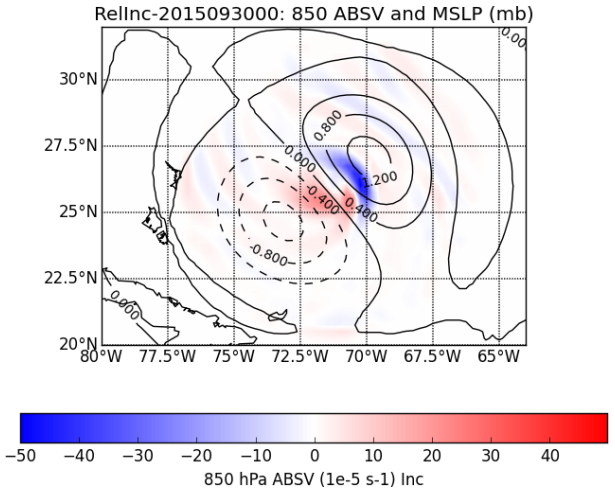
Original F06

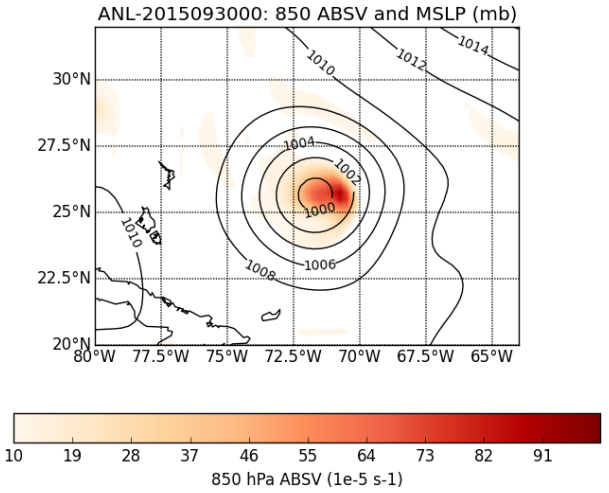




Relocated F06 (Background)

Relocation Increment



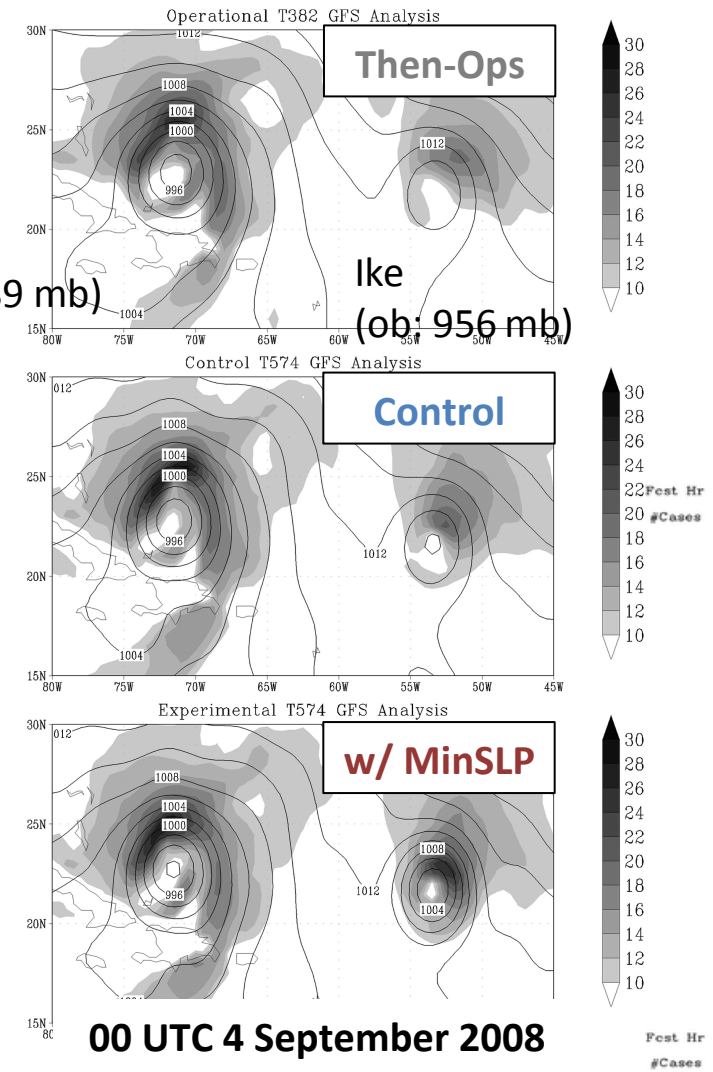


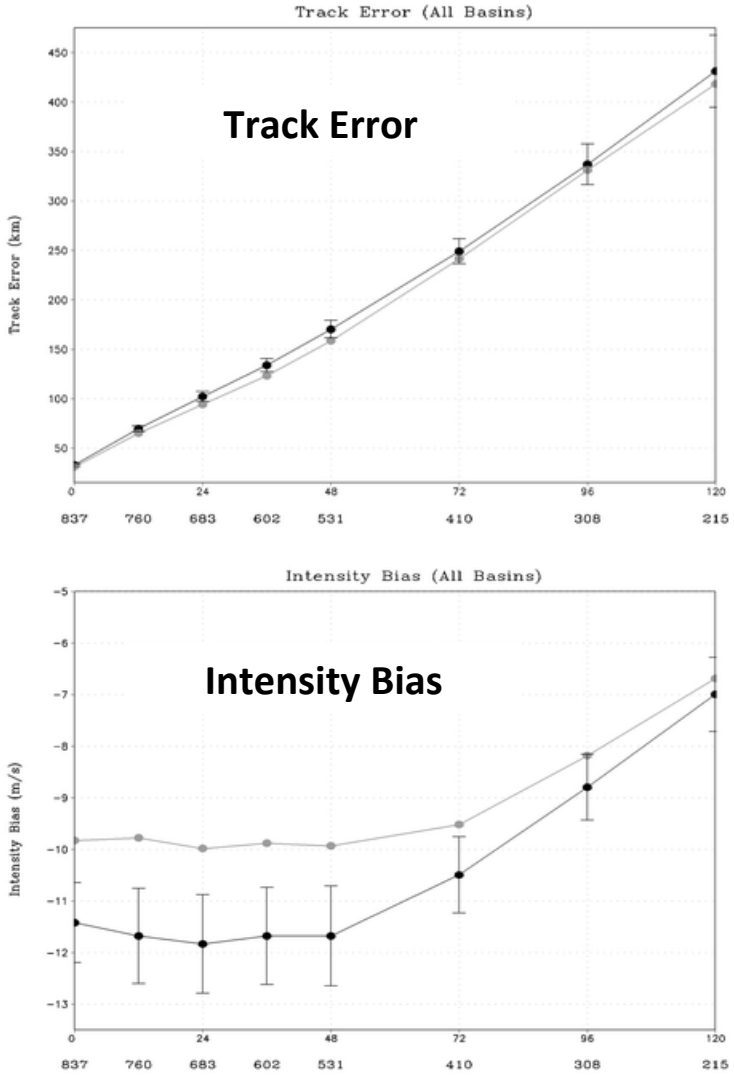
Final Analysis

Advisory MinSLP in GDAS/GFS (Kleist 2011)

Hanna
(ob: 989 mb)

Ike
(ob: 956 mb)





Control

MinSLP

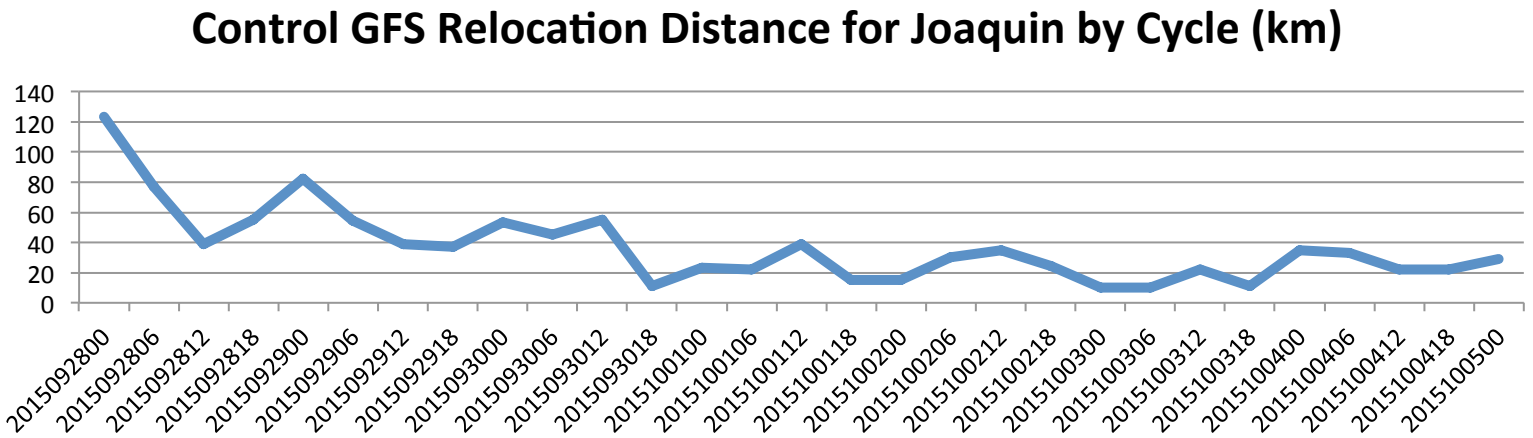
Control

MinSLP

Joaquin (2015) Experiment

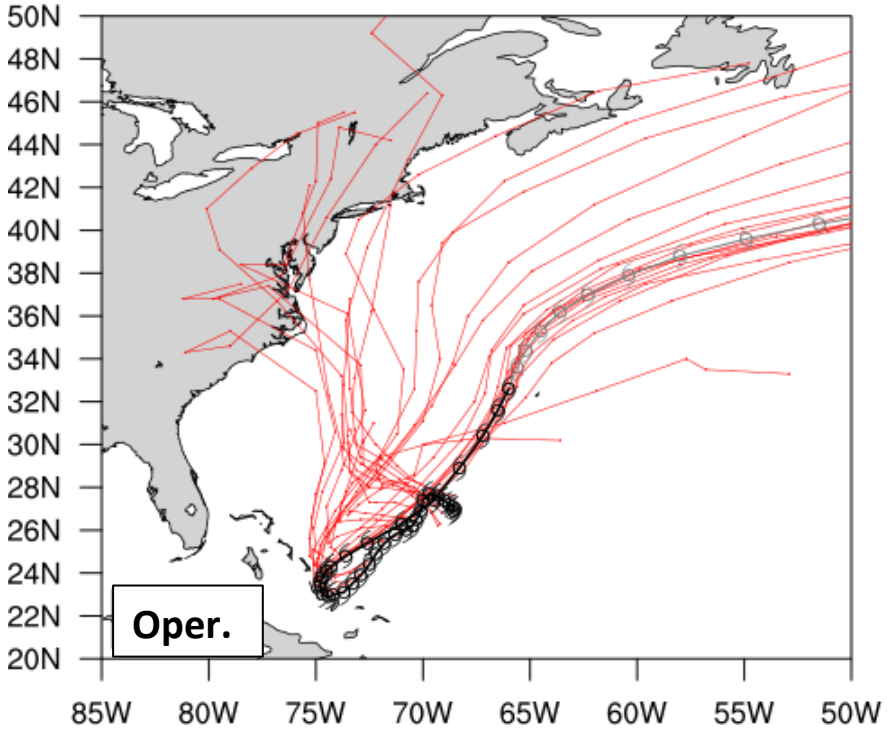
- Motived by some preliminary experiments in 2012 prior to hybrid assimilation implementation in GDAS, decided to carry out a case study on Joaquin
- Fully-cycled (early and late cut-off) T1534L64 GFS with 80 member EnKF-based ensemble for hybrid data assimilation (3D EnVar)
- Control (with relocation) and Experiment (without) started prior to classification of Joaquin as depression
  - For experiment without relocation the effect is cumulative – we are not evaluating the impact of relocation on any individual operational forecast
- Bogus winds were never generated in operations, control, or experiment
- Advisory MinSLP assimilated into hybrid and EnKF for control and experiment

Relocation in Control for Joaquin

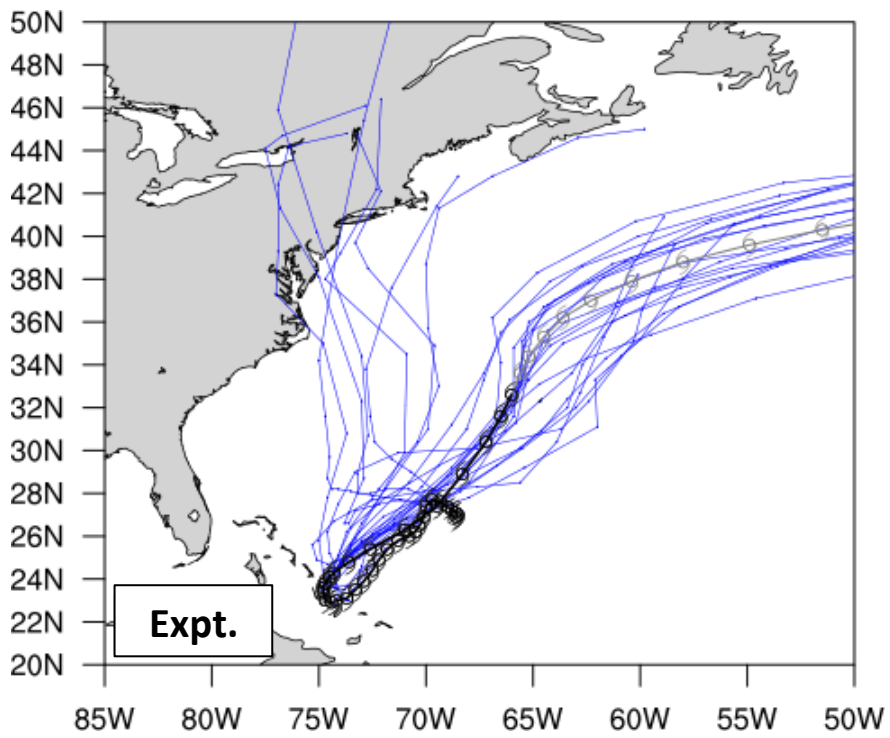


- During depression and TS phase, relocation distance larger than when storm reached hurricane status
- These are approximate – the tracker operates on quarter degree output and relocation is estimated to precision of tenths of degrees
- Also important to keep in mind that NHC analysis position has uncertainty about it as well

Track Summary for Experimental Period

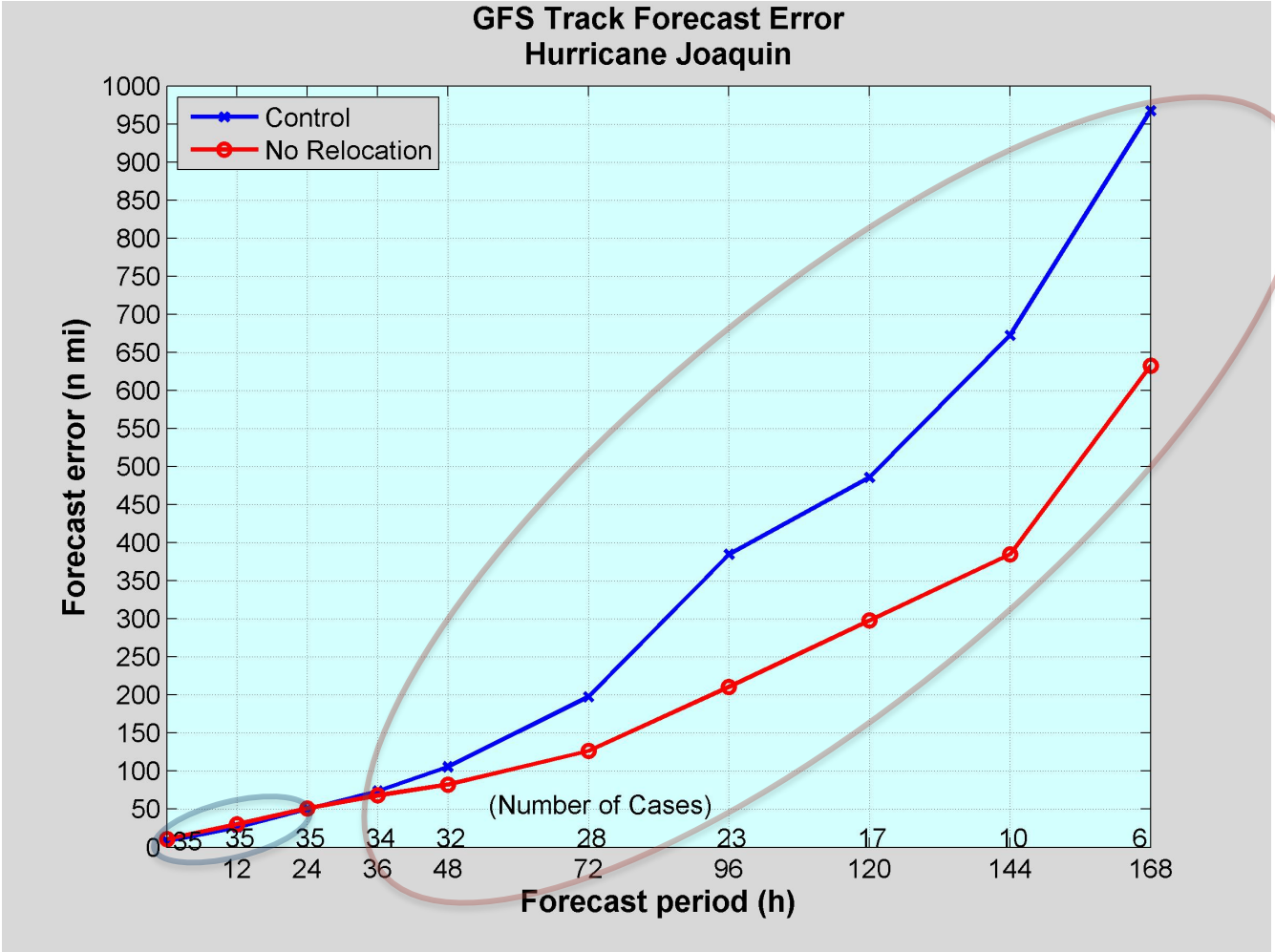


With Relocation



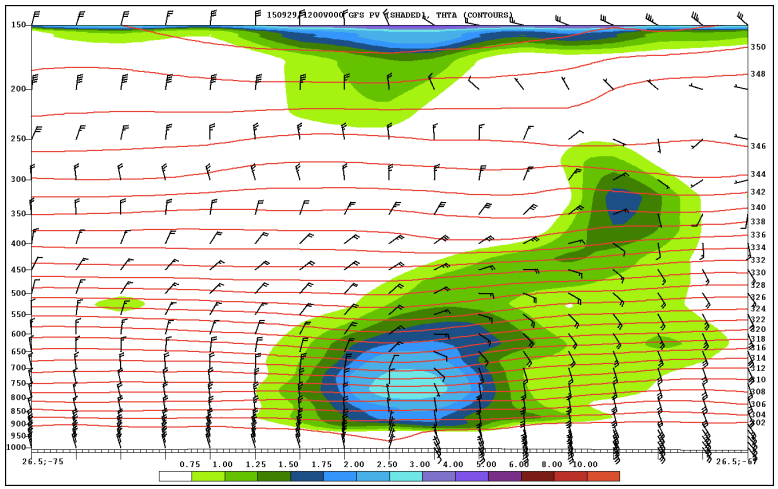
Without Relocation

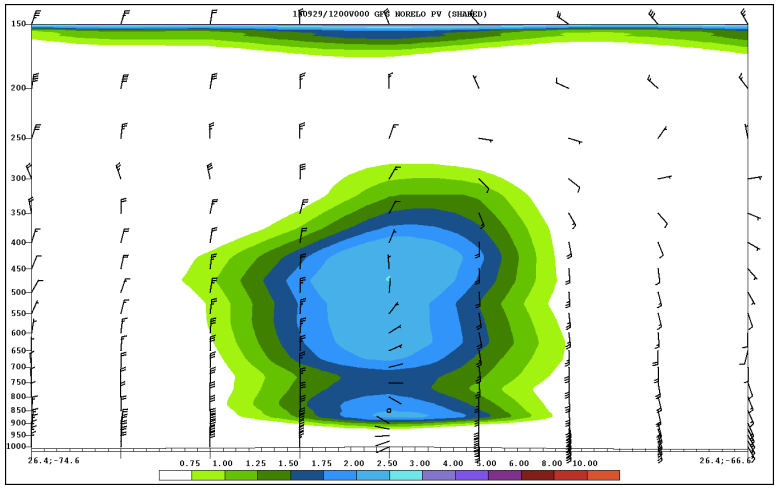
Joaquin Individual Tracks and Mean Errors

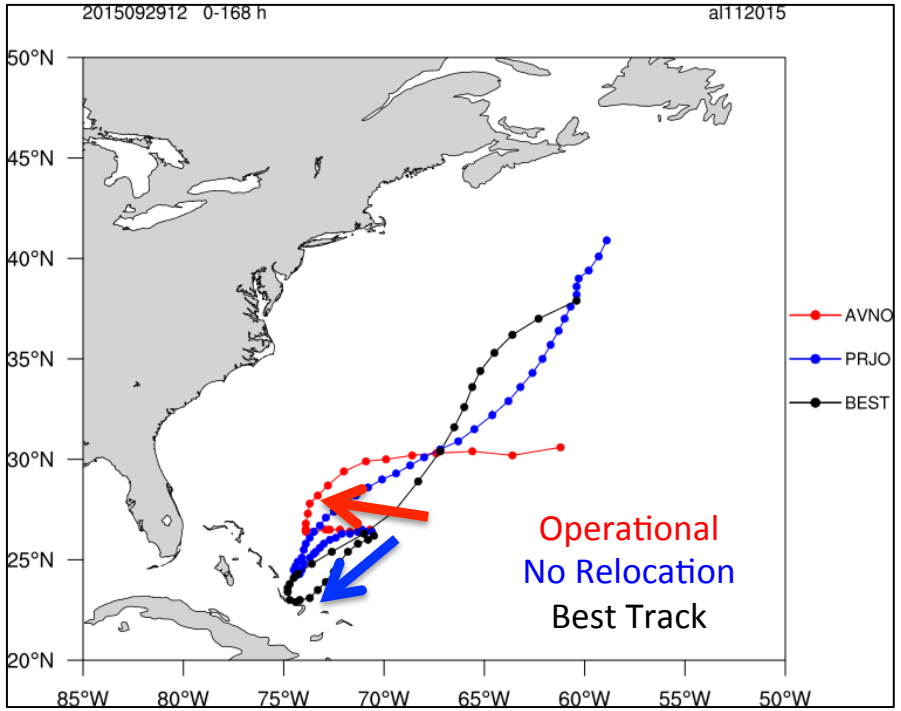


- ***No-relocation runs generally better beyond 24 hours***

29 September 1200 UTC Cycle







Joaquin Summary and Next Steps

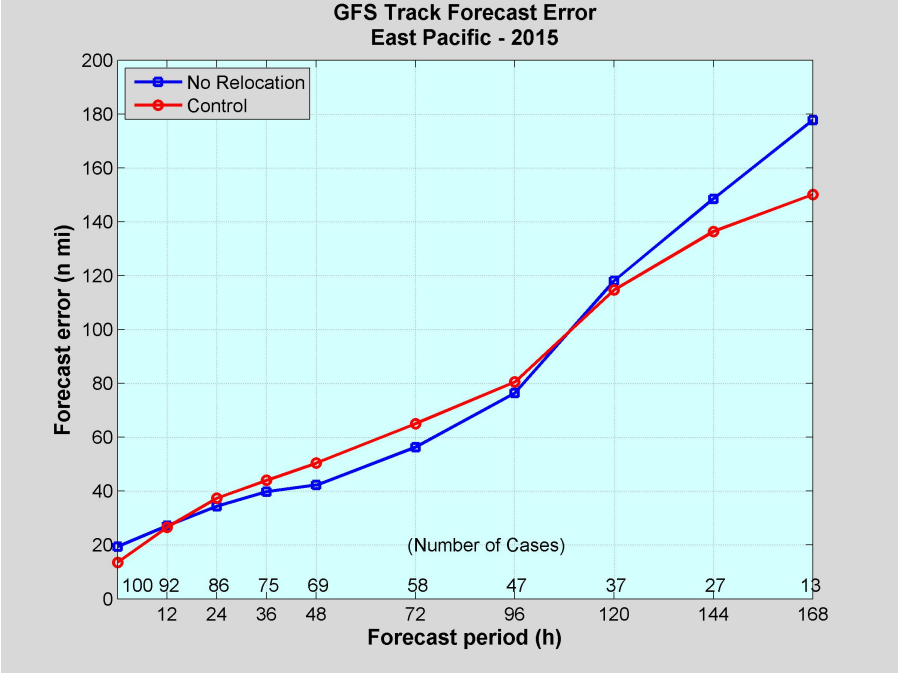
- Operational GFS/GDAS utilizes complex combination of bogusing, vortex relocation, and advisory minSLP assimilation for TC initialization

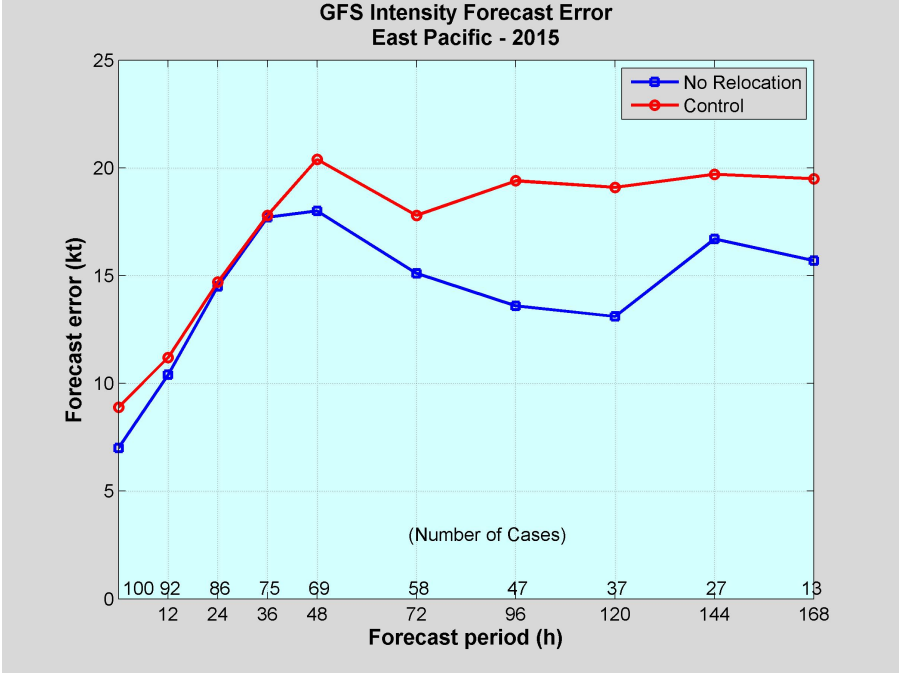
- However, case study reveals that current vortex relocation scheme detrimental to Joaquin forecasts
  - Post-genesis period: no-relocation run better captured SW movement
  - During intensification period, no-relocation run much better predicting eastward track (aside from one particular cycle)
  - After 2 October 0600 UTC, experiment and control similar

- ****** This study has prompted some effort to improve the relocation itself (Qingfu Liu, work ongoing)***

- 2015 Season-Long experiments at T1534L64 (T574L64 80 mem ensemble) with hybrid 4DEnVar underway on Cray
  - No relocation or bogus winds

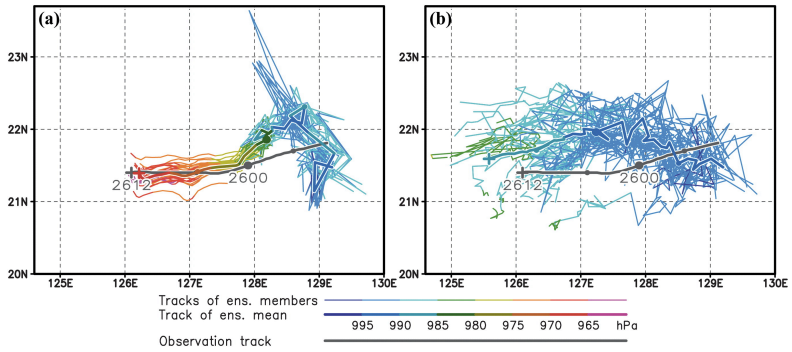
EPAC (Very) Preliminary Results





Assimilation of "Storm Information": Two Possible Solutions

- Direct assimilation of position (and possibly size)
  - Very successful within context of Ensemble Kalman Filter (Chen and Snyder 2007; Wu et al. 2010; Kunii 2015)
  - Non-trivial to develop observation operators for variational assimilation



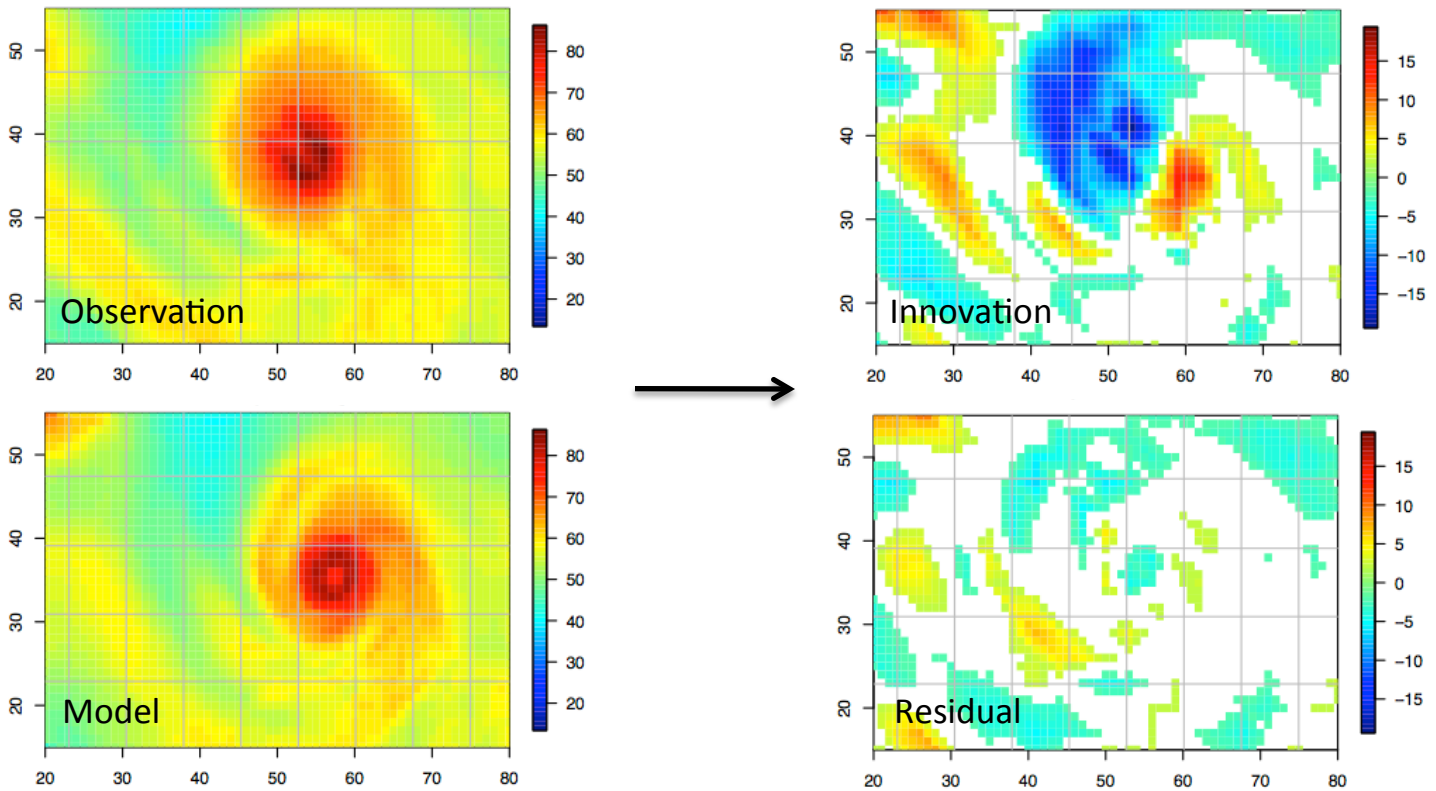
From Wu et al. (2010)

- "Displacement Assimilation" (FCA: Feature Calibration and Alignment)
  - Potentially more general solution applicable to other "features" besides tropical cyclones
  - Originally implemented into WRFDA, JCSDA project to work on porting to GSI
  - dWRF utilizes Feature Alignment Technique of FCA within WRFVAR framework

Field Alignment Technique in WRFDA

- Allow assimilation to operate in two distinct modes
  - Additive increments
  - To compute displacement vectors only
- Utilize observation operators that already exist
  - Full use of observing system to drive displacement computations
- This would then have application to more general, not TC vortex applications (clouds, fronts, etc.)

Displacement in WRF: dWRF
Courtesy Tom Auligne (OSSE study of Katrina)



Integrated Water Vapor

IWV Difference (and displacement vectors)

From: Nehrkorn, Woods, Auligné and Hoffman (MWR 2014)
DOI: 10.1175/MWR-D-14-00127.1

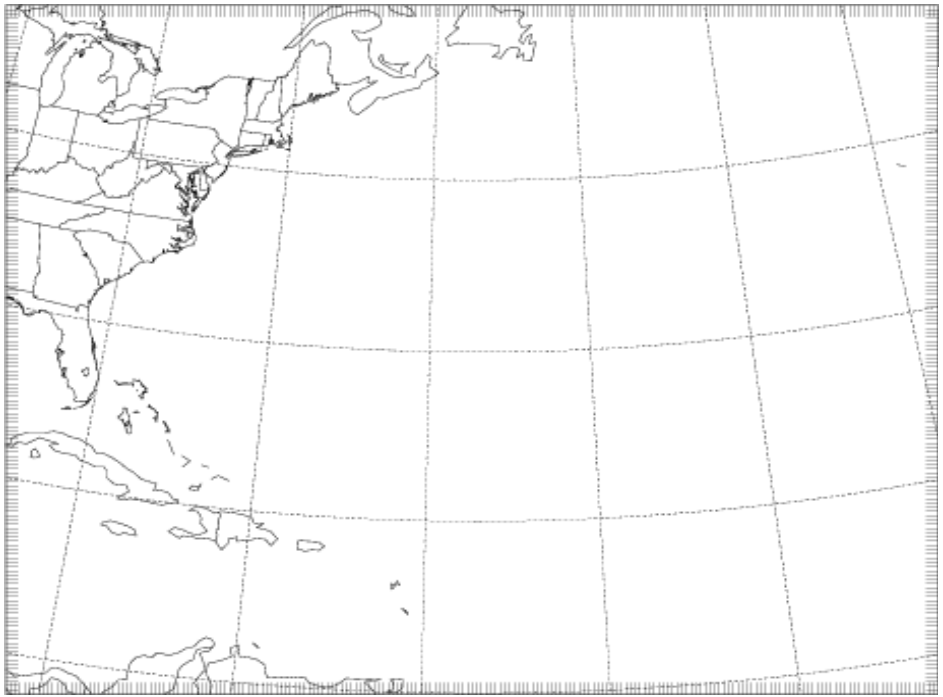
Toward Testing for Real Case

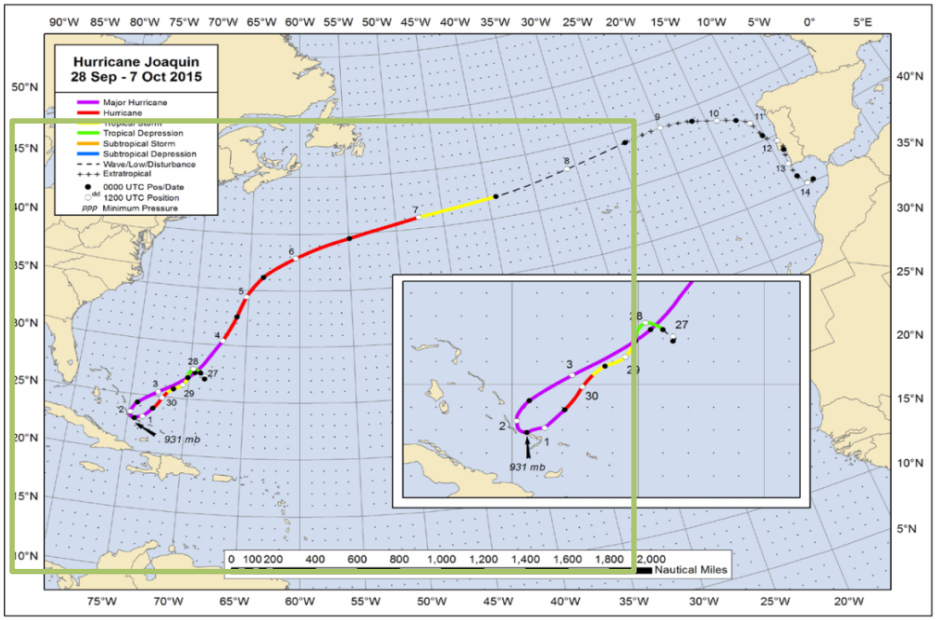
- Before moving to install into GSI, hope to demonstrate applicability to real case with dWRF/WRFDA

- Hurricane Joaquin (2015) selected as first test case, completing a hierarchy of test simulations
  - Cold start WRF runs with GFS initial conditions
  - Ensemble WRF integrations from GFS initial conditions and pseudo-random initial perturbations
  - WRFVAR 3DVAR cycling

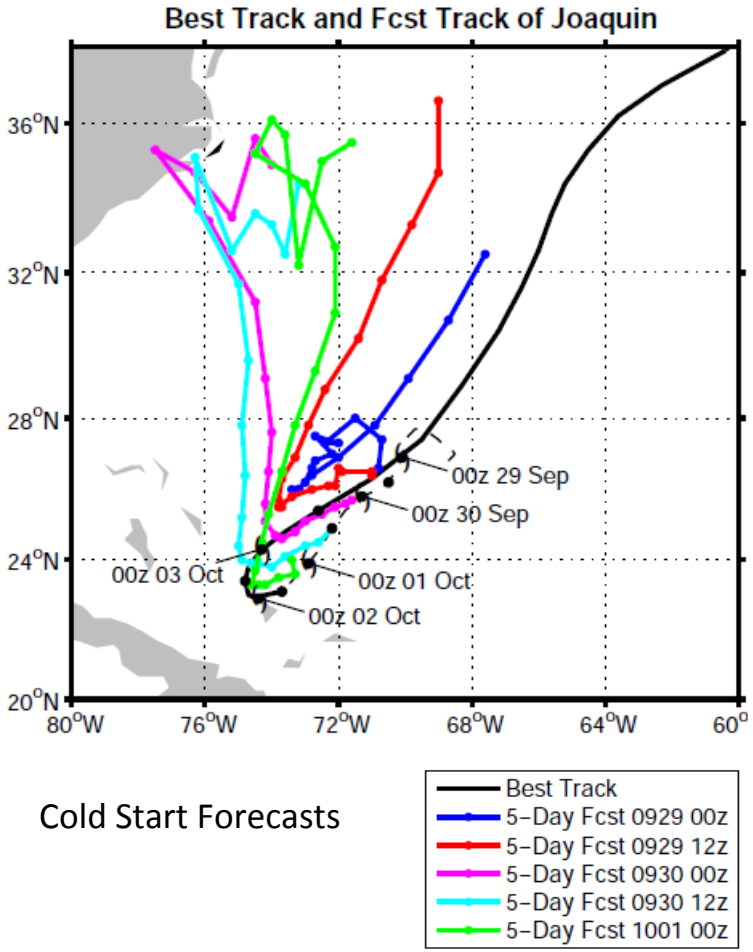
WRF/WRFDA Case Study of Hurricane Joaquin (2015)

Setup	Description
Fcst model	WRF Version 3.7.1
DA system	WRFDA Version 3.7.1
Grid/ Resolution	260 x 420 x 36 levels / 21 km
Initial fields	Cold start from GFS analysis (0.5 x 0.5 degrees)

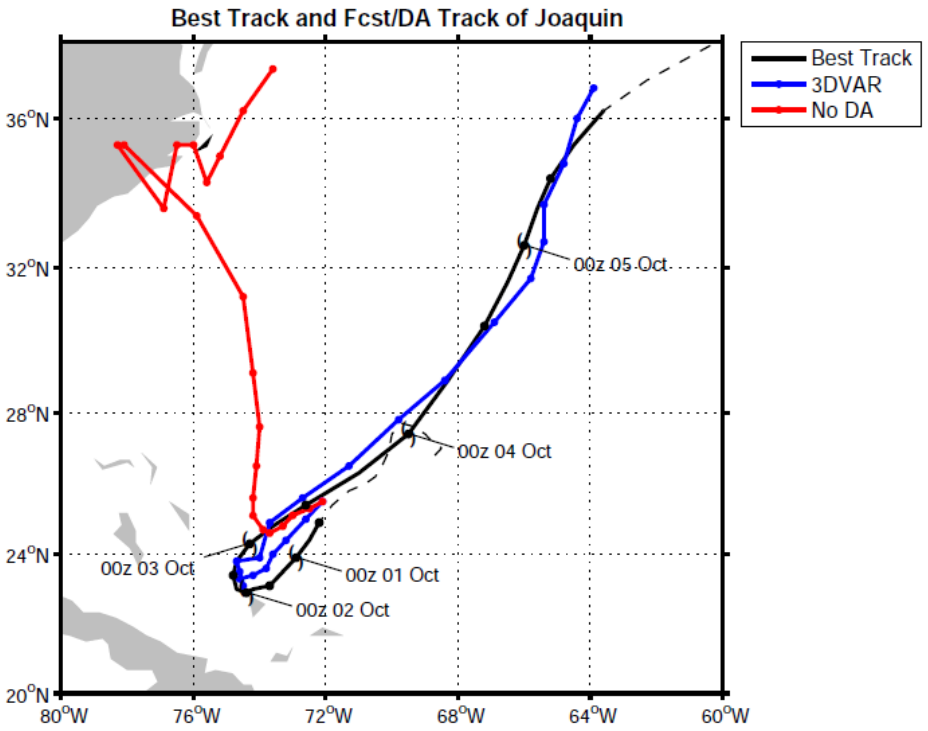




Deterministic Forecast Track Examples



Cold Start Forecasts



3DVAR cycle, forecasts initialized 2015093012

Next Steps for Joaquin Case Study

- Utilize ensemble in hybrid assimilation mode (perhaps 4D)
  - Extend to warm start WRF ensemble with EnKF update
- Assimilation of satellite data and vitals minimum sea level pressure
- Attempt to use dWRF application
  - First as stand alone initialization technique
  - Then, as two-step (displacement + additive) process
- If successful, accelerate transition of software installation into GSI
  - Already underway via JCSDA project.

Project Status

- Direction of project has change slightly
  - Deeper evaluation of relocation process to gain better understanding of potential path forward
  - Toward displacement/Field Alignment Technique as more general solution instead of position assimilation in var

- Current team
  - Close collaboration with EMC and NHC on various fronts
  - One PhD student started in 9/15, bringing on another team member in 9/16 to accelerate research

- Risks/Issues
  - Currently leveraging some JCSDA researchers for graduate student. Access to other resources? How to best assist with transition to operations?

Plans / Directions

- Immediate/Short-Term
  - Continue evaluation of relocation sensitivity experiments
  - Assist in evaluation of impact of IAU on tropical storms in GFS/GDAS
  - Implement assimilation assimilation for EnKF to improve ensemble covariance representations

- Big Picture
  - Test dWRF for Joaquin
  - Contribute to development of "dGSI"
  - Tests with GFS/GDAS and potentially for HWRF
    - Likely case studies pending resources
  - Applicability of scale-dependent localization (currently part of separate project)

- Other small contributions
  - Use of more frequent position fixes from NHC (3 hourly) to constraint 4D EnVar in GFS/GDAS
    - Already available in real-time, some coding will need to be done to utilize

Relation to NGGPS, Deliverables

- Main objective is to streamline and generalize TC initialization in GFS/GDAS by using ***data assimilation*** and test applicability of solution to other NOAA models
  - Field alignment has potential to be best, general solution
- Reduced tropical cyclone errors

- To transition to EMC:
  - Recommendation on use of mechanical relocation (at least for GDAS)
  - Position assimilation for EnKF
  - Software to utilize 3 hourly fixes in GSI
  - Testing of displacement technique for real cases
  - Assist in software development for performing displacement assimilation in GSI (similar to dWRF)
    - Coordinate with JCSDA

Questions and Discussion?

- Thank you to NOAA for the opportunity to continue to work on operationally applicable research.

- Thanks especially to collaborators at JCSDA, NCEP/EMC, and NCEP/NHC.