$\psi - \chi$ Interactions of Tropical Cyclone Cindy

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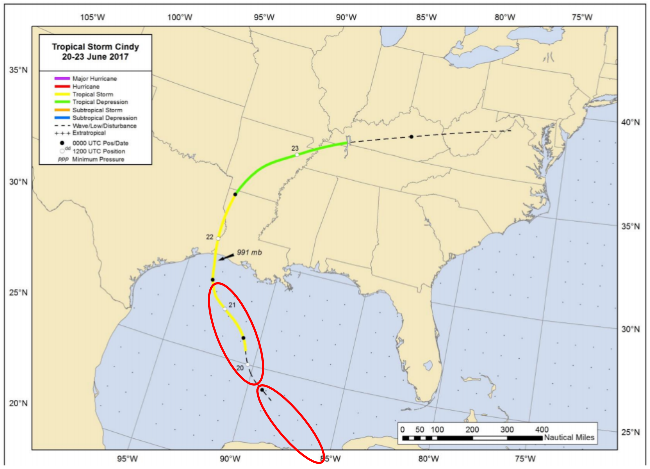
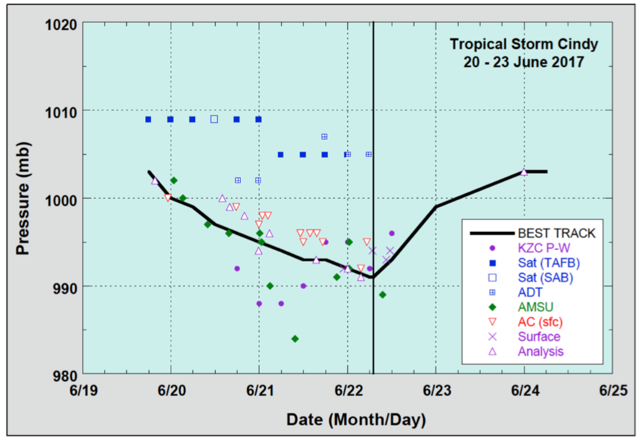
Objectives

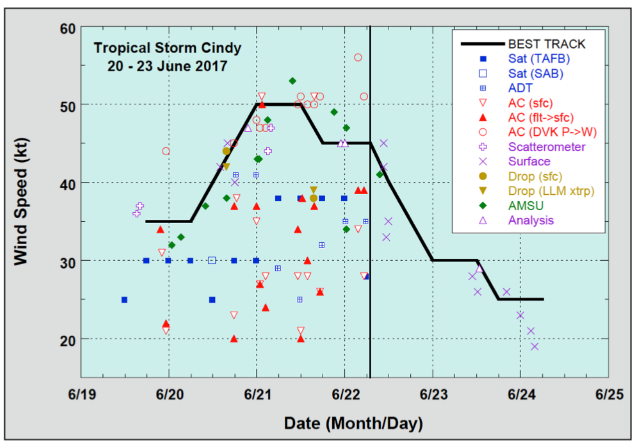
- Why do some convective systems organize to form tropical cyclones?
  - Examining tropical cyclone Cindy observed during CPEX 2017 through two WRF simulations with different configurations---one that verified better than the other.
  - Using the $\varphi - \chi$ (stream function-velocity potential) interaction framework one can objectively analyze this formation.

- What is the impact of dropsonde/DAWN winds on organization of convection?
  - Through assimilation experiments (future)

Tropical cyclone Cindy







From National Hurricane Center

Experiments:

1. Genesis of Cindy (0000UTC JUNE 17-0000UTC JUNE 19)
2. Further Development of Cindy (0000UTC JUNE 19-0600UTC JUNE 21)

Cindy was the only named tropical cyclone during CPEX field phase.

Had aircraft observations (both dropsondes and lidar) for 19th - 21st June, mostly covering its transitioning period.

What is Psi-Chi interaction?

Horizontal wind vector and can be divided into two parts rotational (non-divergent) and divergent (irrotational) components. $\vec{V}_H = \vec{V}_\psi + \vec{V}_\chi$

It should be noted that ψ (Psi) is the stream function and χ (Chi) is the velocity potential.

The energy exchange from divergent to rotational is known as Psi-Chi interactions. A domain averaged (overbars) :-

$$\frac{\partial}{\partial t}\overline{\overline{K_\psi}} = \overline{\overline{f\nabla\psi\cdot\nabla\chi}} + \overline{\overline{\nabla^2\psi\nabla\psi\cdot\nabla\chi}} + \overline{\overline{\nabla^2\chi\frac{|\nabla\psi|^2}{2}}} + \overline{\overline{\omega J\left(\psi,\frac{\partial\chi}{\partial p}\right)}} + \overline{\overline{F_\psi}}$$

Eqn. 1

$$\begin{aligned}\frac{\partial}{\partial t}\overline{\overline{K_\chi}} &= -\frac{\partial}{\partial t}\overline{\overline{APE}} - \frac{\partial}{\partial t}\overline{\overline{K_\chi}} \\ &= -\overline{\overline{\chi\nabla^2\phi}} - \overline{\overline{f\nabla\psi\cdot\nabla\chi}} - \overline{\overline{\nabla^2\psi(\nabla\psi\cdot\nabla\chi)}} \\ &\quad -\overline{\overline{\frac{1}{2}|\nabla\psi|^2\nabla^2\chi}} - \overline{\overline{\omega J\left(\psi,\frac{\partial\chi}{\partial p}\right)}} + \overline{\overline{F_\chi}}\end{aligned}$$

Eqn. 2

$$\overline{\overline{< APE\cdot K_\chi >}} = -\overline{\overline{\chi\nabla^2\phi}} = \frac{\overline{\overline{R\omega T}}}{p}$$

Eqn. 3

The $\psi - \chi$ interaction

$$APE = -\chi\nabla^2\phi = \frac{R\omega T}{p}$$

Model physics determines this

$$\frac{\partial K_\chi}{\partial t} = B_\chi - \chi\nabla^2\phi - \mathrm{f}\nabla\chi.\nabla\psi - \nabla^2\psi\,\nabla\chi.\nabla\psi - \nabla^2\chi\frac{(\nabla\psi)^2}{2} - \omega J(\psi,\frac{\partial\chi}{\partial p}) + F_\chi$$

Initialization should have an impact in characterizing $\nabla\chi$ and $\nabla\psi$

$$\frac{\partial K_\psi}{\partial t} = B_\varphi + \mathrm{f}\nabla\chi.\nabla\psi + \nabla^2\psi\,\nabla\chi.\nabla\psi + \nabla^2\chi\frac{(\nabla\psi)^2}{2} + \omega J(\psi,\frac{\partial\chi}{\partial p}) + F_\psi$$

Overbars (area averages) removed for convenience!

Experiment details

- Initial and boundary conditions: NCEP GFS operational analysis (0.25ºx0.25º)
- Boundary condition interval: 3 hours
- WRF: Single domain @5km grid spacing; two way nesting

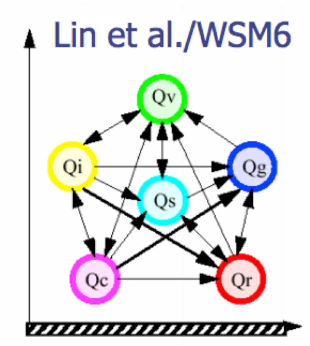
Name	Initial condition	Physics	Duration of simulation
EXP1	00z17Jun	Full microphysics	48 hours
EXP2	00z17Jun	Warm rain	48 hours
EXP1A	006z19Jun	Full microphysics	48 hours
EXP2A (TBD)	006z19Jun	Warm rain	48 hours

Model physics for EXP1 and EXP2 0000UTC 17Jun- 0000UTC 19Jun

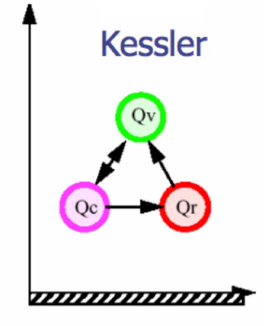
WRF_OPTION	*EXP1*	*EXP2*
Microphysics	**WSM 6-class graupel scheme**	**Kessler scheme**
Longwave Radiation	**RRTMG scheme**	**RRTMG scheme**
Shortwave Radiation	**RRTMG scheme**	**RRTMG scheme**
Surface-Layer Option	**MM5 Monin-Obukhov scheme**	**MM5 Monin-Obukhov scheme**
Land-Surface option	**Thermal diffusion scheme**	**Thermal diffusion scheme**
Boundary-Layer Option	**YSU scheme**	**YSU scheme**
Cumulus Option	**Kain-Fritsch (new Eta) scheme**	**Kain-Fritsch (new Eta) scheme**

Differences in microphysics

EXP1 microphysics

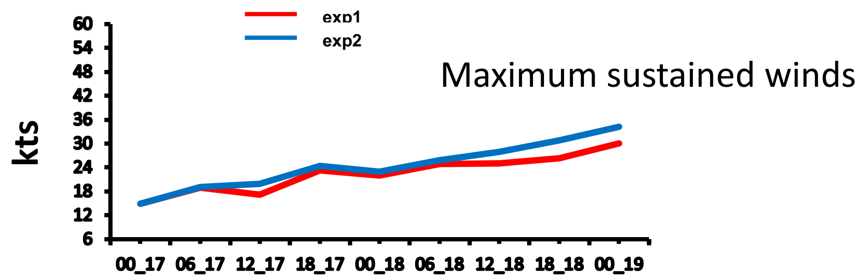


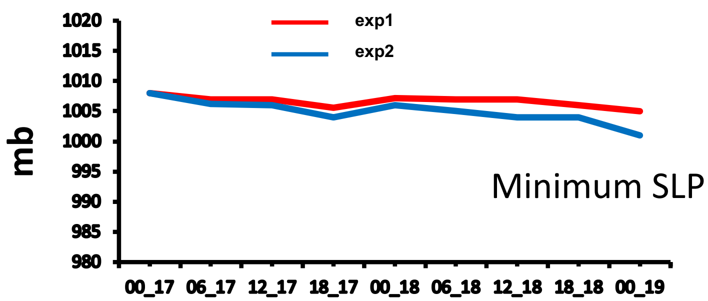
EXP2 microphysics



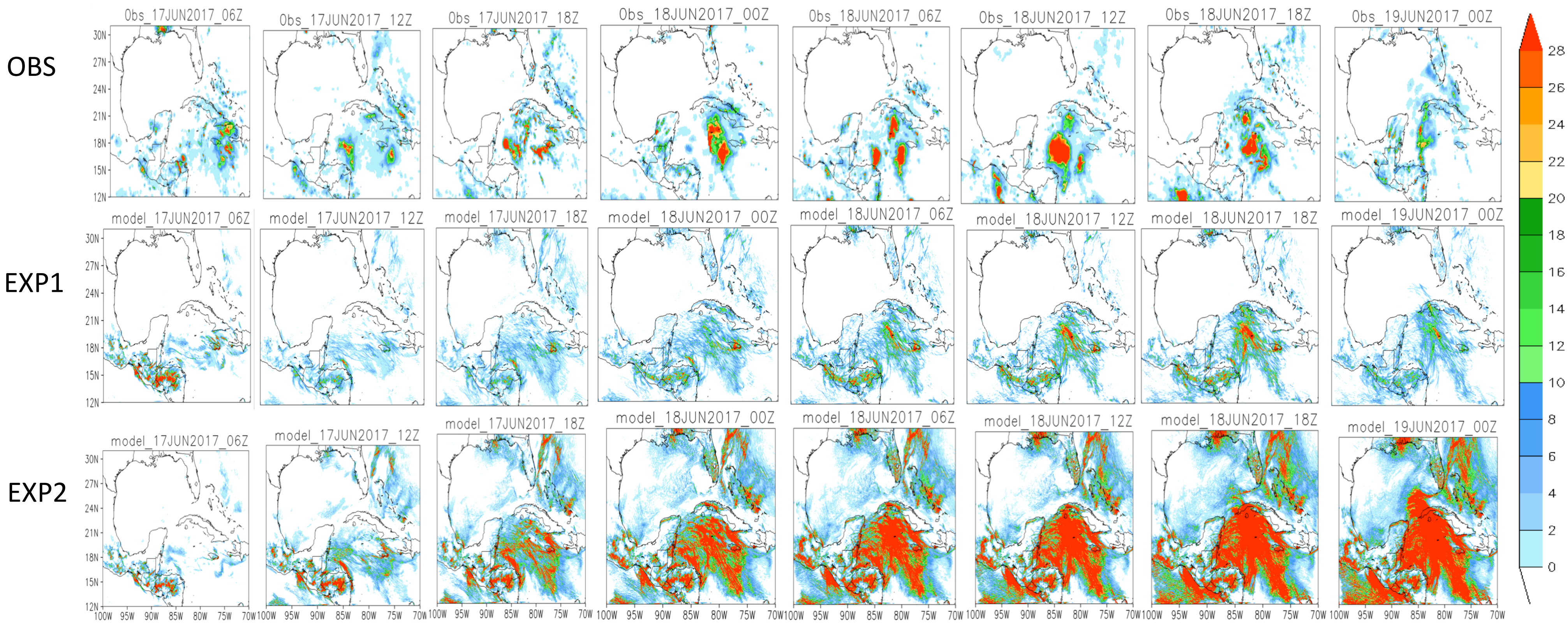
Warm rain process only

Intensity during pre-genesis period of TS Cindy

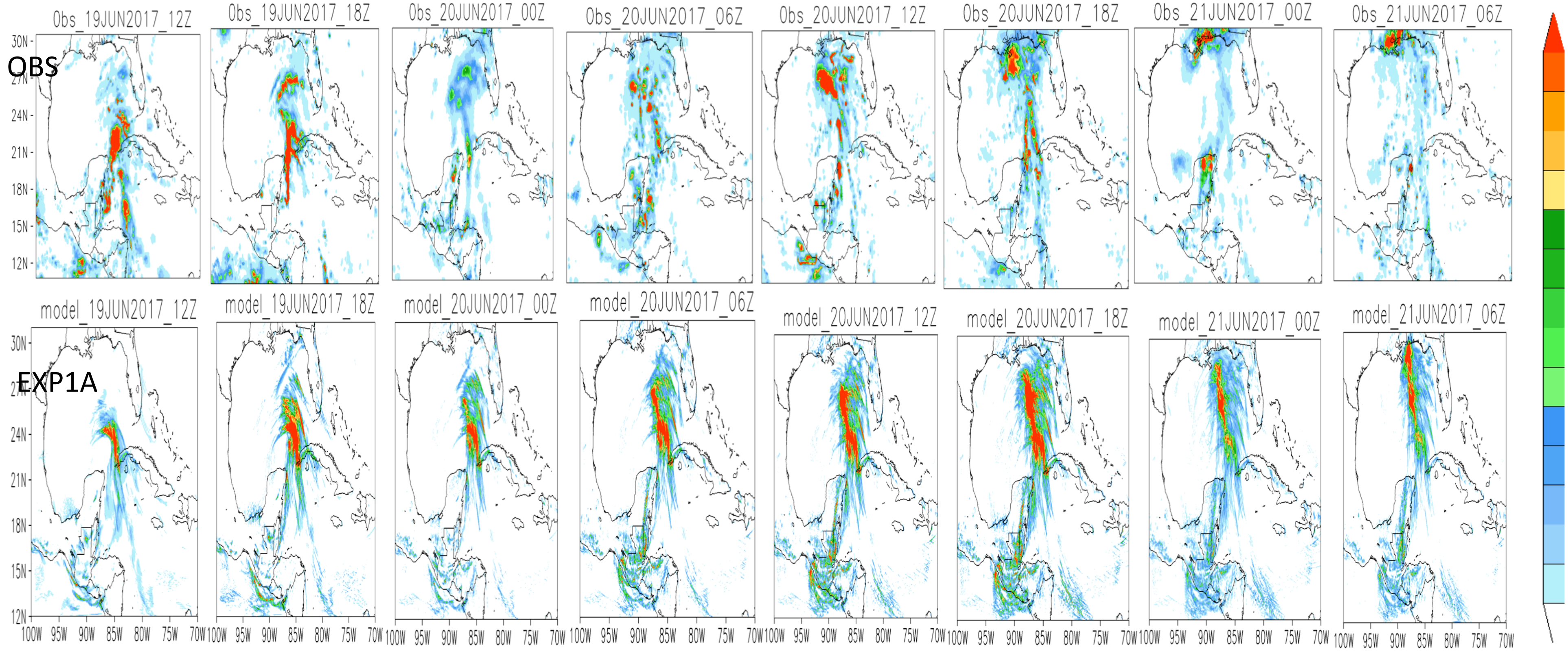




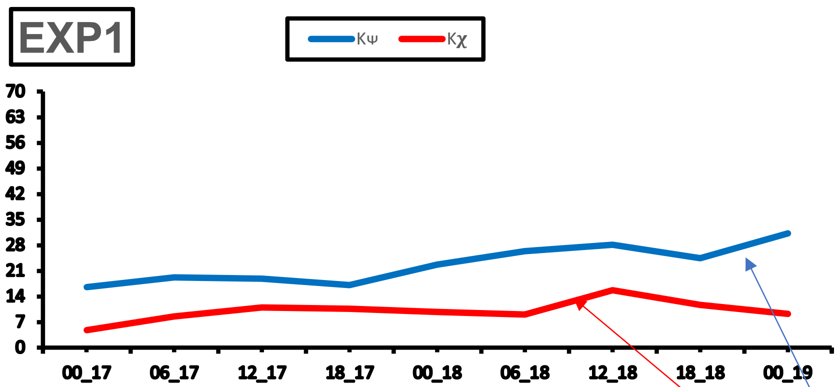
Rainfall verification (mm/hr) 0006UTC 17Jun - 0000UTC 19Jun

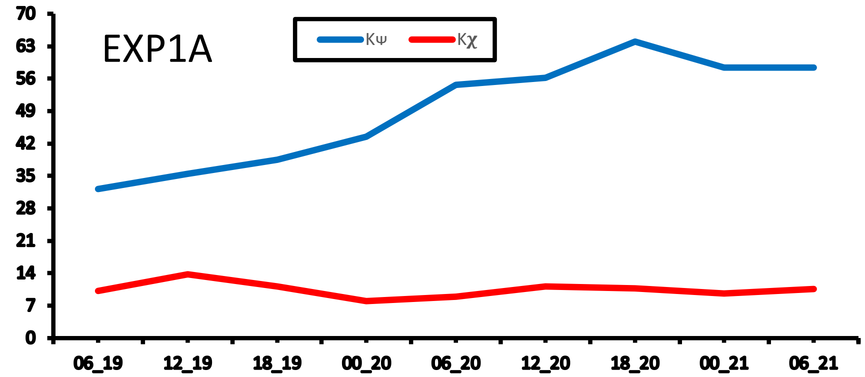


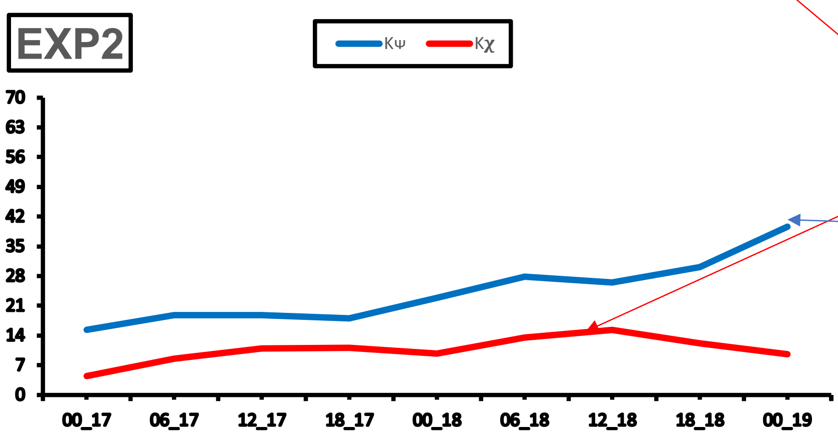
Rainfall verification (mm/hr) 0012UTC 19Jun - 0006UTC 21Jun



Time series of $\overline{\overline{K_\psi}}$ *and* $\overline{\overline{K_\chi}}$ $(in\ m^2 s^{-2})$@ 850hPa

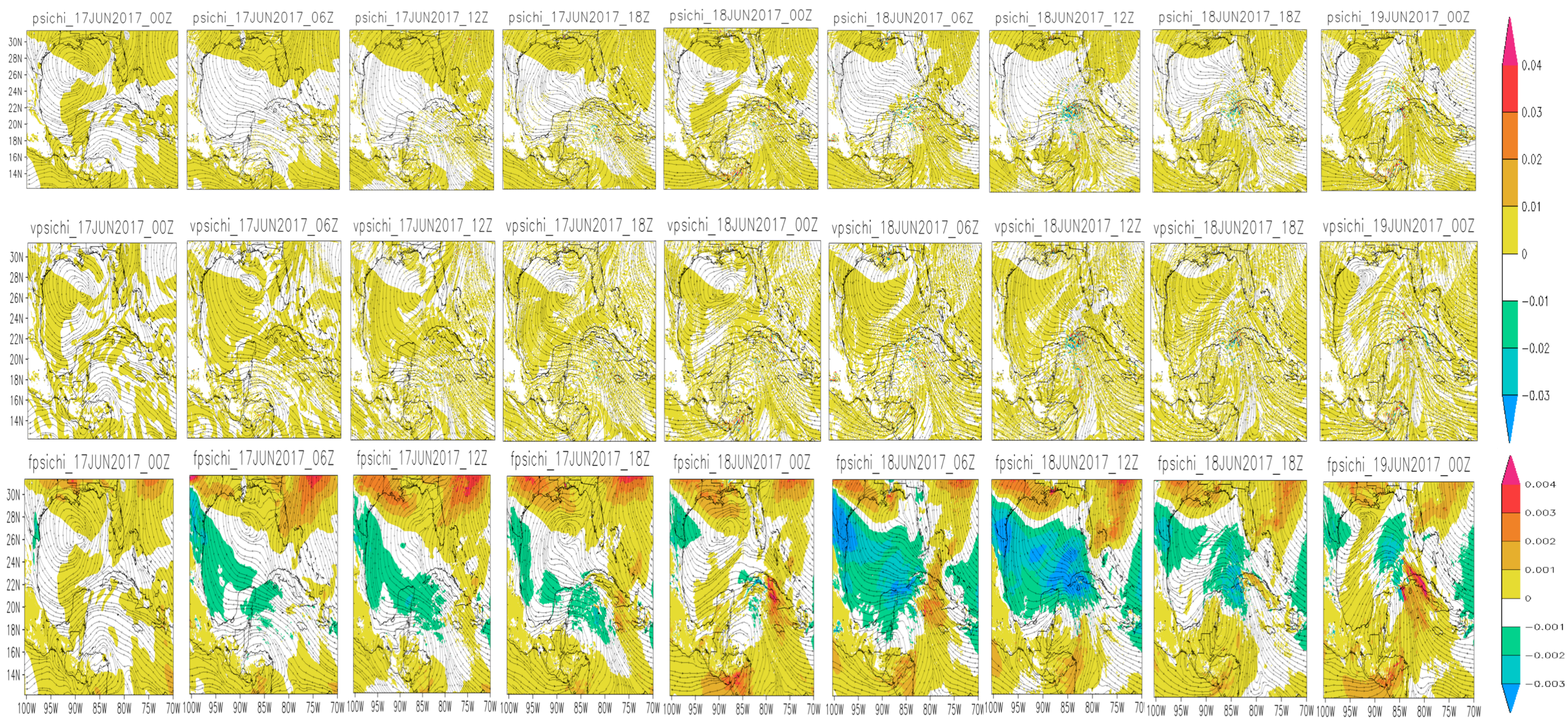




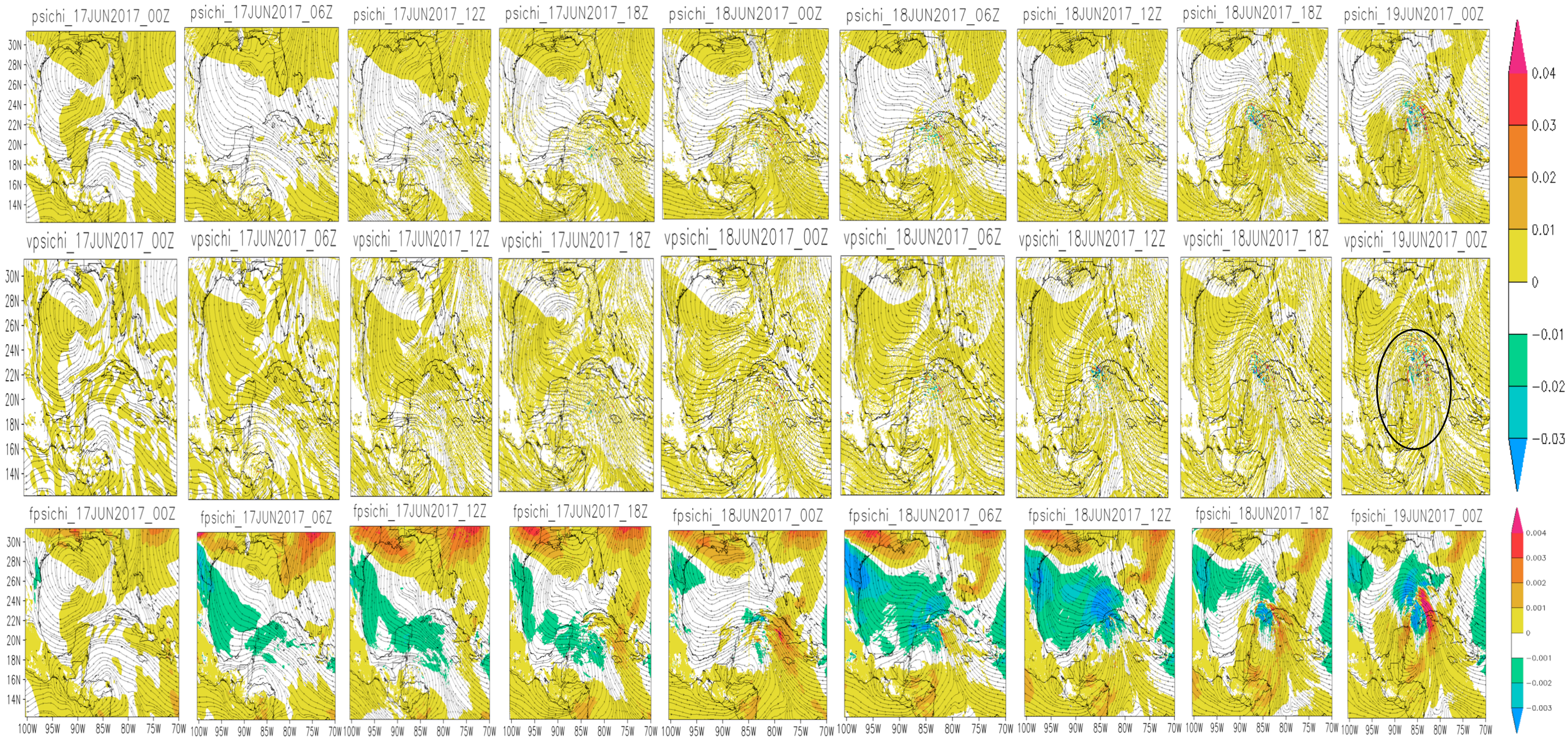


1. There is more K.E. in non-divergent component of the wind throughout the integrations of EXP1, EXP1A, EXP2
2. There is comparable $\overline{\overline{K_\chi}}$ in both EXP1 and EXP1A
3. There is slightly higher $\overline{\overline{K_\psi}}$ in EXP2 than in EXP1, especially towards the end of the integration. Why?

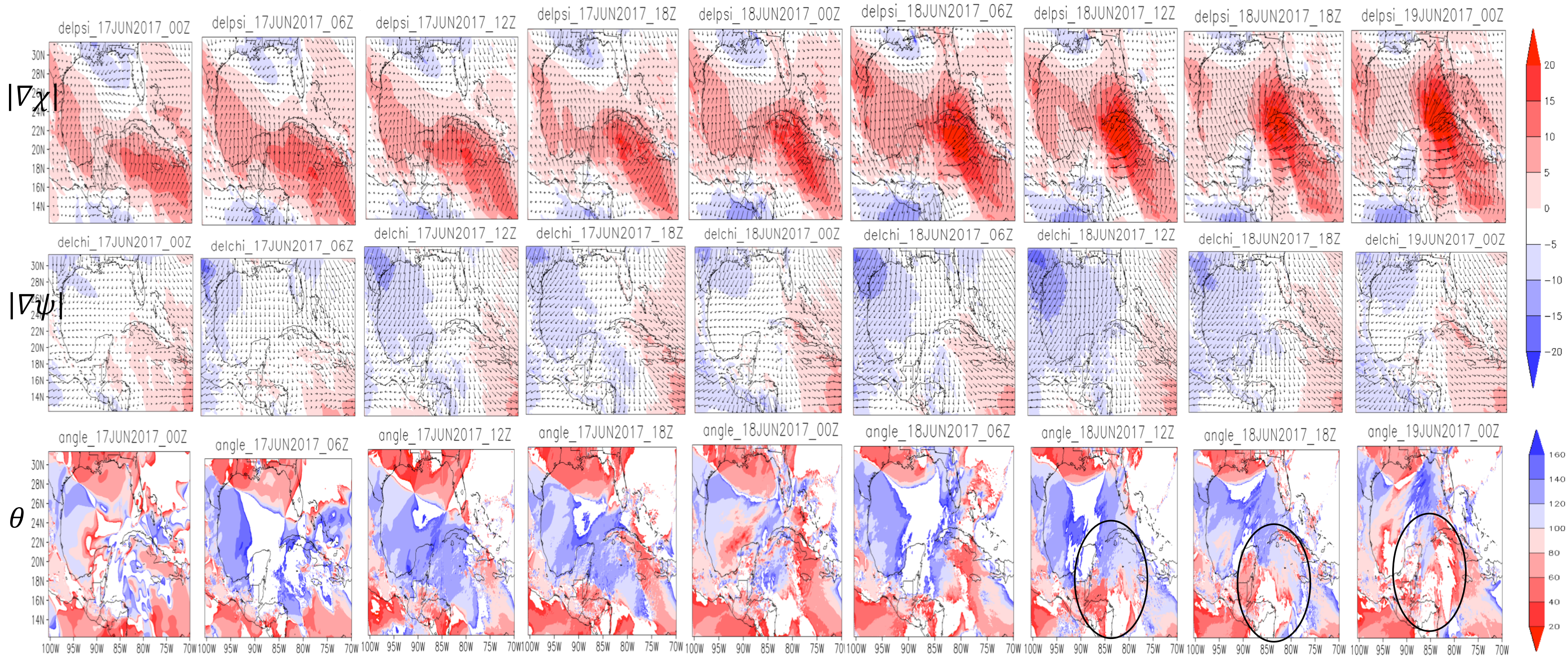
$f\nabla\chi.\nabla\psi + \nabla^2\,\psi\,\nabla\chi.\nabla\psi$@ 850hPa 0000UTC 17Jun - 0000UTC 19Jun (EXP1)



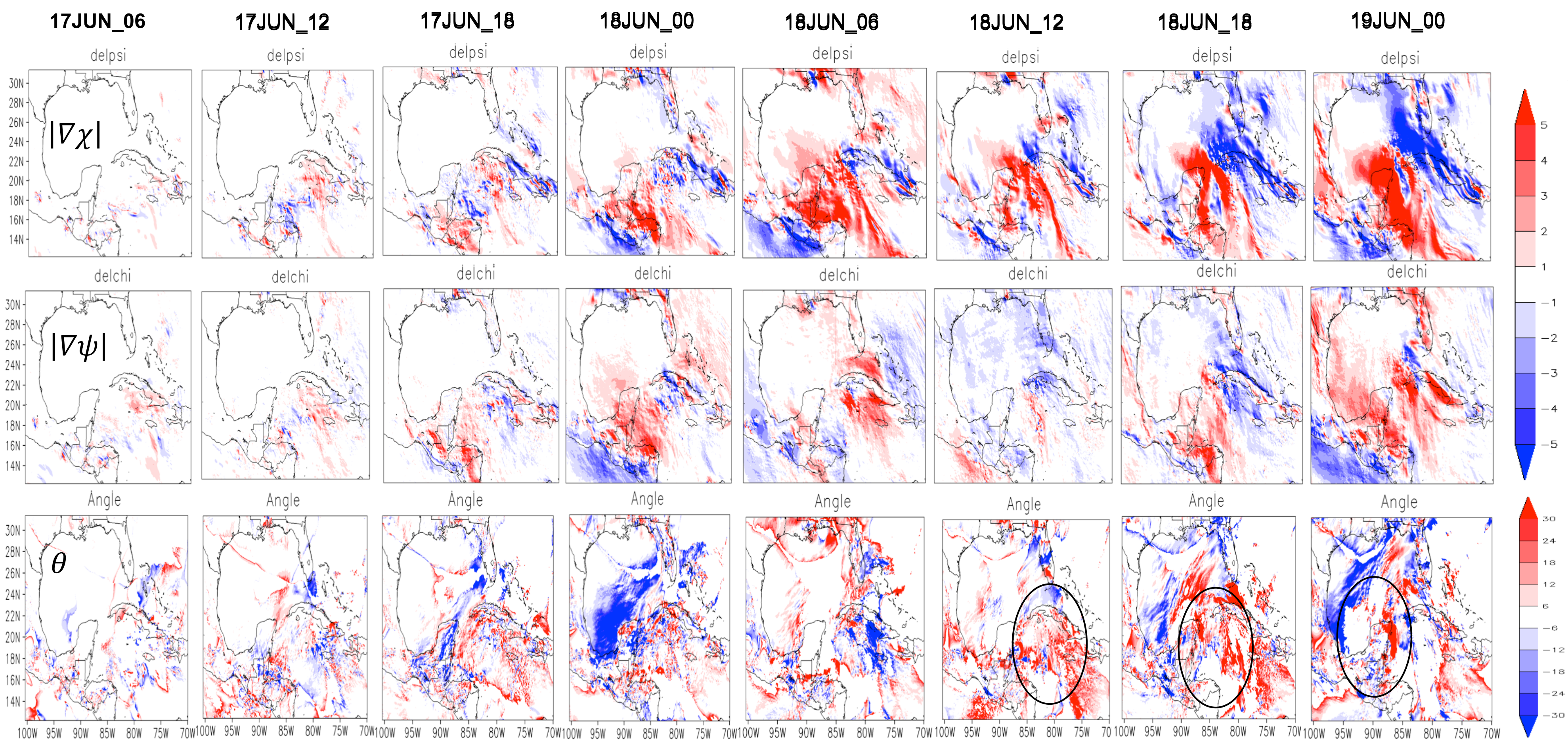
$f\nabla\chi.\nabla\psi + \nabla^2\,\psi\,\nabla\chi.\nabla\psi$@ 850hPa 0000UTC 17Jun - 0000UTC 19Jun (EXP2)



$$\overrightarrow{\nabla\chi}.\overrightarrow{\nabla\psi} = |\nabla\chi||\nabla\psi|\cos\theta$$ ***0000UTC 17Jun - 0000UTC 19Jun (EXP1)***



EXP1-EXP2



17JUN_06
17JUN_12
17JUN_18
18JUN_00
18JUN_06
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delpsi
delchi
Angle
$|\nabla\chi|$
$|\nabla\psi|$
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26N
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22N
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18N
16N
14N
100W
95W
90W
85W
80W
75W
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5
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−4
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30
24
18
12
6
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−12
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−30

Conclusions

- **Preliminary findings:**
  - EXP2 produced TS Cindy by 21 Jun 18Z contrary to observations and EXP1.
  - The orientation of the $\overrightarrow{\nabla\chi}$ and $\overrightarrow{\nabla\psi}$ in EXP2 was more conducive (more parallel) for conversion from $\chi \; to \; \psi$ than in EXP1
  - However the $|\nabla\chi|$ in EXP2 was less than in EXP1 suggesting that the covariance of $\omega \; and \; T$ was not as strong as in EXP1

Future direction

- Can assimilation of winds in EXP2 further improve its simulation through improved analysis of $\overrightarrow{\nabla\chi}$ at initial time?
- At what stage of assimilation of winds have more impact? 00Z17Jun or 06Z19Jun for tropical cyclone Cindy?