The influence of mesoscale mid-level vortices on deep convection and implications for tropical cyclogenesis

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Recent cloud resolving numerical simulations of the transformation of a weak mid-level vortex over a warm ocean into a tropical cyclone show two different pathways:

- Montgomery, Nicholls, Cram and Saunders, 2006: A vortical hot tower route to tropical cyclogenesis. JAS:
  All showed development along the same pathway referred to here as Pathway One.

- Nolan, 2007: What is the trigger for tropical cyclogenesis. Aus. Met. Mag.:
  All showed development along the same pathway referred to here as Pathway Two.

- Nicholls, M. E., and M. T. Montgomery: An examination of two pathways to tropical cyclogenesis occurring in idealized simulations with a cloud resolving numerical model, 2013, ACP
  Showed development along both pathways depending on initial conditions and model physics.

What are these two pathways?

PATHWAY ONE (Montgomery et al.):

- Pathway one proceeds by spin up of cyclonic surface winds that become greater than those of the initial weak mid-level vortex, until they become large enough that they reach tropical depression strength.
- Development is characterized by a gradual decrease of the radius of maximum surface winds.
- Vorticity is concentrated in numerous deep convective towers, called Vortical Hot Towers (VHTs), that collectively drive a system-scale inflow.
- Vorticity gradually builds in the center as the system-scale inflow produces increasing cyclonic vorticity and as small-scale vorticity anomalies are converged at low levels and undergo aggregation.

PATHWAY TWO (Nolan):

- A mid-level vortex develops in excess of 10 m s^{-1} that is considerably stronger than the typical mid-level vortex associated with the stratiform region of a MCS.
- The system development is then followed by the sudden formation of a small surface concentrated vortex near the center of the larger-scale circulation.
- Once formed, the small vortex becomes the focus of a strengthening cyclonic circulation that grows in size, and often develops rapidly into a small TC.

THIS LOOKS SIMILAR TO A BIRFURCATION IN DYNAMICAL SYSTEMS.

THE SECOND PATHWAY IS PREDICTED BY MODEL RESULTS. IT HAS NOT BEEN OBSERVED.

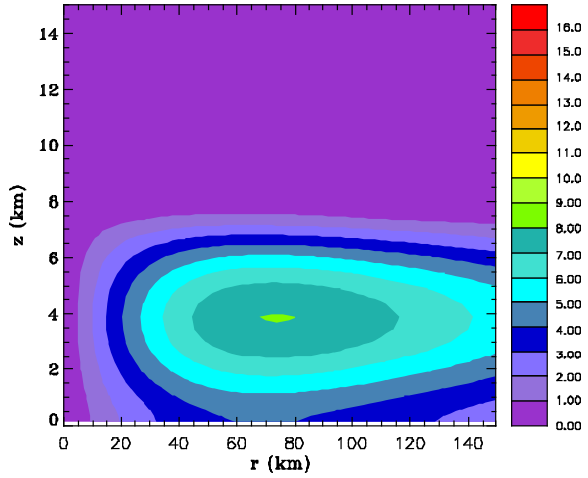
This talk discusses a simulation that evolves along pathway Two, that develops a strong mid-level vortex before genesis

Main features of the model configuration

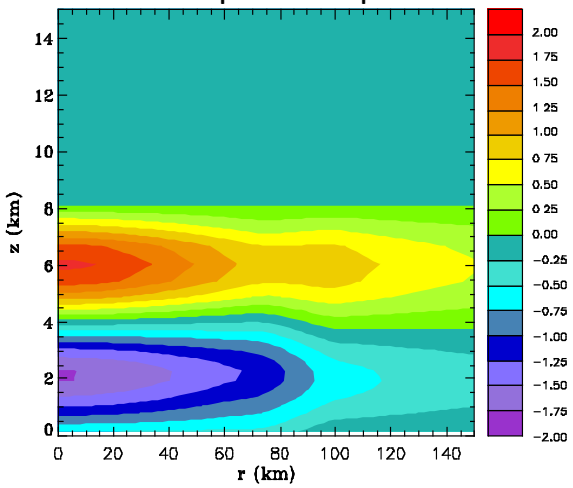
- Regional Atmospheric Modeling System (RAMS)
- 3 grids that are nested
- The fine scale grid has a horizontal grid increment of 1 km
- Two-moment microphysics
- No radiation
- SST 28 ^{0}C

The Initial vortex is in gradient wind balance, and has a moisture anomaly in the core. Max winds 8 m s^{-1} at z= 4 km, at a radius of 75 km.

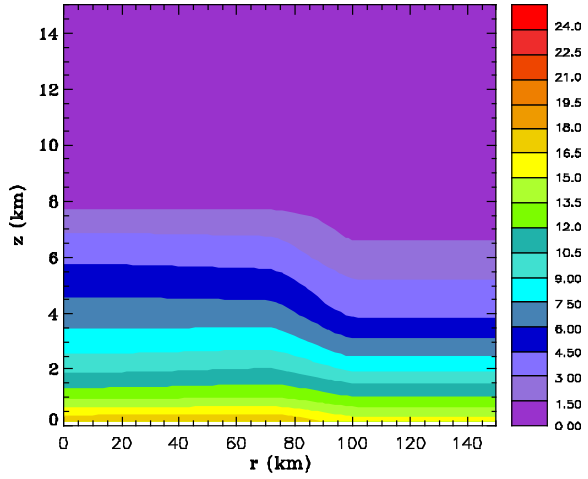
Tangential velocity



Potential temperature perturbation



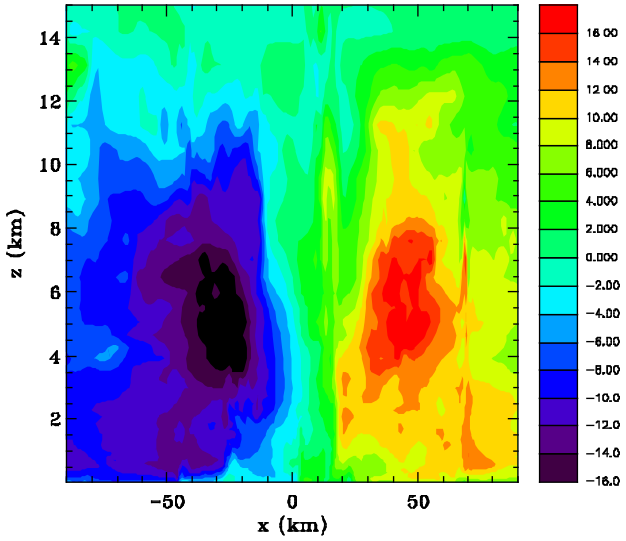
Water vapor mixing ratio



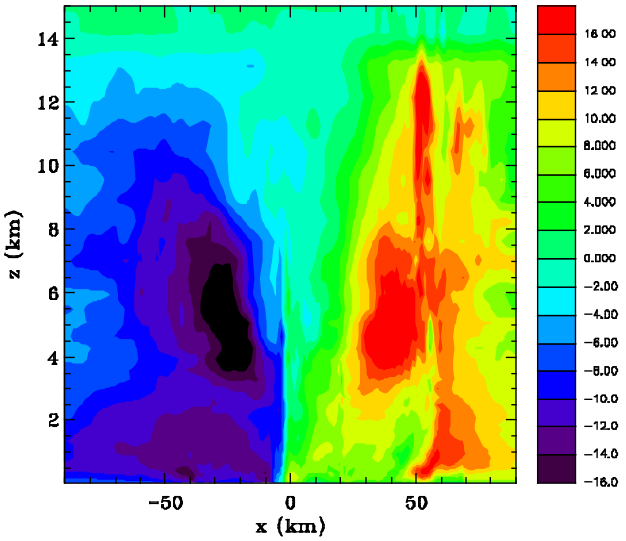
Initial conditions for a small weak vortex with a moisture anomaly. (a) Tangential velocity. The contour interval is 1 m s^{-1}. (b) Potential temperature anomaly. The contour interval is 0.25 K. (c) Water vapor mixing ratio. The contour interval is 1.5 g kg^{-1}.

Y-component of winds, v

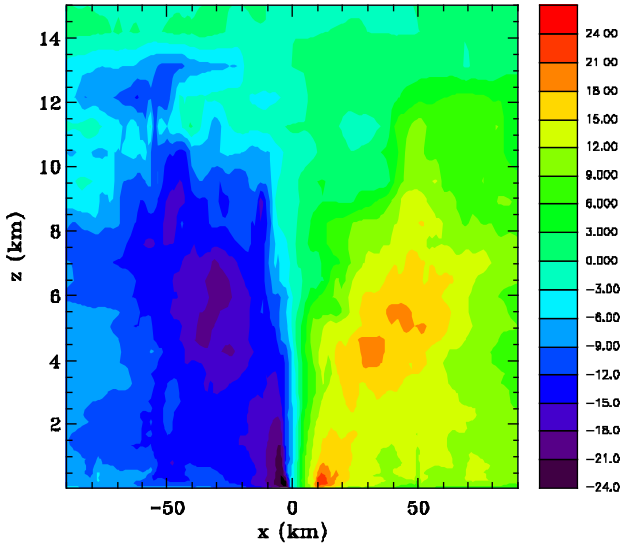
t=87 h Vmax = 14 m s^{-1}



t=90 h



t=97 h Vmax=21 m s^{-1}

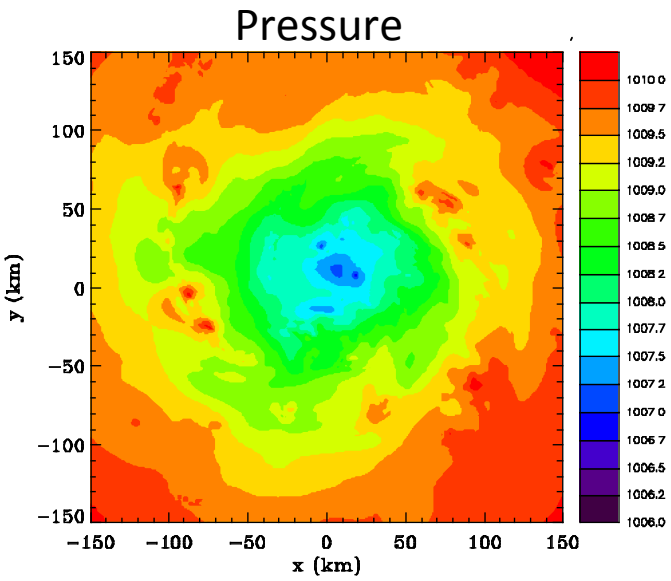


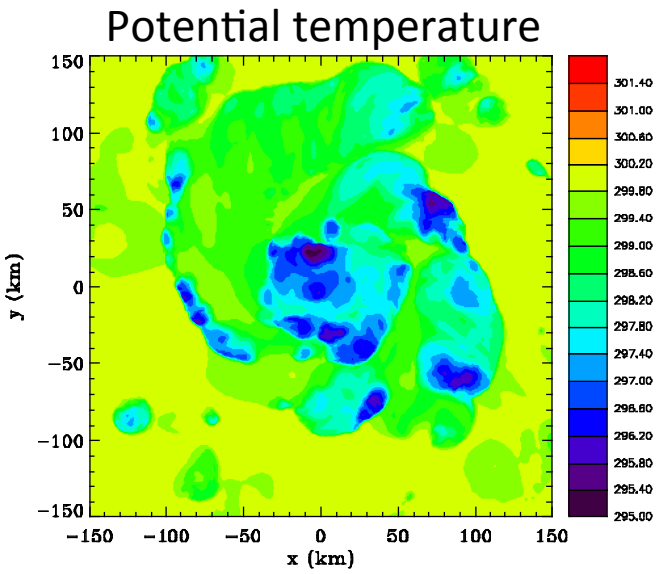
Vertical x/z section of the y-component of velocity v through the centre of the domain,

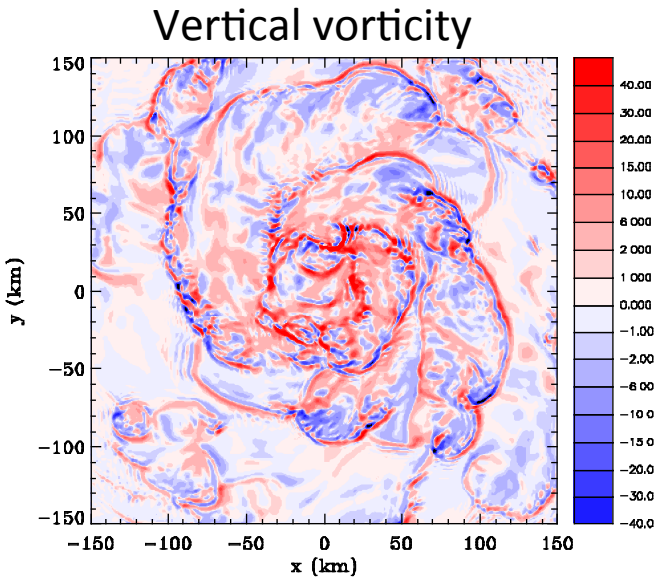
A mid-level inflow developed beneath the Stratiform ice layer aloft which converged the pre-existing circulation leading to the spin up.

A very small vortex forms at 90 h which rapidly intensifies.

Evolution of the small vortex: t=86 h







Horizontal sections at t=86 h. (a) Pressure (mb) (b) potential temperature (K) and (c) vertical vorticity (x10-4 rad s^{-1}), at z=29.5 m.

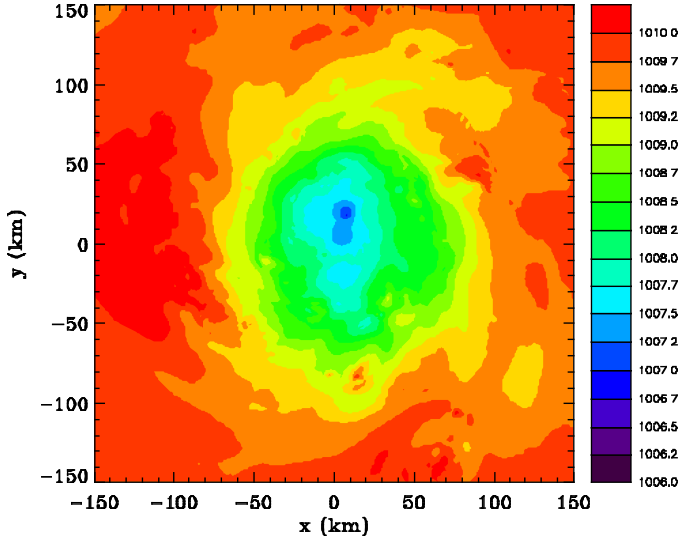
A small pressure and vorticity anomaly Is about 20 km from the center on the edge of a central cold pool.

Note how positive vertical velocity tends to be found at the edges of cold pools.

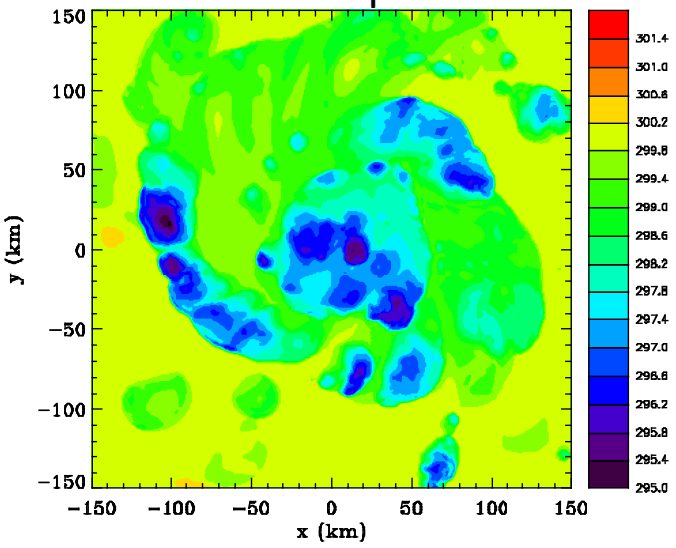
ΔT in cold pools about minus 2-3 Kelvin

Evolution of the small vortex: t=87 h

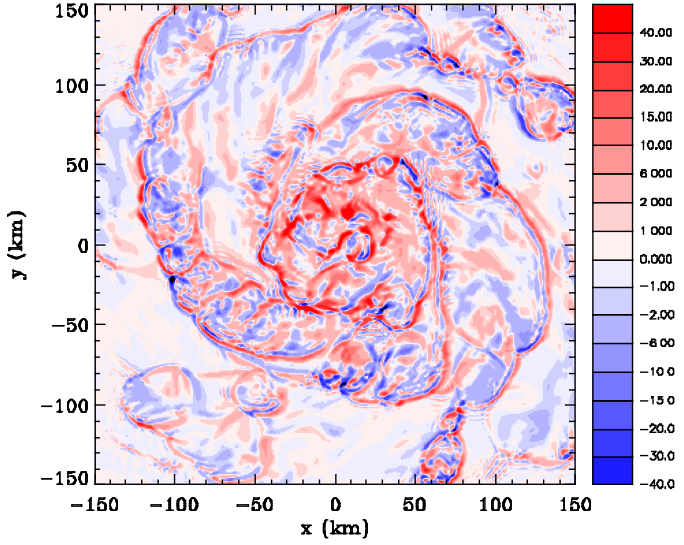
Pressure



Potential temperature



Vertical vorticity

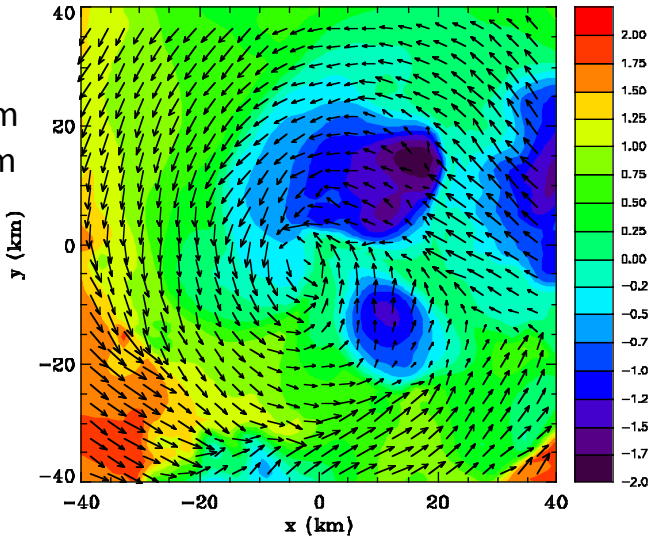


Strong convection above the low-level anomaly caused it to intensify. It is still on the edge of the central cold pool which is very inhomogeneous. It is made up of a number of cold pool outflows that are aggregating at the centre.

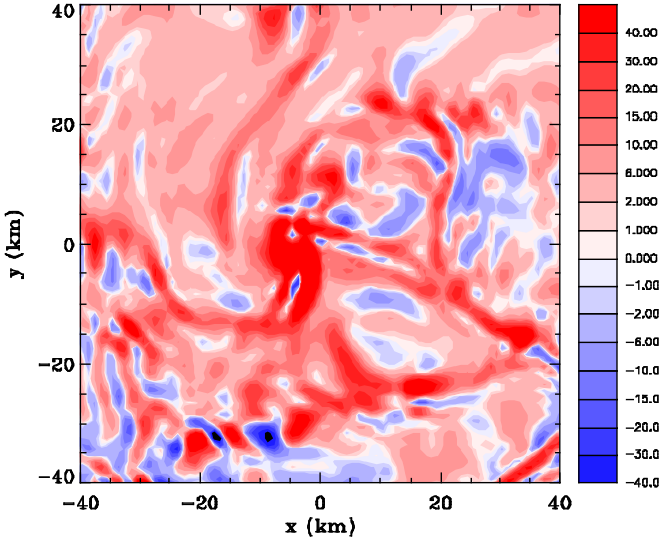
Zoomed fields at t=89 h when the small vortex forms

Convection feeds on relatively warm and moist air from the north

Temperature perturbation at z=29.5 m X/Y



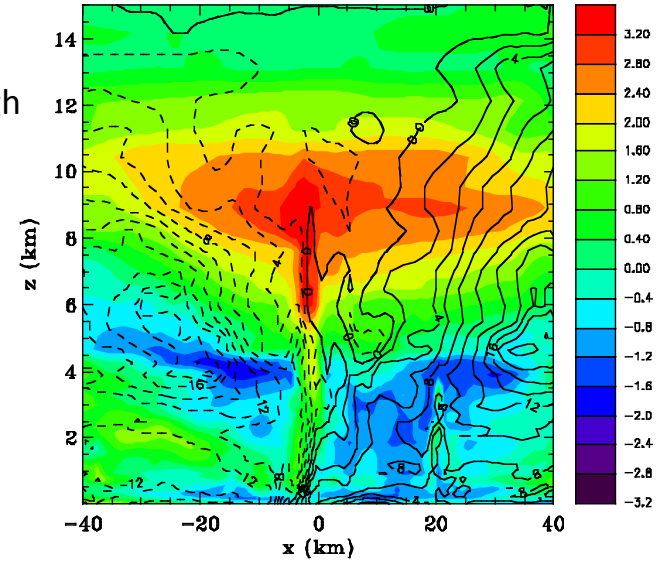
Vertical vorticity at z=29.5 m X/Y



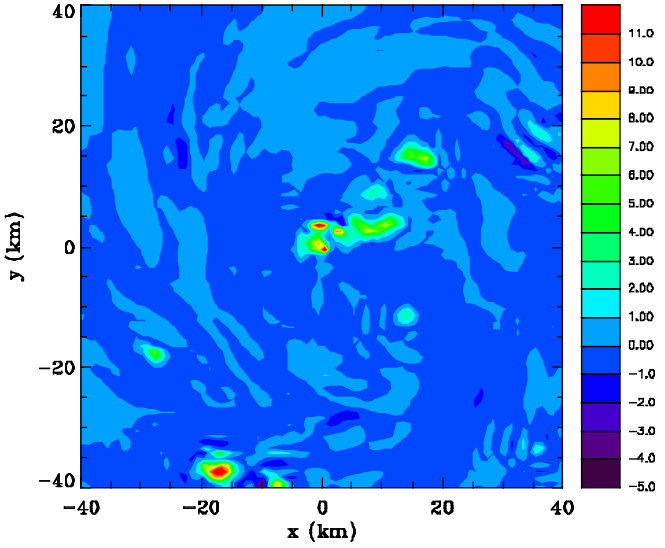
A large amount of positive vertical vorticity is present

A column of warm air extends through the cold low level air and is near the centre of the mid-level vortex

Potential temperature perturbation, v X/Z



Vertical velocity at z=4.3 km X/Y



The updraft is above the edge of the cold pool

CONCLUSIONS

- Numerical simulations by Nolan (2007) and Nicholls and Montgomery (2013) suggest there is a second pathway leading to tropical cyclogenesis that might exist which is vey different to the pathway discussed by Montgomery et al. (2006). It involves the development of a strong mid-level vortex.
- This situation resembles a bifurcation where small changes to the initial conditions can result in a dramatic change in the solution.
- The second pathway depends on the ice phase being activated. Liquid only simulations do not show spin up of a strong mid-level vortex. However, a lot of the simulations that had ice activated still evolved along the first pathway.
- SST was found to be a significant parameter. Simulations with higher SST's tended to evolve along the second pathway. Higher SST's lead to deeper more intense convective cells that produce more ice.
- The details of how the small vortex forms can be quite different than this case. One case formed a squall line, another an MCS. There is a fuzziness to the solution due to the fortuitous nature of convection and mesoscale processes. Usually a small anomaly forms about 20 km from the centre, which then spirals into the centre where it intensifies.

Factors influencing the development of the small vortex

- Low level stability is reduced at the center as as the strong mid-level vortex forms since there is a low-level cooling centered at about 4 km above the surface.
- Positive vertical vorticity is enhanced around the edges of surface cold pools which tend to merge at the center of the system.. This seems to be a significant source of vorticity for the small vortex.
- The efficiency of the conversion of latent heat energy to the kinetic energy of the cyclonic wind field increases as the mid-level vortex forms, in accordance with the theory of Schubert and Hack (1980), as shown by Nolan (2007).

So far this second pathway hasn't been observed in nature, but it might be a way that some small tropical cyclones form.

Weak wind shear of 3 m s^{-1} prevents a strong mid-level vortex from forming.

So far there is no evidence of strong mid-level circulations like this existing prior to Medicanes developing.