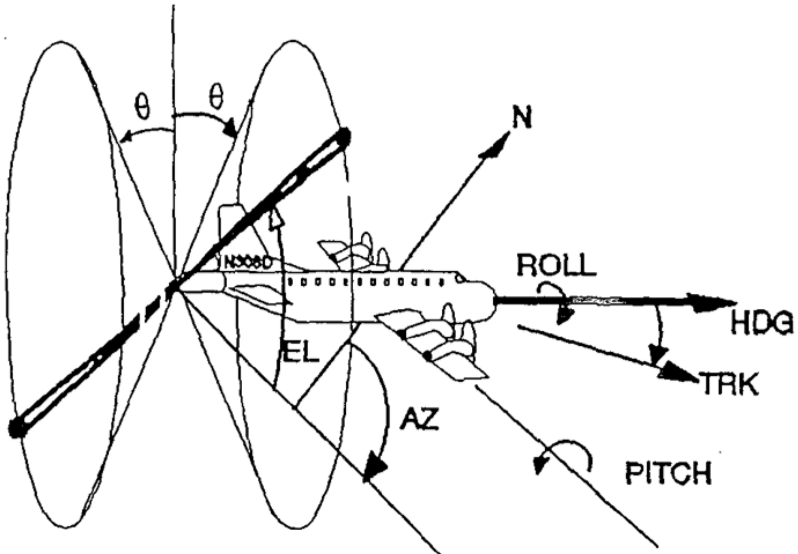
Christopher Melhauser – Group Meeting – 08.17.2015

# A SMÖRGÅSBORD OF MODELING FUN: KARL, ~~SANDY~~, AND EDOUARD

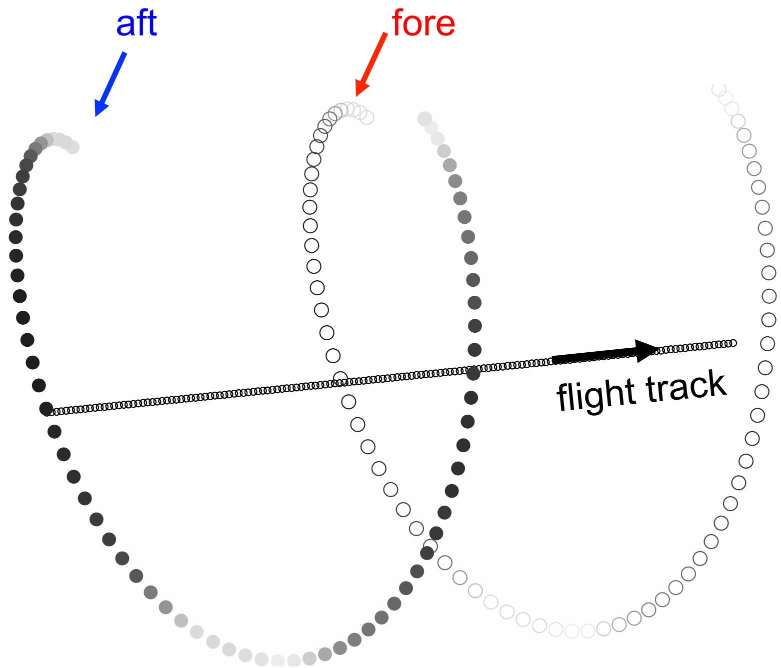
# Research Questions…

- How does assimilating coplane observations impact the forecast track and intensity of Hurricane Karl (2010) during its strengthening period over the Bay of Campeche?
- Is there a benefit of modifying the coplane observation error based on distance from aircraft and elevation angle?

# Coplane Geometry

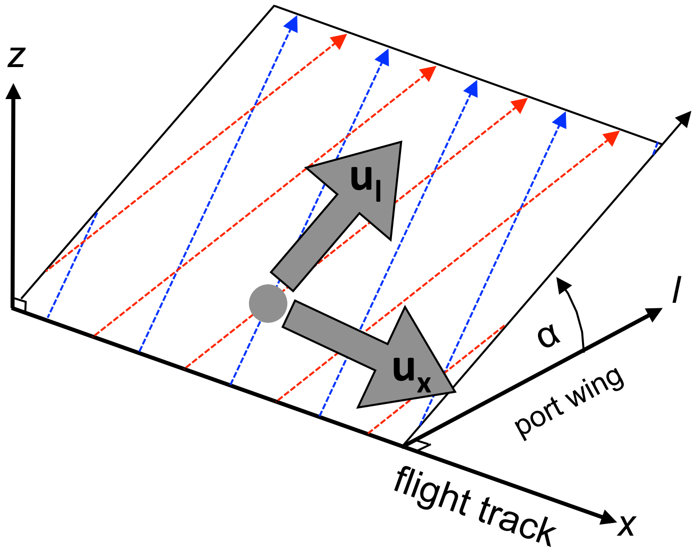


*Chong and Testud (1996)*



- All α-planes:
  - Unambiguously define mean wind component along flight track
- α-lane parallel with wings:
  - Unambiguously define mean horizontal wind component perpendicular to flight track

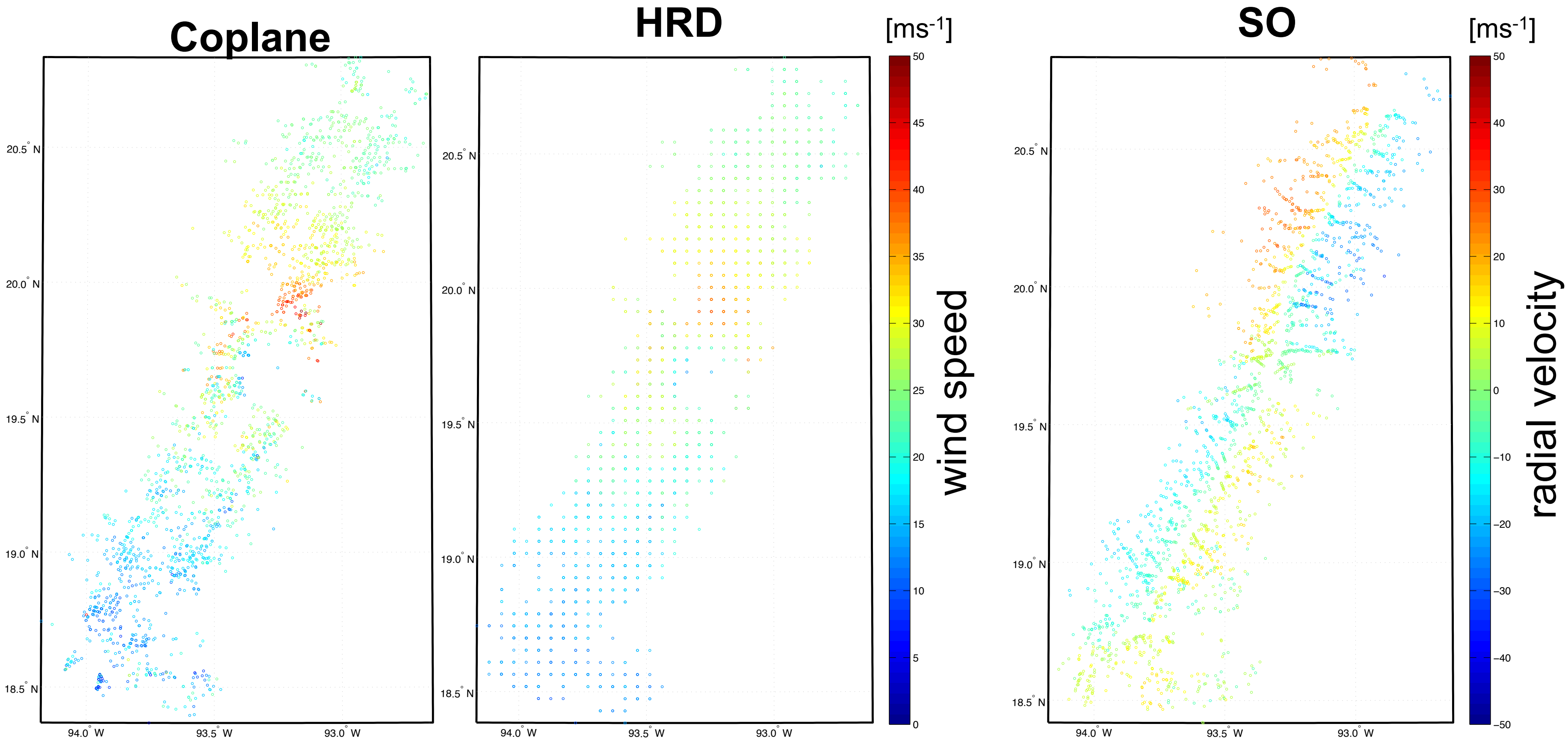
- Exploit geometry to produce low error u- and v-wind estimates



# Example Data Distribution Hurricane Karl (2010) – Flight Leg 1

1800-1900 UTC 16 September 2010

1937 observations



- The same number of observations are used for all observation types
- HRD and SO observations are the closest observations in 3D space to the coplane observations position

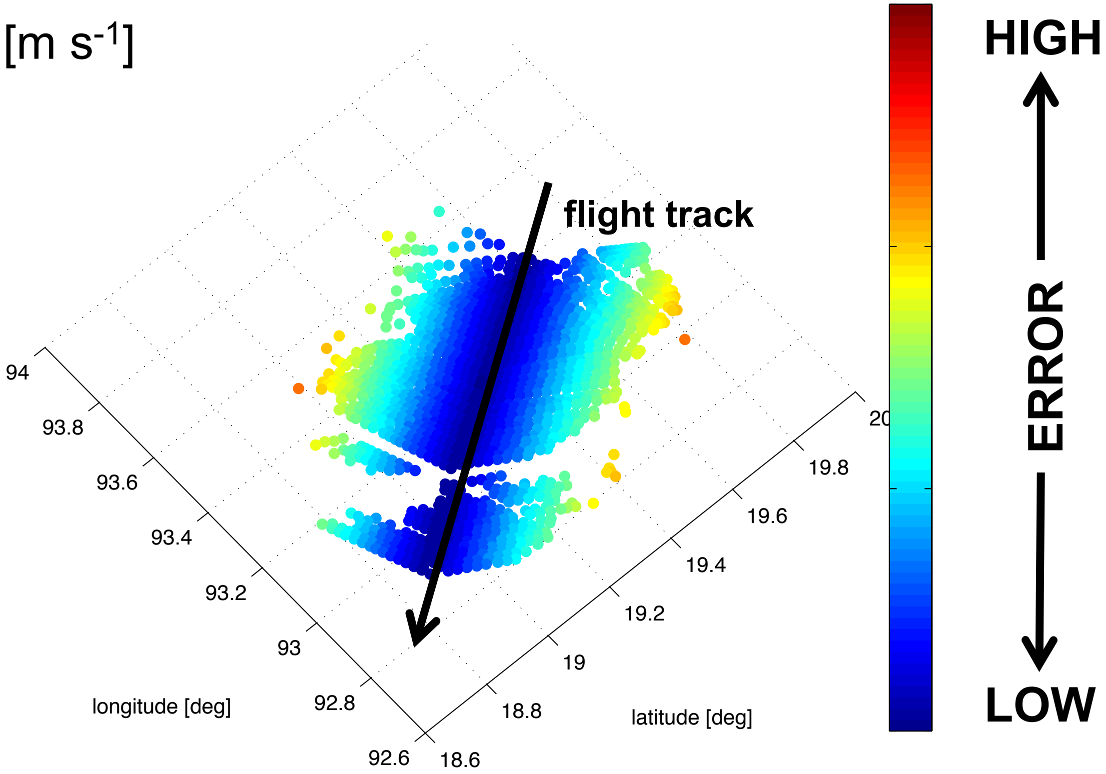
# Error Specification Algorithm

$$Error = Error_{base} + Error_{\alpha} + Error_{\Psi}$$

$$Error_{\alpha} = |\sin\alpha| \cdot maxError_{\alpha}\, , maxError_{\alpha} = 1.5 \quad [\mathrm{m\ s^{-1}}]$$

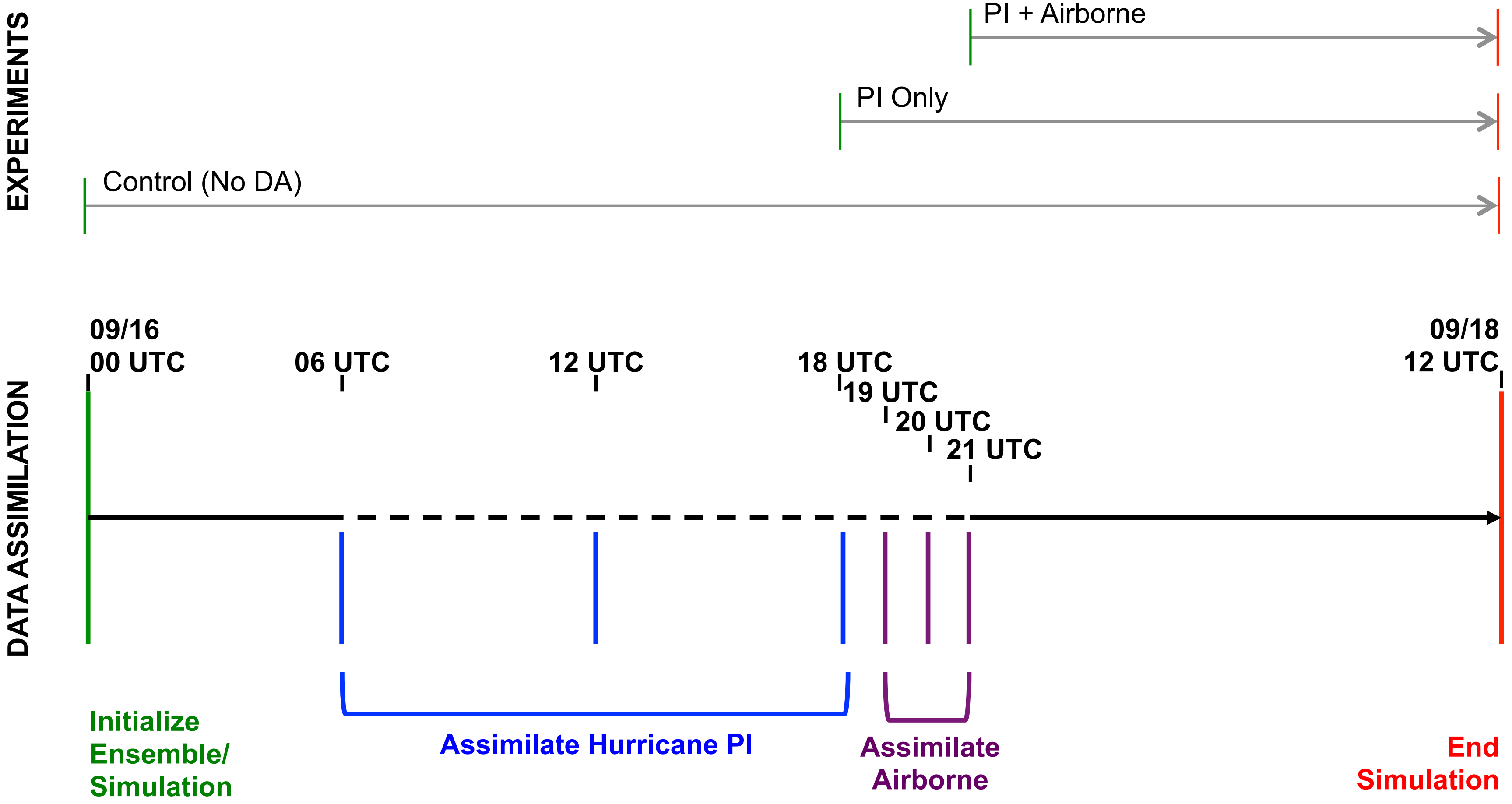
$$Error_{\Psi} = \frac{l}{30} \cdot maxError_{\Psi}\, , maxError_{\Psi} = 1.0 \quad [\mathrm{m\ s^{-1}}]$$

$$Error_{\mathrm{base}} = 1.5 \quad [\mathrm{m\ s^{-1}}]$$



# Hurricane Karl (2010) – EnKF Assimilation Strategy

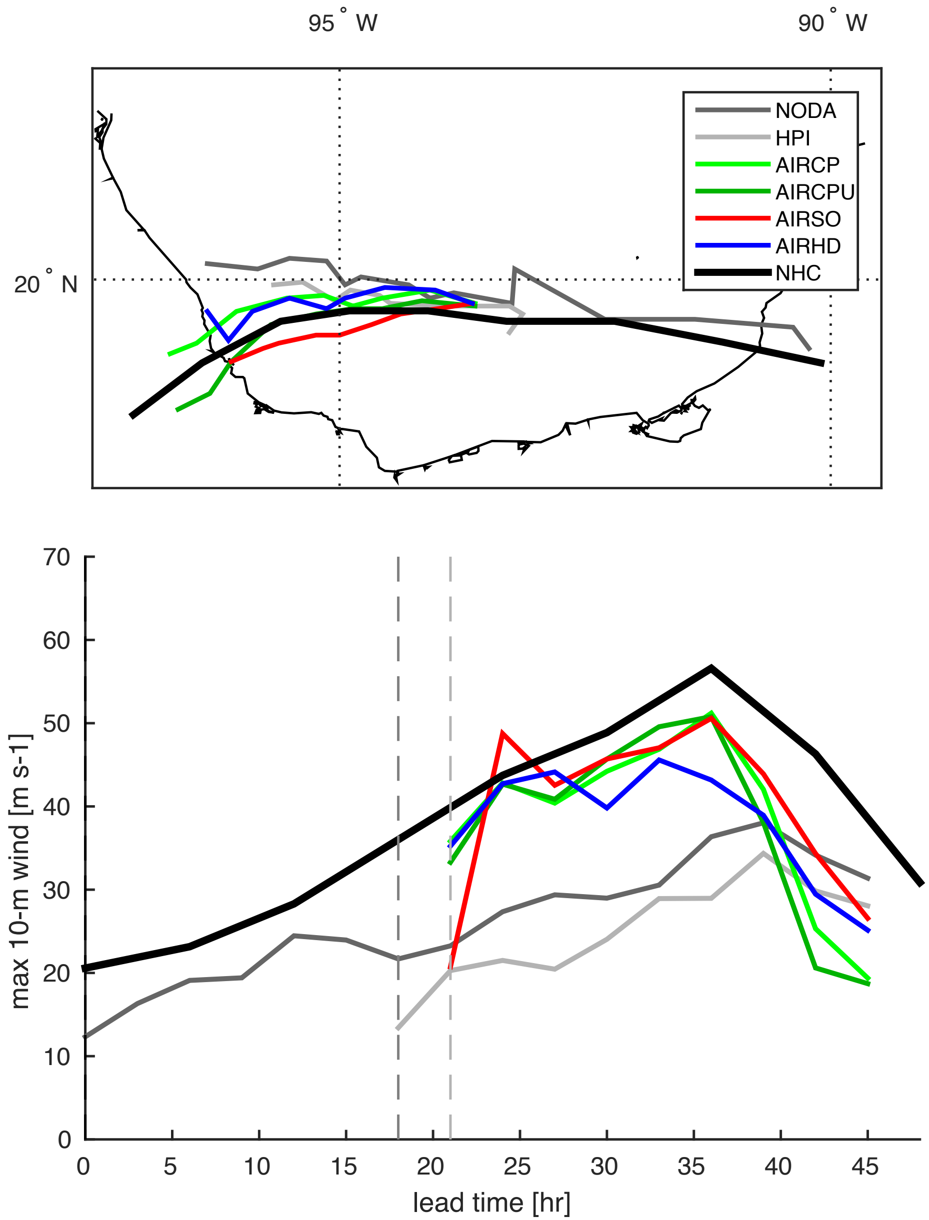
Initialized: 00 UTC 16 September 2010



1. Perturbed GDAS w/ WRF-DA (cv3) → ensemble IC
2. Perturbed GFS Forecast w/ WRF-DA (cv3) → ensemble BC

# Hurricane Karl (2010) – Forecast Track and Intensity

00 UTC 16 September 2010 → 00 UTC 18 September 2010



## EXPERIMENT KEY

**NODA:** no data assimilation (nature run)

**HPI:** position and intensity

**AIRSO:** position and intensity + airborne Vr winds with SO error*

**AIRCP:** position and intensity + airborne coplane u, v winds with SO error*

**AIRCPU:** position and intensity + airborne coplane u, v winds with error specification algorithm**

**AIRHD:** position and intensity + airborne HRD u, v winds with SO error*

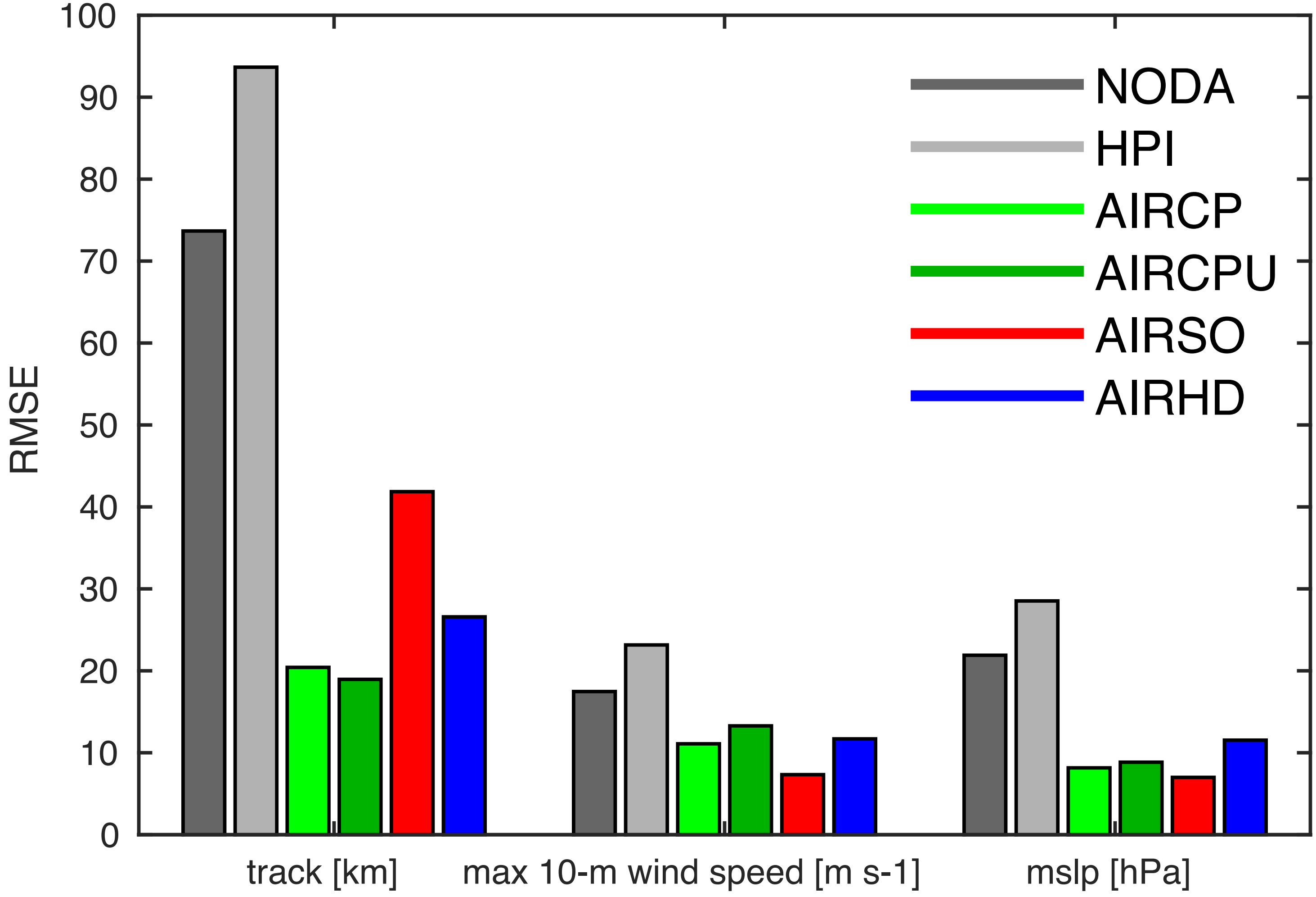
*SO error 3 m $s^{-1}$

**error specification algorithm ranges 1.5 → 4 m $s^{-1}$

# Hurricane Karl (2010) – RMSE position and intensity

00 UTC 16 September 2010 → 00 UTC 18 September 2010

- NHC best track 6 hourly position and intensity for verification
- 00 through 18 UTC 17 September (4 times)



# Discussion

- For a single flight test case during Hurricane Karl (2010), assimilating coplane analysis observations:
  - improves track forecasts compared to HRD analysis and SO radial velocities.
  - using a user specified error algorithm improves track forecasts compared with a static error.
- Assimilating u- and v-wind generally improves the TC environment and thus track, while radial velocity improves inner core processes, improving TC intensity (Li et al 2014).

# Research Questions…

Given pseudo-operational configurations of three TC-tuned regional models:

1) How do the mean and spread of an ensemble with the same initial perturbations evolve using multiple models?

2) Is single-core multi-physics ensemble sufficient for representing model uncertainties in TC prediction or do we need multi-core multi-physics ensembles?

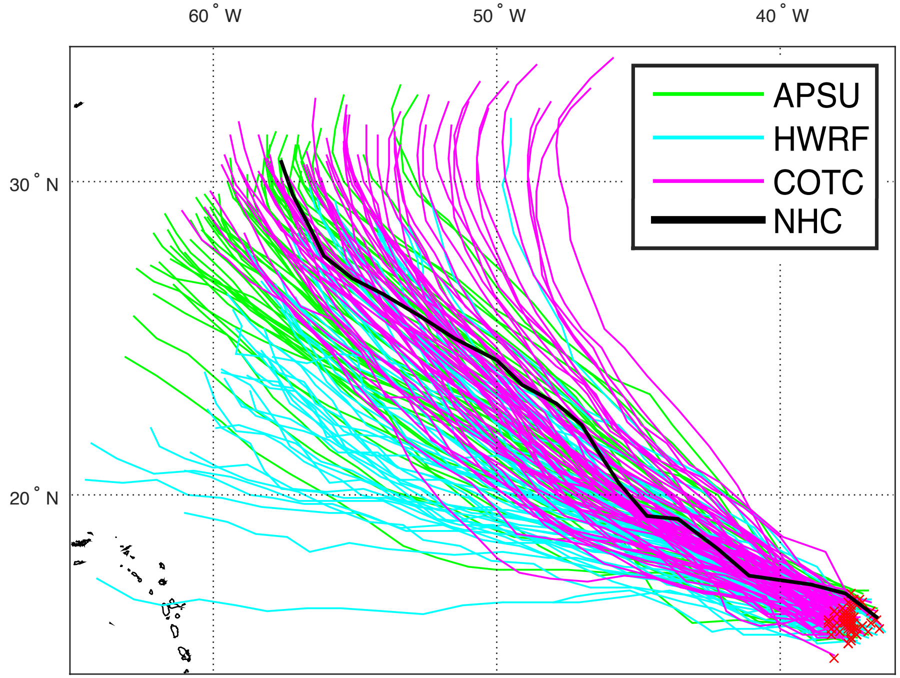
# Hurricane Edouard (2014) Ensemble Spread

- 5 day forecast initialized 2014-09-11 12 UTC

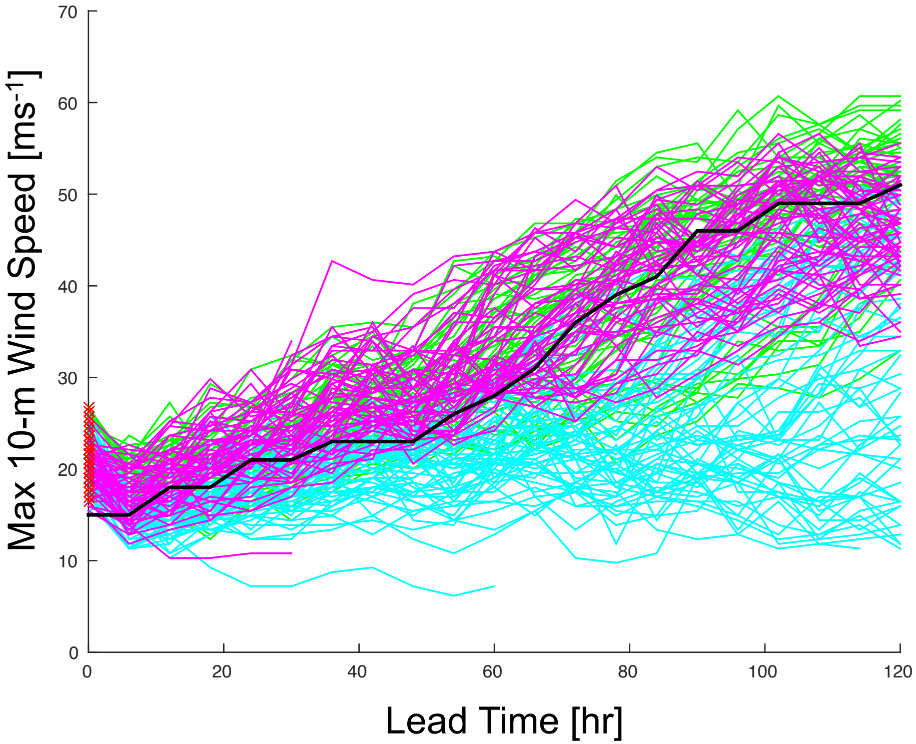
- Multi-core ensemble spread larger than any individual single-core

- Spread:
  APSU ~ COTC !~ HWRF

**Track - Ensemble**



**Intensity - Ensemble**



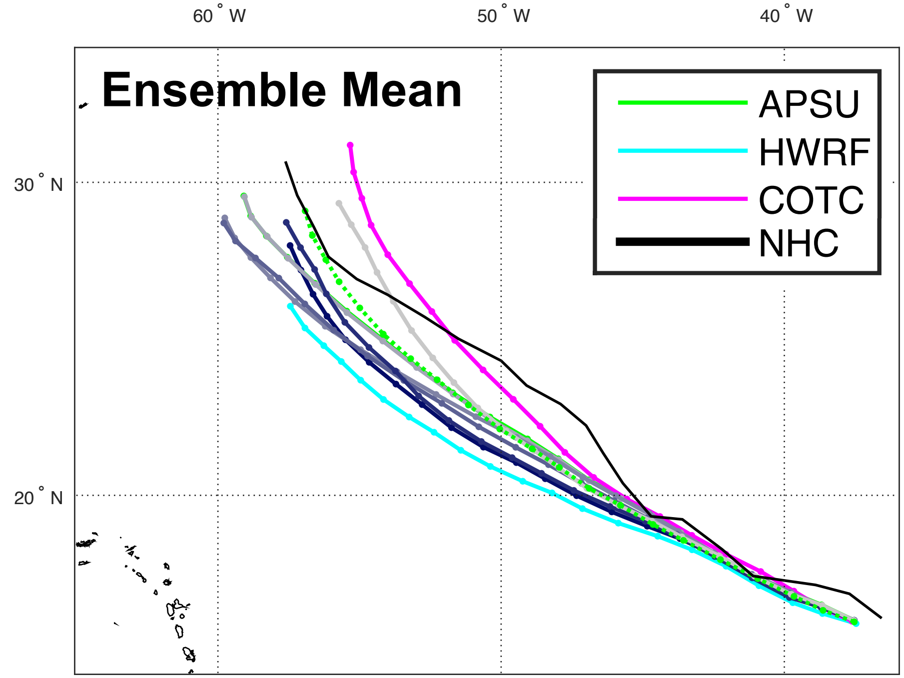
# Hurricane Edouard (2014) Ensemble Mean – Physics

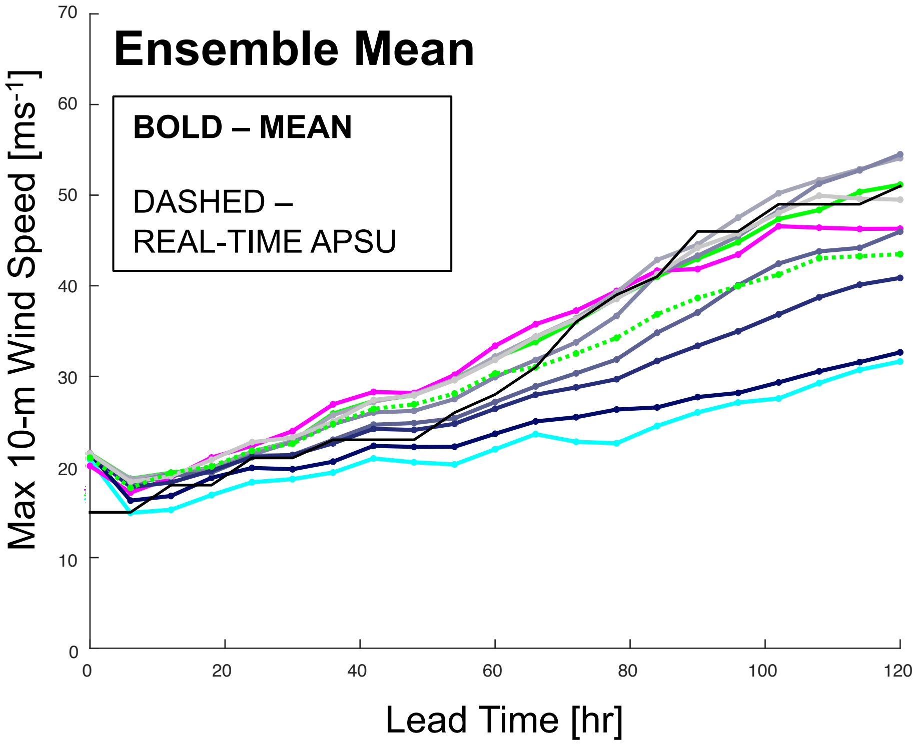
**“APSU-Like” Physics**

*Modify microphysics, radiation, PBL, surface drag, cumulus*

**“HWRF-Like” Physics**

- Distinct difference when modifying single-core physics schemes
- Shift single-core mean to mimic a completely different model-core and physics configuration
- Physics can dominate intensity and track evolution of TC



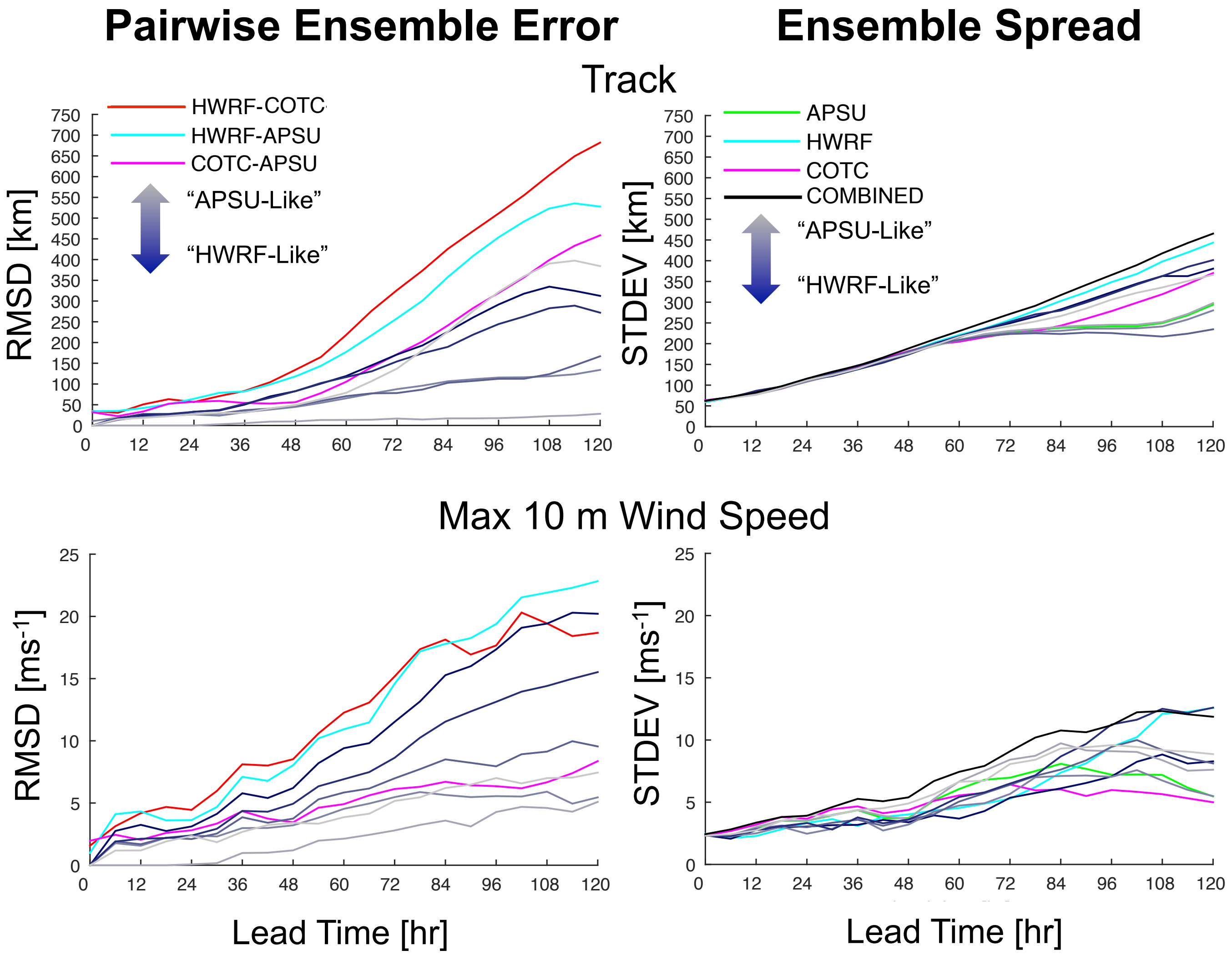


# Hurricane Edouard (2014) Model & IC Error Growth

**Root Mean Square Difference (RMSD)**
Measure of relative model error

**Standard Deviation (STDEV)**
Measure of IC error

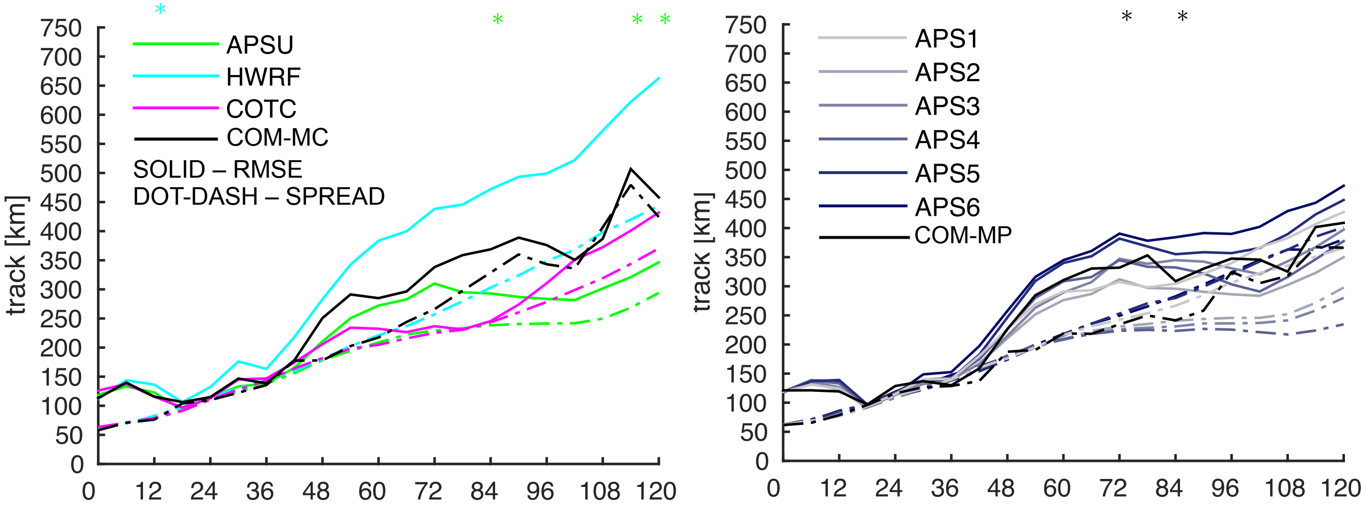
- Pairwise error growth rate and magnitude within single-core → can be highly dependent on physics
- Shift single-core ensemble spread to mimic a different model-core and physics configuration



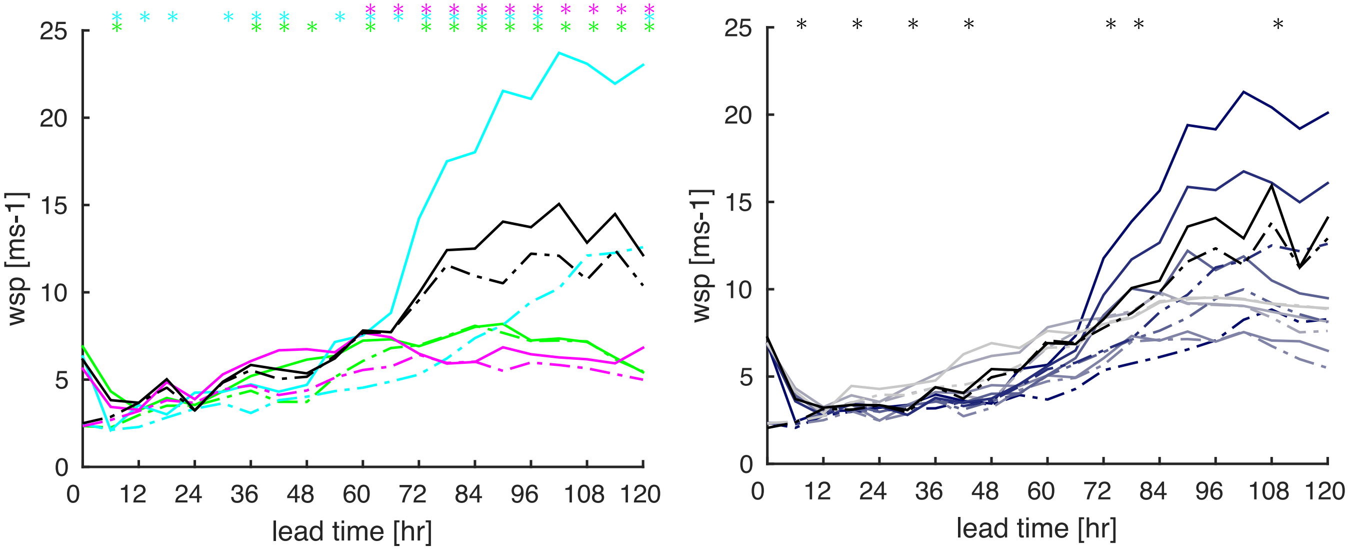
# Hurricane Edouard (2014) Verification

- Combined ensemble RMSE/spread more consistent at longer lead times than constituent models.
- Track spread (and mean) statistically indifferent between multi-core/single-model multi-physics ensemble.

## Track



## 10-m Wind Speed



# Discussion

- Ensemble track mean and spread reproduced by each model-core track and intensity solutions using identical initial perturbations
  - Generally, systematic biases in mean and ensemble spread evident between model-core and single-core multi-physics at longer lead times (~ > 48 h) for cases studied

- Modifying single-core physics → change mean and spread to resemble entirely different model-core

- Single-core multi-physics may be sufficient for TC track prediction

# References

Chong, M., and J. Testud, 1996: Three-dimensional air circulation in a squall line from airborne dual-beam Doppler radar data: A test of coplane methodology software. J. Atmos. Ocean. Technol., 13, 36–53.

Li, X., J. Ming, Y. Wang, K. Zhao, and M. Xue, 2013: Assimilation of T-TREC-retrieved wind data with WRF 3DVAR for the short-term forecasting of typhoon Meranti (2010) near landfall. J. Geophys. Res. Atmos., 118, 10361–10375.

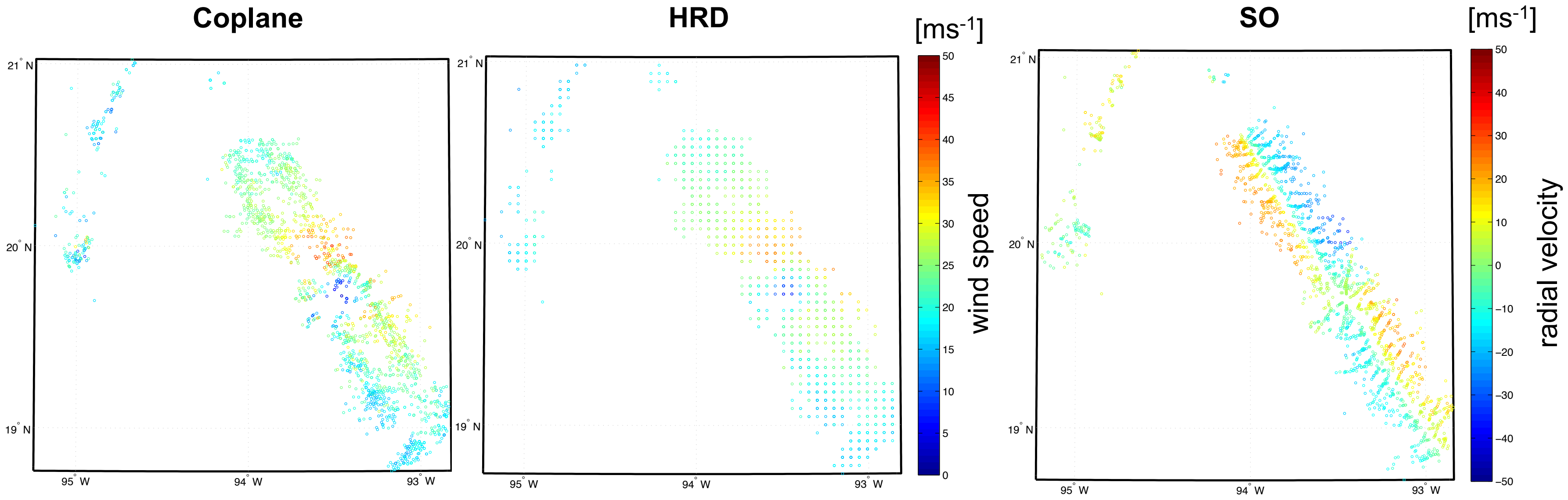
Weng, Y., and F. Zhang, 2012: Assimilating airborne Doppler radar observations with an ensemble Kalman filter for convection-permitting hurricane initialization and prediction: Katrina (2005). Mon. Weather Rev., 140, 841–859.

# SUPPLEMENTARY SLIDES

# Hurricane Karl (2010) – Flight Leg 2

16 September 2010 1900-2000 UTC → Assimilated at 20 UTC

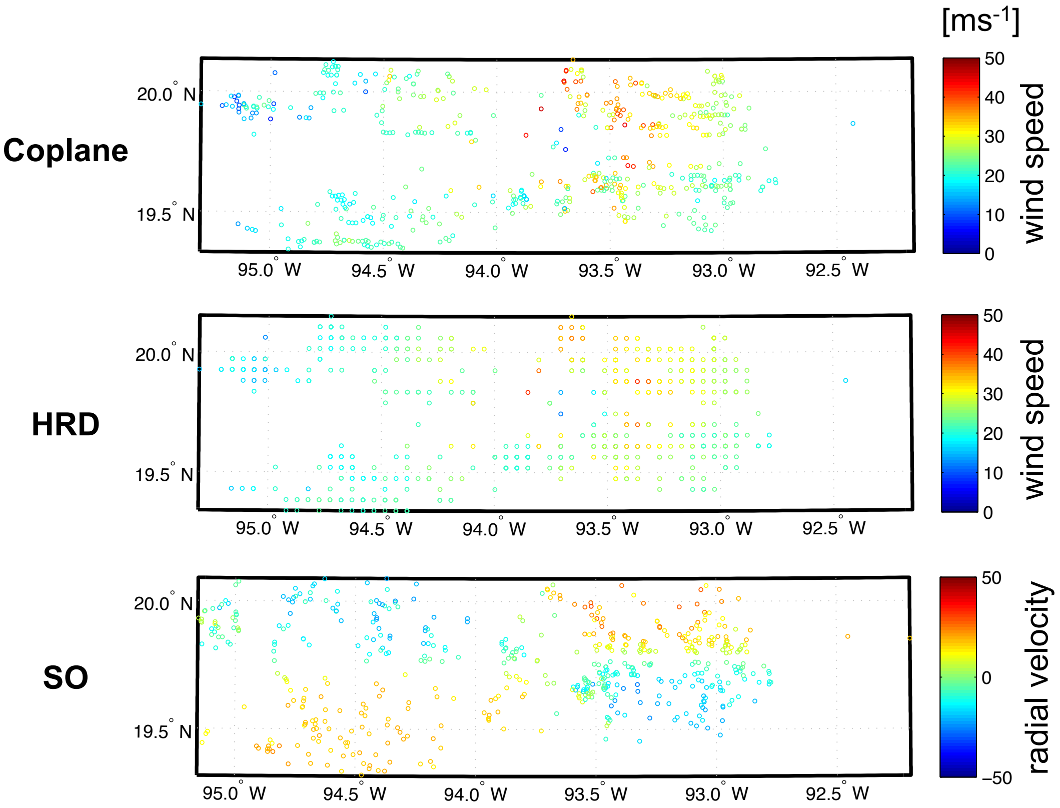
Observations: 1758 U,V or Vr (thinned to ~4.5km spacing)



# Hurricane Karl (2010) – Flight Leg 3

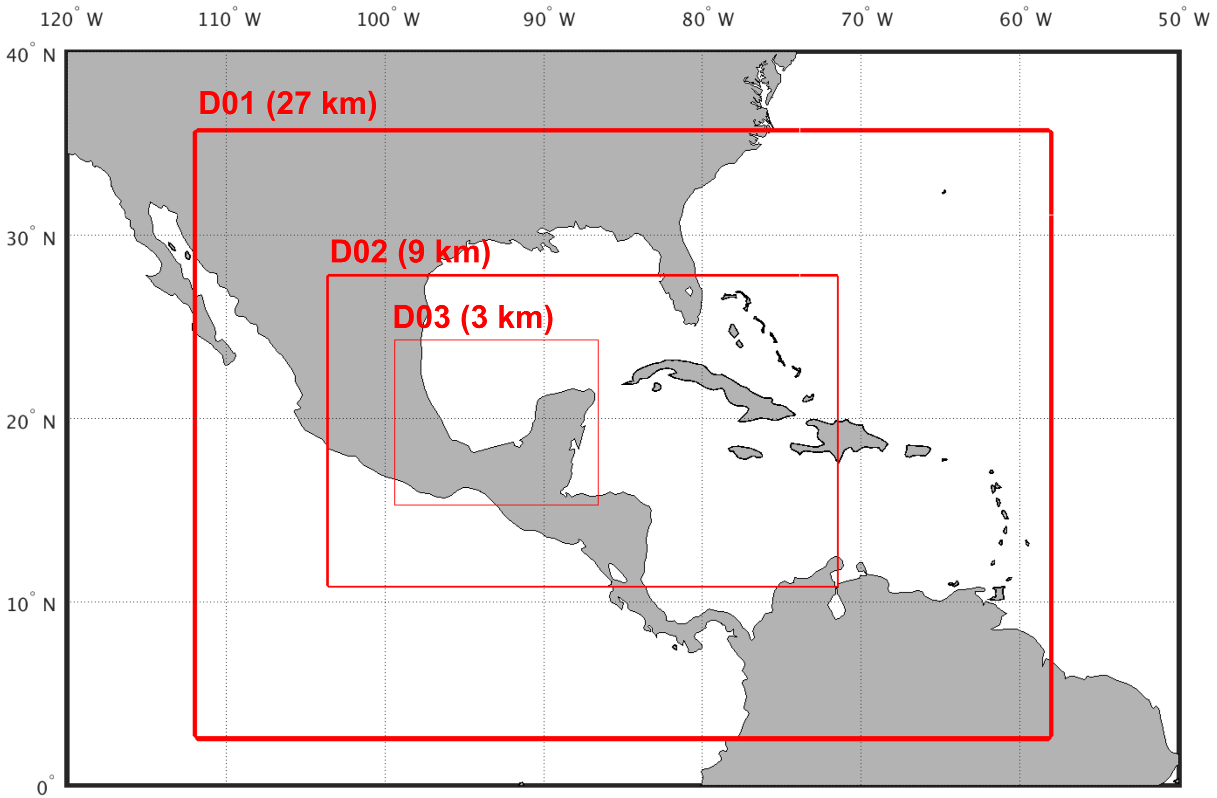
16 September 2010 2000-2100 UTC → Assimilated at 21 UTC

Observations: 550 U,V or Vr (thinned to ~4.5km spacing)



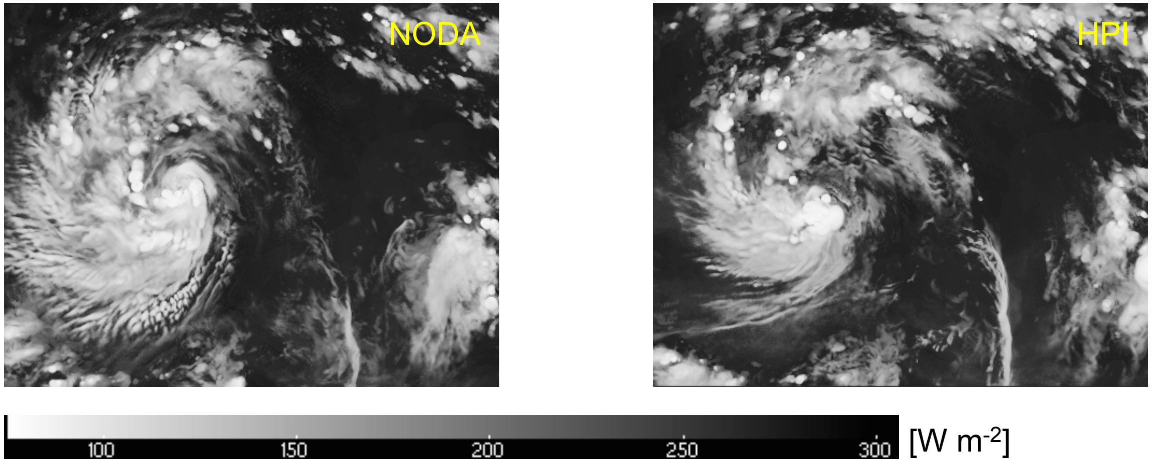
# Hurricane Karl (2010) – Model Setup

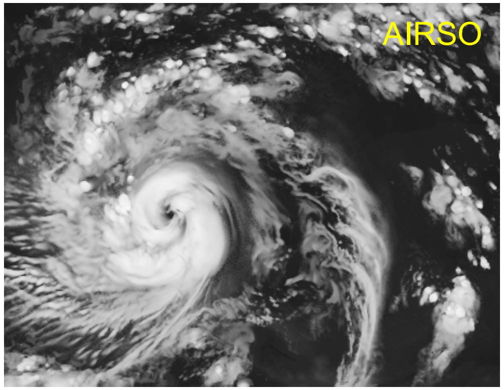
00 UTC 16 September 2010 → 00 UTC 18 September 2010

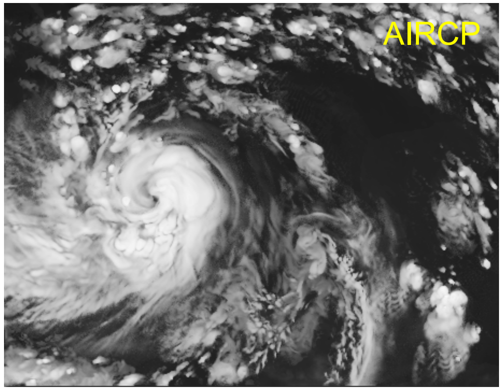


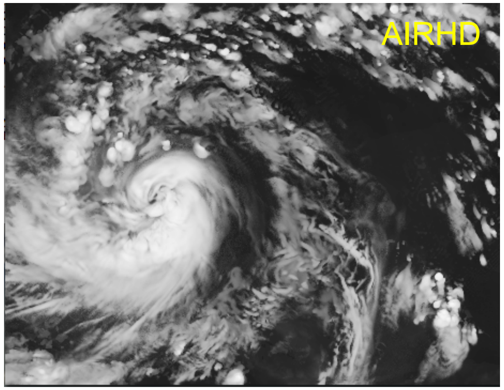
| | |
|---|---|
| WRF | WRF-ARW v3.6 |
| Domains | D01 (27 km; 225x150)<br>D02 (9 km; 400x226)<br>D03 (3 km; 478x358)<br>Vertical (43 levels; ptop 10 hPa) |
| Physics | WSM6 MP<br>RRTMG LW/SW<br>YSU PBL<br>Tiedtke CU (D01 ONLY)<br>Donelan Cd + Garratt Ck (isftcflx) |

# Hurricane Karl (2010) – Simulated Outgoing Longwave Radiation









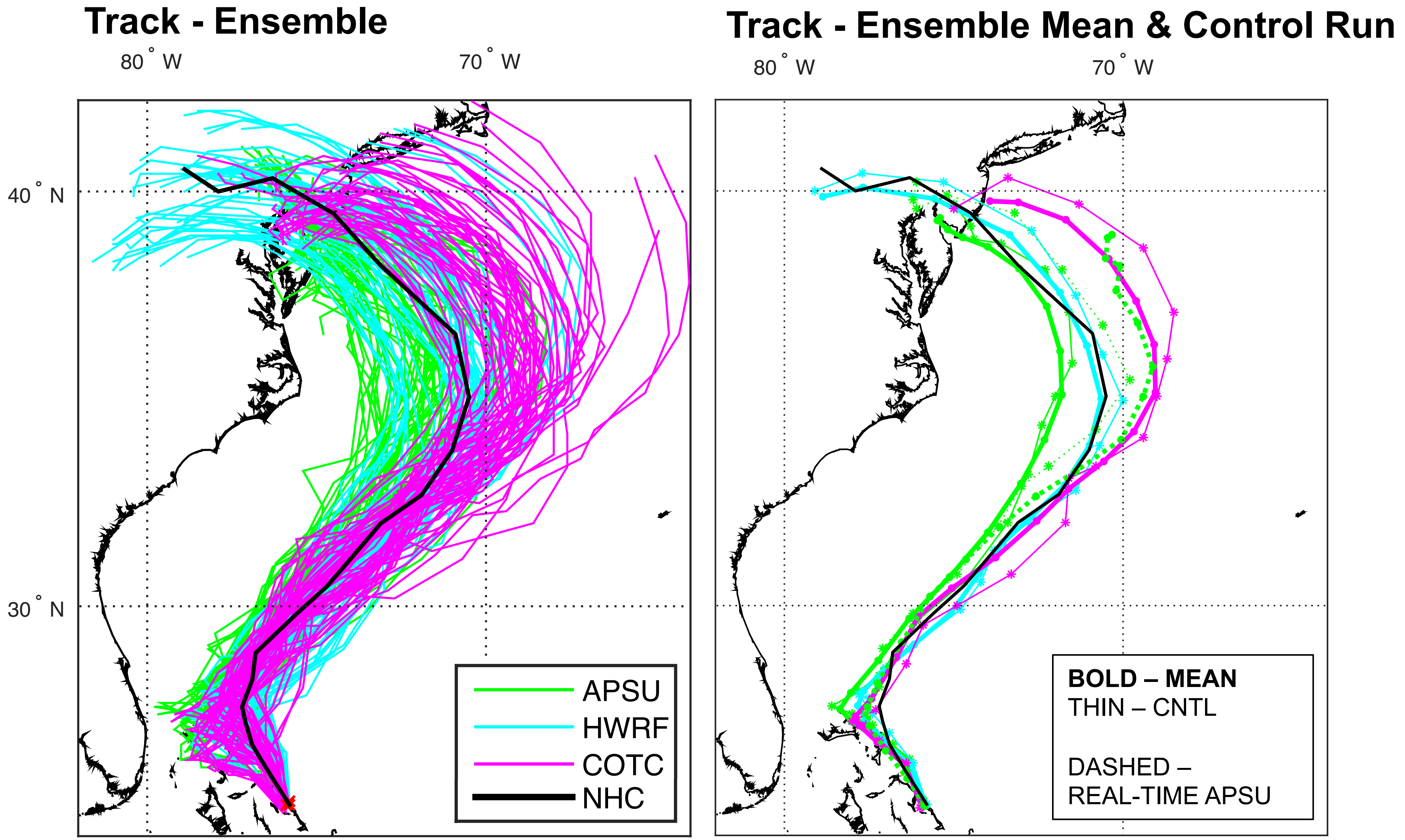
**EXPERIMENT KEY**

NODA: no data assimilation (nature run)
HPI: position and intensity
AIRSO : position and intensity + airborne Vr winds
AIRCP: position and intensity + airborne coplane u, v winds
AIRHD: position and intensity + airborne HRD u, v winds

# Hurricane Sandy (2012) Track

- 5 day forecast initialized 2012-10-26 00 UTC

- Ensemble track mean and spread reproduced by each model-core
  - Systematic bias at longer lead times (~> 60 h)



# Table 1

| **Model** | DOMAIN | CP | MP | PBL | RAD | SFC |
|---|---|---|---|---|---|---|
| **APSU (2014)**<br>(WRF-ARW) | D01: 27km (379x244)<br>D02: 9km (304x304)<br>D03: 3km (304x304)<br>Vertical Levels: 43<br>Model Top: 10 hPa | D01 ONLY<br>Grell-Freitas<br>(Grell et al. 2013) | WSM-6<br>(Hong and Lim 1996) | YSU<br>(Hong et al. 2006) | Dudhia shortwave<br>(Dudhia 1989)<br>RRTM longwave<br>(Mlawer et al. 1997) | - Modified MM5 similarity (WRF option 91)<br>- PSU formulation surface TC flux (Green and Zhang, 2013)<br>- 5-layer thermal diffusion land surface |
| **HWRF (2013)**<br>(modified WRF-NMM) | D01: 0.18 deg (216x432)<br>D02: 0.06 deg (88x170)<br>D03: 0.02 deg (180x324)<br>Vertical Levels: 43<br>Model Top: 50 hPa | D01 & D02<br>New SAS (HWRF)<br>(Han and Pan 2011) | Tropical Ferrier<br>(Ferrier 2005) | Modified GFS<br>(Hong and Pan(1996); e.g. Gopalakrishnan et al. (2013); Zhang et al. (2013)) | GFDL shortwave and longwave<br>(Fels and Schwarzkopf 1981) | - HWRF surface physics<br>- GFDL hurricane slab model land surface (Bob Tuleya 2011) |
| **COTC (2015)**<br>(COAMPS-TC) | D01: 27km (379x244)<br>D02: 9km (304x304)<br>D03: 3km (304x304)<br>Vertical Levels: 40<br>Model Top: ~ 12 hPa | D01 ONLY<br>Kain-Fritsch scheme<br>(Kain and Fritsch, 1983) | COAMPS v2 single-bulk (Rutledge and Hobbs, 1983) w/ drizzle | Mellor-Yamada 2.5 scheme (Mellor and Yamada 1982) w/ prognostic TKE | NOGAPS SW/LW<br>(Harshvardhan et al., 1987) | COAMPS surface physics (Louis, 1979) |

# Table 2

| Model | Time Discretization | Spatial Discretization | Prognostic Variables | Advection | Diffusion |
|---|---|---|---|---|---|
| **APSU (2014)**<br>(WRF-ARW)<br>(see Skamarock et al. 2008 and references therein) | Runge-Kutta 3rd order predictor-corrector scheme (Wicker and Skamarock (2002)) with short time step time-splitting for high frequency acoustic modes | Horizontal: Arakawa C-grid<br>Vertical: mass + U,V and vertical velocity staggering | U, V, W, perturbation potential temperature, perturbation geopotential, perturbation surface pressure of dry air, TKE, $Q_v$ , $Q_r$, $Q_s$ , $Q_g$ , $Q_i$ , $Q_c$ | 6th order accurate for momentum, scalars and geopotential | 6th order accurate |
| **HWRF (2013)**<br>(modified WRF-NMM)<br>(see Janjic et al. (2010), Tallapragada et al. (2013, and references therein) | Forward-backward scheme with an implicit scheme for high frequency vertically propagating modes | Horizontal: Arakawa E-grid<br>Vertical: Lorenz staggering (mass + U,V on consistent levels) | U, V, T, non-hydrostatic pressure, hydrostatic surface pressure, $Q_v$ , $Q_r$, $Q_i$ , $Q_{ci}$ , $Q_c$ | Horizontal: modified Adams-Bashforth, for horizontal advection of u,v, and T, and Coriolis terms,<br>Vertical: Crank Nicholson for vertical advection of u,v, and T,<br>Scalars: upstream Lagrangian forward time differencing | 2nd order accurate |
| **COTC (2015)**<br>(COAMPS-TC)<br>(see Hack (1996), Chen et al. (2003), and references therein) | Centered-in-time (i.e. leap frog) 2nd order scheme with short time step time-splitting for high frequency acoustic modes | Horizontal: Arakawa C-grid<br>Vertical: mass + U,V and vertical velocity staggering | U, V, W, $\theta$, $\pi$, TKE, $Q_v$ , $Q_r$, $Q_i$ , $Q_g$ , $Q_s$, $Q_c$ | 2nd order accurate upstream, forward-in-time advection | 4th order accurate |