Overview of NRL TCI Research

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Sponsor: Office of Naval Research

Hurricane Patricia from the NASA WB-57 (Joe Gerky, Pilot)

NRL-Monterey TCI Research

Convective Envelopes in TCs

- **Dave Ryglicki, Jim Doyle**
- **Objective:** Investigate ~4 h convective bursts in sheared TCs
- **Technical Approach:**

➢ Idealized modeling of sheared TCs that undergo rapid intensification

Preliminary Findings

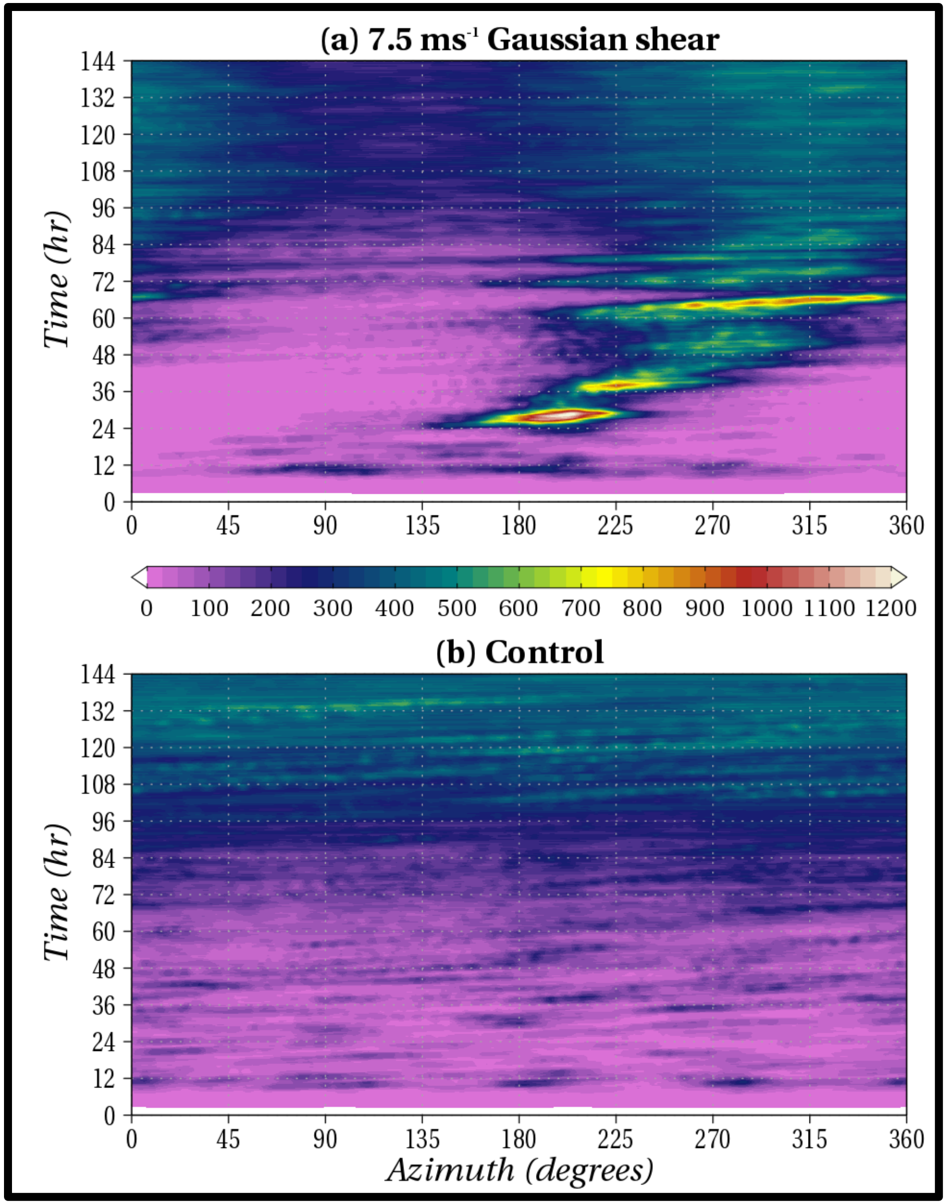
➢ Convective maximum migrates slowly, counter-clockwise

➢ Follows tilt precession

Next Steps

➢ Upper-level impacts of convective aggregates or "envelopes"

➢ Lower- and mid-level impacts of convective envelopes



NRL-Monterey TCI Research
Outflow-Environment Interface

- **Dave Ryglicki, Jim Doyle**
- **Objective:** Investigate Outflow-Environment Interface of sheared TCs undergoing rapid intensification
- **Technical Approach:**

➢ Idealized modeling of sheared TCs

Preliminary Findings

➢ Below 11 km, trajectories indicate some entrainment, but some drop to 1 km

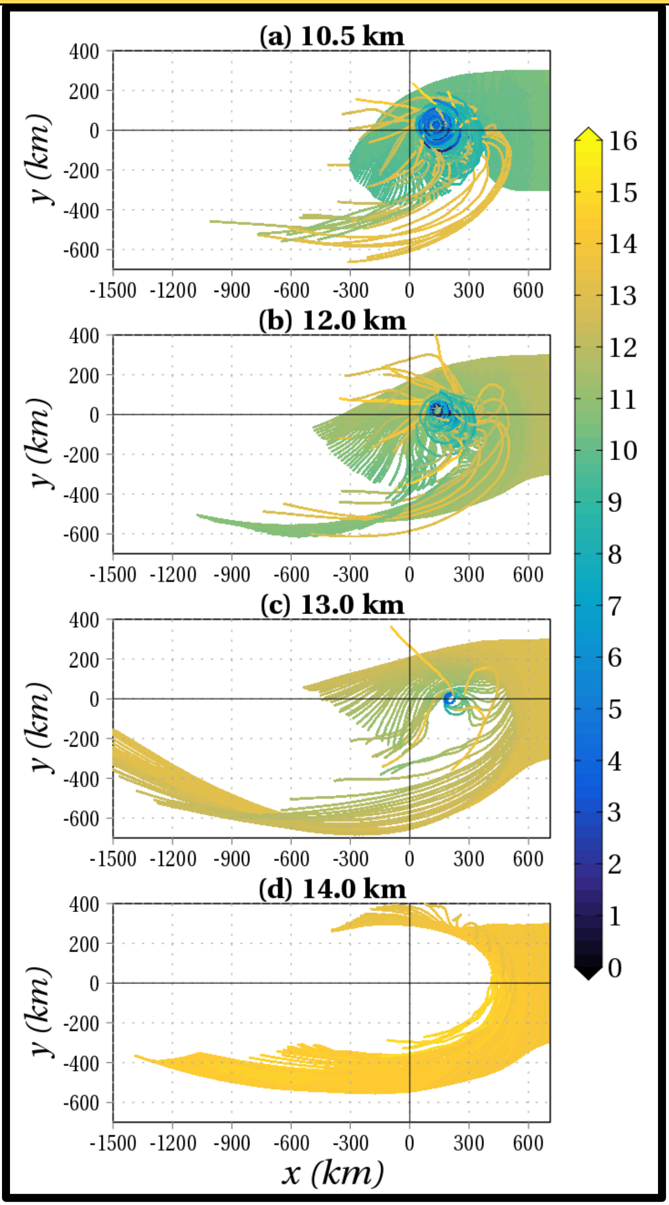
➢ Above 11 km, divergent outflow blocks large part of environmental flow

Next Steps

➢ Statistical analysis of trajectories

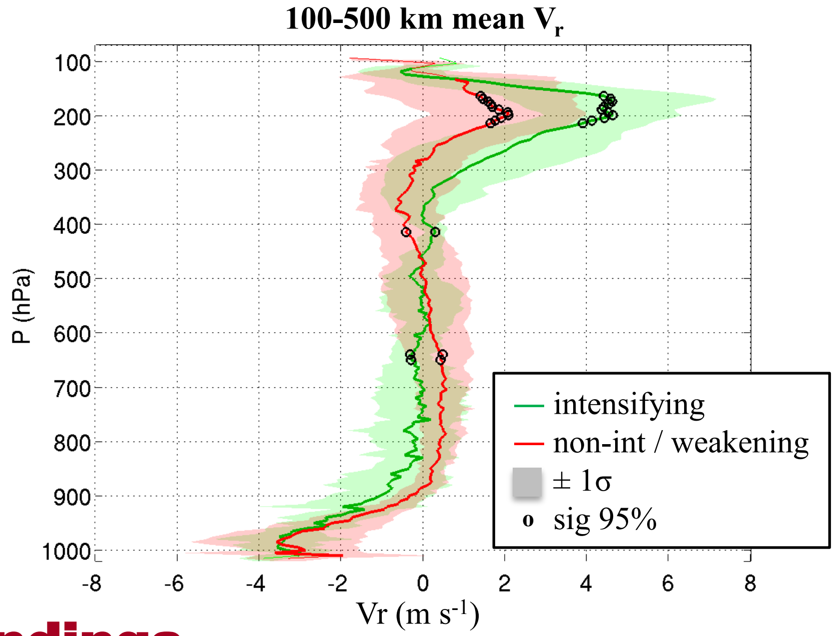
➢ Analyze downstream outflow jet

➢ Theoretical aspects



NRL-Monterey TCI Research
Outflow & Warm Core Structure

- **Will Komaromi, Jim Doyle**
- **Objective:** Investigate structure of outflow and warm core via in-situ observations, relate outflow to inner core
- **Technical Approach:**
  - ➢ Interpolate TCI & HS3 drops to 3D grids
  - ➢ Composite sondes over multiple cases: strong vs weak; intensifying vs weakening TCs



Preliminary Findings

- ➢ Intensifying TCs associated with stronger upper-level divergence and radial outflow than non-intensifying TCs, regardless of current intensity
- ➢ Layer of 2-4 m s^{-1} inflow 20-50 hPa deep observed above outflow, associated with lower-stratospheric descent above the eye

Next Steps

- ➢ Results revised and re-submitted to MWR
- ➢ Incorporate additional obs for further analysis of Joaquin & Patricia outflow

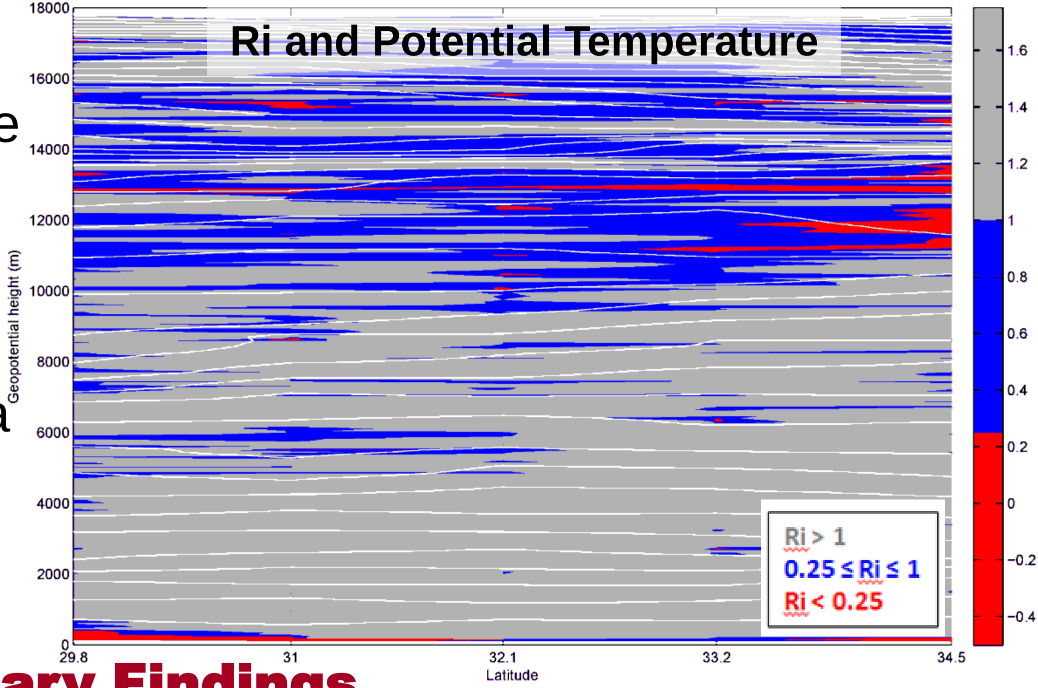
NRL-Monterey TCI Research

Outflow Criticality

- **Jon Moskaitis, Jim Doyle**
- **Objective:** Investigate structure of outflow, vertical shear, stability, tropopause, Richardson number
- **Technical Approach:**

➢ Utilize TCI & HS3 dropsonde data

➢ Analysis of Ri diagnostics & compare with model forecasts



Preliminary Findings

➢ Layers with Ri<1 above jet and below jet

➢ Models (COAMPS) under-forecast strength of shear & stability jump at the tropopause; Ri too large. Implications for Emanuel & Rotunno theory?

Next Steps

➢ Continue analysis for TCI storms, particularly Joaquin, SHOUT analysis

➢ Publish result from HS3, TCI, SHOUT

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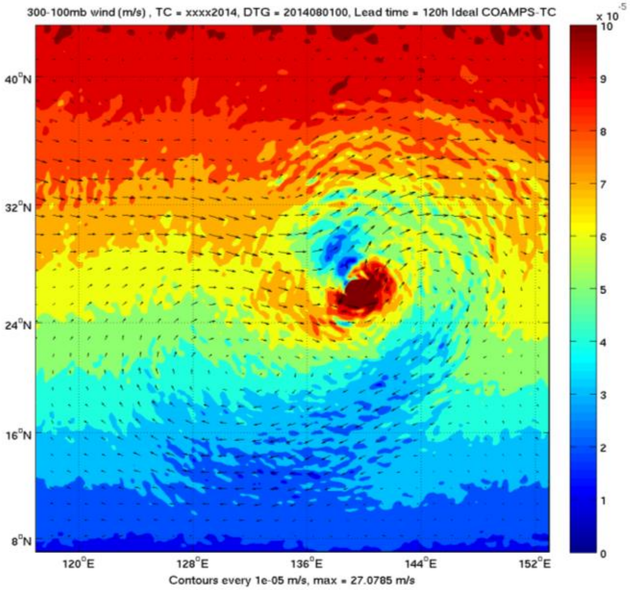
TC-Trough and Outflow Interactions



300-100 mb mean wind (vectors) and inertial stability (shaded) at time of peak intensity

- **Will Komaromi, Jim Doyle**
- **Objective:** Understand physical mechanisms of trough interaction & TC intensification
- **Technical Approach:**

➢ Initialize TC south of a zonal jet and/or configurable trough in geostrophic balance

➢ Explore sensitivity to initial vortex, location and strength of trough, SST, physics

Preliminary Findings

➢ Storm intensity very sensitive to distance between TC and trough

➢ Optimal spacing reduces inertial stability in region of enhanced upper-level divergence N of TC; trough still far enough from TC to not increase shear

Next Steps

➢ Additional sensitivity tests, further analysis

➢ Publish results

NRL-Monterey TCI Research

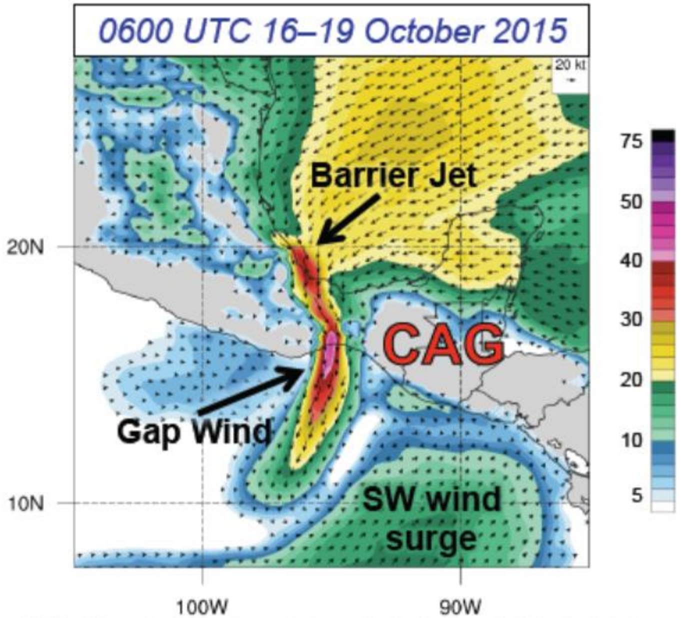
Genesis of Patricia

- **M. Peng, J. Doyle, H. Jin, L. Bosart (SUNY-Albany)**
- **Objective:** Explore the role of gap flow in the genesis of Patricia.
- **Technical Approach:**

➢ Dropsonde analysis (document the structure of the outflow jet)

➢ High-resolution real-data simulations using COAMPS (1.7 km or less)

Northerly Gap Winds



925-hPa wind (vectors, kt) and wind speed (shaded, kt)

From Lance Bosart

Preliminary Findings

➢ Strong gap flow may have contributed to the spin-up of vorticity due to the strong northerly gap flow in Gulf of Tehuantepec

Next Steps

➢ High-resolution COAMPS simulations

➢ Analysis of HDSS dropsondes, particularly on 20 October

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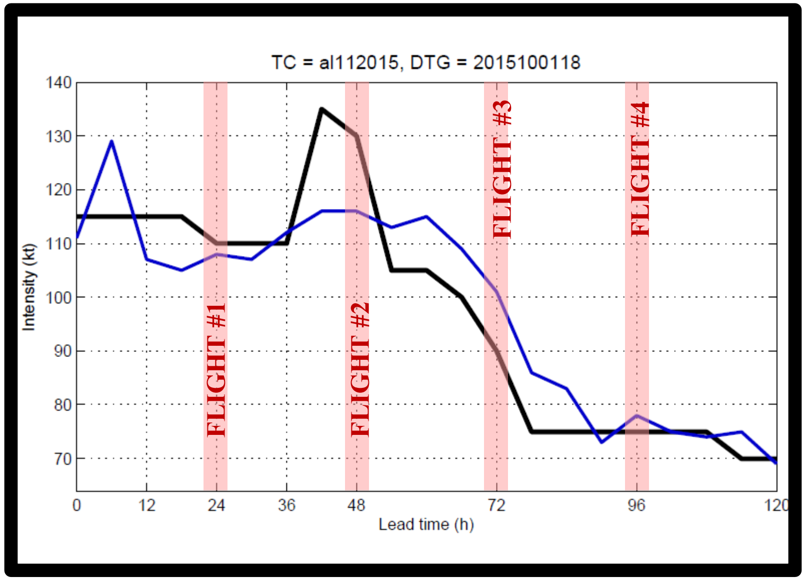
Real-time COAMPS-TC during TCI

- **Jon Moskaitis, Rich Hodur**
  Jim Doyle, COAMPS-TC Team
- **Objective:** Understand performance of real-time forecasts; identify forecasts for detailed comparison with TCI obs
- **Technical Approach:**

➢ Track, intensity, structure evaluation



Preliminary Findings

➢ Forecasts are available with accurate track and intensity in the short-range. Appropriate for examination of detailed structure of outflow layer, inner core, and surface wind field using TCI observations

Next Steps

➢ Model forecast vs. TCI data comparison

➢ Collaborate with those interested in COAMPS-TC model validation

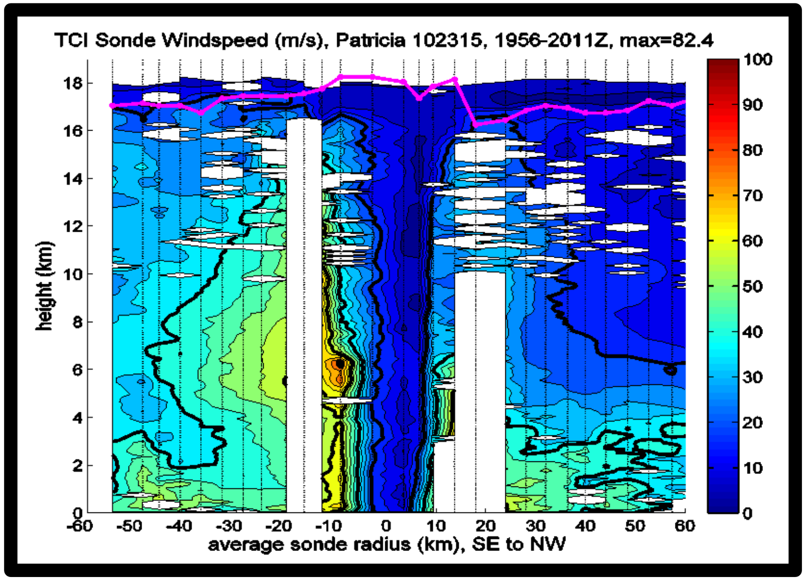
NRL-Monterey TCI Research

Atypical Mid-Level Wind Speed Maxima

- **Daniel Stern, Jim Doyle, George Bryan, Jeff Kepert**
- **Objective:** Understand the dynamics of mid-level wind maxima that have been observed in Patricia and several other intense/small TCs.
- **Technical Approach:**

➢ TCI Dropsondes, P3 Doppler Radar

➢ Idealized Simulations with CM1



Preliminary Findings

➢ Intense and/or small TCs may have mid-level max. in eyewall wind speed.

➢ Simulations reproduce mid-level max., which is due to unbalanced flows.

Next Steps

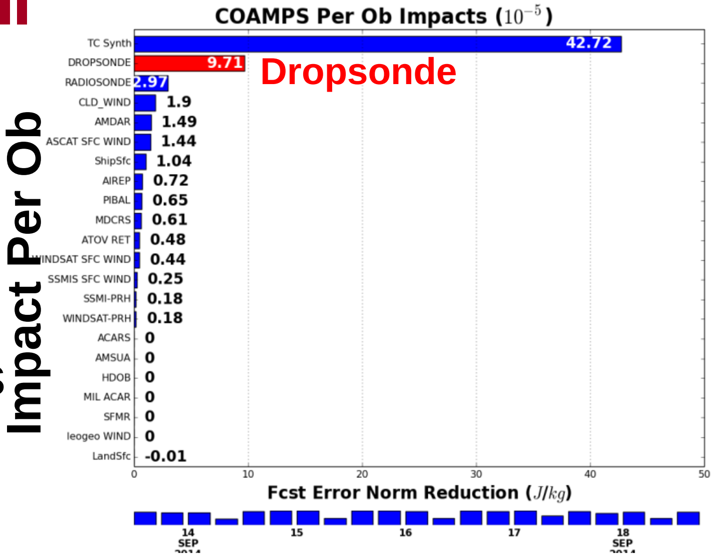
➢ Use a boundary layer model to diagnose the effect of surface friction on driving the unbalanced jets that are responsible for the wind maxima.

NRL-Monterey TCI Research
Observation Impact

- **J. Doyle, C. Amerault, X. Wang, D. Cecil**
  C. Velden, D. Tyndall
- **Objective:** Quantify the forecast impact of HDSS dropsondes, AMV, HIRAD observations
- **Technical Approach:**

➢ Utilize 4D-Var, perform data denial experiments

➢ Utilize COAMPS 4D-Var adjoint-based observation impact capability



➢ Inform assessment of frequency and spacing requirements for dropsondes

Preliminary Findings

➢ Prototype experiments assimilating dropsondes in 3D-Var for Hurricane Joaquin and assessment of impact (inconclusive so far)

➢ Dropsonde impact of other TCI storms underway

Next Steps

➢ Ensembled based DA for TCI (in collaboration with OU)

➢ Impact of AMVs on outflow structure, and track and intensity for TCI TCs

NRL-Monterey TCI Research

Initial State Sensitivity and Predictability

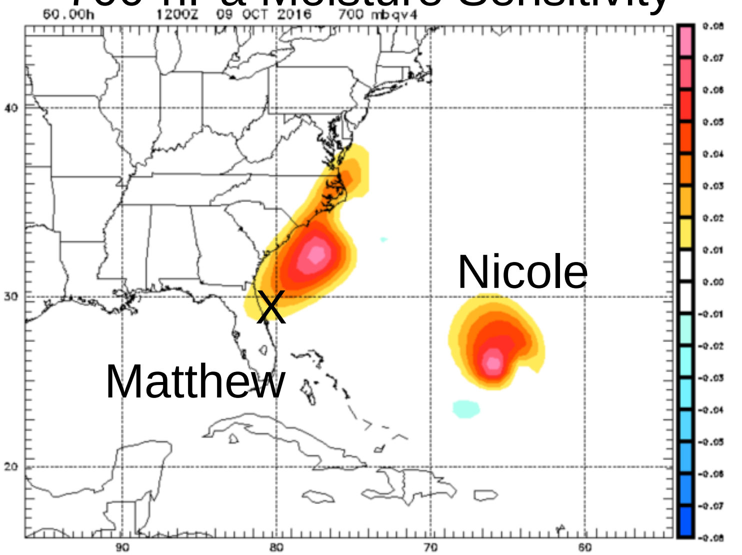
- **J. Doyle, W. Komaromi, D. Holdaway (NASA), S. Majumdar (UM)**
- **Objective:** Quantify sensitivity of predicted TC track, intensity, & outflow to initial state.
- **Technical Approach:**

➢ Nested COAMPS adjoint sensitivity using microphysics and hurricane PBL

➢ Real-time sensitivities for SHOUT, TCI, HS3

➢ New cost functions: Vorticity, PV, P’, KE

700-hPa Moisture Sensitivity



Preliminary Findings

➢ Real-time sensitivities for SHOUT in close agreement with ECMWF & HWRF ensemble sensitivities (from R. Torn)

➢ Moisture sensitivity is large in Patricia; Interesting synoptic-scale sensitivity for Joaquin (links to a trough); may explain poor track forecasts

Next Steps

➢ Assimilate TCI, SHOUT observations in sensitive regions; upper levels only

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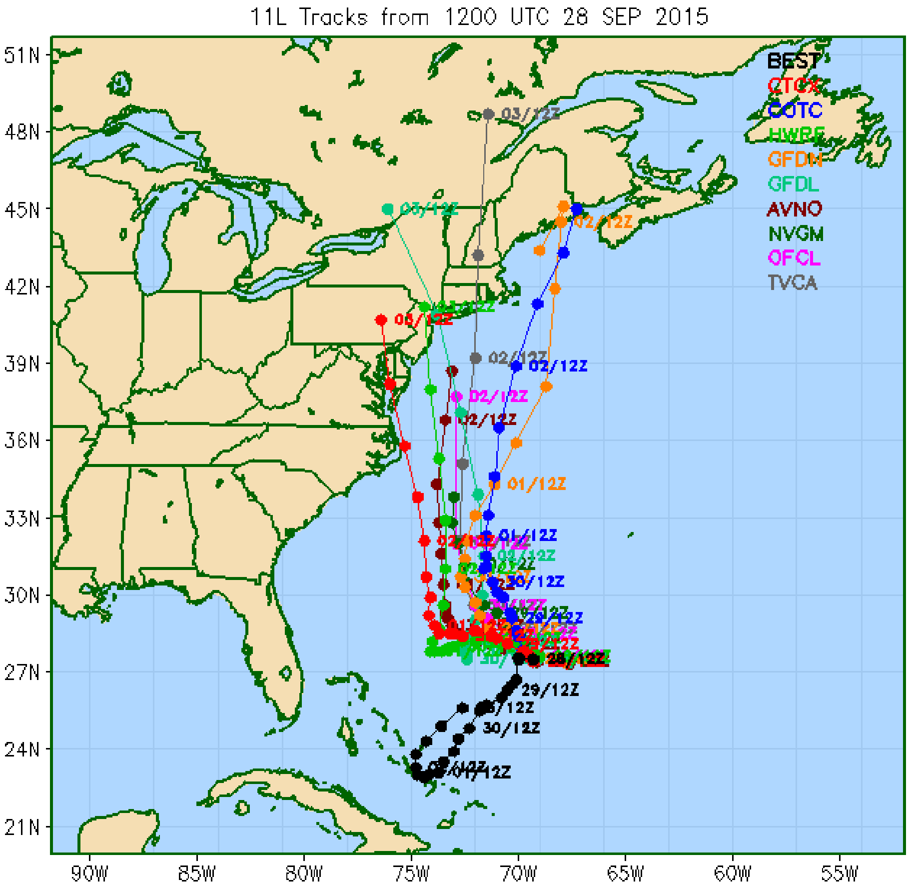
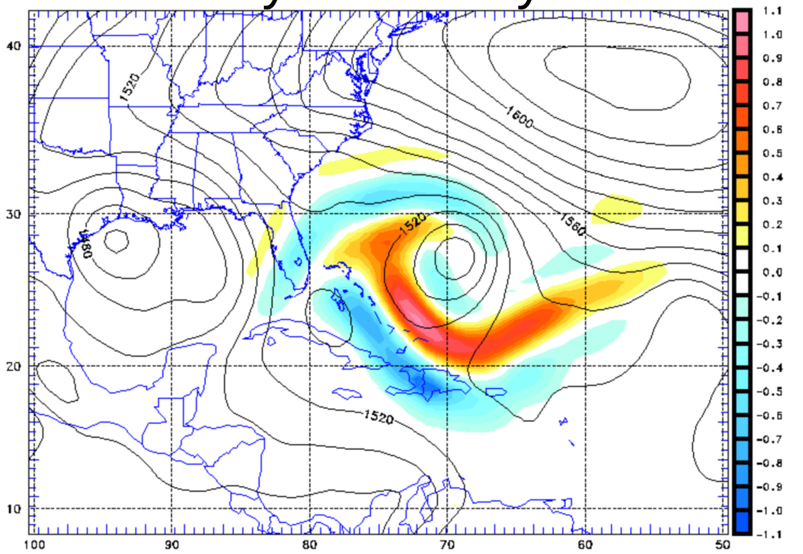
Initial State Sensitivity and Predictability

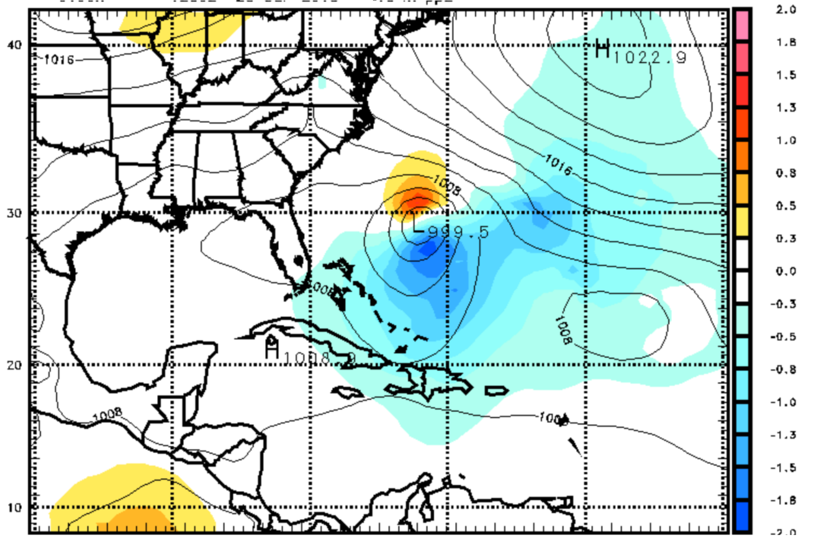
Forecast Tracks and Best Track (black)
12Z 28 Sep 2015 (Joaquin)



36-h Vorticity Sensitivity & Initial SLP



Evolved P' (Color) and SLP 00Z 30 Sep



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Summary

- Analysis of TCI, HS3, SHOUT observations
  - Dropsonde analysis of outflow and structure
  - Dropsonde analysis of outflow criticality
- Idealized modeling
  - Sheared TCs and rapid intensification; Role of outflow
  - TC, outflow, and trough interactions
- Real-data modeling
  - Evaluation of real-time forecasts
  - High-resolution case studies
  - Genesis of Patricia
- Predictability, observation impact, data assimilation
  - Adjoint based COAMPS studies – outflow and TC predictability
  - Data denial and impact studies using 4D-Var and ob-impact tools
  - Ensemble-based data assimilation
- Collaborative projects
  - Patricia structure (CSU, Michael Bell)
  - Ensemble-based data assimilation (OU, Xuguang Wang)
  - Joaquin and Patricia studies (NPS, Eric Hendricks)
  - Predictability (UM, S. Majumdar)

NRL-Monterey TCI Research

NRL TCI Related Journal Papers

Referred Publications

Black, P.G., L. Harrison, M. Beaubien, R. Bluth, H. Jonsson, A. B. Penny, R. W. Smith and J. D. Doyle, 2016: High Definition Sounding System (HDSS) for atmospheric profiling, *J. Atmos. Oceanic Technol.,* To Appear.

Hendricks, E.A., M.A. Kopera, F.X. Giraldo, M.S. Peng, J.D. Doyle, Q. Jiang, 2016: Evaluation of the utility of static and adaptive 1 mesh refinement for idealized tropical cyclone problems in a spectral element shallow water model. Submitted to *Mon. Wea. Rev*.

Hendricks, E.A., Y. Jin, J.R. Moskaitis, J.D. Doyle, M. Peng, C.-C. Wu, H.-C. Kuo, 2016: Numerical simulations of Typhoon 1 Morakot (2009) using a multiply-nested tropical cyclone prediction model. To Appear in *Wea. Forecasting*.

Jiang, Q., P. Sullivan, S. Wang. J.D. Doyle, L. Vincent, 2016: Impact of Swell on Air-Sea momentum flux and Marine Boundary Layer under Low-Wind Conditions. To Appear in *J. Atmos. Sci*.

Komaromi, W.A., and J.D. Doyle, 2016: Tropical cyclone outflow and structure as revealed by high-resolution HS3 dropsonde data. Submitted to *Mon. Wea. Rev*

Penny, A., P. Harr, J.D. Doyle, 2016: Sensitivity to the representation of microphysical processes in numerical simulations during tropical storm formation. To appear in *Mon. Wea. Rev.*

Rabier, F., A.J. Thorpe, A.R. Brown, M. Charron, J.D. Doyle, T.M. Hamill, J. Ishida, B. Lapenta, C.A. Reynolds, M. Satoh, 2015: Global environmental prediction. Chapter in *Seamless Prediction of the Earth System*, edited by G. Brunet. WMO publisher.

Ryglicki, D.R., J. Cossuth, D. Hodyss, J. Doyle, 2016: Temporal patterns of clouds of sheared, rapidly intensifying tropical cyclones in satellite observations. Revised to be submitted to *Mon. Wea. Rev.*