HIWRAP observations from the HS3 campaign: Comparing retrieval techniques

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INTRODUCTION

The High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP) is a dual-beam, dual-frequency, Doppler radar system designed for operation on board the Global Hawk aircraft unmanned aircraft system. The antennas of HIWRAP point downward and scan conically at two different tilt angles. This scanning geometry, which is unlike the traditional tail radar fore/aft scanning technique, presents unique challenges to retrieving the full three-dimensional wind field. We compare two well-established dual-Doppler retrieval techniques that were redesigned for the HIWRAP geometry.

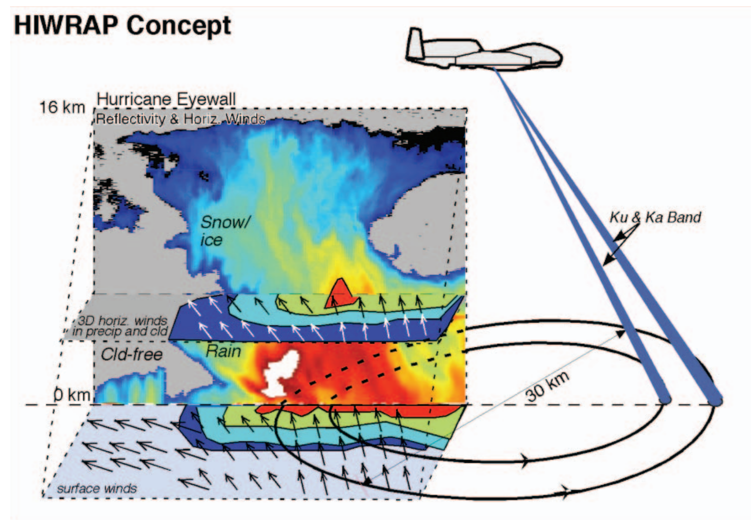
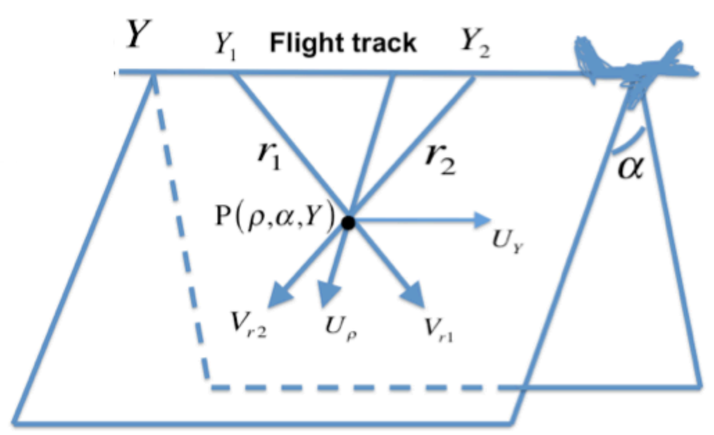


Figure 1. HIWRAP measurement concept

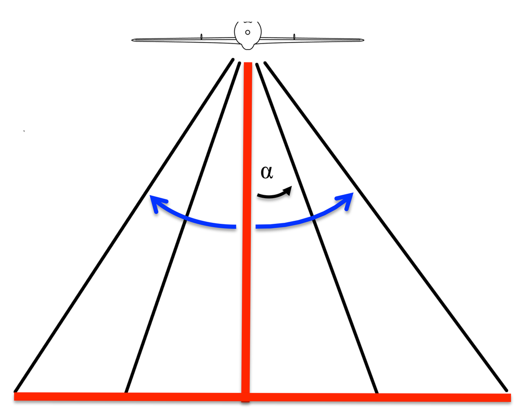
COPLANE ANALYSIS

(Armijo 1969, Chong and Testud 1996)

- Utilizes natural coordinates of scanning geometry
- Interpolates fore and aft observations to cylindrical coordinates (ρ, α, Y)
- Calculates two components (U_ρ, U_Y) in each α plane
- Third component U_α retrieved by integrating anelastic mass continuity equation



$$U_\rho = \frac{-r_1(Y-Y_2)V_{r1} + r_2(Y-Y_2)V_{r2}}{\rho(Y_2-Y_1)} \qquad U_Y = \frac{r_1V_{r1} - r_2V_{r2}}{Y_2-Y_1}$$



BOUNDARY CONDITIONS

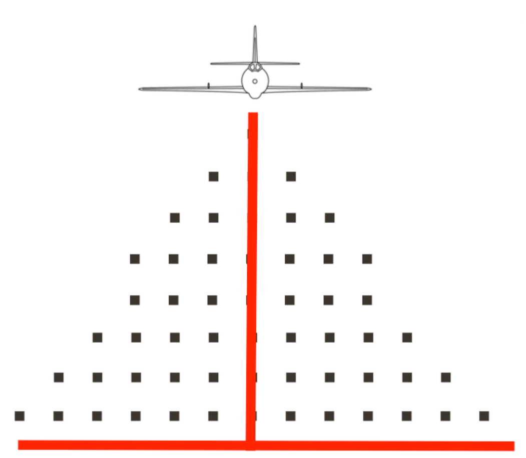
- Surface boundary condition: $w = 0$
- Nadir boundary condition: $U_\alpha = U_{\alpha,\ \mathrm{nadir}}$
  - Assumes constant vertical velocity and linear cross-track winds across small distance

$$U_{\alpha,\ \mathrm{surface}} = \frac{U_\rho}{\cot\alpha} \qquad U_{\alpha,\ \alpha=0} = \frac{V_{r1} - V_{r2}}{2\sin\alpha}$$

GLOBAL OPTIMIZATION ANALYSIS

(Guimond et al. 2014, Reasor et al. 2009)

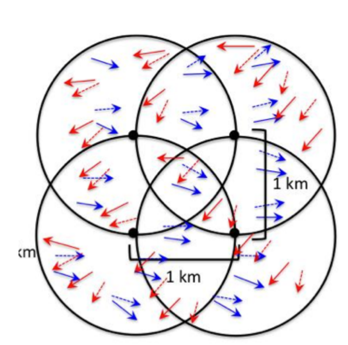
- Minimizes cost function that includes differences between observations and solution
- Applies anelastic mass continuity and surface boundary conditio
- Includes Laplacian function as filter for real data
- Additional boundary condition* at nadir: $U_\alpha = U_{\alpha,\ \mathrm{nadir}}$



$$F = \lambda_1 F_1 + \cdots + \lambda_N F_N + \lambda_{MC} F_{MC} + \lambda_{LF} F_{LF} + \lambda_{BC} F_{BC}$$

$$F_n = \sum_{m=1}^{M_n}\sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{i=1}^{I} \delta_{ijkm}[V_{R,mn} - \alpha_{mn}u_{ijk} - \beta_{mn}v_{ijk} - \gamma_{mn}(w_{ijk} - V_{T,ijk})]^2$$

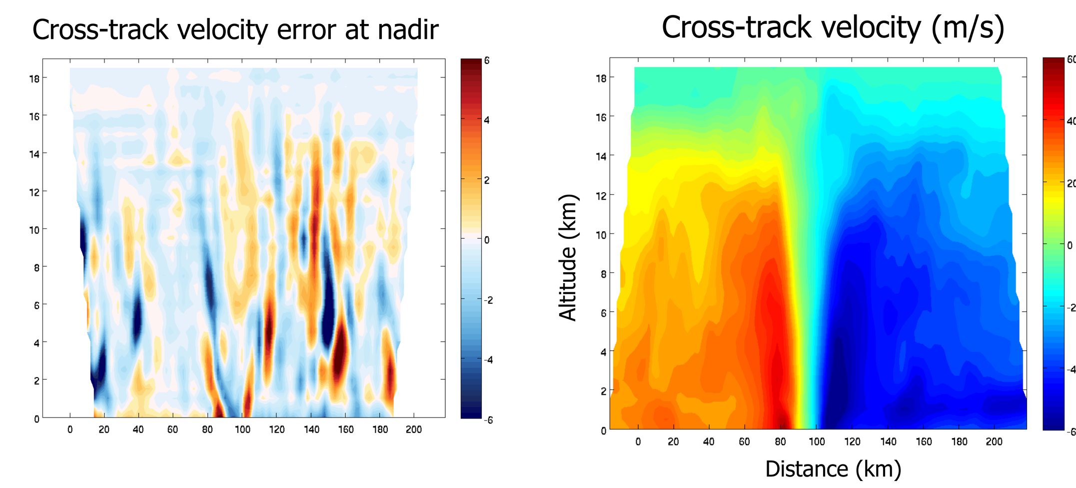
$$F_{BC} = \sum_{j=1}^{J}\sum_{i=1}^{I} w_{ij1}^2 + \sum_{k=1}^{K}\sum^{Nadir}[U_{\alpha,\ \alpha=0} - u_{k,\ \mathrm{nadir}}\cos TR - v_{k,\ \mathrm{nadir}}\sin TR]^2$$

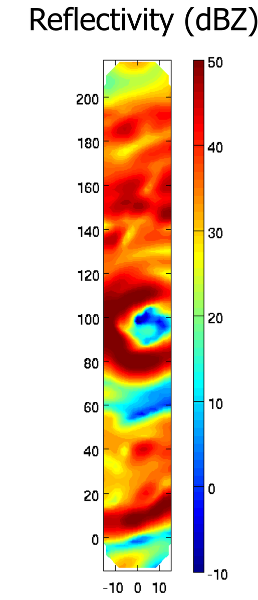


*Applied to simulated data only

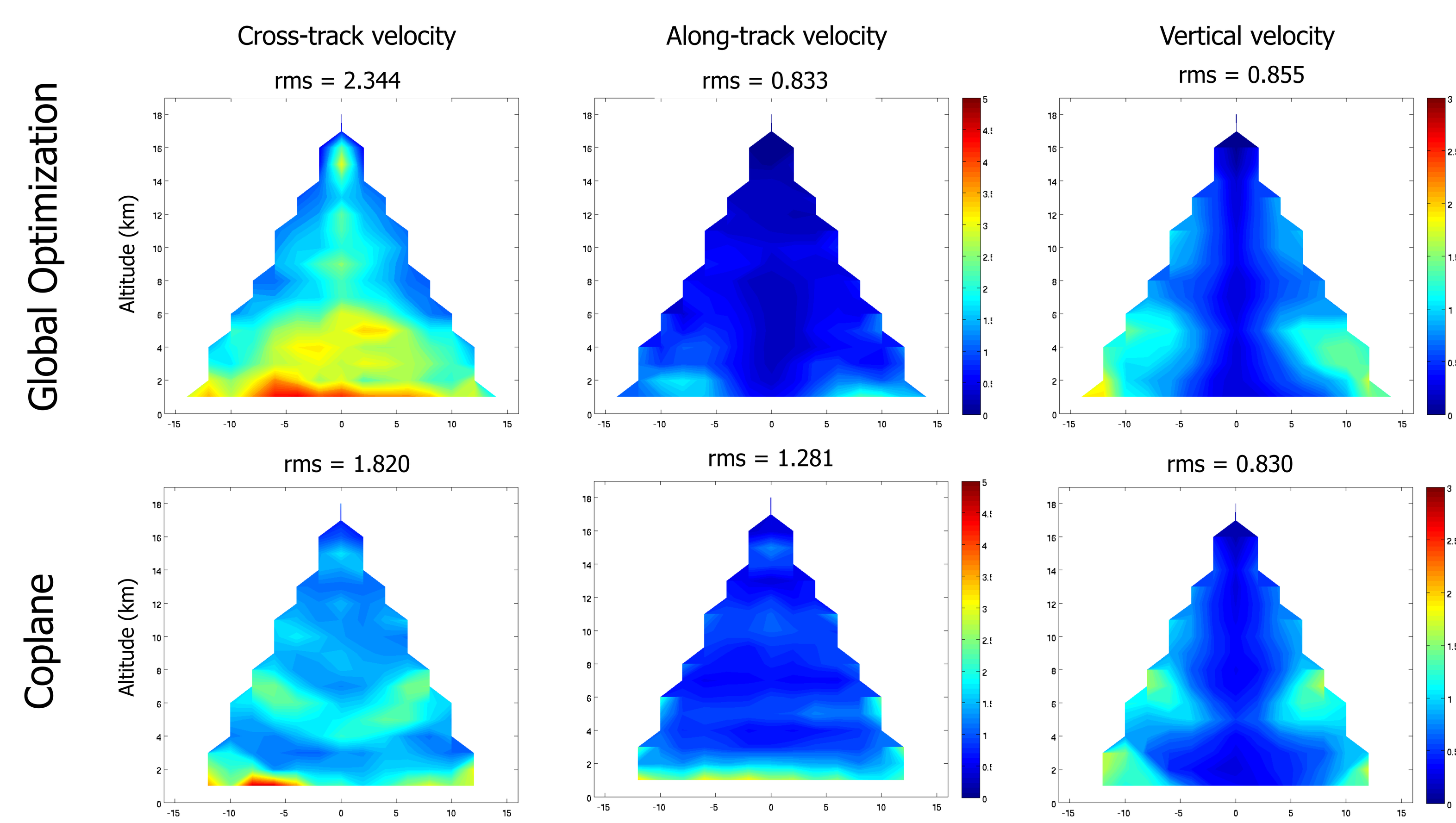
SIMULATED DATA

- Simulated HIWRAP scan of MM5 simulation of Hurricane Rita
- Tilt angle of 40°





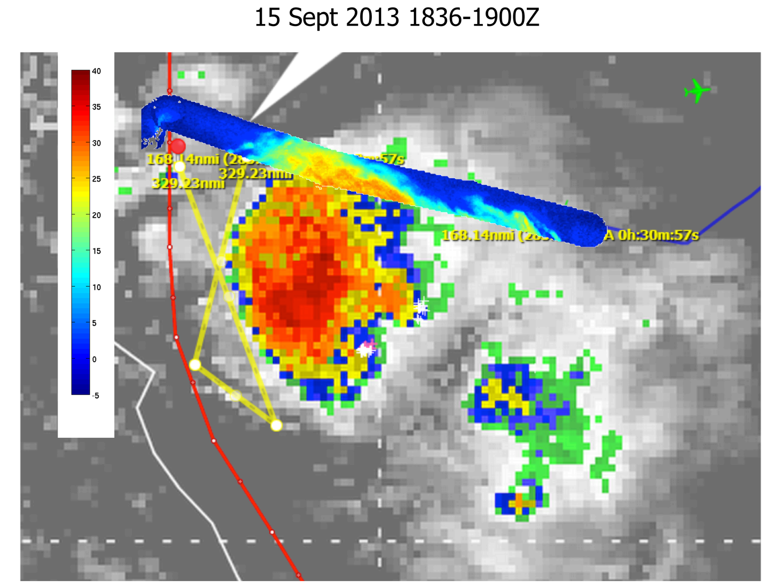
ROOT-MEAN-SQUARE ERRORS (m/s)



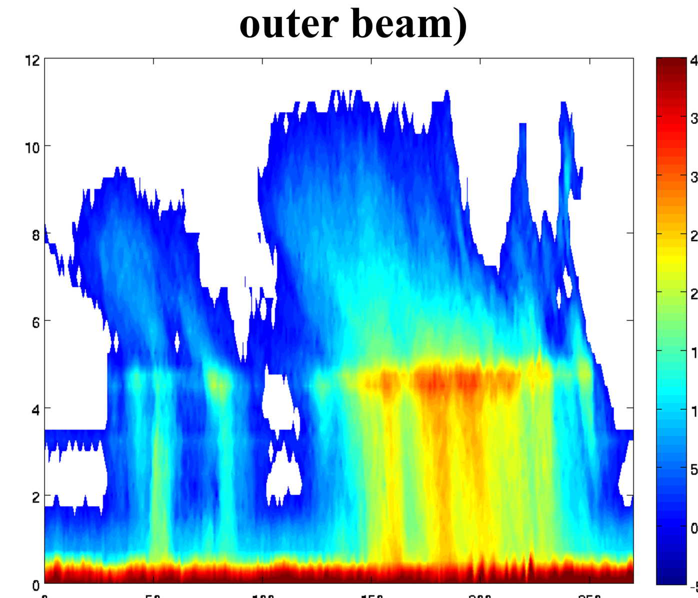
DATA FROM HS3 CAMPAIGN

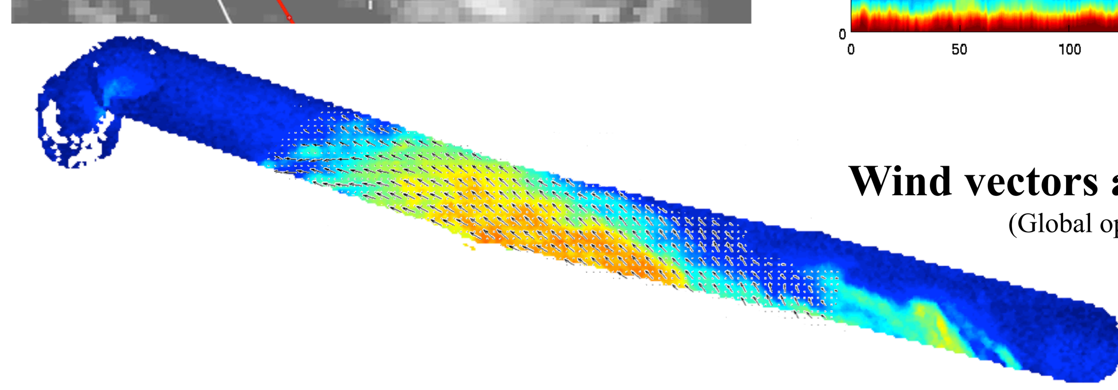
Hurricane Ingrid

15 Sept 2013 1836-1900Z



Reflectivity at nadir (Ku band, outer beam)

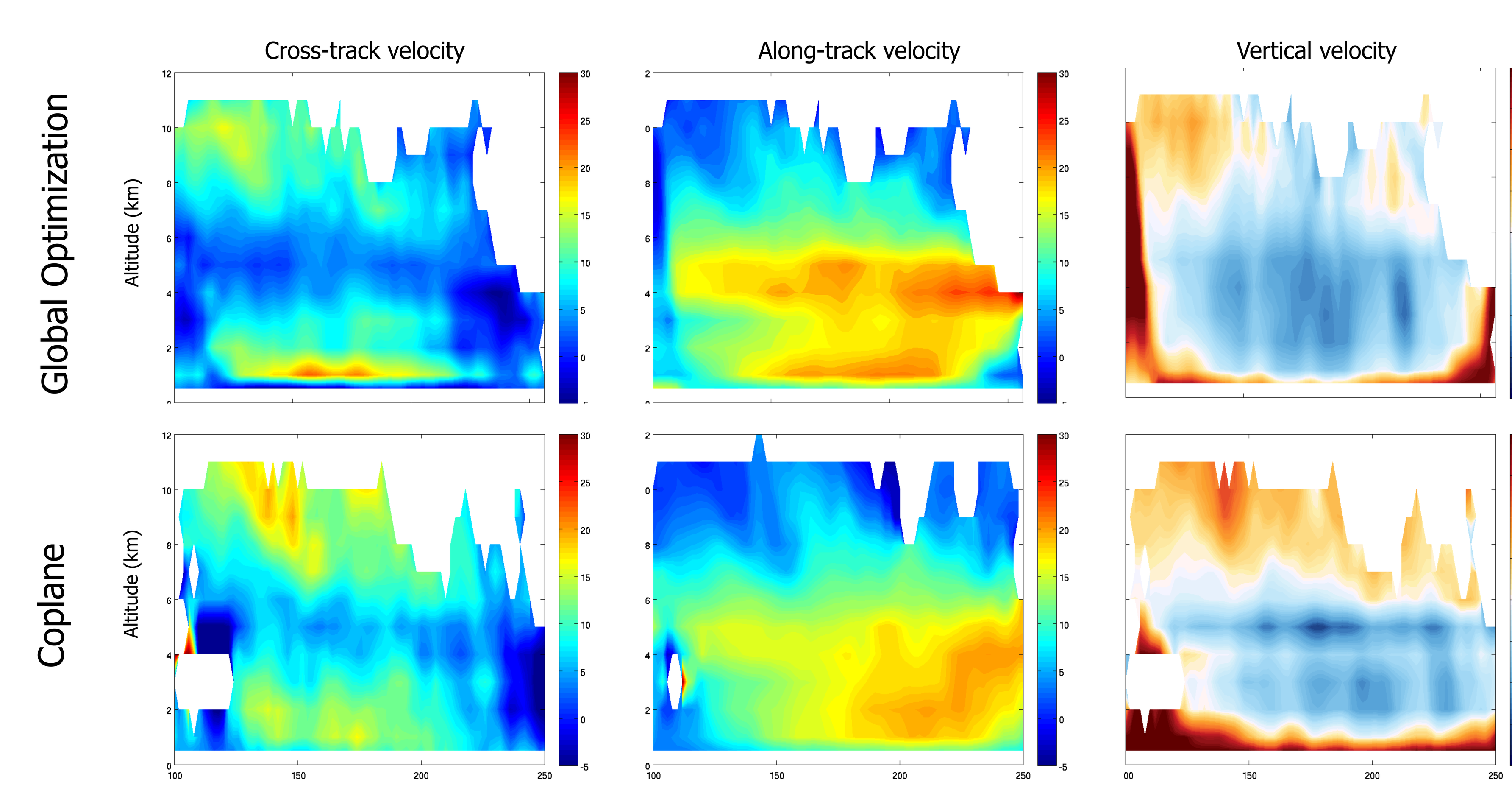




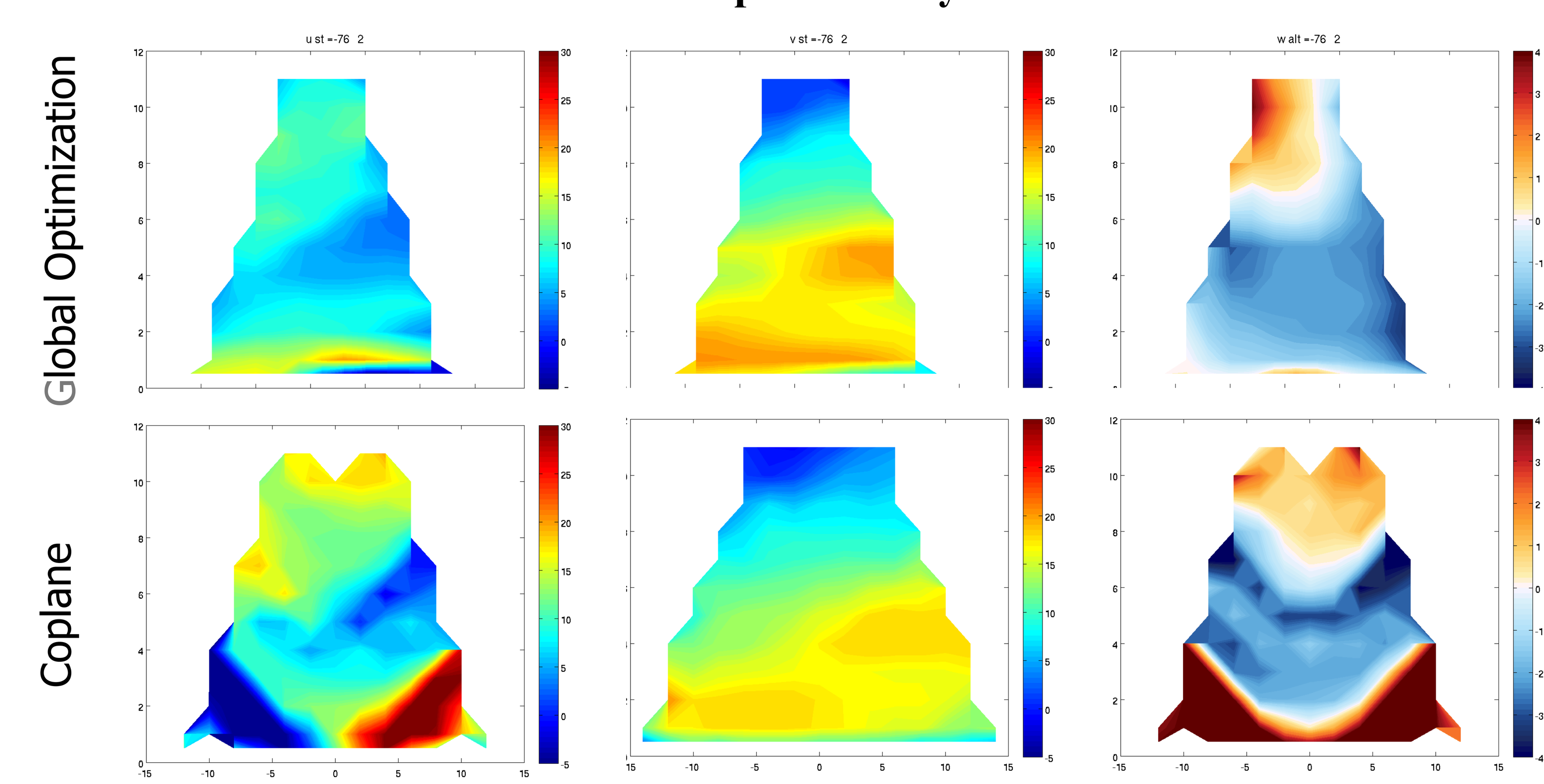
Wind vectors at 3 km altitude

(Global optimization)

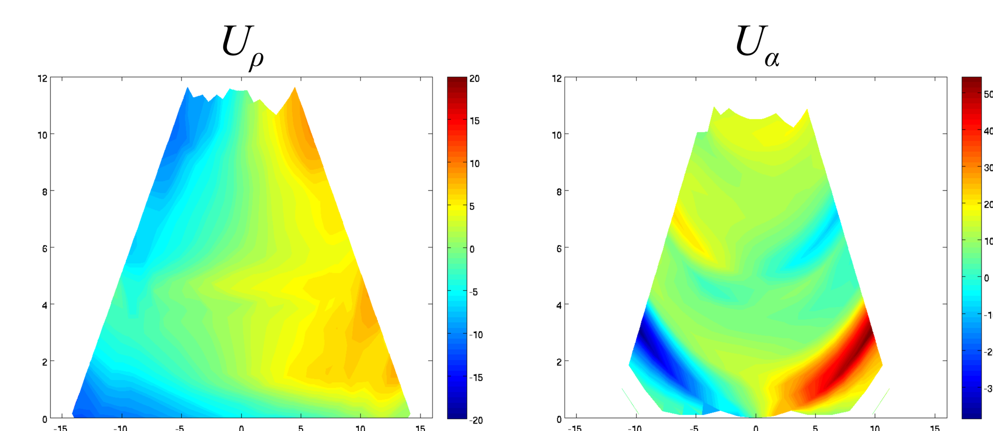
Wind components at nadir (m/s)



Wind components at y=180 km



Wind components for Coplane Analysis in cylindrical coordinates



CONCLUSIONS

- Both dual-Doppler methods performed well in retrieving the simulated wind field.
- In the simulation, the coplane analysis had slightly lower cross-track velocity errors, while the global optimization analysis had slightly lower along-track velocity errors.
- Both schemes performed similarly well with vertical velocity retrieval.
- For the HS3 data, both schemes retrieved similar wind fields at nadir, indicating the robustness of the observation patterns.
- Away from nadir, retrievals generally agree above 4km, but deviate below this level in the unobserved u-theta wind component.
- Global optimization provides a solution that is consistent with the radar measurements including measurement errors that are spread across the wind components.
- The coplane analysis solution remains consistent with observations for the observed wind components, while the unobserved component highlights where non-physical observations occur.