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Tropical Cyclone Interactions Within Central American Gyres

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1) Motivation

- TCs occasionally interact with large-scale cyclonic circulations, known as Central American gyres (CAGs) in the Atlantic basin (Papin 2014)
- One potential interaction occurred in October 2005 where TC Stan possibly interacted with a CAG, resulting in:
  1. A poor track forecast by the National Hurricane Center (Fig. 1, red) when TC Stan deviated equatorward in the Gulf of Mexico (Fig. 1, green).
  2. Over 1000 fatalities due to catastrophic rainfall associated with both systems (Fig. 1, shaded).
- Pasch and Roberts (2006) attributed track error to a stronger than expected deep-layer anticyclone north of TC Stan
- This study aims to investigate track deviation associated with the previously unidentified CAG.

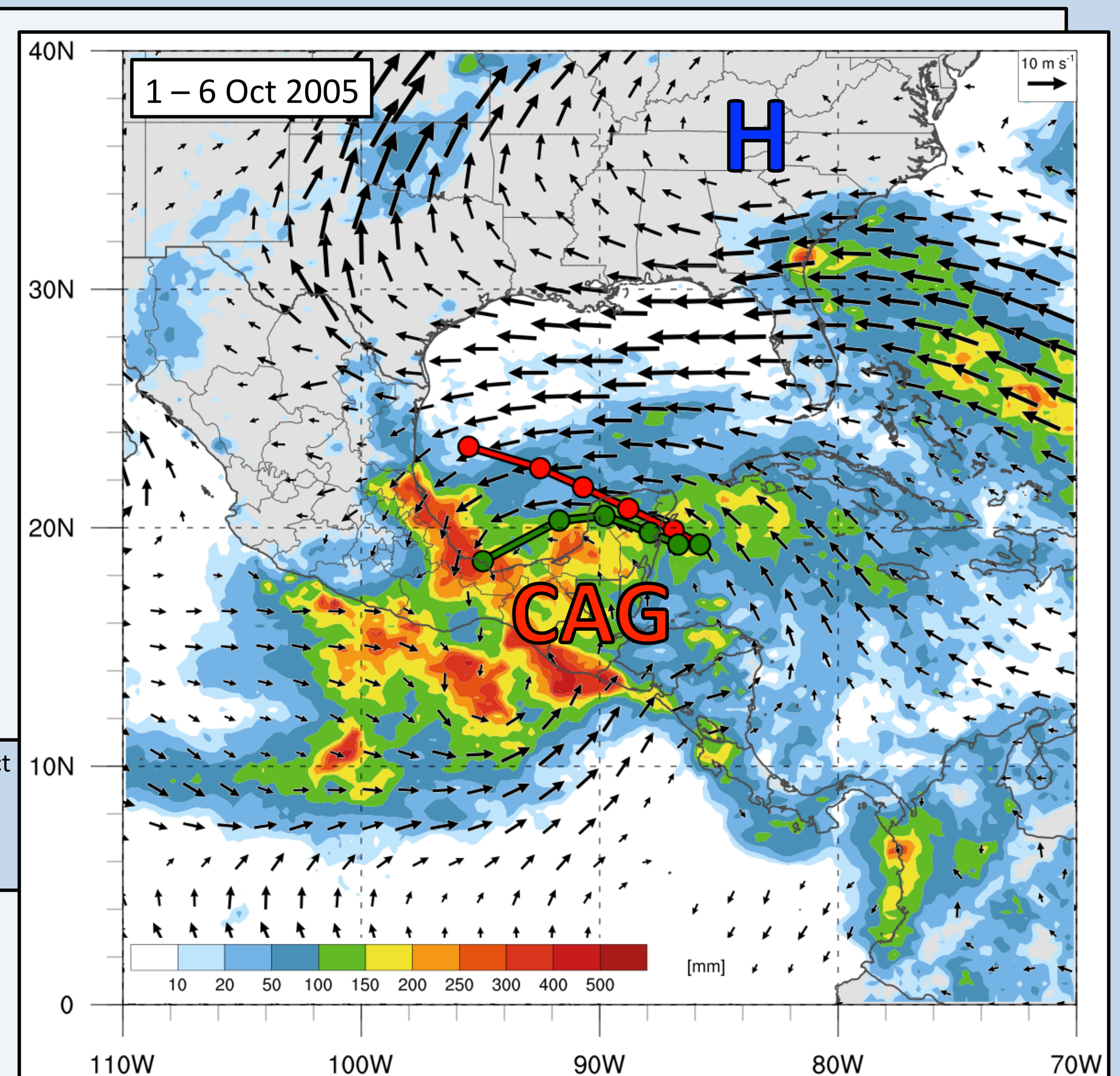

Fig 1. TRMM derived total rainfall (shaded, mm) and 850-hPa time-mean winds (vectors, m s^{-1}) from 1 Oct – 6 Oct 2005. 72 h NHC forecast track in red, best track in green, where dots along each track denote 12 h periods.

2) CAG Identification

- CAGs are comprised of numerous vorticity maxima rotating around a common broad center
- CAGs were identified in Papin (2014) using a sophisticated algorithm that filters out TCs, non-closed circulations, and weaker circulations that are not of sufficient longevity (≥ 48 h)
- 42 CAGs were identified from May – Nov (1980 – 2010) with ~50% associated with at least one TC < 1000 km from the CAG.
- A CAG was identified during TC Stan's evolution, and is representative of the typical size and intensity of the CAG climatology (Fig. 2)

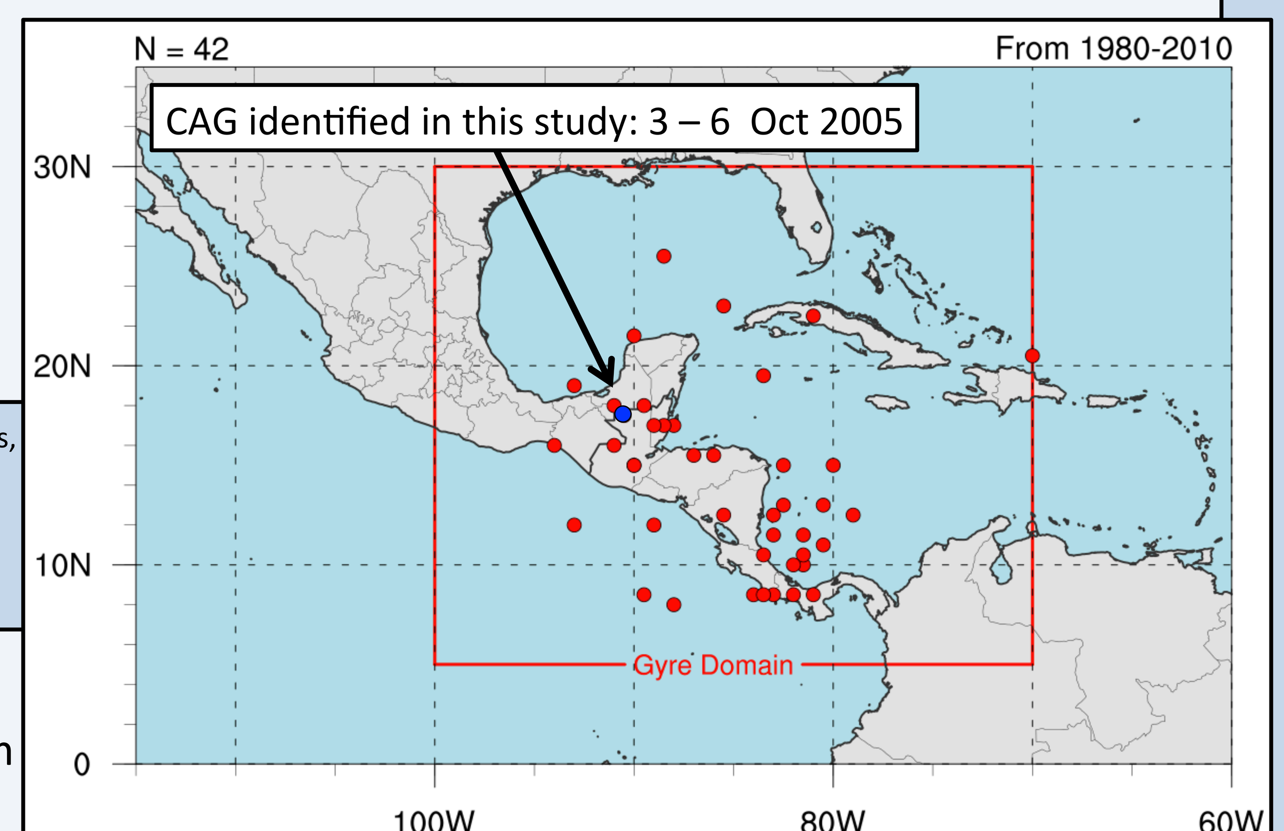

Fig 2. Position of CAGs at genesis from 1980-2010 identified in Papin 2014. Individual CAGs depicted as red circles, while the CAG discussed in this study is highlighted as a blue circle.

3) CFSR Analysis Vs. GFS Forecast

- This study investigates TC Stan's interaction with CAG qualitatively from a vorticity (microscopic) and circulation (macroscopic) perspective
- Using Stokes' theorem, circulation is equivalent to area average vorticity

$$C = \iint_{Area} \zeta \, dx \, dy$$

- CFSR suggests binary barotropic interaction between TC Stan and the larger CAG circulation (Fig. 3a – c)
- GFS forecast depicts TC Stan displaced poleward and does not develop a CAG (Fig. 3d – f)
- GFS forecast forms a possible TC in east Pacific

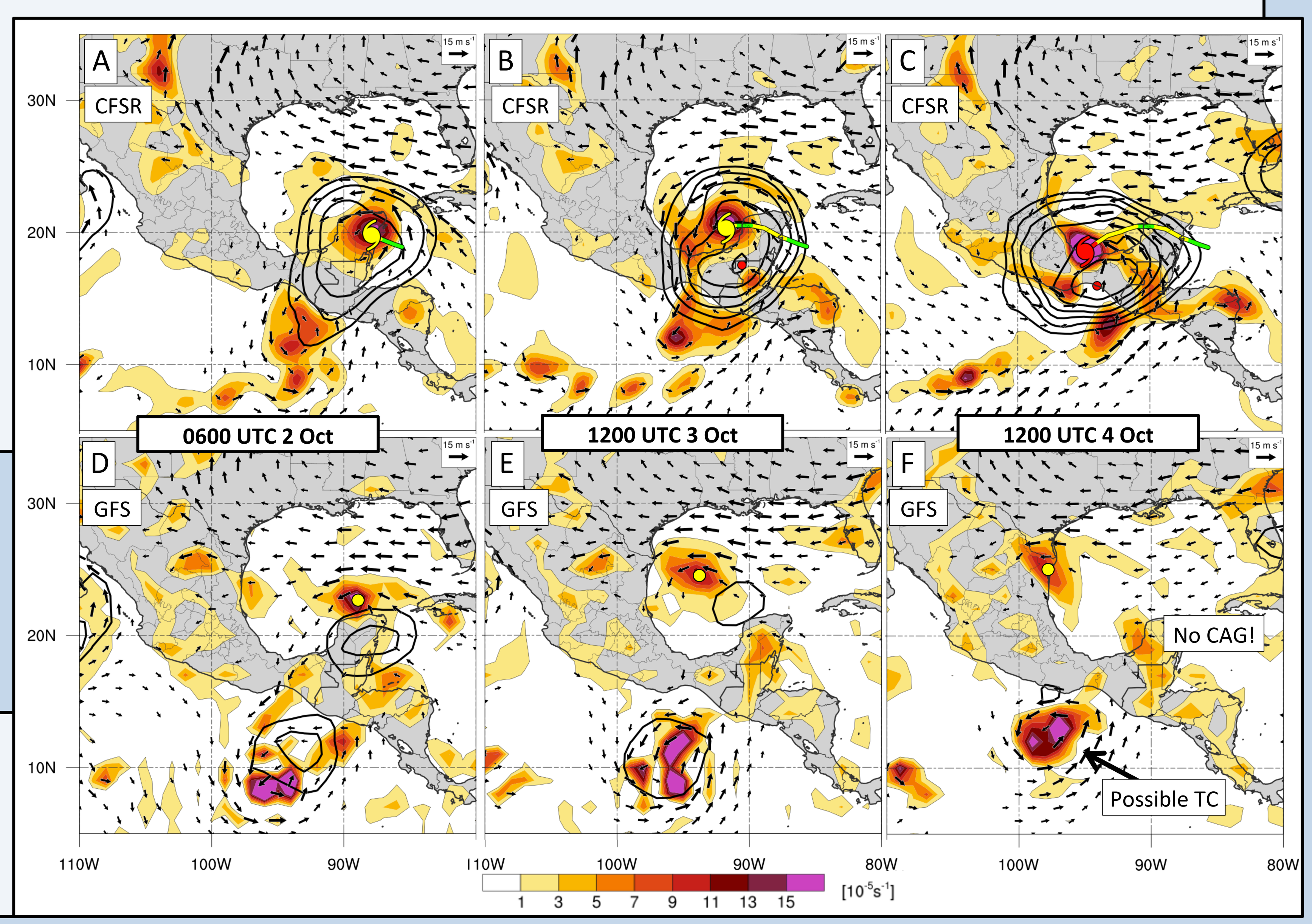

Fig. 3. 850-hPa relative vorticity (shaded, starting at 1x10^{-5} s^{-1}), 500-1000 km radial mean 850-hPa area average vorticity (black contours, starting at 1x10^{-5} s^{-1}), 850-hPa total wind (vectors, between 5-15 m s^{-1}) for (a) and (d) 0600 UTC 2 Oct, (b) and (e) 1200 UTC 3 Oct, and (c) and (f) 1200 UTC 4 Oct. CFSR analysis is plotted on (a) – (c) while a GFS forecast initialized on 0000 UTC 1 Oct is plotted on (d) – (f).

Datasets

- NCEP Climate Forecast System Reanalysis (CFSR)
- GFS forecast initialized at 0000 UTC 1 Oct 2005
- NASA TRMM 3B42 (v7) Rainfall
- NCDC IBTrACS

4) Piecewise Vorticity Inversion

- Adapted from Davis et al. (2008), where inverted vorticity and divergence is used to obtain nondivergent and irrotational winds individually for both the CAG and outside environment
- Steering flow obtained by removal of TC Stan vortex
  1. averaged over TC Stan radius (2.5°)
  2. averaged from 925 – 500-hPa; consistent with expected steering depth of strong tropical storm (Galarneau and Davis 2012)

$$\nabla^2\psi = \begin{cases} \zeta & \text{for} \quad r \le r_0 \\ 0 & \text{for} \quad r > r_0 \end{cases} \qquad \nabla^2\chi = \begin{cases} \delta & \text{for} \quad r \le r_0 \\ 0 & \text{for} \quad r > r_0 \end{cases} \qquad \vec{V}_\psi = \hat{k} \times \nabla\psi \qquad \vec{V}_\chi = \nabla\chi$$

$$\vec{V}_{gyre} = \vec{V}_\psi + \vec{V}_\chi \qquad \vec{V}_{env} = \frac{1}{\pi r_0^2} \int_0^{2\pi} \int_0^{r_0} \vec{V} r dr$$

Fig 4. Schematics of radii where vorticity inversion is preformed for (a) the CAG, (b) the CAG without TC Stan, and (c) the total environment without the CAG

Test 1
Obtain CAG winds
$r_{gyre} \le 7°$

Test 2
Same as test 1 except remove TC Stan vortex
$r_{gyre} \le 7°$
$r_{Stan} \ge 2.5°$

Test 3
Obtain environmental winds
$r_{env} \ge 7°$

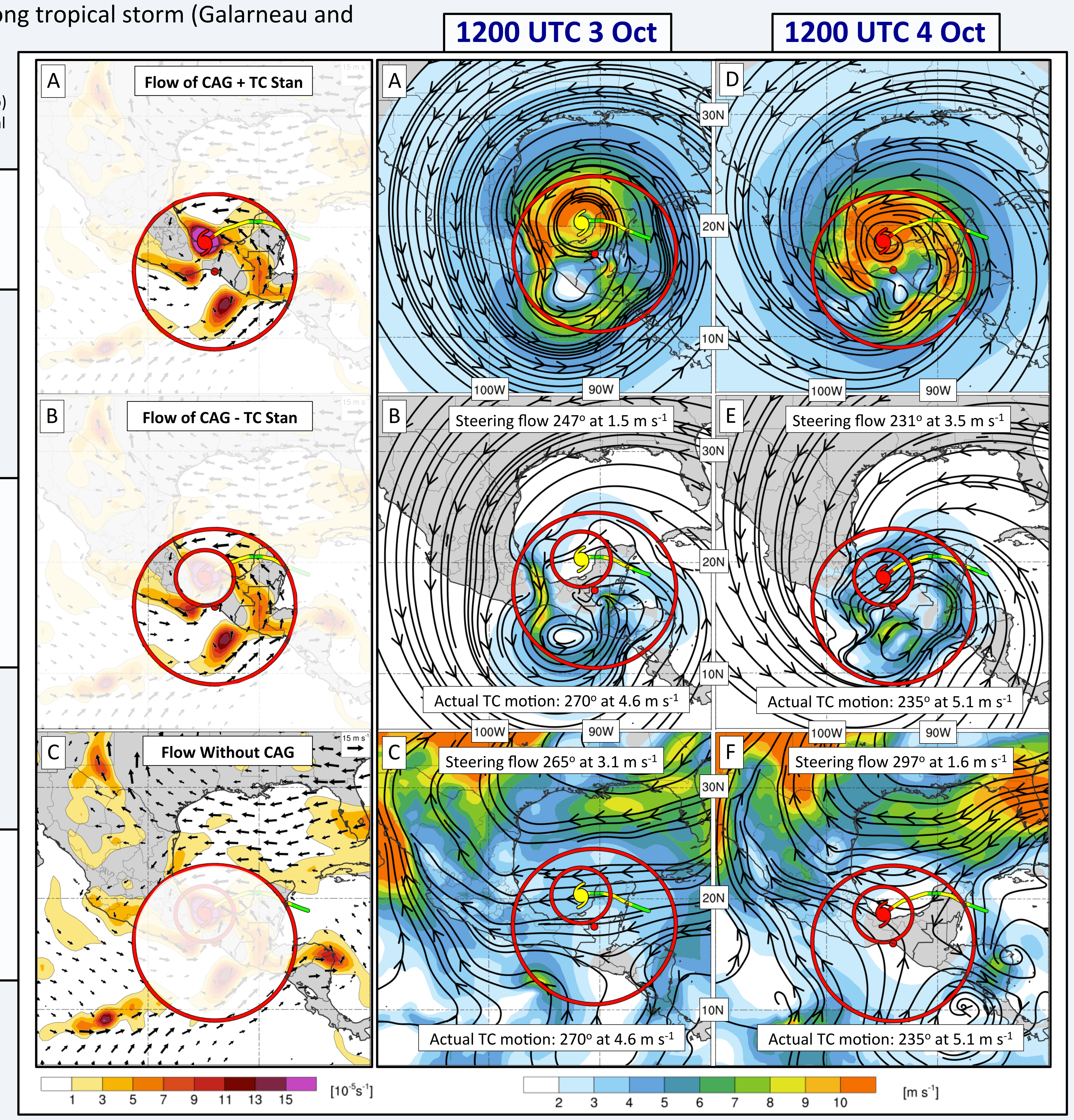

Fig 5. 925 – 500-hPa layer average total wind (shaded, m s^{-1}) and streamlines for vorticity inverted fields at 1200 UTC 3 Oct (a) – (c) and 1200 UTC 4 Oct (d) – (f)

5) Discussion and Conclusions

- Large cyclonic circulation (CAG) interacted with TC Stan, resulting in an unexpected equatorward deviation in track (Fig. 3a – c)
- TC Stan tracked more poleward in GFS forecast, possibly due to failure to develop a CAG. (Fig. 3d – f)
- Piecewise vorticity inversion conducted to quantify CAG steering impact of TC Stan relative to the environment (Fig. 4a – c)
  1. Deep-layer anticyclone initially contributes to majority of westward steering flow of TC Stan into Gulf of Mexico (Fig. 5e – f)
  2. When TC Stan turns equatorward, CAG steering flow dominates over steering flow by deep-layer anticyclone(Fig. 5a – c)
  3. Piecewise inversion of GFS forecast only has steering flow from deep-layer anticyclone due to lack of CAG (not pictured)
- Thus, equatorward track deviation of TC Stan is primarily caused by steering flow of CAG, resulting from the binary barotropic interaction of both circulations

References and Acknowledgments

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