U.S. NAVAL RESEARCH LABORATORY

DEPARTMENT OF THE NAVY
ONR
Science & Technology

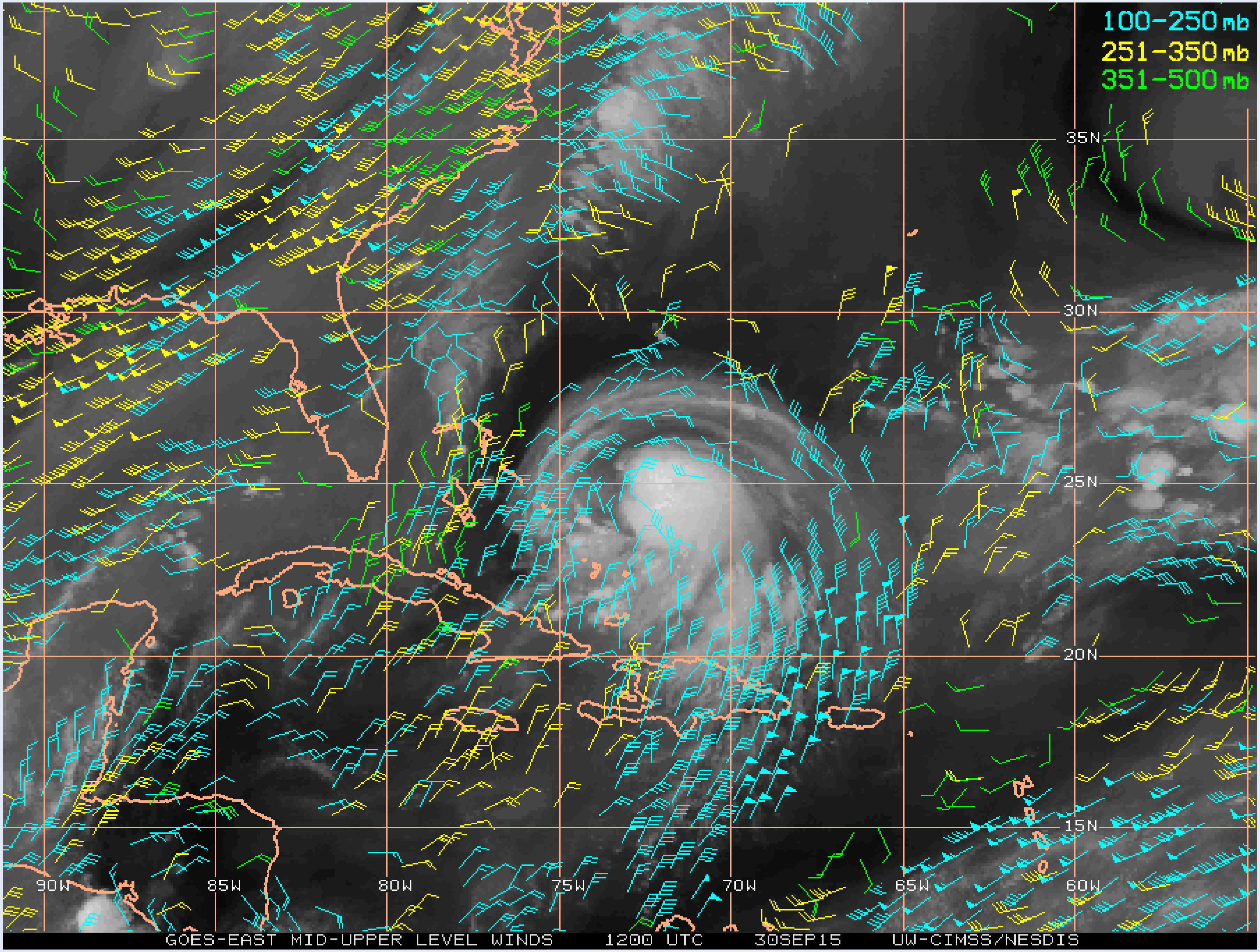
Simulating TC-trough interaction in an idealized modeling framework

Will Komaromi
Jim Doyle
Naval Research Lab - Monterey
will.komaromi@nrlmry.navy.mil

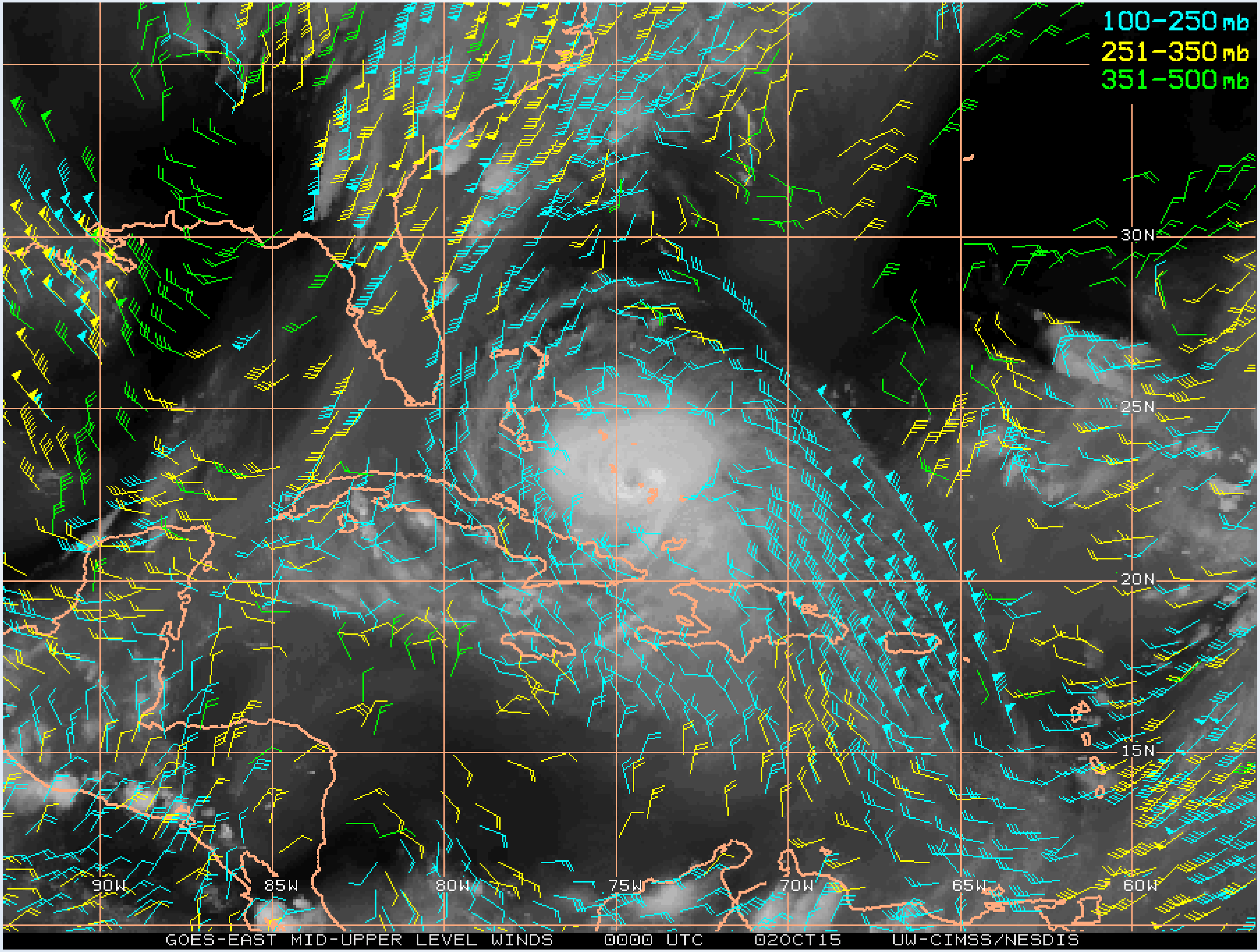
TCI Science Meeting
18 October 2016

Stage 1: pre-interaction, outflow entirely to S

Hurricane Joaquin (2015)

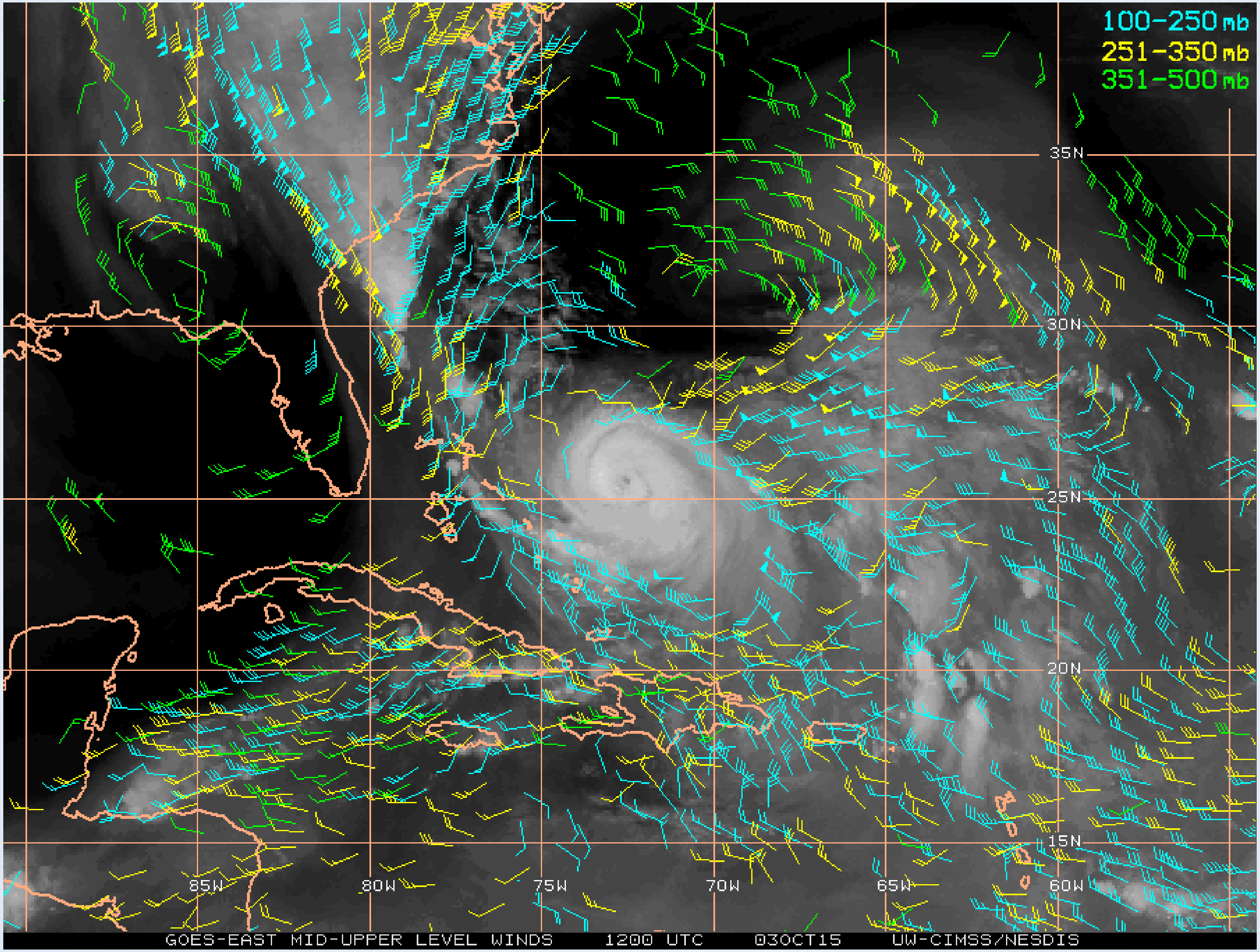


Stage 2: dual outflow channels develop, slight weakening as shear increases



Stage 3: Strongest outflow to NW & NE (but still have decent outflow to S)

- peak intensity occurs at this time



How can trough interaction theoretically be favorable for TC intensification?

- Enhanced upper-level divergence
- Enhanced ascent associated with trough's secondary circulation and/or right-entrance region of jet streak
- TCs primarily interact with environmental flow at upper levels where inertial stability (I) is weaker, as I resists motion in radial direction. Reduction in I may allow stronger radial outflow to develop

$$I = \sqrt{\left(f + \frac{2v_t}{r}\right)(f + \zeta)} \text{ where } \zeta = \frac{1}{r}\frac{\partial(rv_t)}{\partial r}$$

- Flux convergence of angular momentum by azimuthal eddies (EFC) may trigger structural changes which ultimately lead to intensification of TC. For many real cases window of positive impacts associated with EFC may be short: EFC may be too far from TC, or shear may be too great once EFC is close enough to have effect on TC

$$\mathrm{EFC} = -\frac{1}{r}\frac{\partial}{\partial r}\left(r^2\overline{v_r'v_t'}\right)$$

Of course, trough interaction can also be unfavorable to a TC, primarily due to increased vertical wind shear

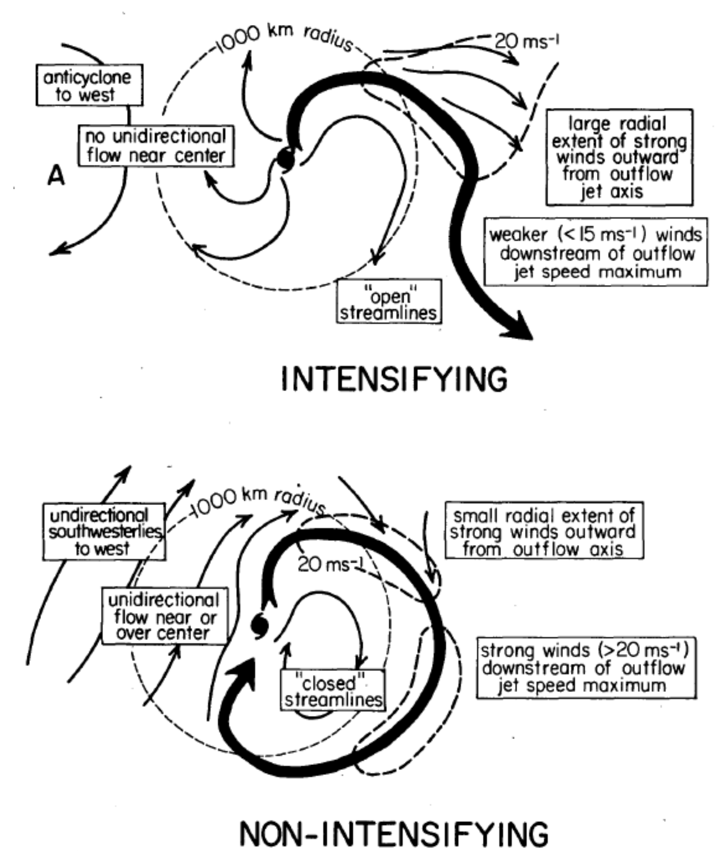


FIG. 11. Inclusive summary of outflow layer differences between composite intensifying (top) and nonintensifying (bottom) hurricanes.

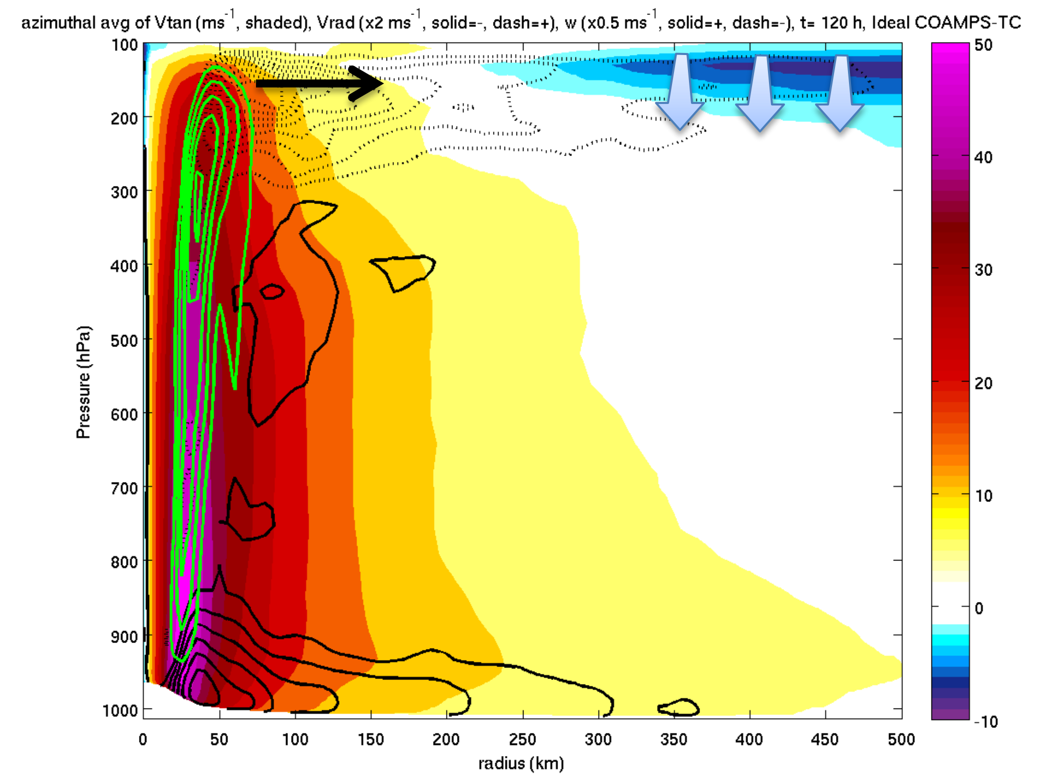
AMV / rawinsonde / commercial aircraft composites from Merrill (1988)

Model Configuration

- COAMPS-TC v4
- 5km res, 801x801 grid points (4005x4005 km)
- 40 vertical levels
- No cumulus parameterization
- Periodic in x, wall boundaries in y
- Modified Mellor-Yamada PBL scheme
- Lin et al. (1983) 5-class single moment microphysics
- Radiation off
- β-plane
- Fixed SST – 28.0 °C
- θ (K) and q (g/kg) from Dunion (2011) MT sounding
- Initialized with rankine vortex
  - rmw = 90 km, $V_t \rightarrow 0$ = 240 km

How can we test TC sensitivity to "environmental" forcing in outflow region?

- Option A: enhance V_r (similar to nudging, but with balanced pressure gradient) → tried without much success, won't be presenting today
- Option B: Reduce V_t at slightly larger r via zonal jet or trough in order to reduce I, which should result in environment more favorable for enhanced V_r. Trough interaction should also promote EFC, which may indirectly intensify the TC



Azimuthal avg V_t (ms^{-1}, shaded), V_r (2 ms^{-1} increments solid<0, dashed>0), w (0.5 ms^{-1} increments)

We define jet in terms of u_g. From u and v momentum equations, incorporating a large-scale flow:

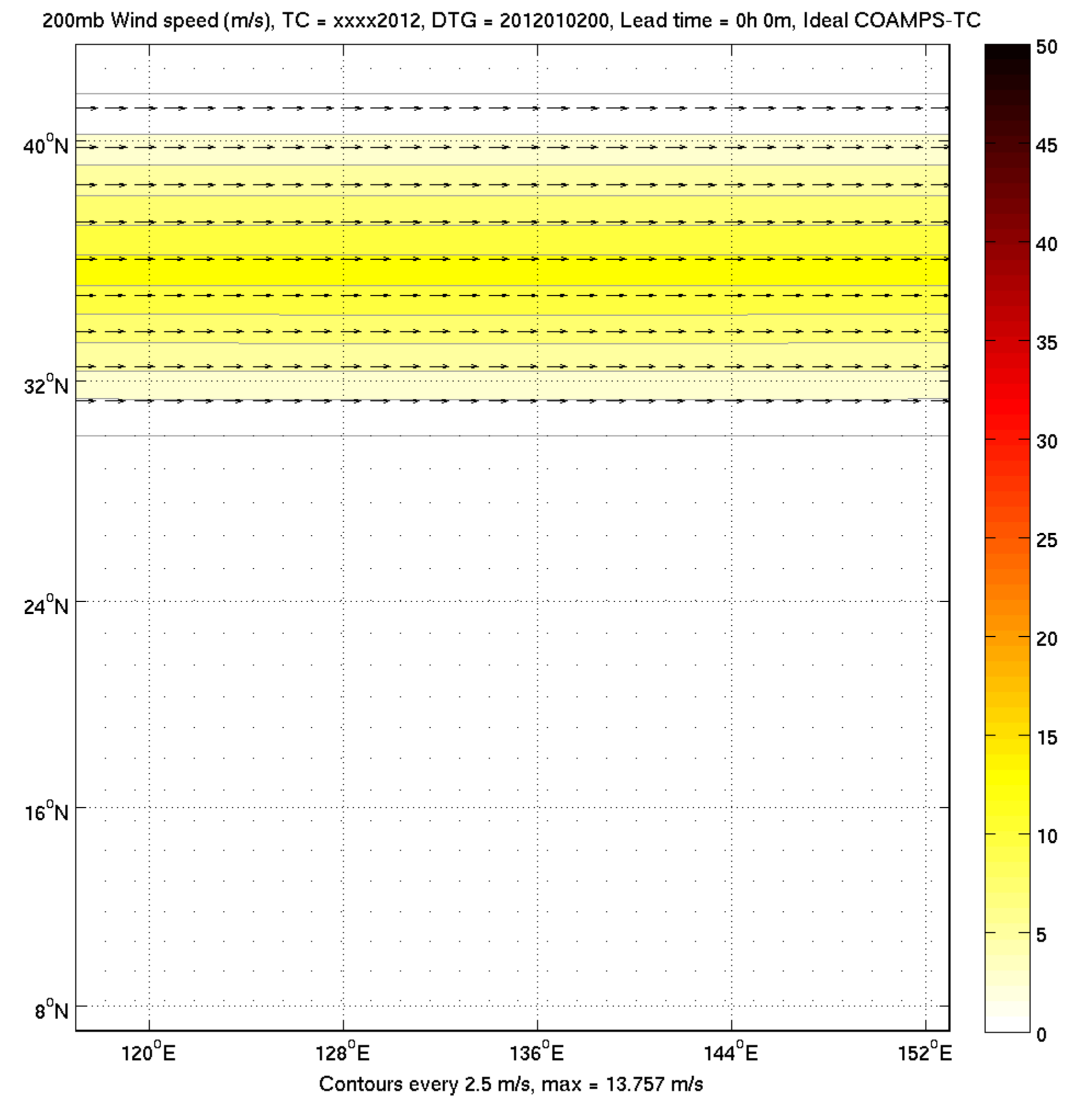
$$\frac{\partial u}{\partial t} \sim f(v - v_g)$$

$$\frac{\partial v}{\partial t} \sim -f(u - u_g)$$

where $\begin{bmatrix} u_g \\ v_g \end{bmatrix}$ is balanced by a background $\begin{bmatrix} -\frac{\partial \Pi}{\partial y} \\ \frac{\partial \Pi}{\partial x} \end{bmatrix}$ and

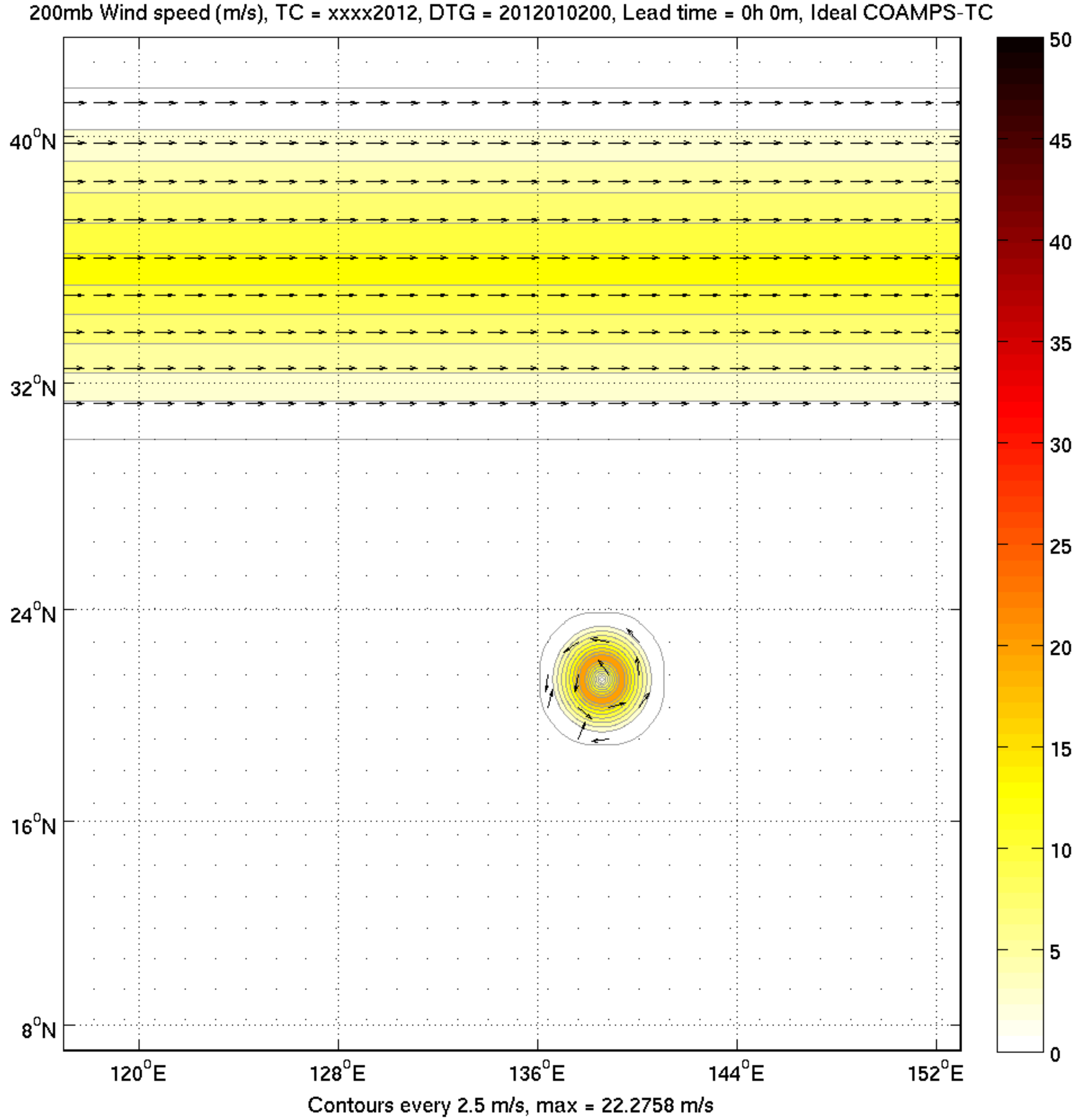
$$\Pi = \left(\frac{p}{p0}\right)^{\frac{R_d}{c_p}}$$

Jet extends from ~500-100 hPa, strongest at 300 hPa decaying linearly above and below



TC + zonal jet

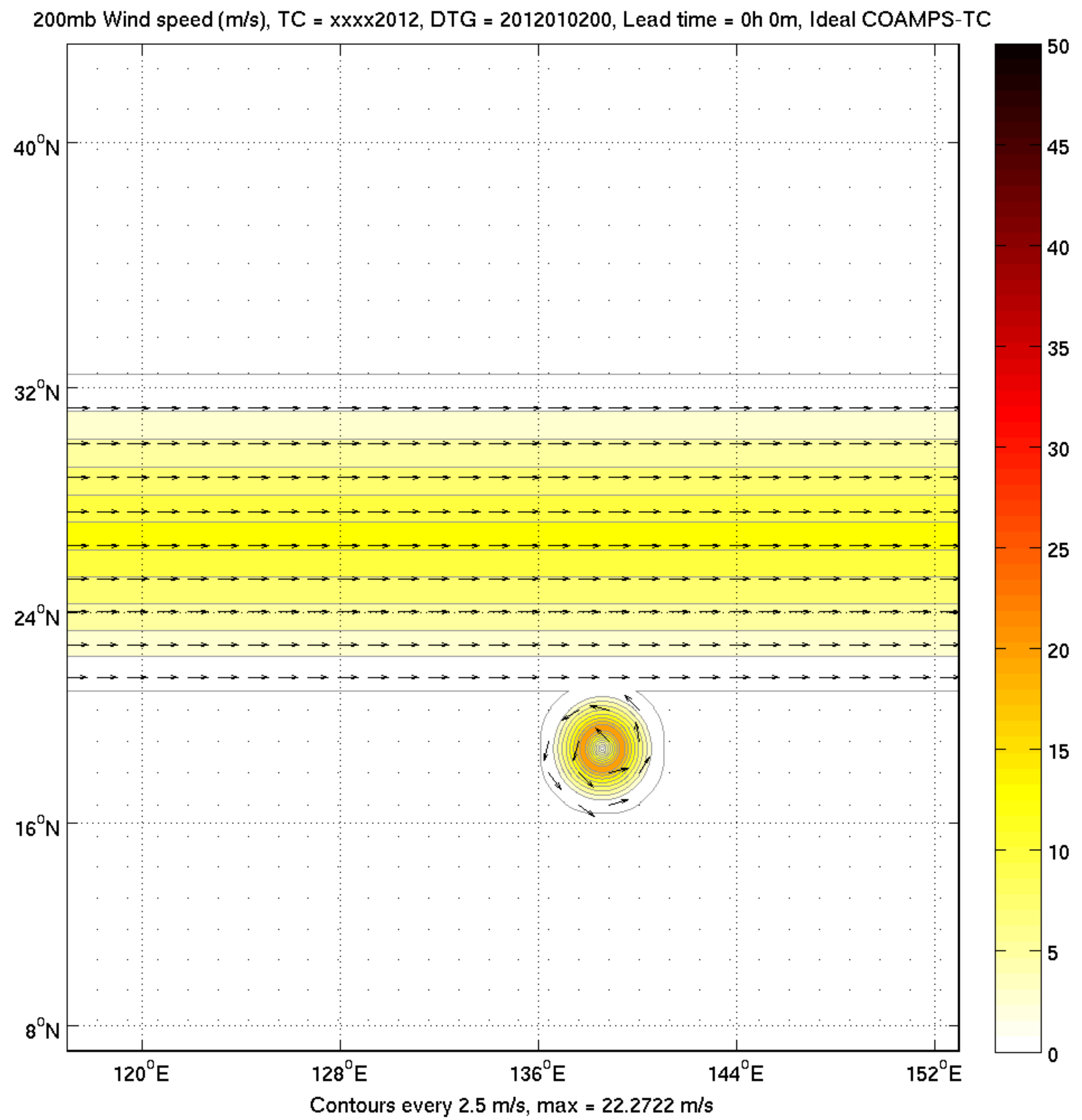
tcyo= 0.40n



Here the TC is too far south to experience significant interaction with the jet

Here we move the jet S towards the TC (as opposed to moving the TC N towards the jet), otherwise changes in I will be dominated by changes in *f*

Here the TC interacts more strongly with the jet, although the TC appears to be sheared by the end of the simulation

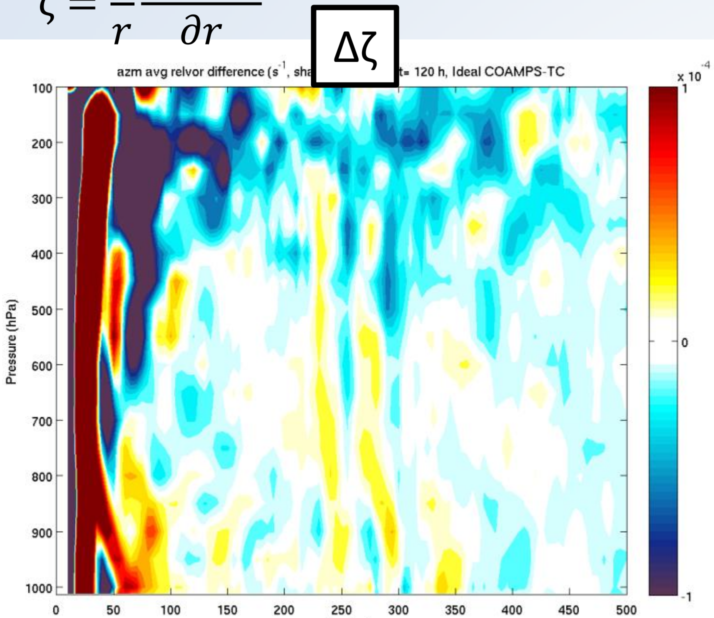


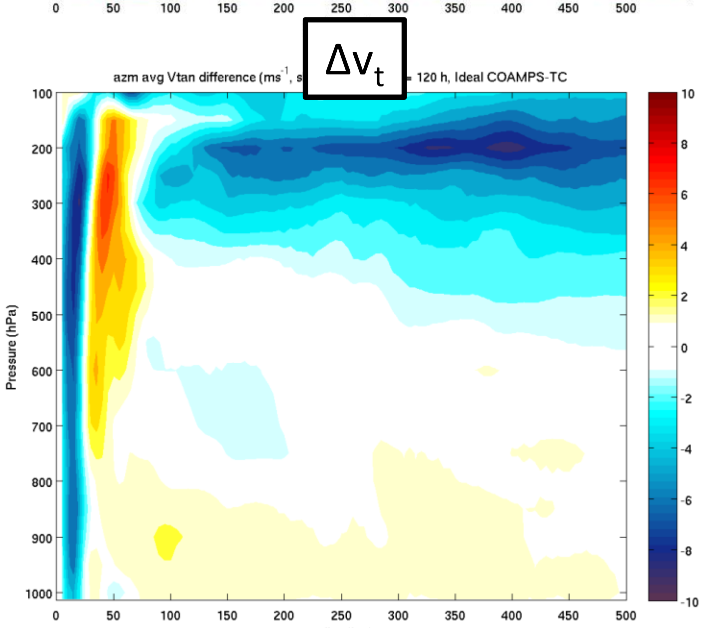
Quantifying change in inertial stability: azimuthal means in radius-pressure

$$\zeta = \frac{1}{r}\frac{\partial(rv_t)}{\partial r}$$

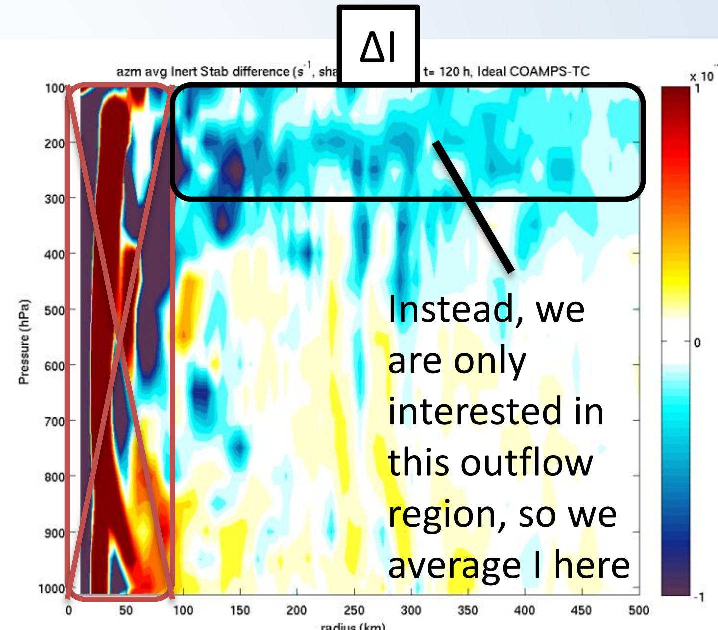
Jet interaction "minus" control run (no jet)

Both v_t and ζ are reduced N of TC in presence of jet, resulting in reduction of I

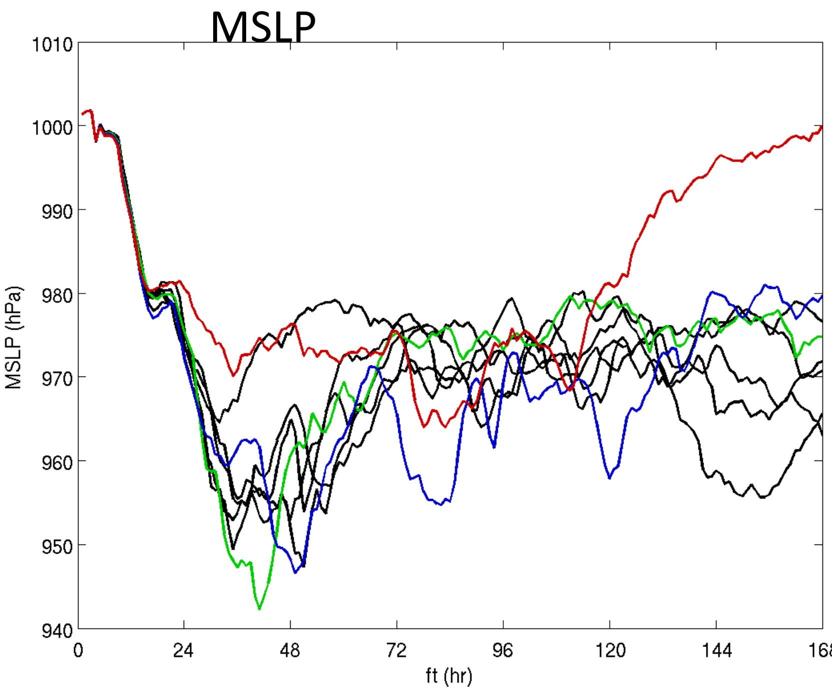


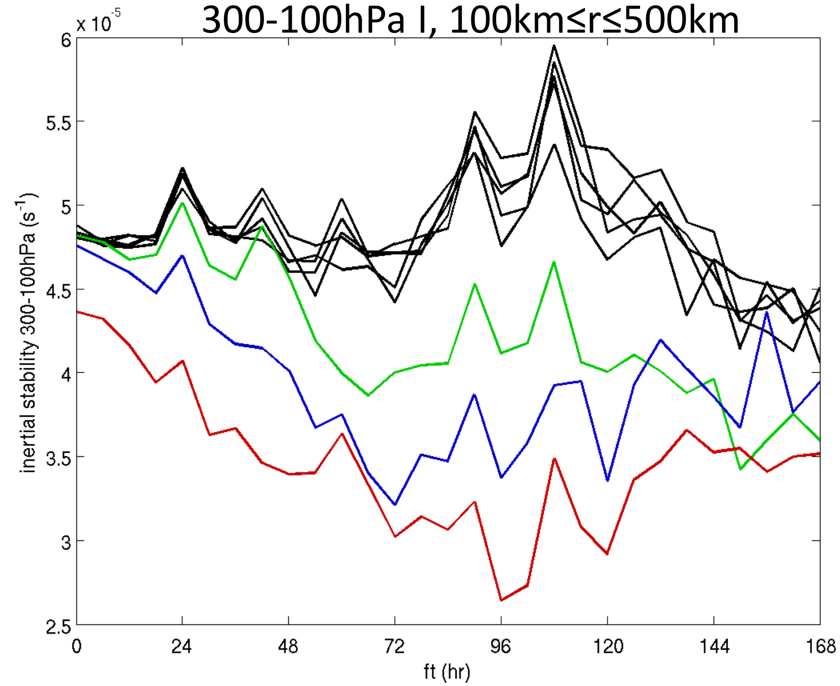


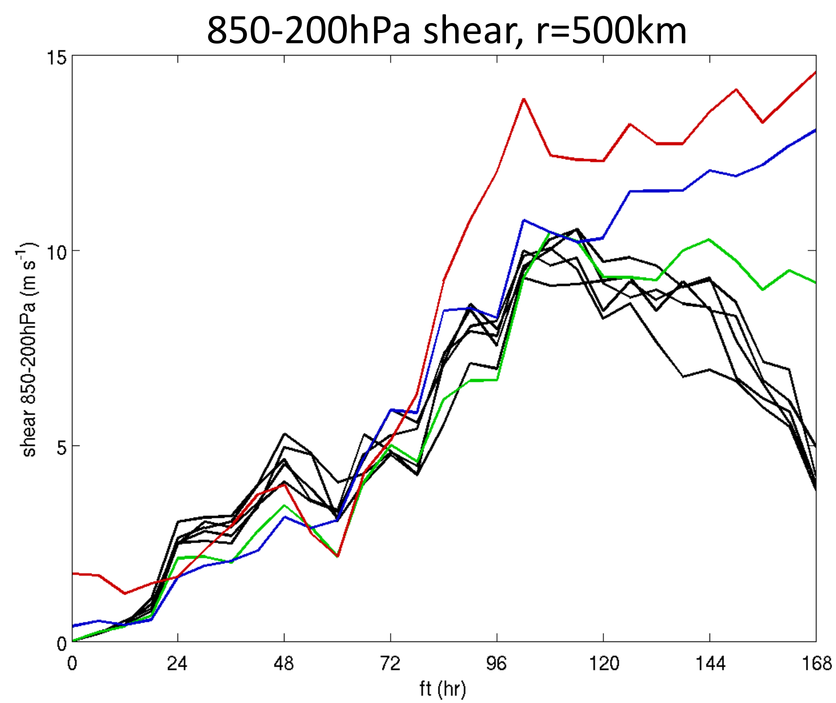
$$I = \sqrt{\left(f + \frac{2v_t}{r}\right)(f + \zeta)}$$



Differences in I here dominated by size and strength of vortex itself, not included in calculation







Control simulation(s)
Too far from jet
Just right
Too close to jet

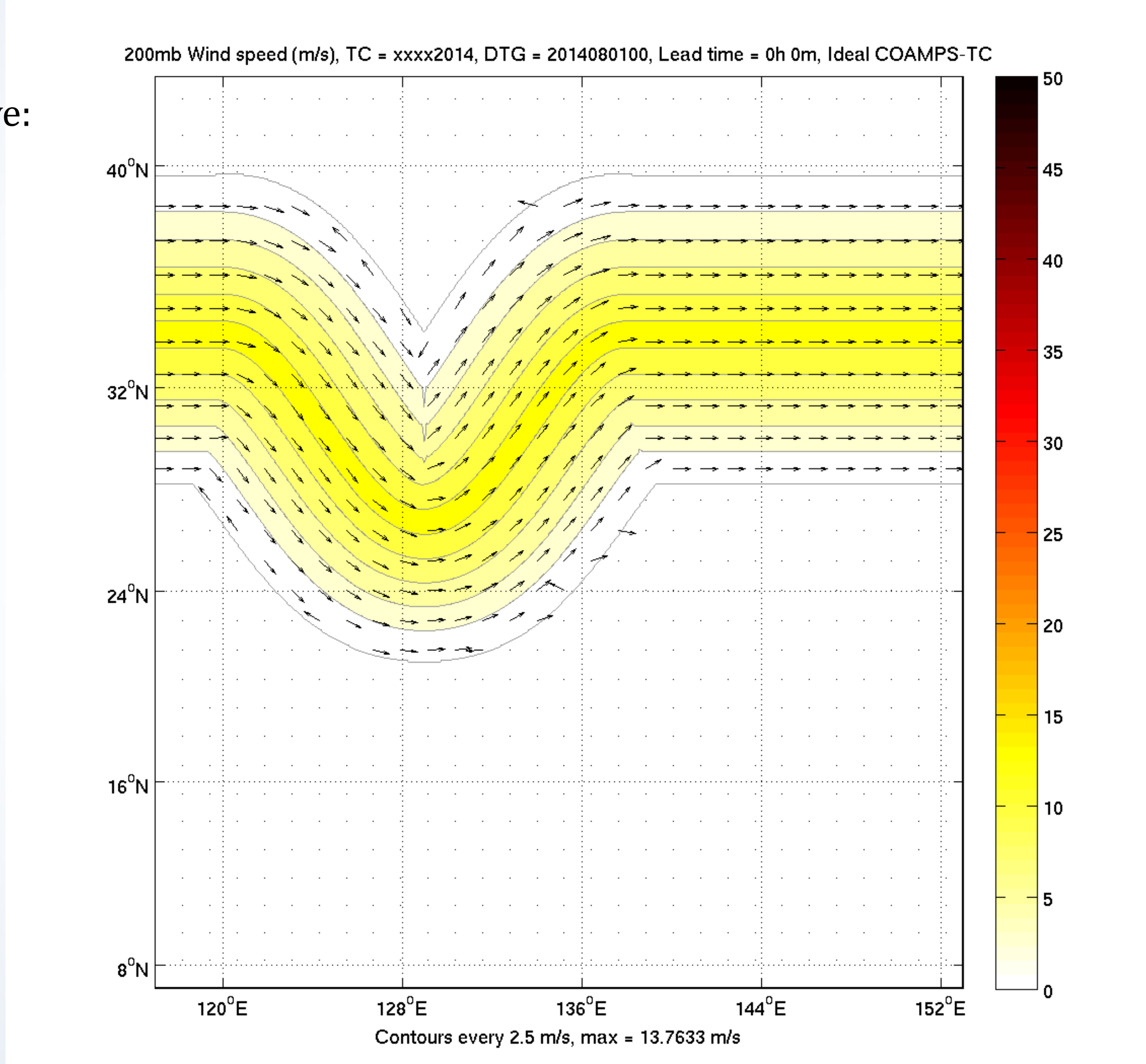
There appears to be a sensitive balance between I, shear and intensity

Jet extends from ~500-100 hPa, strongest at 300 hPa decaying linearly above and below

We define a trough using a cos wave:

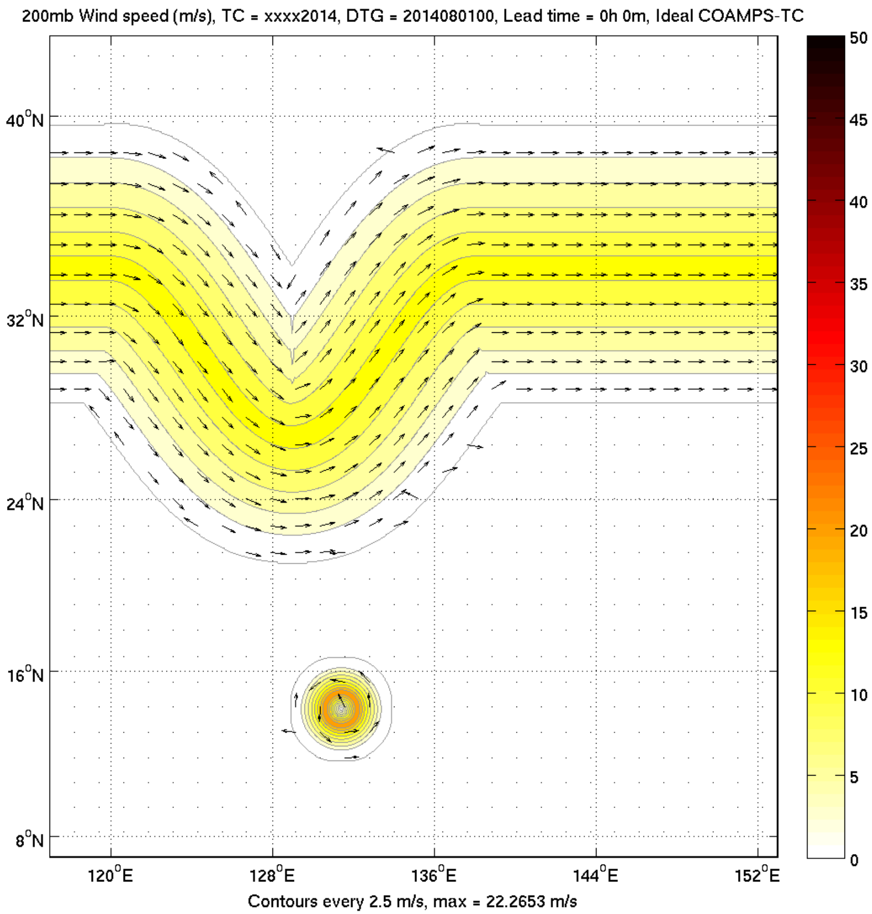
$$y = A\cos\left(\frac{4\pi x}{X} + \frac{5\pi}{3}\right) + y_0 - A$$

A = trough amplitude
(here 400km)
x = location in x
X = size of domain in x
y_0 = displacement in y

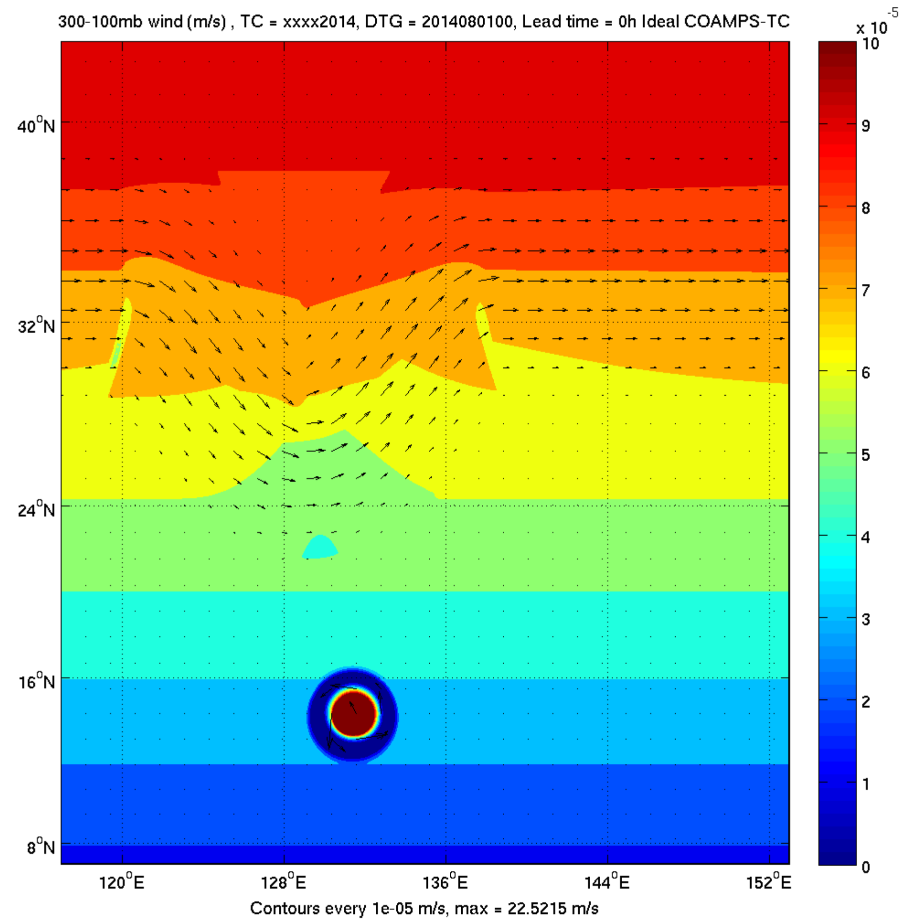


Minimal interaction: TC is too far south

200hPa wind

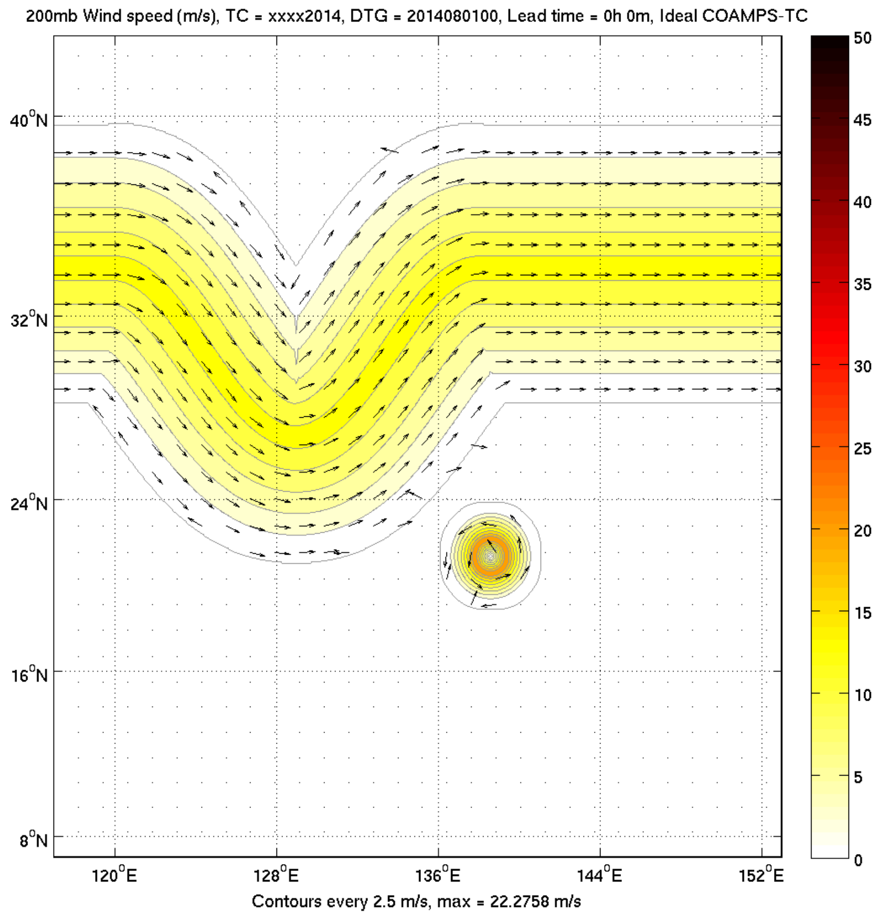


300-100hPa avg inertial stability (vortex relative)

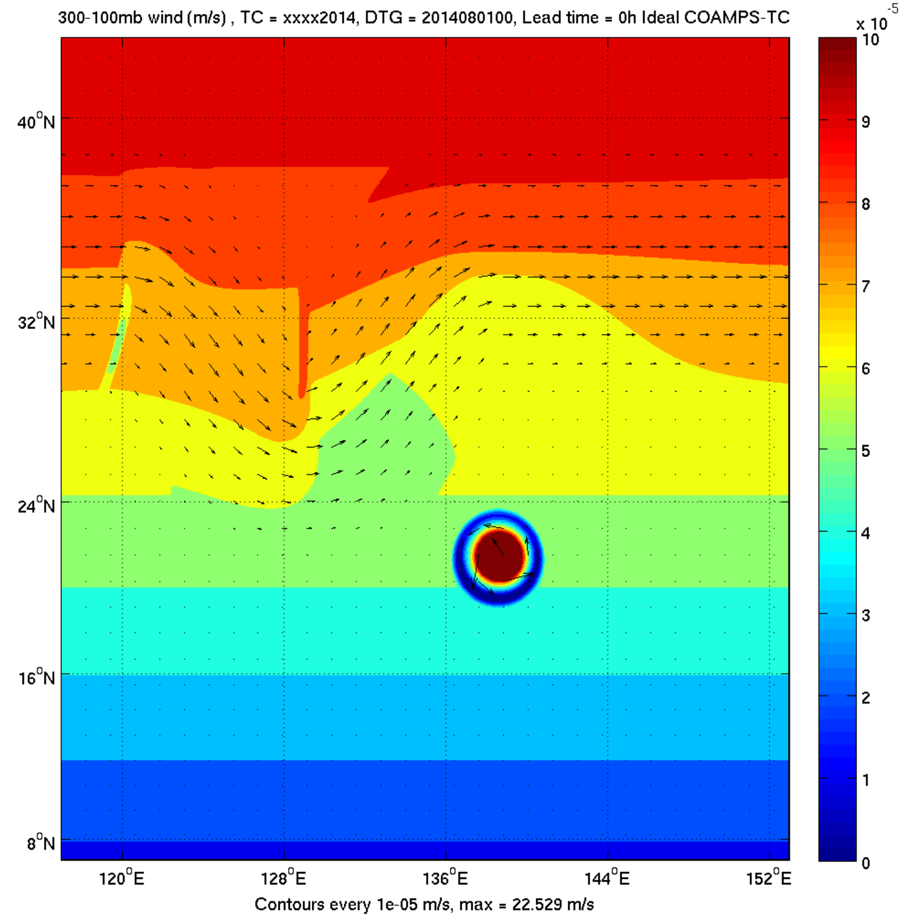


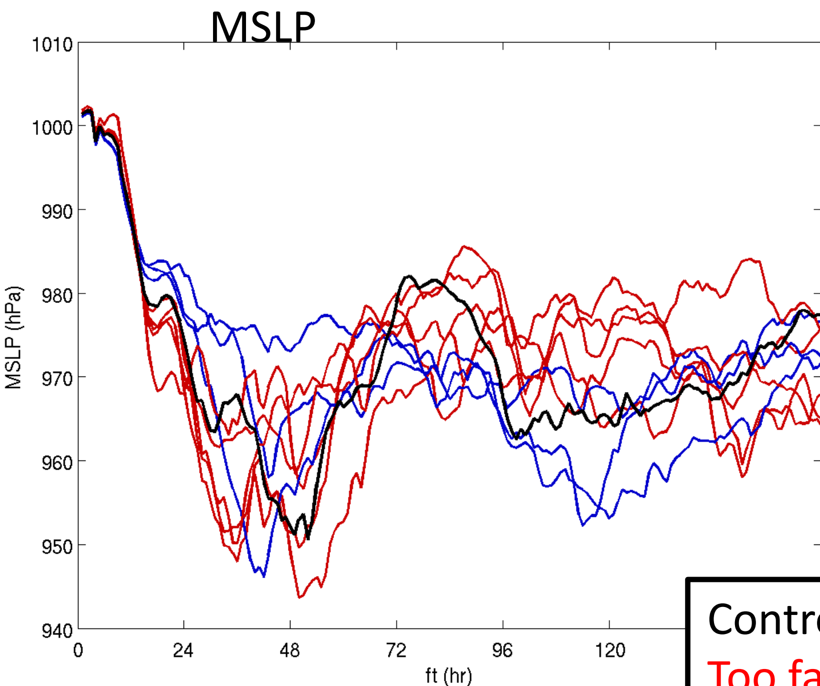
Favorable TC-trough interaction

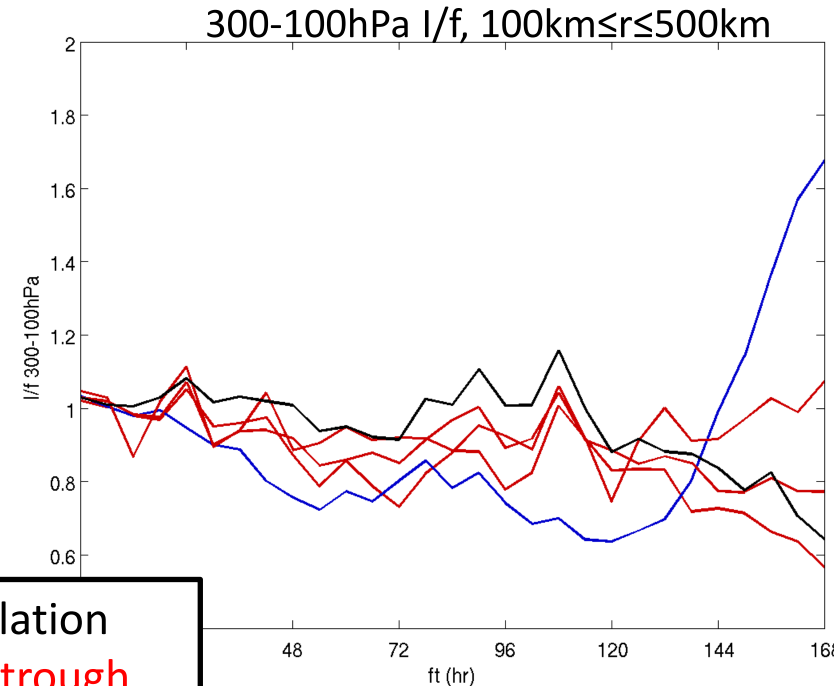
200hPa wind



300-100hPa avg inertial stability (vortex relative)



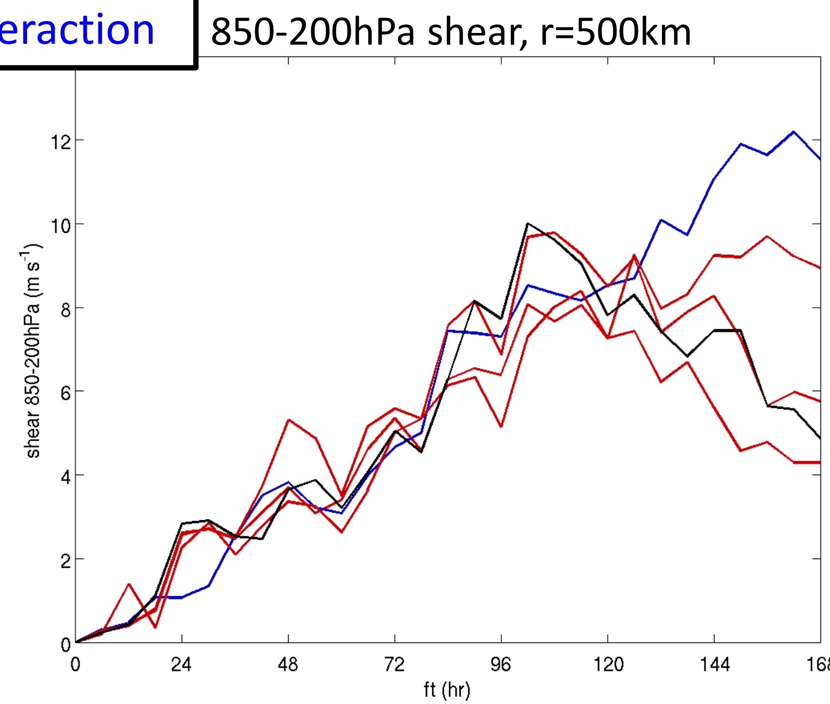




Control simulation

Too far from trough

Favorable interaction



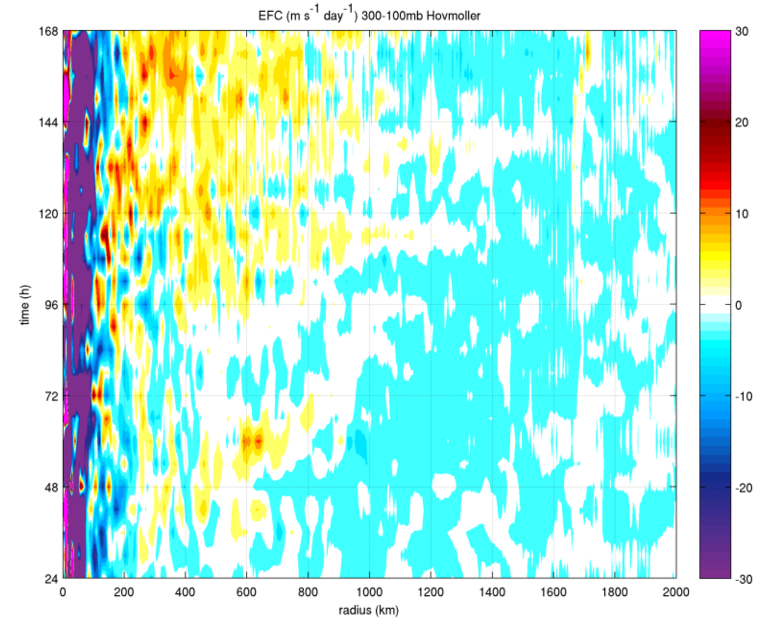
Significant variability in intensity associated with internal dynamics / stochastic processes

Nonetheless, meaningful intensification occurs in simulations with significant trough interaction, and not when TC is too far S

Trough appears to strengthen TC more "reliably" than zonal jet, likely due to greater period of decreased I without increased shear

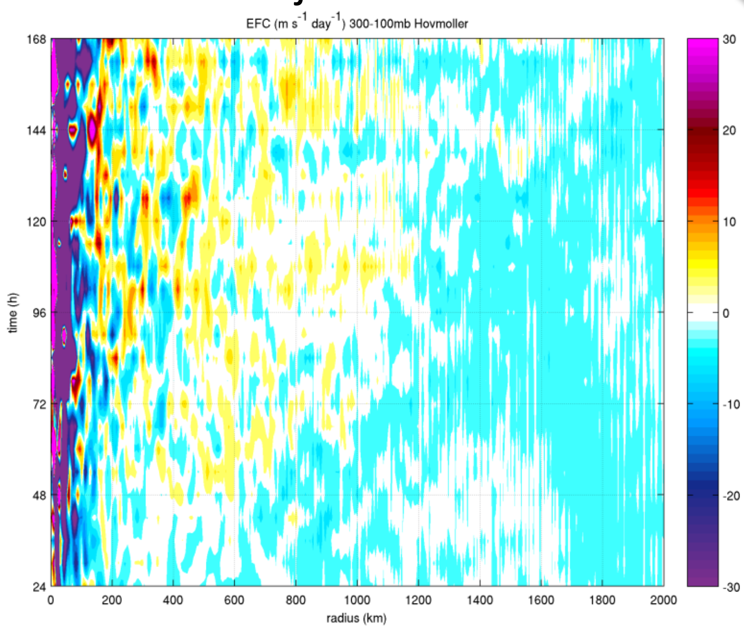
Hovmollers of EFC 300-100mb mean, r = 0→2000km

No jet simulation (control)

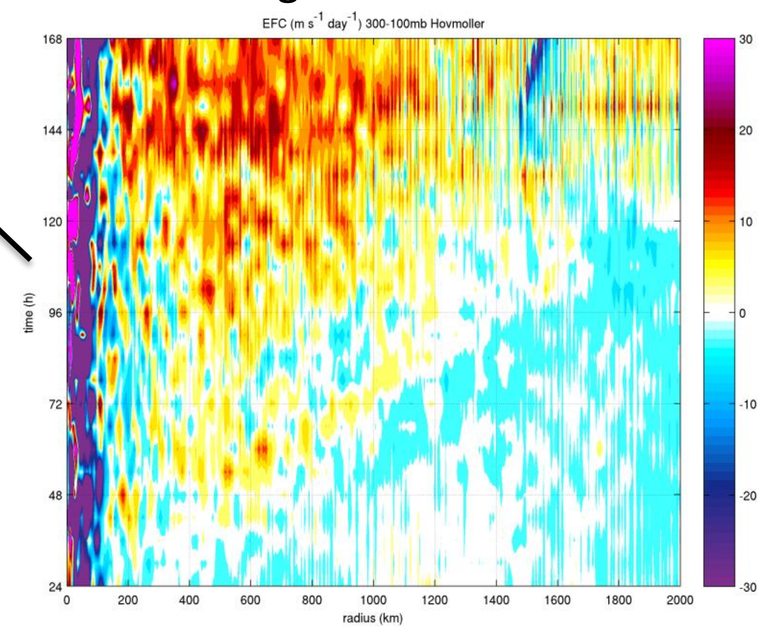


Greater EFC from 96-120h (time of intensification) vs other 2 simulations. Even greater EFC beyond 120h, but by this time TC has weakened due to increased shear

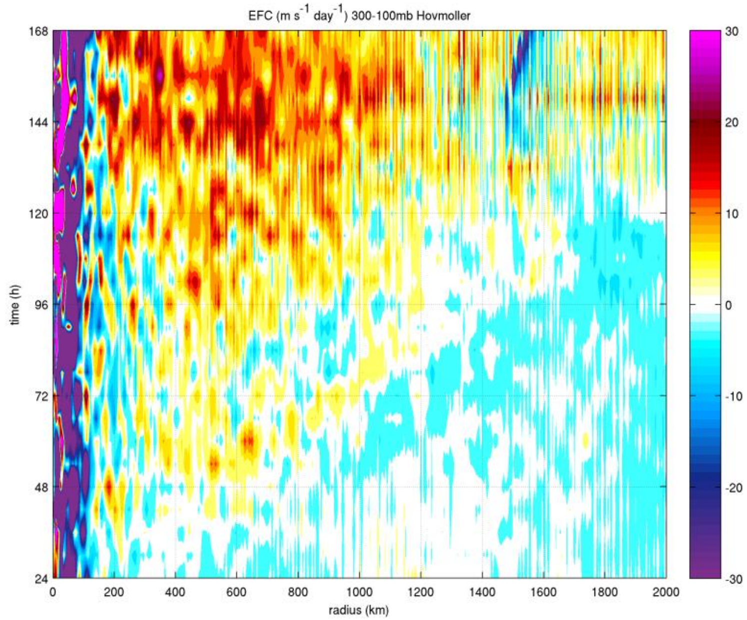
Zonal jet simulation



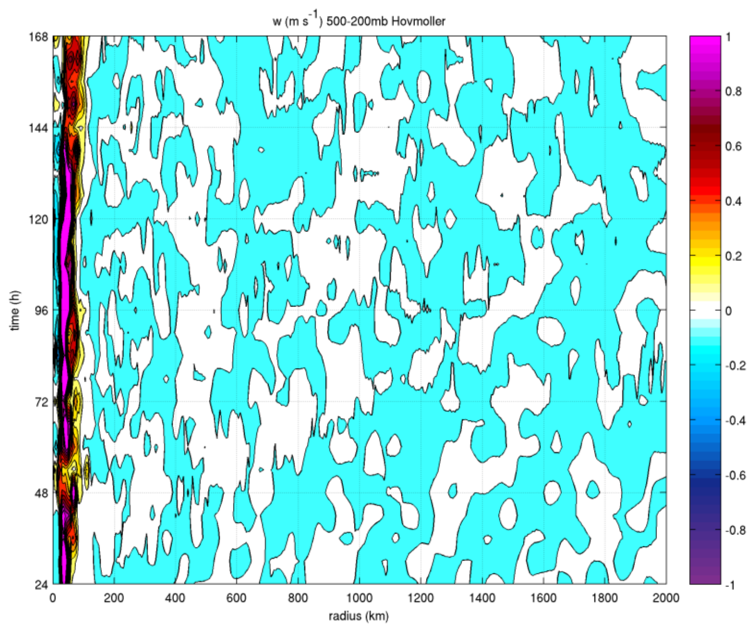
Trough interaction

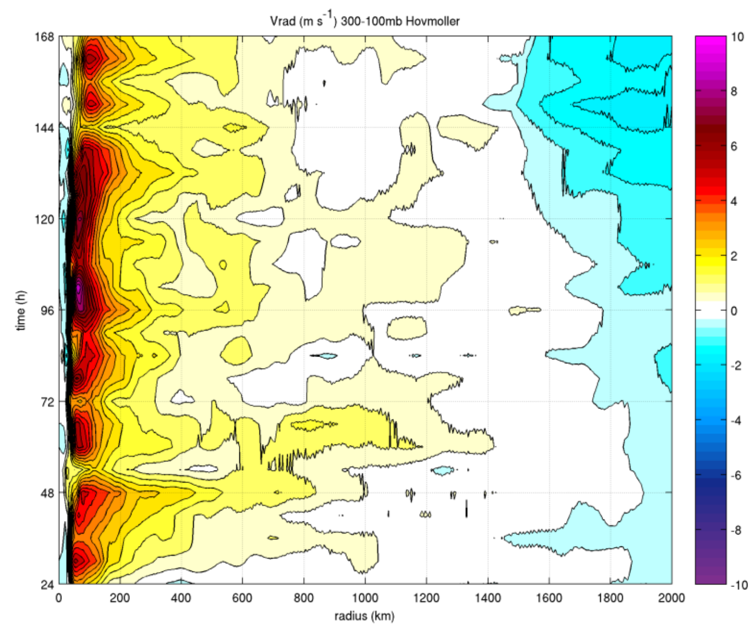


Does large +EFC trigger inward-propagating maximum (either local or absolute) in v_r or w?



At least in these simulations, it doesn't appear so





Summary

- We have examined the interaction between a trough/jet and TC:
- If the TC is too far from the trough, minimal interaction occurs and the result is similar to a control run (no trough)
- If the TC is close enough to the trough, favorable interaction occurs from 96-120h during the period of maximum reduction in inertial stability
- Beyond 120h, the TC drifts N (due to beta effect and southerly flow ahead of trough) and weakens under stronger shear
- Trough appears to strengthen TC more "reliably" than zonal jet, likely due to greater period of decreased I without increased shear
- If EFC is indeed contributing to TC intensification, mechanism is still somewhat unclear
  - Neither an inward-propagating maximum in v_r nor w is observed
- Currently running additional sensitivity tests, testing for robustness of results