Scaling for the Nontraditional Coriolis Term in Diabatic-Forced Dynamics

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Objectives

NCT is ignored in most of the current global atmospheric models. This study attempts to scale the direct effect of omitting NCT on the zonal wind field in an idealized diabatic-forced dynamical system. Effects of omitting NCT on the fields of vertical motion and potential temperature are also explored.

Methods

The idealized system applies the following approximations:

1. Anelastic,
2. Zonally symmetric,
3. Beta plane,
4. Linearized around a motionless stratified reference state,
5. Prescribed constant dissipation time of 20 days,
6. Prescribed ITCZ-like diabatic forcing, and
7. Steady state.

We derived the meridional-vertical circulation equation; the other fields can be inverted from the mass streamfunction:

$$[\alpha^2 + 4\Omega^2 + N^2]\frac{\partial^2\Psi}{\partial y^2} + 2[2\Omega\beta y]\frac{\partial^2\Psi}{\partial y\partial z} + [\alpha^2 + \beta^2 y^2]\frac{\partial^2\Psi}{\partial z^2} + \left[\frac{\alpha^2}{H_\rho} + 2\Omega\beta\right]\frac{\partial\Psi}{\partial z} = \frac{\hat{\rho}g}{\hat{\theta}}\frac{\partial\dot{\theta}}{\partial y}$$

$$v \equiv -\frac{1}{\hat{\rho}}\frac{\partial\Psi}{\partial z}, \qquad w \equiv \frac{1}{\hat{\rho}}\frac{\partial\Psi}{\partial y}$$

$$u = \frac{1}{\alpha}(\beta y v - 2\Omega w), \qquad \theta' = \frac{1}{\alpha}\left(\dot{\theta} - \frac{d\hat{\theta}}{dz}w\right)$$

The green terms emerge from NCT. The results without NCT minus with NCT are the effects of omitting NCT.

Terminology

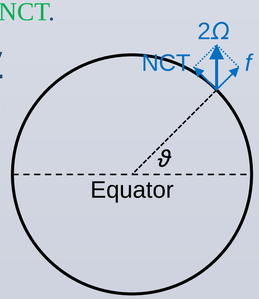
NCT ($2\Omega\cos\vartheta$): nontraditional Coriolis term

$\dot{\theta}$: diabatic forcing

α: dissipation rate

Ψ: meridional-vertical mass streamfunction

a: radius of Earth



Results (Control)

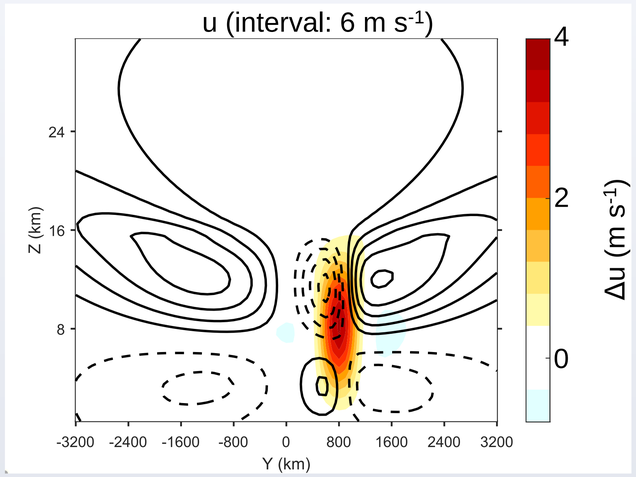


Figure 1. Zonal wind with NCT (contour), and the effect of omitting NCT (without NCT minus with NCT) on zonal wind (shaded).

Omitting NCT causes the westerly wind field proportional to the diabatic heating field but does not affect the westerly jet maxima.

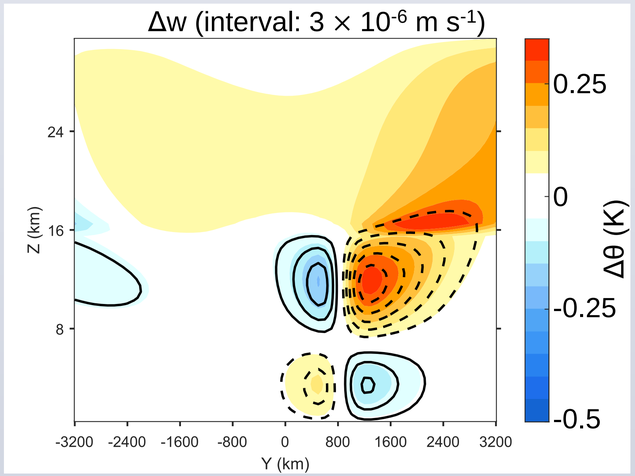


Figure 2. The effects of omitting NCT on vertical velocity (contour) and potential temperature (shaded).

Omitting NCT causes thermal-wind-balanced potential temperature field associated with the westerly wind effect.

Results (Parameter Space)

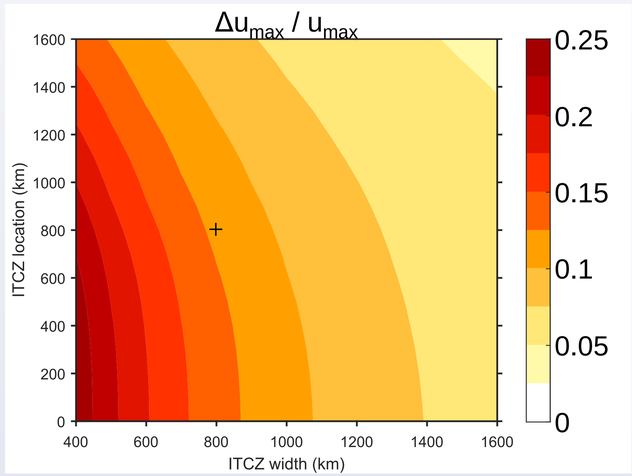


Figure 3. The ratio of the maximum effect of omitting NCT on zonal wind and the maximum zonal wind with NCT on the parameter space of ITCZ width within which 95% of precipitation occurs and ITCZ location away from the equator. The "+" sign denotes the location of the control settings on this parameter space.

Scaling

The ratio in Figure 3 can be explained with a dimensionless number.

$$\hat{O} \equiv \frac{2\Omega w}{\beta y v} = \frac{aw}{yv}$$

The closer the ITCZ is to the equator, the smaller the y is, so the $\hat{O}$ number is larger. Also, the narrower the ITCZ is, the larger the w is with respect to v, so the $\hat{O}$ number is larger.

Implications

Omitting NCT affects the simulated large-scale circulation response to the ITCZ-like diabatic forcing, including a westerly bias and thermal-wind balanced potential temperature biases. The significance of the westerly bias with respect to the westerly jet increases with the ITCZ narrowing or approaching the equator.

These direct effects of omitting NCT may further affect convection and atmosphere-ocean interaction, which are left for future studies.

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