Conversion from Shear Vorticity To Curvature Vorticity, Organization of Convection, and Hurricane Genesis

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Numerical Weather Prediction

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Outline

- Introduction: Dynamics Review
- Methodology
- Model Overview
- Results
- Conclusions

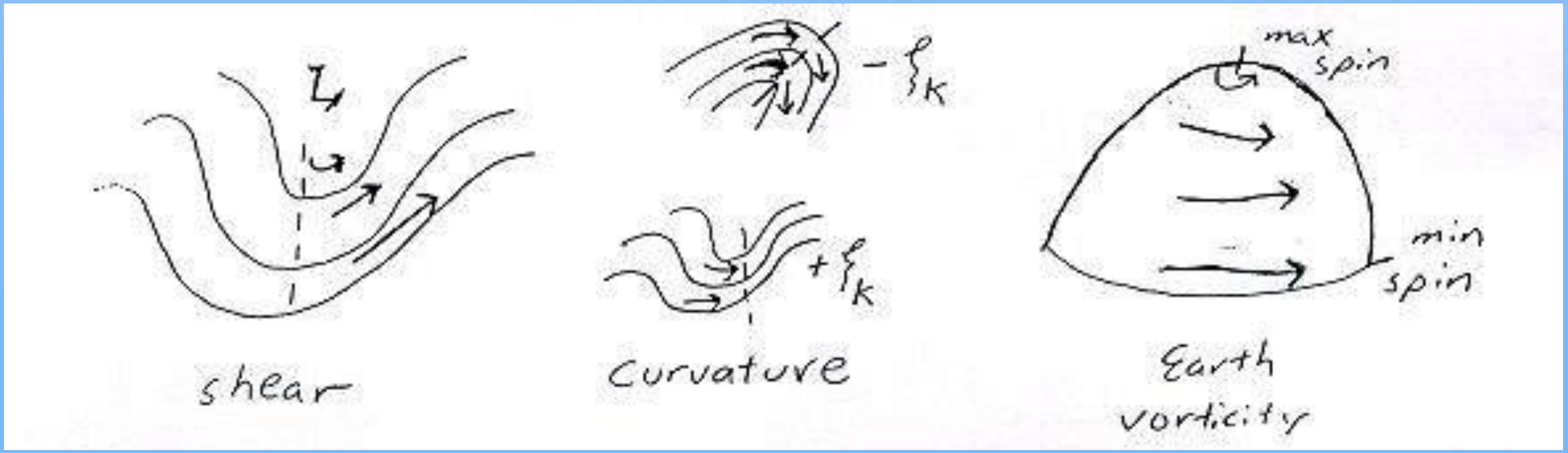
Introduction

- Krishnamurti et. al. (1986) showed a non-divergent BAROTROPIC model had more skill than persistence for 48 hours over West Africa
- Norquist et. al. (1977) observed that conversion of energy via barotropic processes plays important role in wave maintenance and amplification after wave moves off African continent
- Thorncroft and Hodges (2001) showed correlation between occurrence of 850 mb vorticity centers and frequency of hurricanes in Atlantic
- Ability to predict genesis from AEWs key to improving tropical cyclone forecasts

Dynamics Review

- Absolute vorticity composed of three components:
  1. Shear Vorticity
  2. Curvature Vorticity
  3. Planetary Vorticity

$$\xi = -\frac{\partial V}{\partial n} + \frac{V}{R} + f$$



Haby, 2007: Example of shear, curvature, and planetary vorticity

Background Theory

- Study argues importance of barotropic dynamics in the *formation* of a tropical cyclone
- Assuming there are no significant changes in latitude, absolute vorticity is materially conserved:

$$\frac{d\xi}{dt} = 0 = \frac{d\varsigma_c}{dt} + \frac{d\varsigma_s}{dt}$$

- As shear goes into curvature, parcels will move radially inward towards the center of the disturbance leading to an "organization of convection"
- The concentration of convection will allow for baroclinic based convective processes to further intensify the storm

Dynamics Review

- Keyser and Bell (1993) derive curvature and shear vorticity tendency equations in natural coordinates:
- Curvature Vorticity Tendency Equation:

$$\frac{d}{dt}\left(f+V\frac{\partial\alpha}{\partial s}\right)=\boxed{-\frac{\partial V}{\partial s}\frac{d\alpha}{dt}-\frac{\partial}{\partial n}\left(\frac{\partial\phi}{\partial s}\right)}-\left(f+V\frac{\partial\alpha}{\partial s}\right)\nabla_p\cdot\vec{V}-\vec{V}\frac{\partial\omega}{\partial s}\frac{\partial\alpha}{\partial p}$$

- Shear Vorticity Tendency Equation:

$$\frac{d}{dt}\left(-\frac{\partial V}{\partial n}\right)=\boxed{\frac{\partial V}{\partial s}\frac{d\alpha}{dt}+\frac{\partial}{\partial n}\left(\frac{\partial\phi}{\partial s}\right)}-\left(-\frac{\partial V}{\partial n}\right)\nabla_p\cdot\vec{V}-\vec{V}\frac{\partial\omega}{\partial n}\frac{\partial V}{\partial p}$$

Methodology

- MM5 used as source for u, v, and φ that are needed for calculating shear vorticity to curvature vorticity conversions for Cartesian coordinates as derived by Bell and Keyser (1993)
- 3 single way nests with resolutions of 27 km, 9 km, and 3 km with 23 unevenly spaced vertical levels
- NCEP 1° x 1° FNL used for boundary and initial conditions for 27 km domain
- Innermost domain run for 48 hours
- MM5 Model Configuration:
    - Blackadar planetary boundary layer
    - Explicit convection
    - Goddard cloud microphysics
    - Cloud radiation scheme

Methodology

- Used FSU Barotropic Model initialized with 3 km MM5 data 6 hours into forecast
  - u and v from this time were used to calculate streamfunction
- Model run for total of 42 hours with time step of 1 second
- Study involves developing and non-developing case:
  1. Hurricane Helene (2006): 09/13/06 18Z – 09/15/06 18Z
  2. NAMMA Wave #3 (2006): 08/26/06 12Z – 08/28/06 12Z

Barotropic Model Review

- Nondivergent barotropic model used:

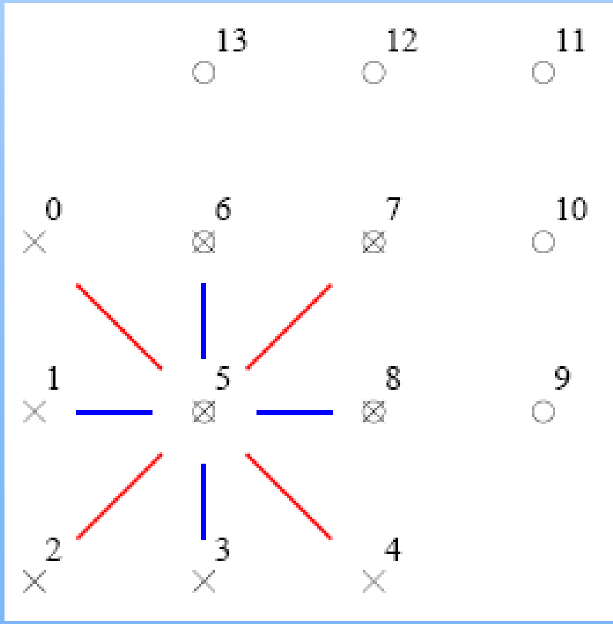
$$\frac{d\xi}{dt} = \frac{\partial \varsigma}{\partial t} + J(\psi, \varsigma + f) = 0$$

$$J(\psi, \varsigma + f) = u\frac{\partial \varsigma}{\partial x} + v\frac{\partial \varsigma}{\partial y} + \beta v$$

- Relative vorticity generated through movement of parcels to different latitudes

Barotropic Model Review

- Advective term calculated using 9-point Arakawa Jacobian



$$J^n = \frac{1}{3}(J_{++} + J_{\times+} + J_{+\times})$$

- Conserves energy and enstrophy preventing nonlinear instability!

Matsuno Time Scheme

- Multistep scheme involving "predictor" step and "corrector" step
- Predictor Step: Use forward explicit difference scheme to obtain u^{n+1^*}:

$$u^{n+1^*} - u^n = \Delta t g(u^n)$$

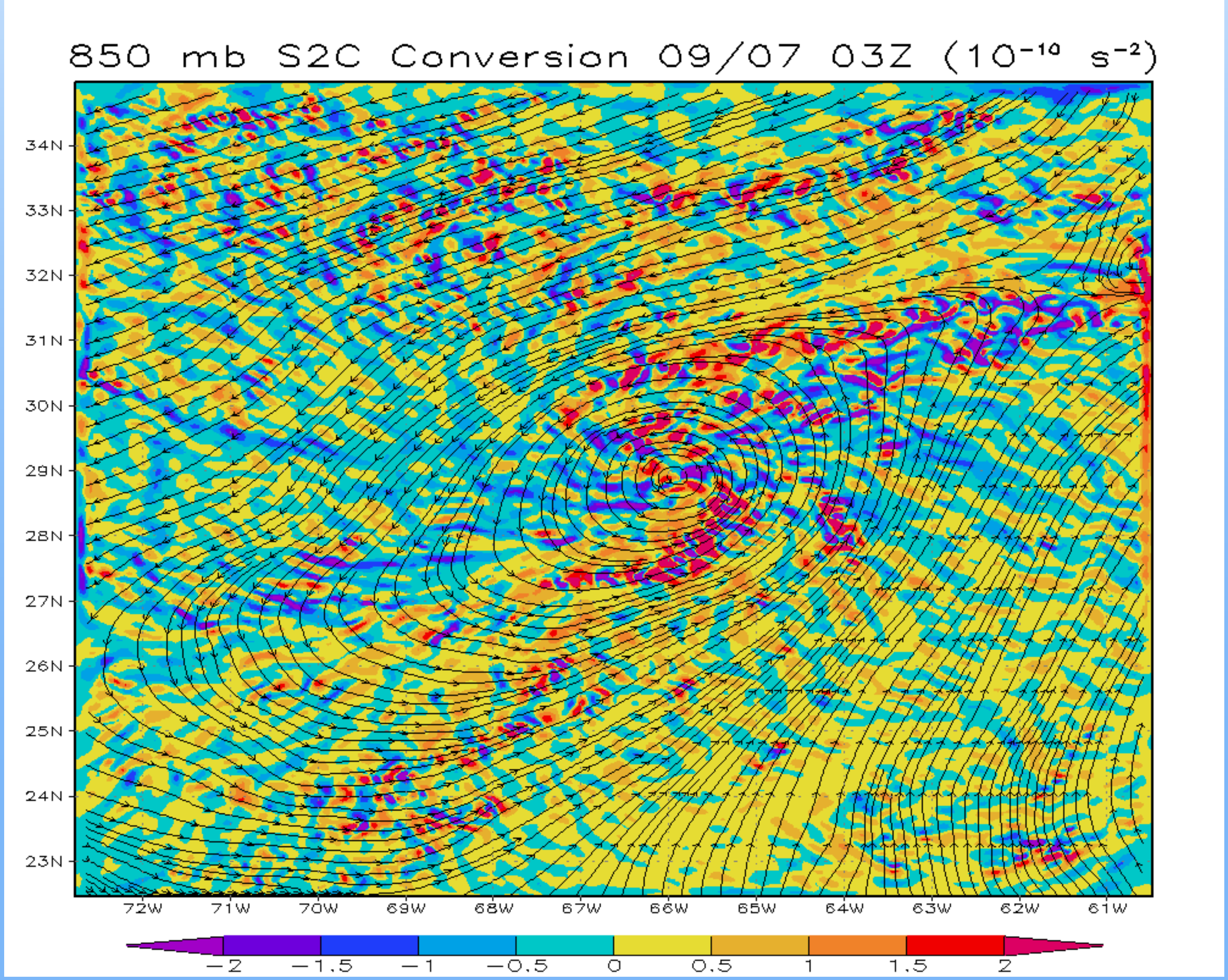
- Solve for $g(u^{n+1^*})$ using u^{n+1^*}
- Predictor Step: Use $g(u^{n+1^*})$ to solve for u^{n+1} using backward implicit difference scheme:

$$u^{n+1} - u^n = \Delta t g(u^{n+1^*})$$

Matsuno Time Scheme

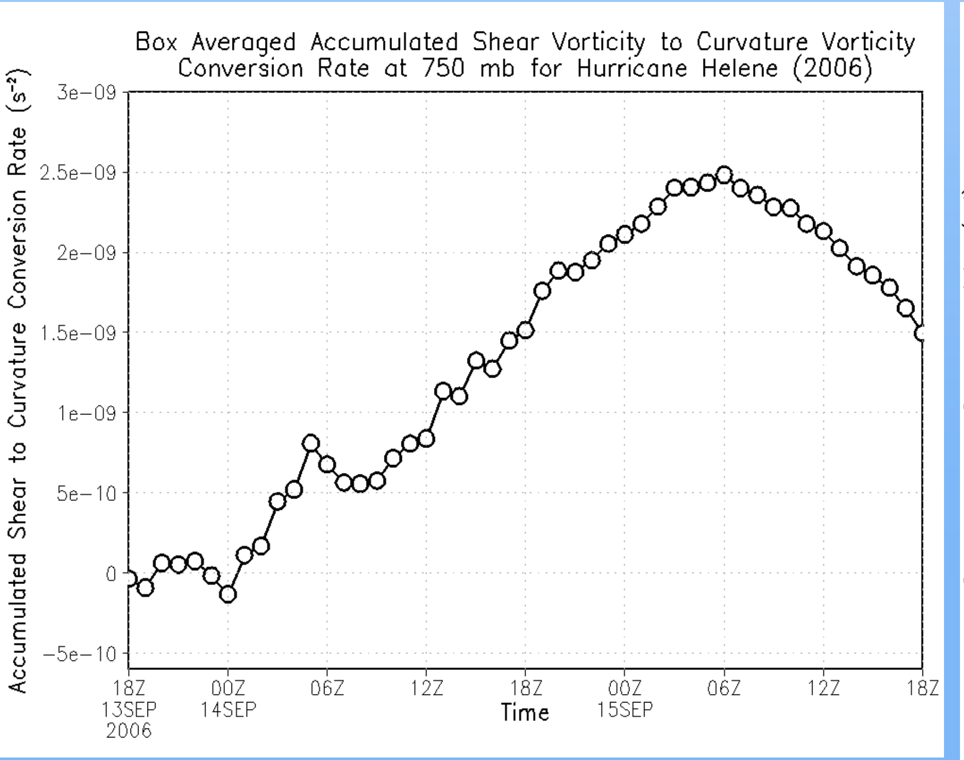
- Advantages:
  - higher accuracy: second order accuracy
  - Forward explicit and backward implicit are only first order accurate
  - can use larger time step
- Disadvantage:
  - computationally expensive because evaluating $g(u^n)$ several times

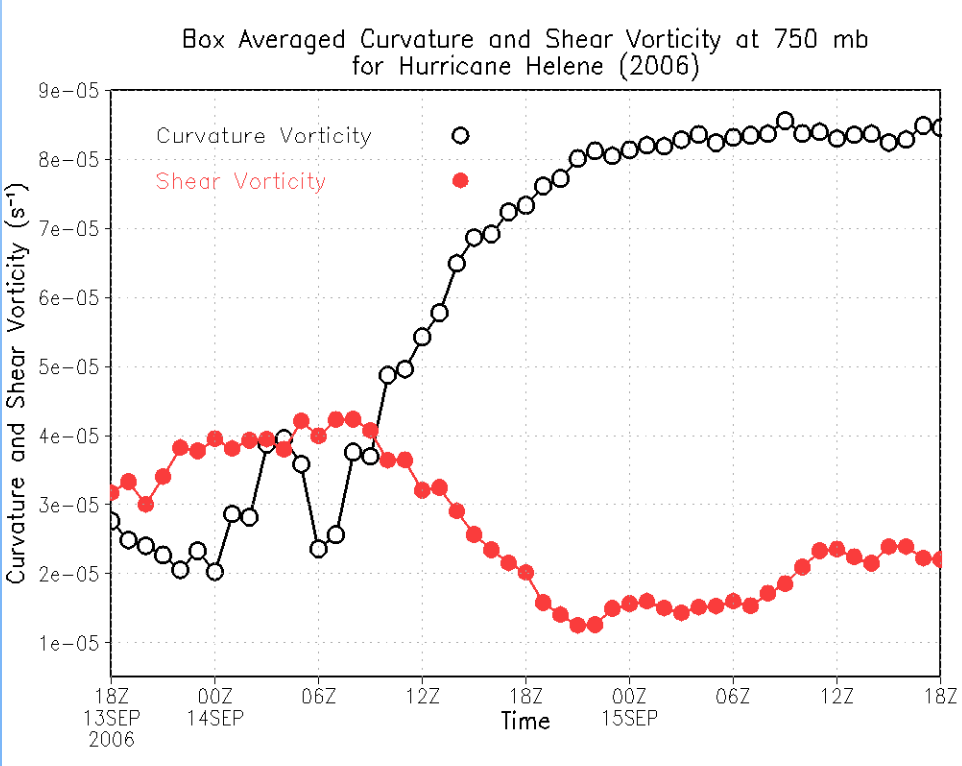
Shear Vorticity Conversions To Curvature Vorticity Conversions



Accumulated Shear to Curvature for MM5 Run for Hurricane Helene

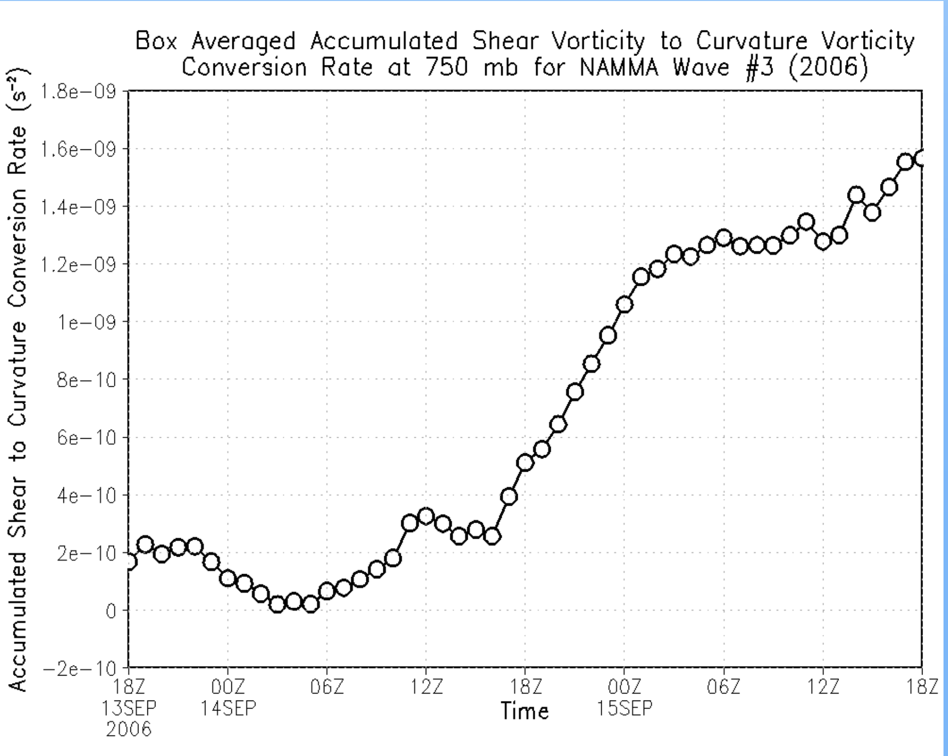
- Notice consistent conversion of shear vorticity to curvature vorticity in developing case
- Mutual exchange of shear vorticity and curvature vorticity

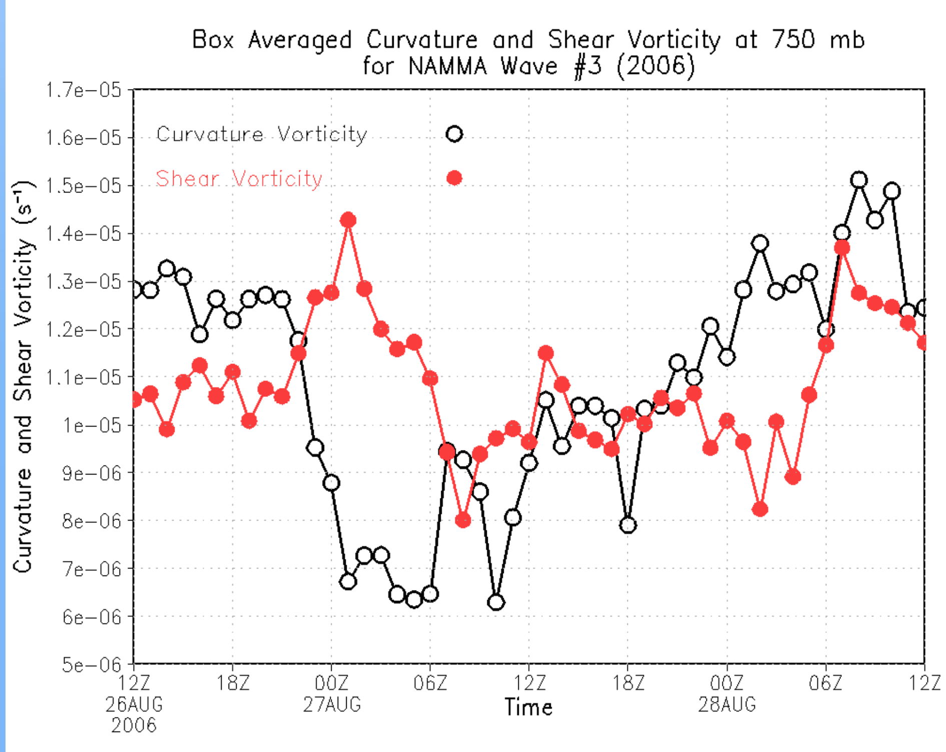




Accumulated Shear to Curvature for MM5 Run for NAMMA Wave #3

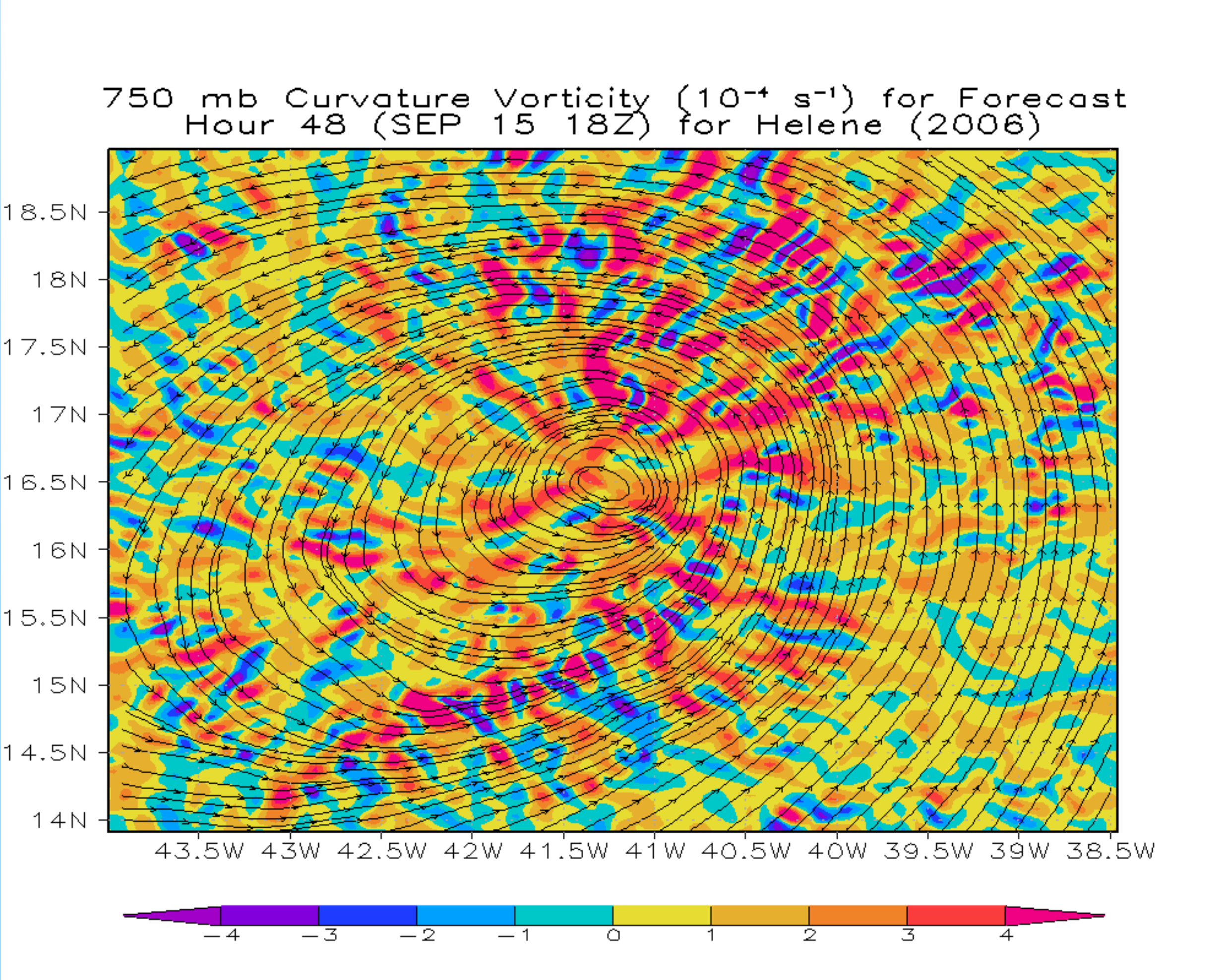
- Magnitude of conversions are smaller
- Curvature vorticity does increase, but no corresponding decrease in shear vorticity





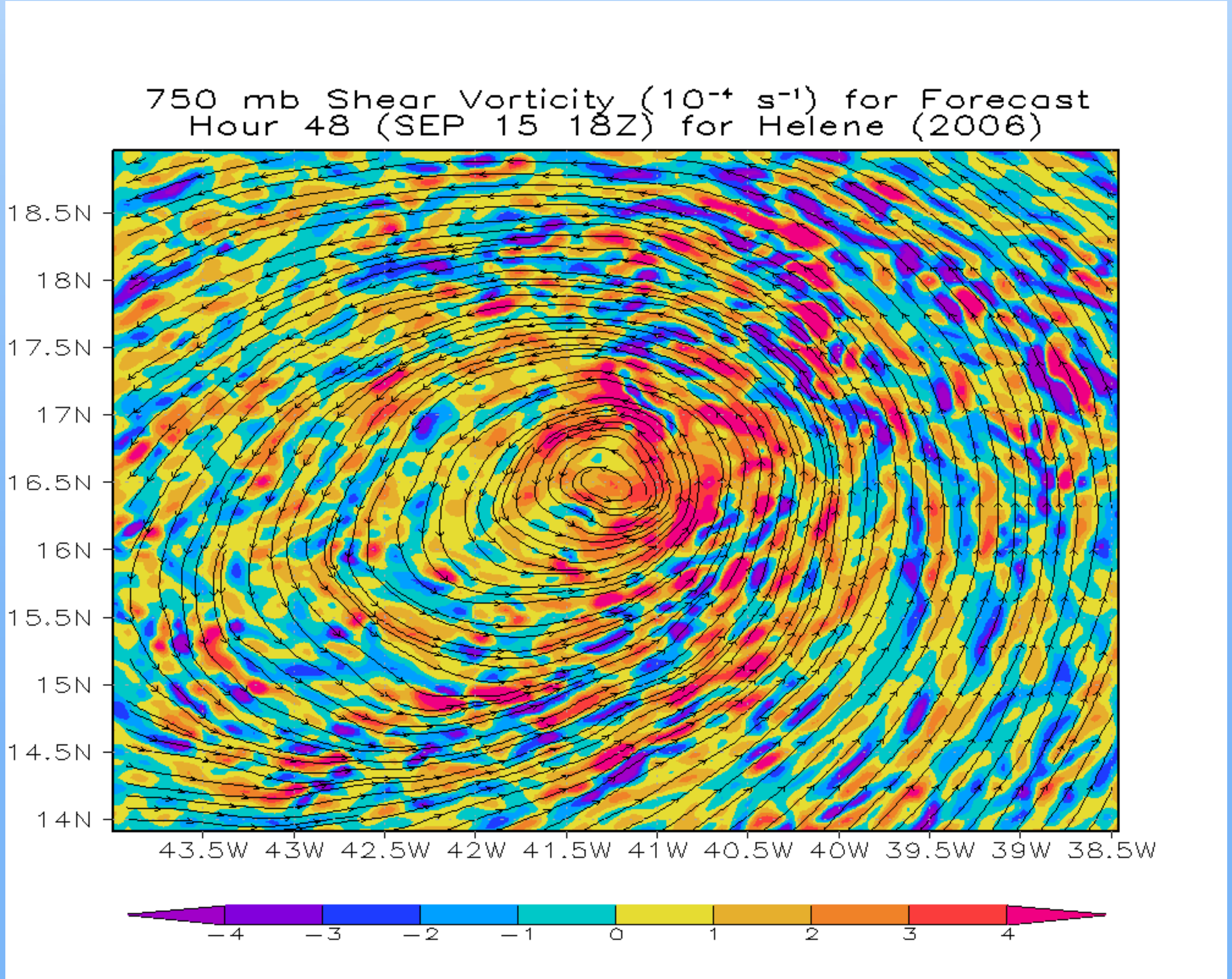
Curvature Vorticity and Shear Vorticity Plots

- Curvature Vorticity normal to flow



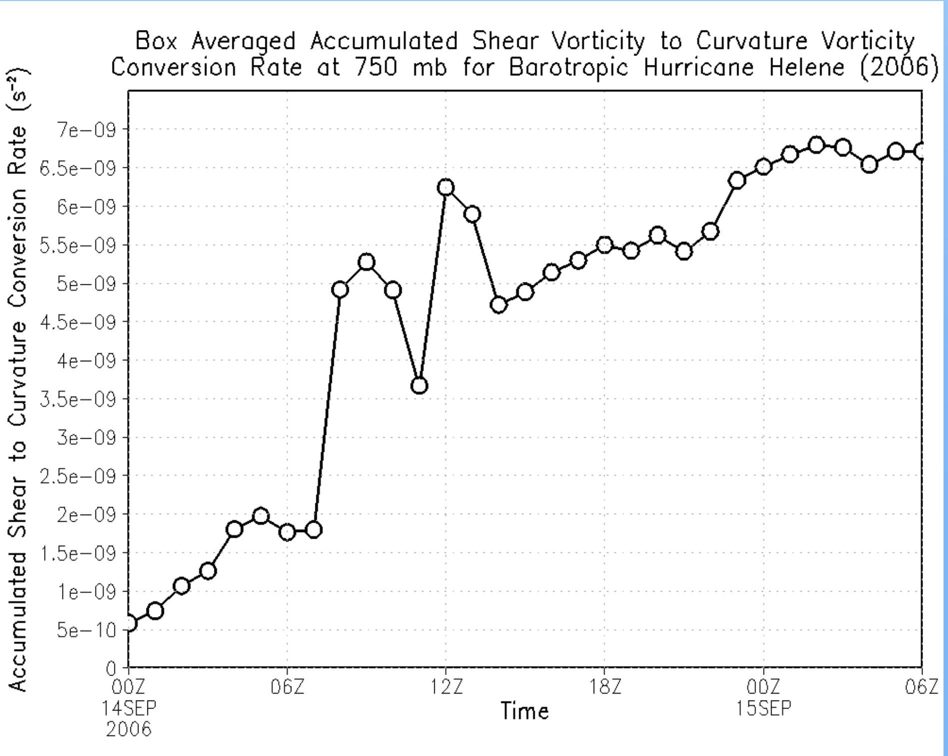
Curvature Vorticity and Shear Vorticity Plots

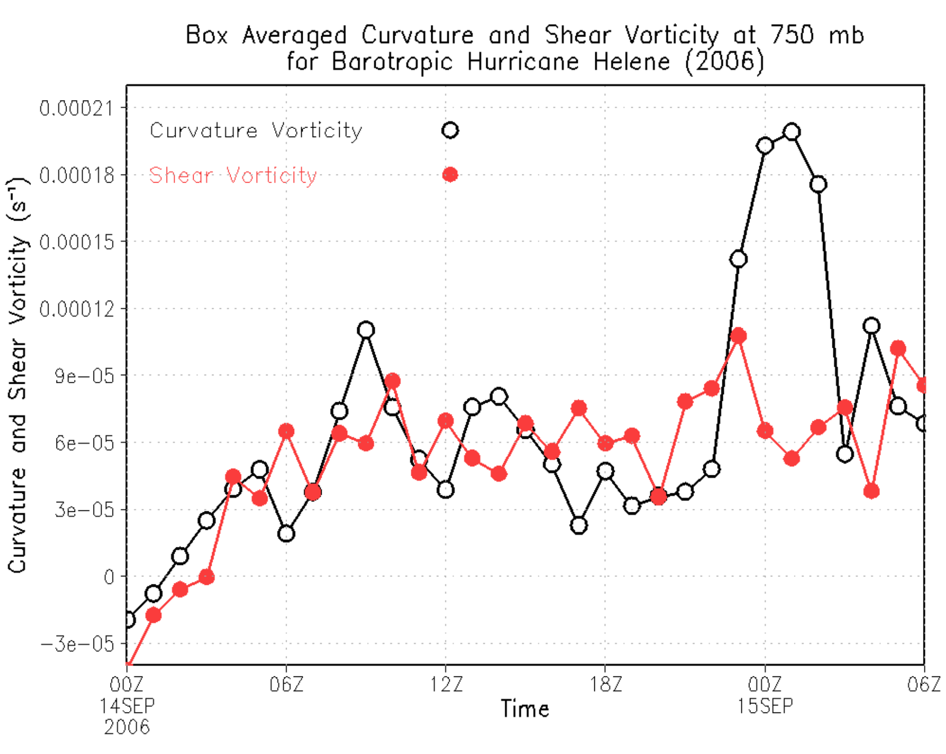
- Shear Vorticity parallel to flow



Barotropic Model Results

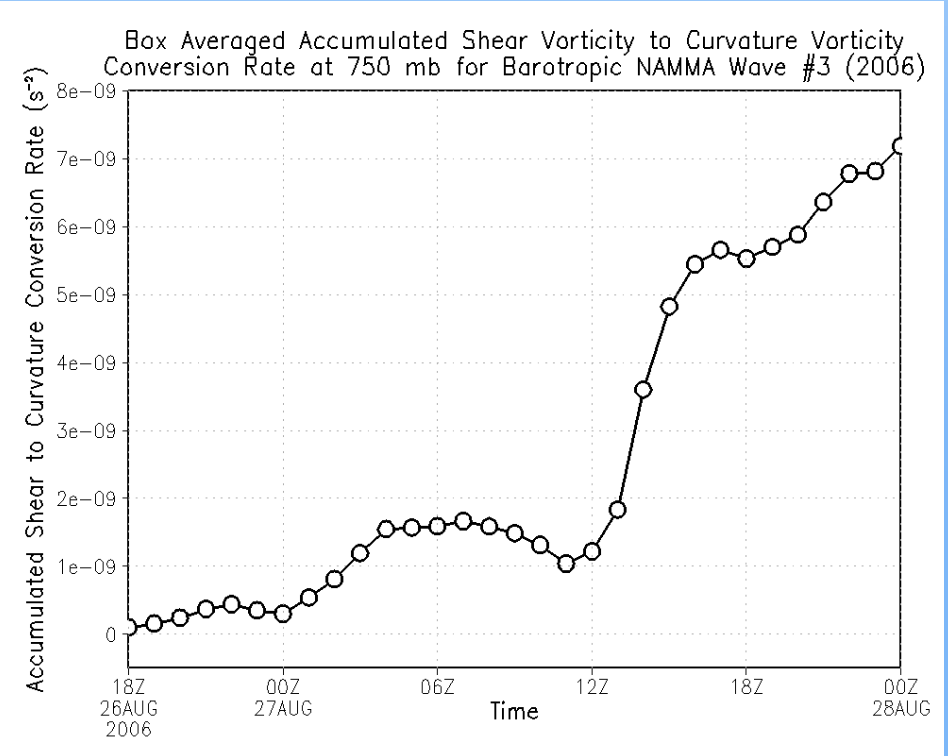
- Consistent increase in amount of shear vorticity being converted to curvature vorticity
- Signal from shear vorticity and curvature vorticity budgets is more ambiguous

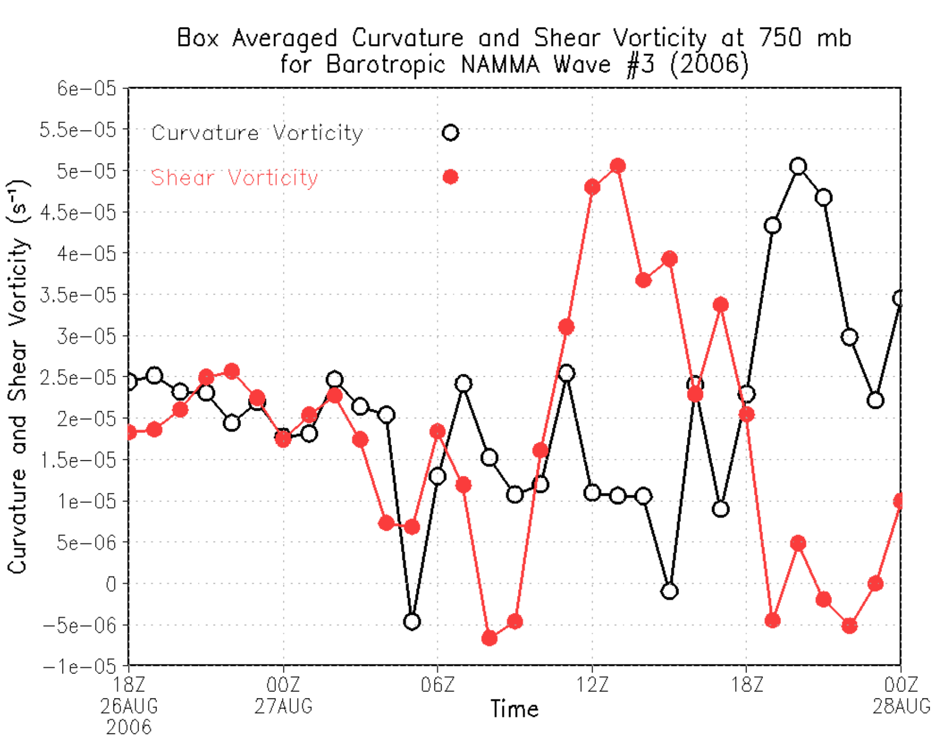




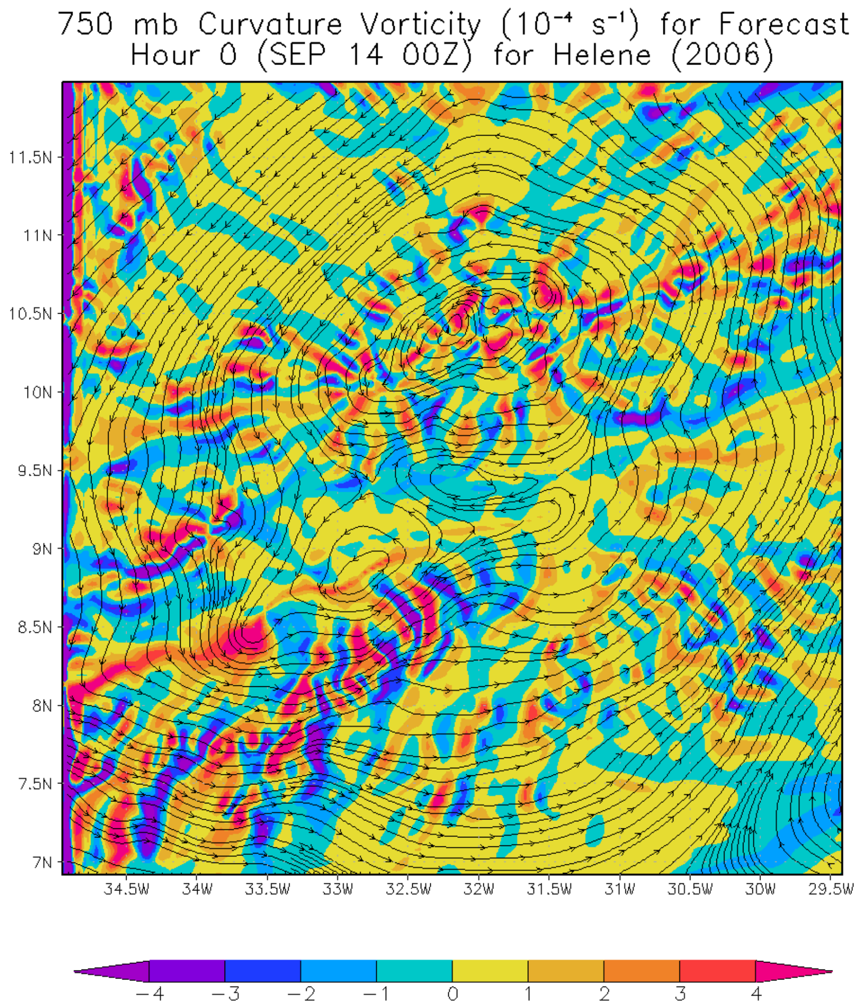
Barotropic Model Results

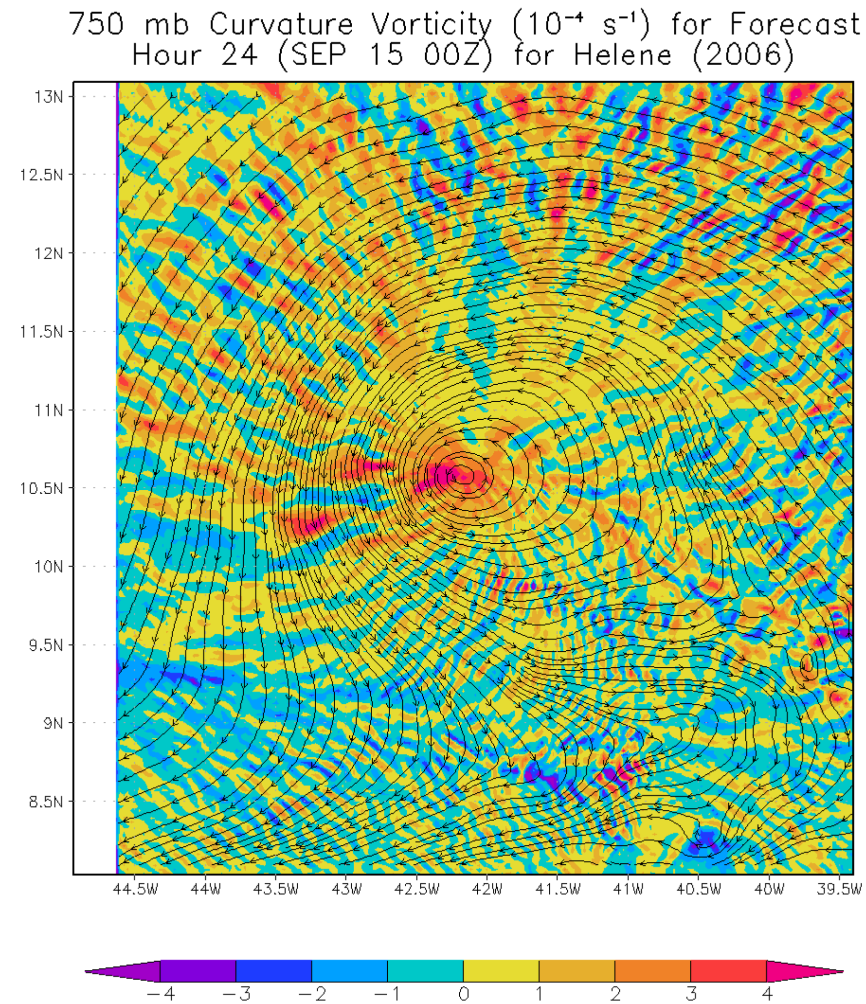
- Shear vorticity being converted to curvature vorticity, but ambiguous response in shear vorticity and curvature vorticity budgets



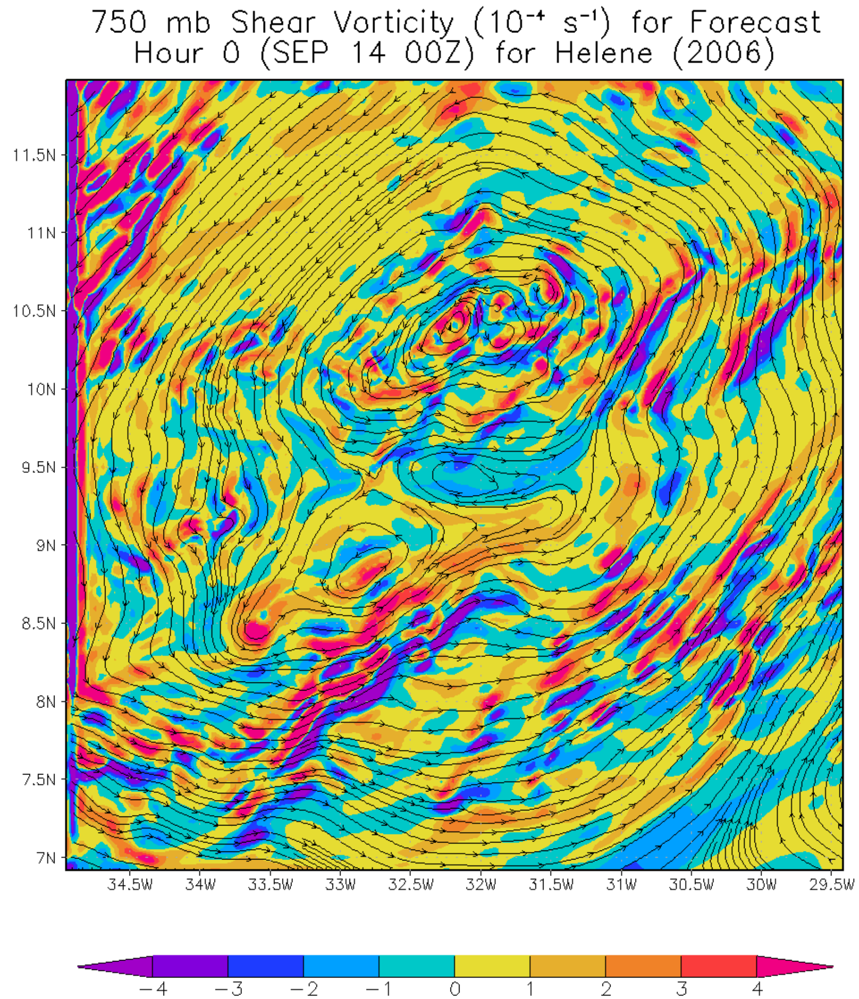


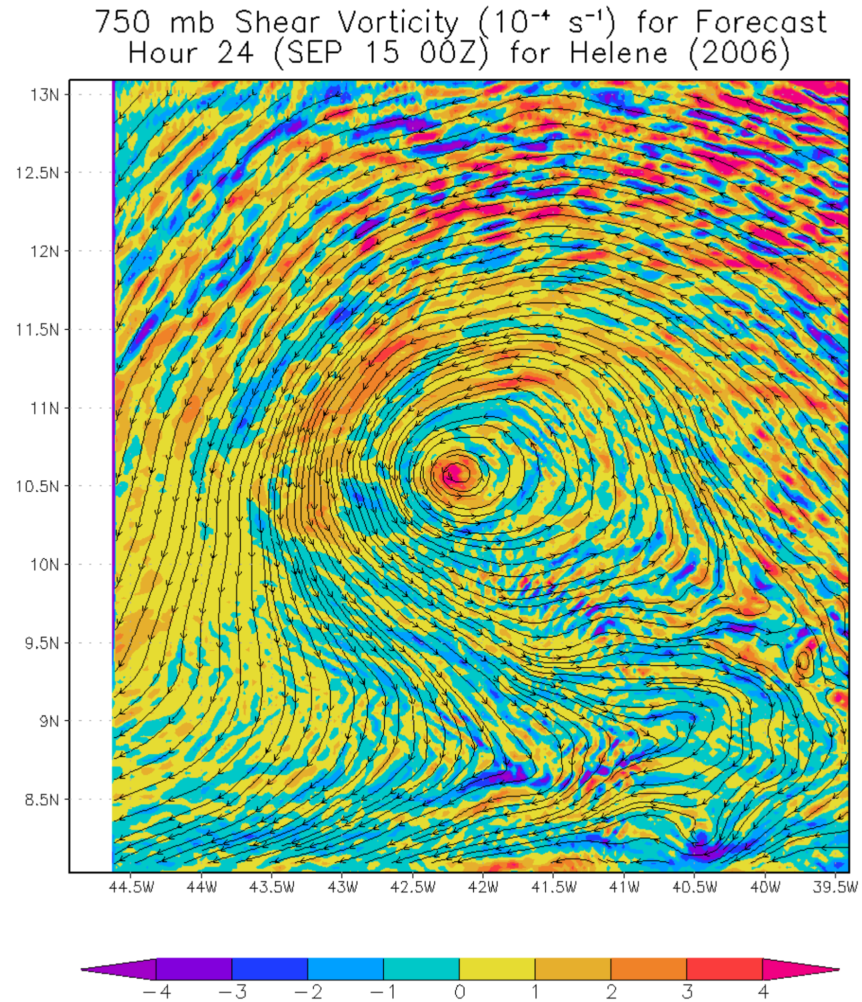
Barotropic Model Results: Curvature Vorticity





Barotropic Model Results: Shear Vorticity





Conclusions

- While MM5 hints that shear vorticity to curvature vorticity conversions are important for accounting for curvature vorticity, results from barotropic model are not definitive
  - No difference between developing and non-developing cases in terms of shear vorticity and curvature vorticity conversions
  - Response among vorticities in barotropic model runs not as clear
- Spatial structure of curvature vorticity and shear vorticity similar for MM5 and barotropic model → can be explained using barotropic dynamics

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