Analysis of Aircraft Observations in Tropical Cyclones Using SAMURAI

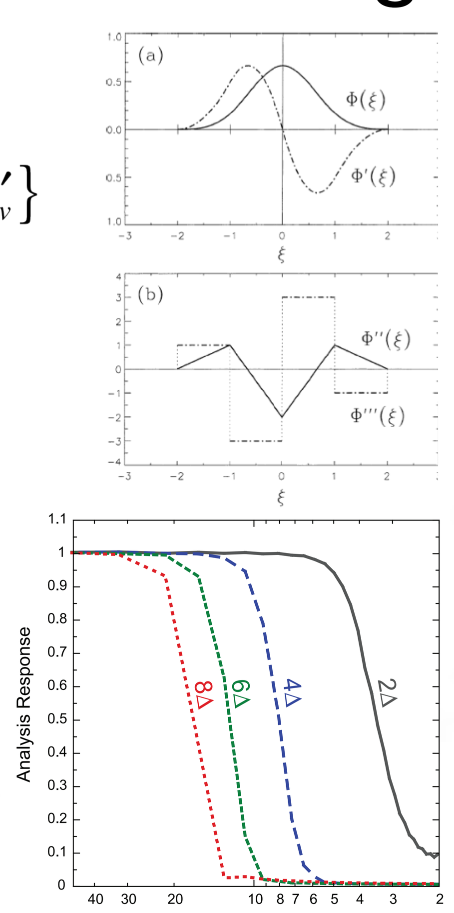
Michael M. Bell
University of Hawai'i at Manoa
mmbell@hawaii.edu

Introduction

A new finite-element based variational technique called SAMURAI (Spline Analysis at Mesoscale Utilizing Radar and Aircraft Instrumentation) has been developed in order to integrate aircraft observations from multiple instruments into comprehensive mesoscale composites. SAMURAI analysis can be performed with only a mass continuity constraint to ensure high fidelity to the data, or can incorporate *a priori* background estimates from a global or other mesoscale analysis.

$$\hat{x}(x,y,z) = \{\rho u, \rho v, \rho w, T', \rho_a', q_v'\}$$
$$\hat{x}(r,z) = \{\rho r v, \psi, T', \rho_a', q_v'\}$$

- Analyze dropsonde, in situ, satellite vector winds, SFMR, and Doppler radar data in inertial frame with or without background
- Thermodynamics analyzed as perturbations to hydrostatic reference state (Dunion 2011)
- Background error covariance modeled by Gaussian recursive filter (Purser et al. 2003)



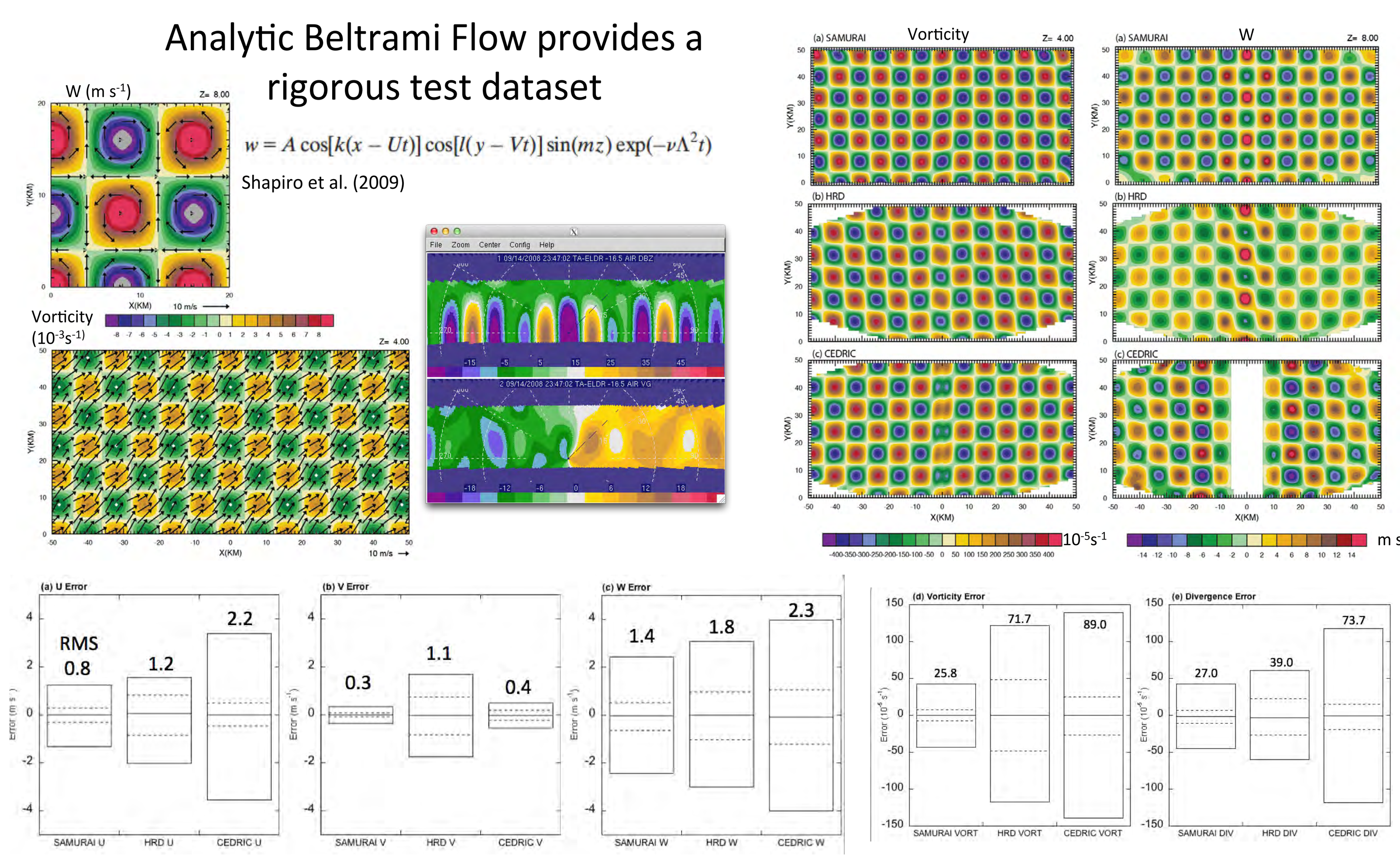
$$J(\hat{\mathbf{x}}) = \frac{1}{2}\hat{\mathbf{x}}^T\hat{\mathbf{x}} + \frac{1}{2}(\mathbf{HC}\hat{\mathbf{x}} - d)^T\mathbf{R}^{-1}(\mathbf{HC}\hat{\mathbf{x}} - d)$$
$$\nabla J(\hat{\mathbf{x}}) = (\mathbf{I} + \mathbf{C}^T\mathbf{H}^T\mathbf{R}^{-1}\mathbf{HC})\hat{\mathbf{x}} - \mathbf{C}^T\mathbf{H}^T\mathbf{R}^{-1}d$$
$$\delta\mathbf{x} = \mathbf{C}\hat{\mathbf{x}} = \mathbf{SDF}\hat{\mathbf{x}}$$
$$\mathbf{S} = (\mathbf{P} + \mathbf{Q})^{-1}$$
$$\mathbf{P} = [p_{mm'}]^T, \qquad p_{mm'} = \int_D \phi_m(r)\phi_{m'}(r)dr$$
$$\mathbf{Q} = [q_{mm'}]^T, \qquad q_{mm'} = \int_D \epsilon_q(r)\phi_m'''(r)\phi_{m'}'''(r)dr$$
$$\phi_m(r) = \Phi\left(\frac{r - r_m}{\Delta r}\right), \quad \text{for } m \in M \text{ and } r \in D$$

Ooyama (2002)

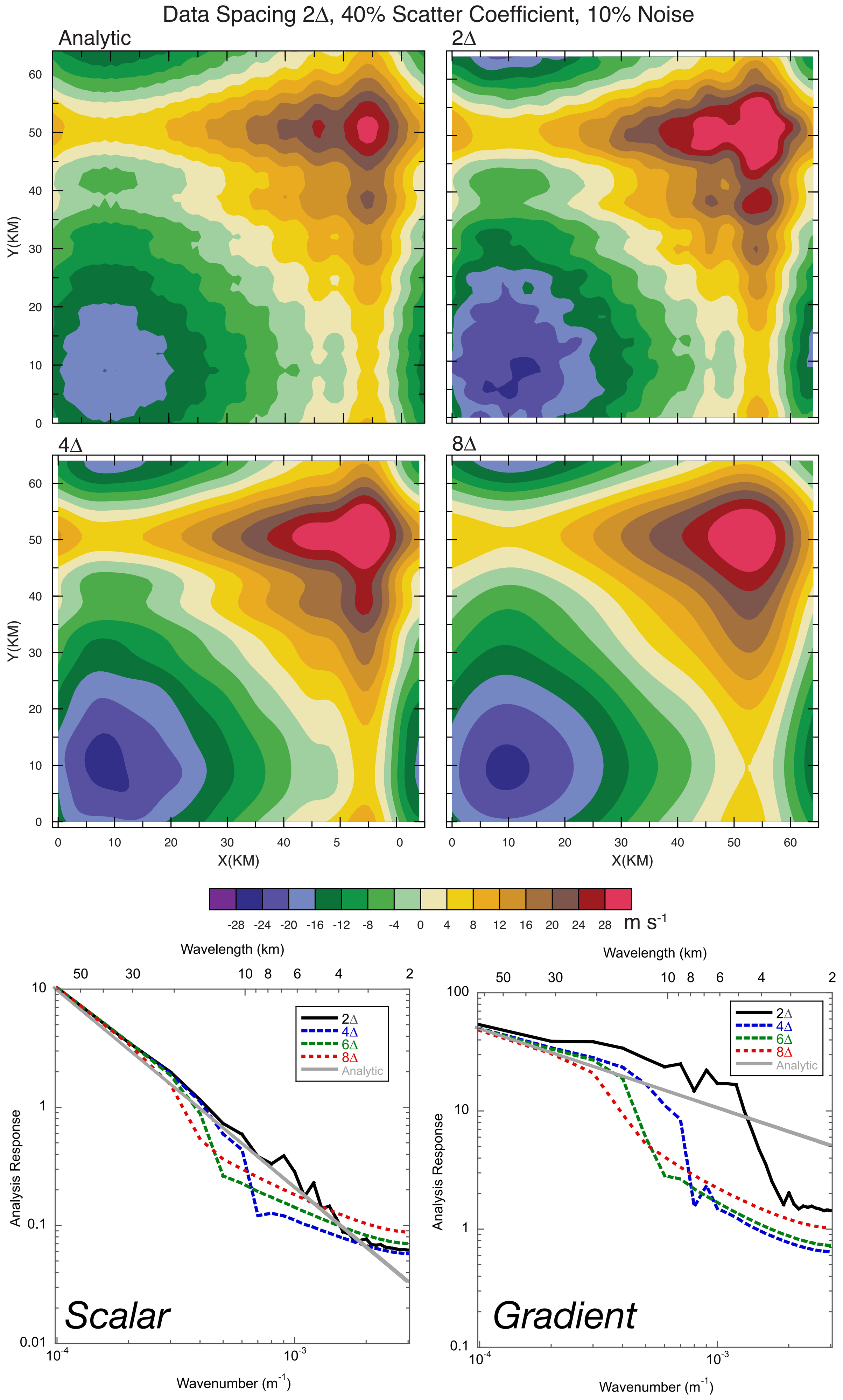
Analytic Tests and Validation

One distinguishing characteristic of the SAMURAI technique compared to other 3DVAR packages is the use of a cubic B-spline basis. The basis is computationally efficient and continuously differentiable to second order, allowing for accurate interpolation to observation locations, flexible incorporation of boundary conditions, and high numerical accuracy of kinematic derivatives. A variety of analytic tests have been performed to ensure accuracy and analysis quality.

Doppler Radar Analysis

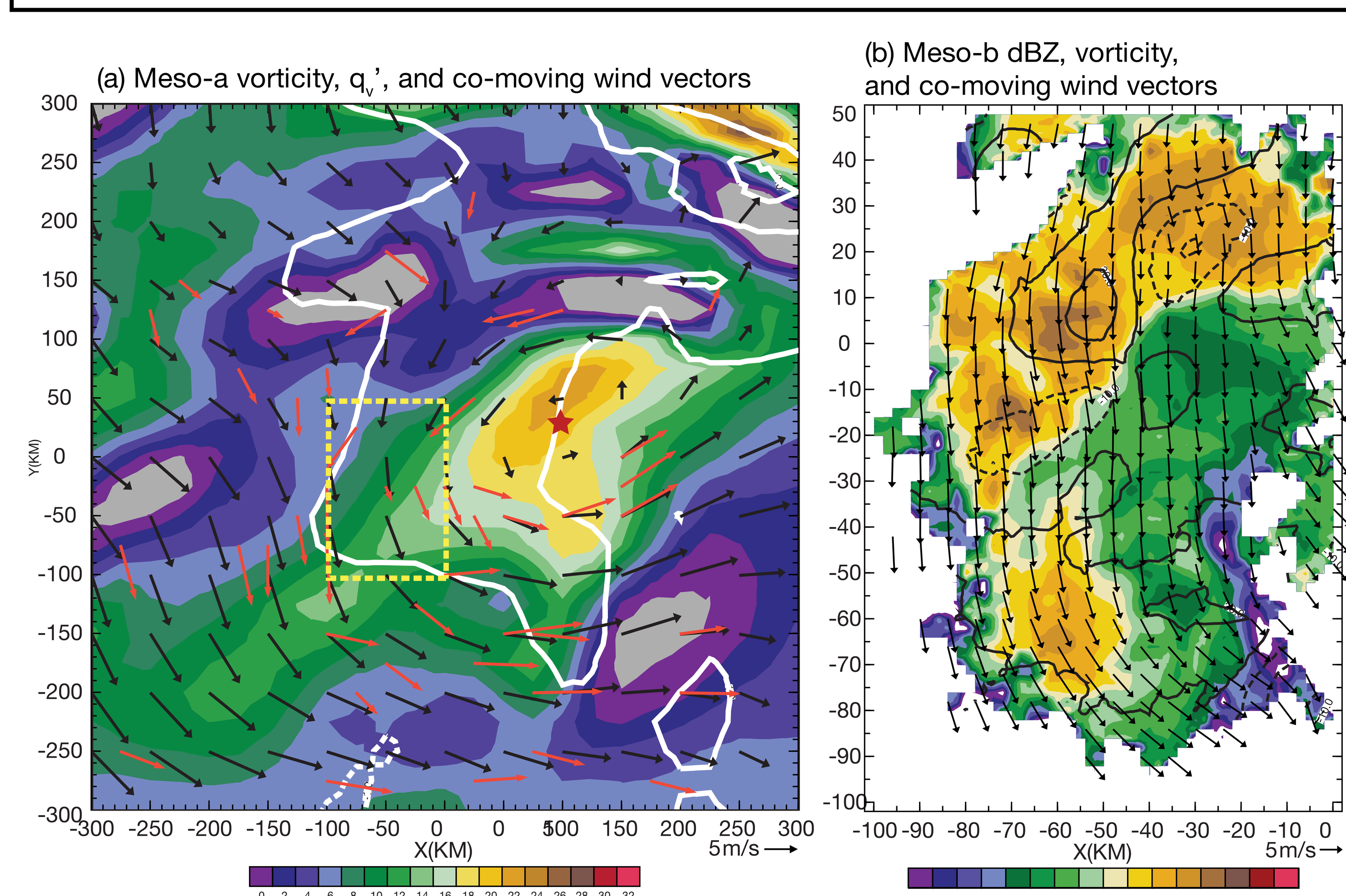


In Situ Analysis

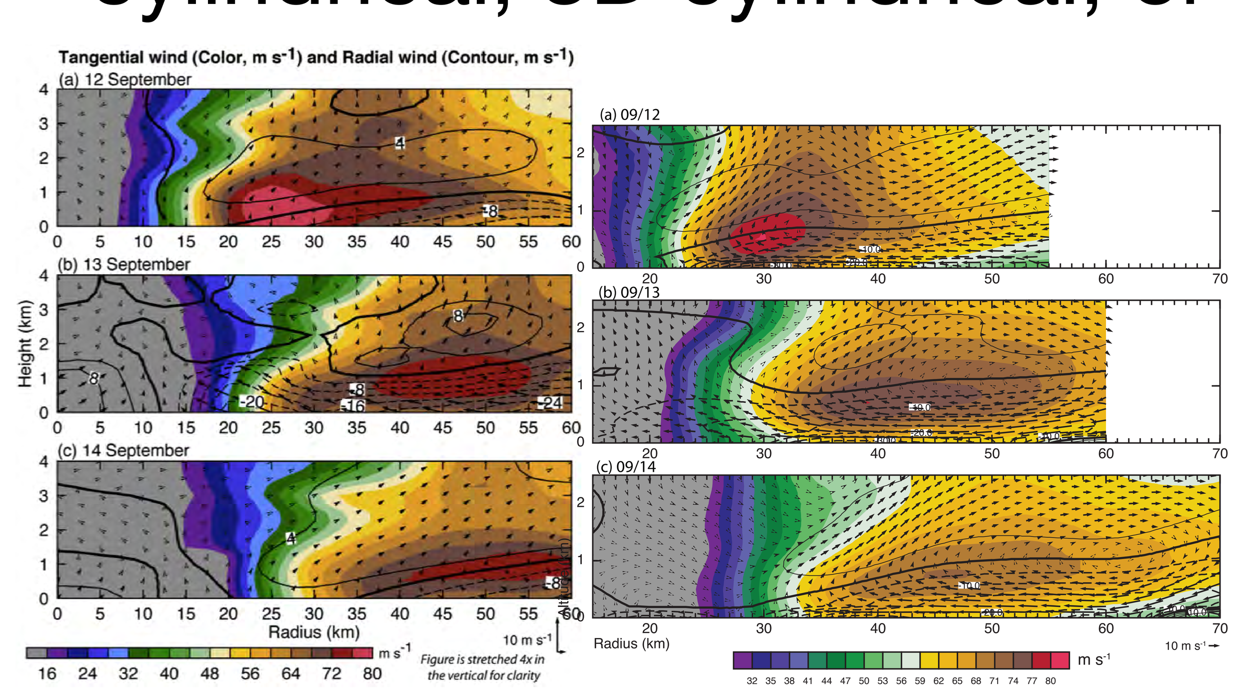


Real Data Examples

Data analysis can be performed in 2D axisymmetric cylindrical, 3D cylindrical, or 3D Cartesian coordinates.

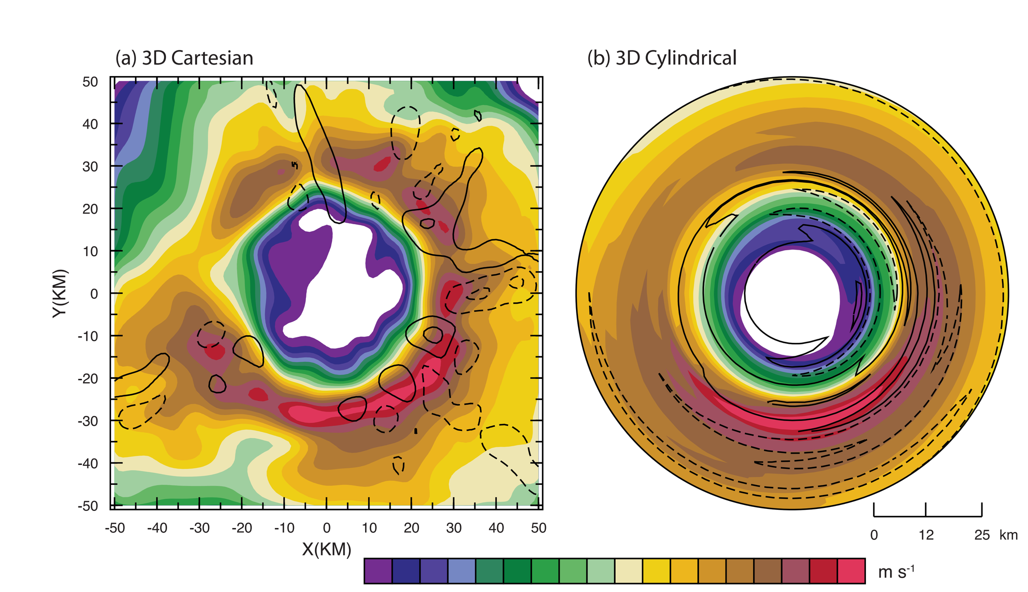


SAMURAI analysis of pre-depression Karl (2010) on 13 Sept. 00 UTC at 1.5 km altitude. Left panel uses ECMWF as background field for dropsonde analysis, right panel analyzes NOAA P3 Tail Doppler Radar.



Bell and Montgomery (2008)   Bell et al. (2012)

Axisymmetric tangential wind (color), radial wind (contour), and secondary circulation (vector) from Isabel (2003) on 12 – 14 Sept. Left panel shows Barnes analysis, right panel shows SAMURAI analysis.



Storm-relative wind speed (color) and vertical velocity (contour) from Isabel on 12 Sept. ~18 UTC at 1 km altitude. Left panel shows 3D Cartesian analysis, right panel shows 3D Cylindrical analysis.

SAMURAI is open source and available by request.

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