Axisymmetric and nearly inviscid models of the atmosphere

$$0 = -\nabla\cdot(\mathbf{v}M) + \frac{\partial}{\partial z}\left(\nu\frac{\partial M}{\partial z}\right),$$

where

$$M = \Omega a^2\cos^2\theta + ua\cos\theta$$

$$u_M \equiv \Omega a\sin^2(\theta)/\cos(\theta).$$

$$\nu\partial_y M = 0$$

Radiative equilibrium

Angular momentum conservation

For equinoctial Held and Hou model

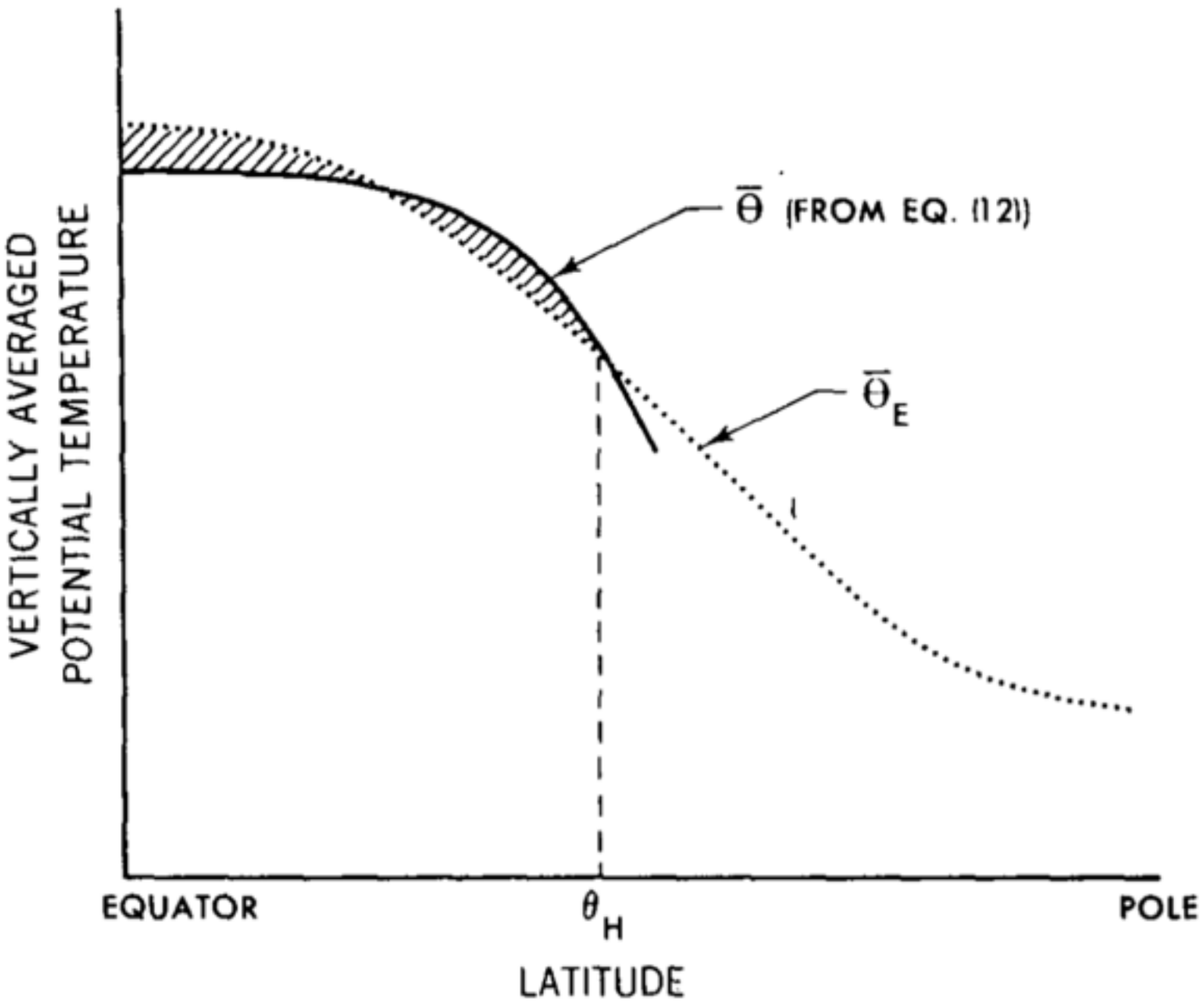


FIG. 1. The equal-area geometric construction equivalent to the argument of Section 4a. The two shaded areas are equal.

$$fu + \frac{\tan\phi}{a}u^2 \approx -\frac{1}{a}\frac{\partial\Phi}{\partial\phi},$$

v must be hemispherically asymmetric
since M is constant around the equator,
u is hemispherically symmetric
hence
temperature is hemispherically symmetric

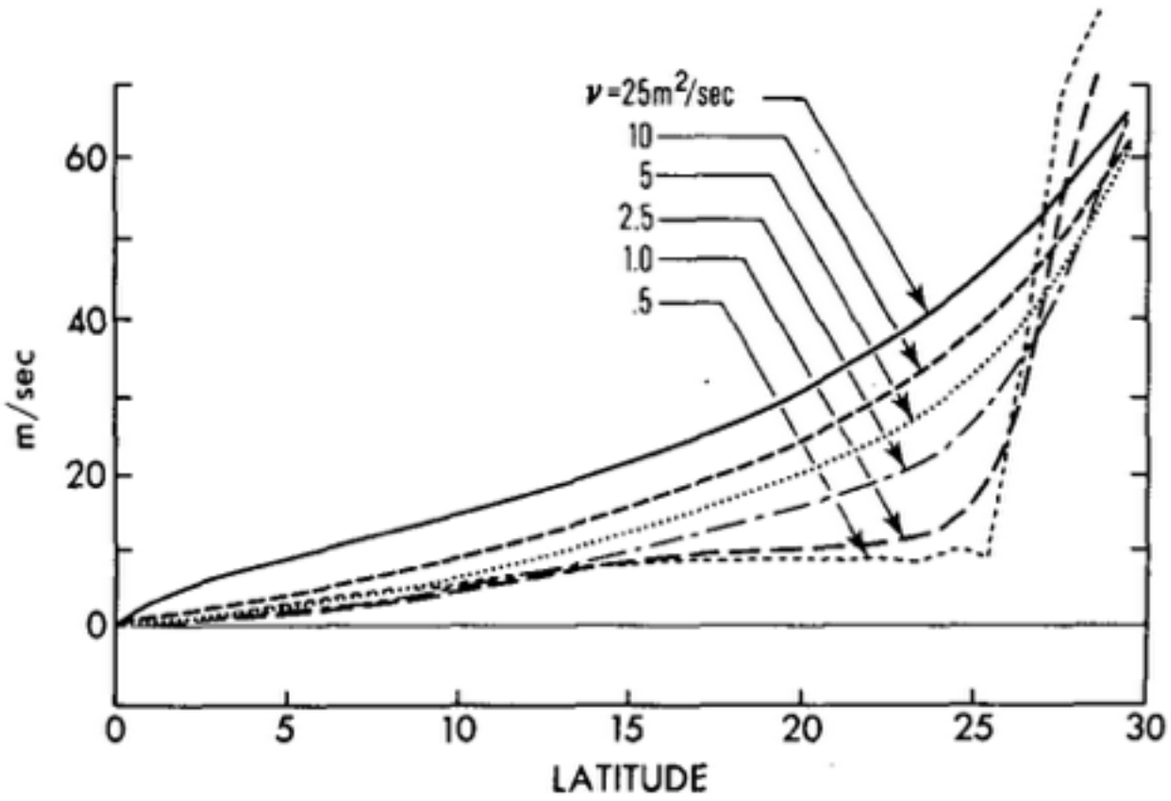


FIG. 6. $\Omega a \sin^2(\theta) - u \cos(\theta)$ at $z = H$ for various values of ν in the standard case.

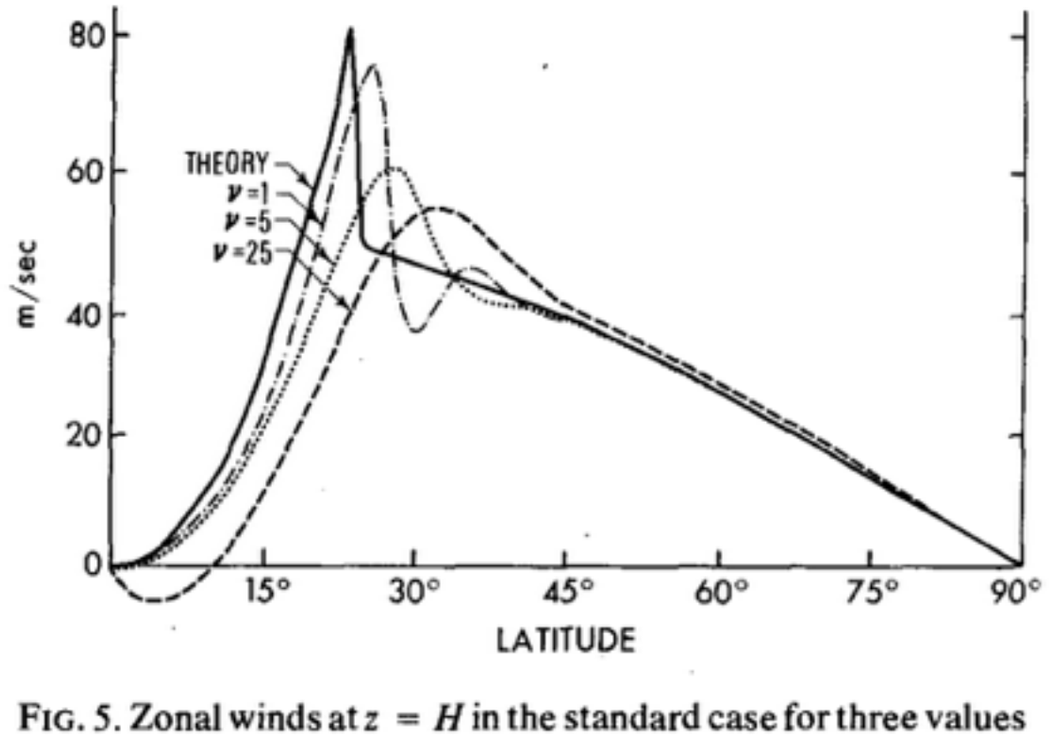


FIG. 5. Zonal winds at $z = H$ in the standard case for three values of ν, compared with the theoretical prediction for $\nu \to 0$.

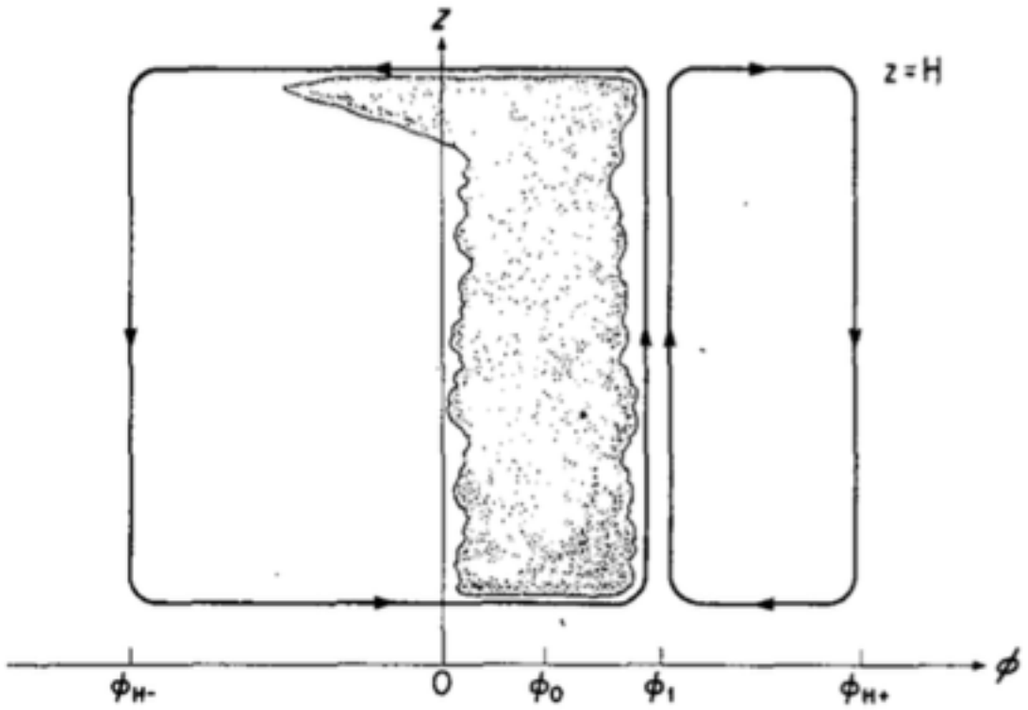


FIG. 3. Schematic illustration of the Hadley circulation.

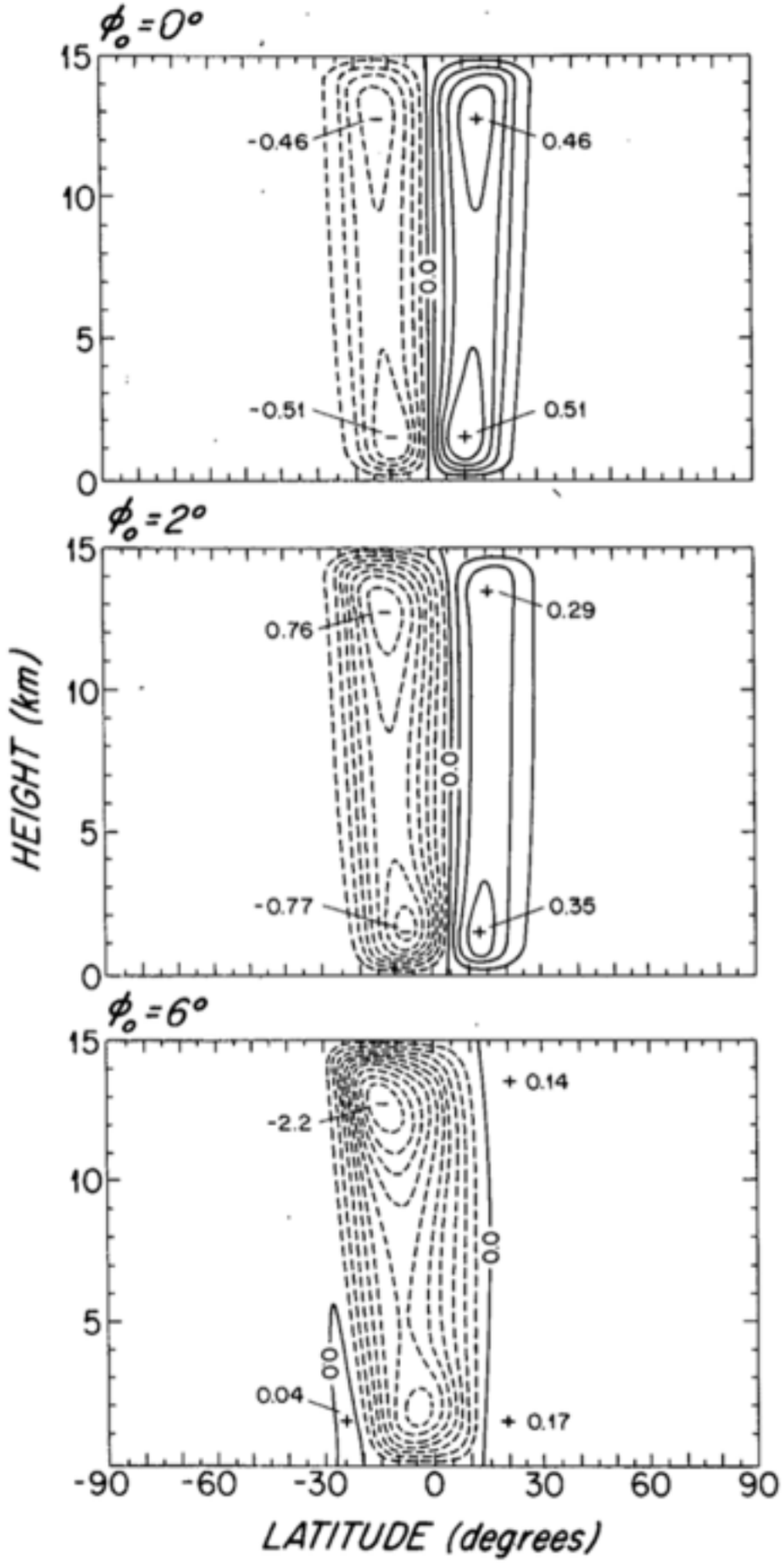


FIG. 9. Numerical model results for ψ for (a) $\phi_0 = 0°$, (b) $\phi_0 = 2°$, and (c) $\phi_0 = 6°$. Units are in 10^{10} kg s^{-1} and the contour interval is 0.1×10^{10} kg s^{-1} for (a) and (b); twice this value for (c).

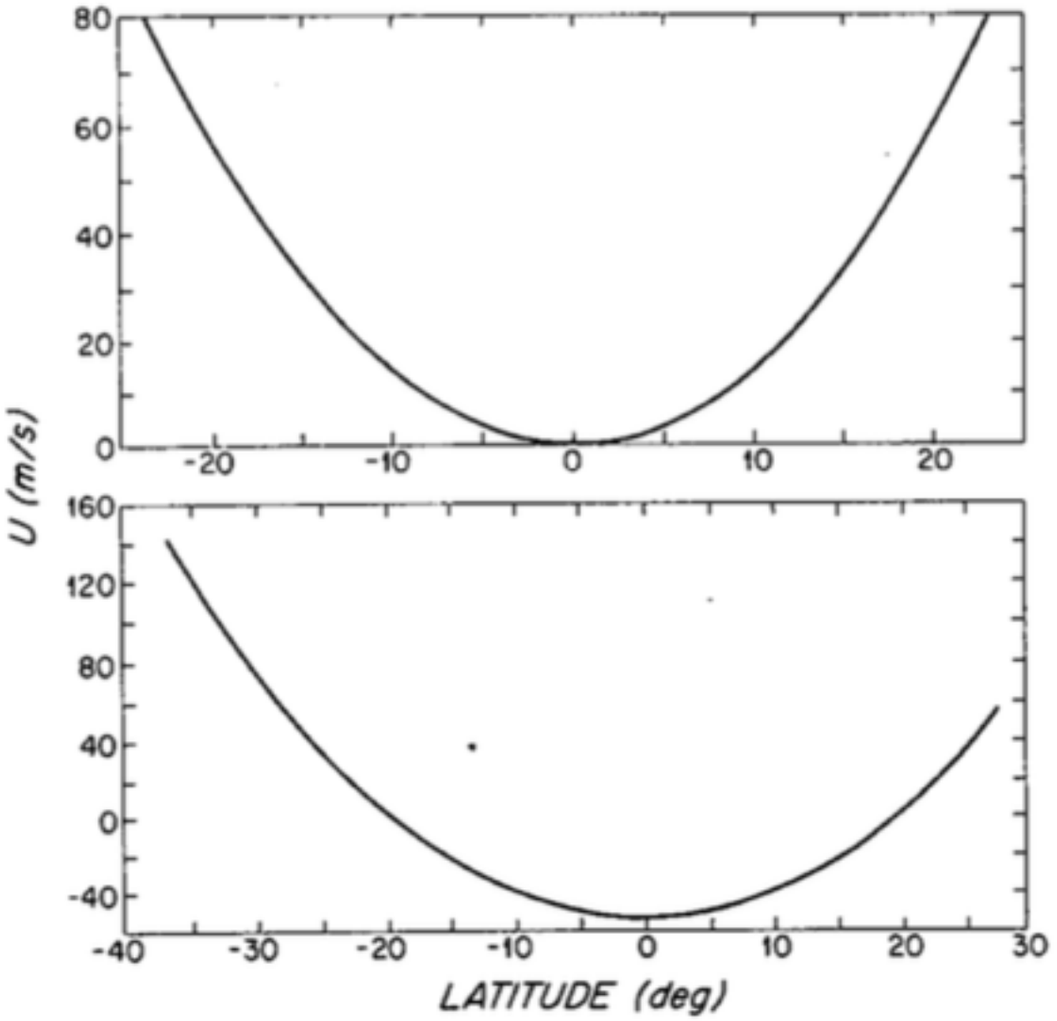


FIG. 6. $u(H, \phi)$ as a function of ϕ using the simple model. (a) $\phi_0 = 0$. (b) $\phi_0 = 6°$.

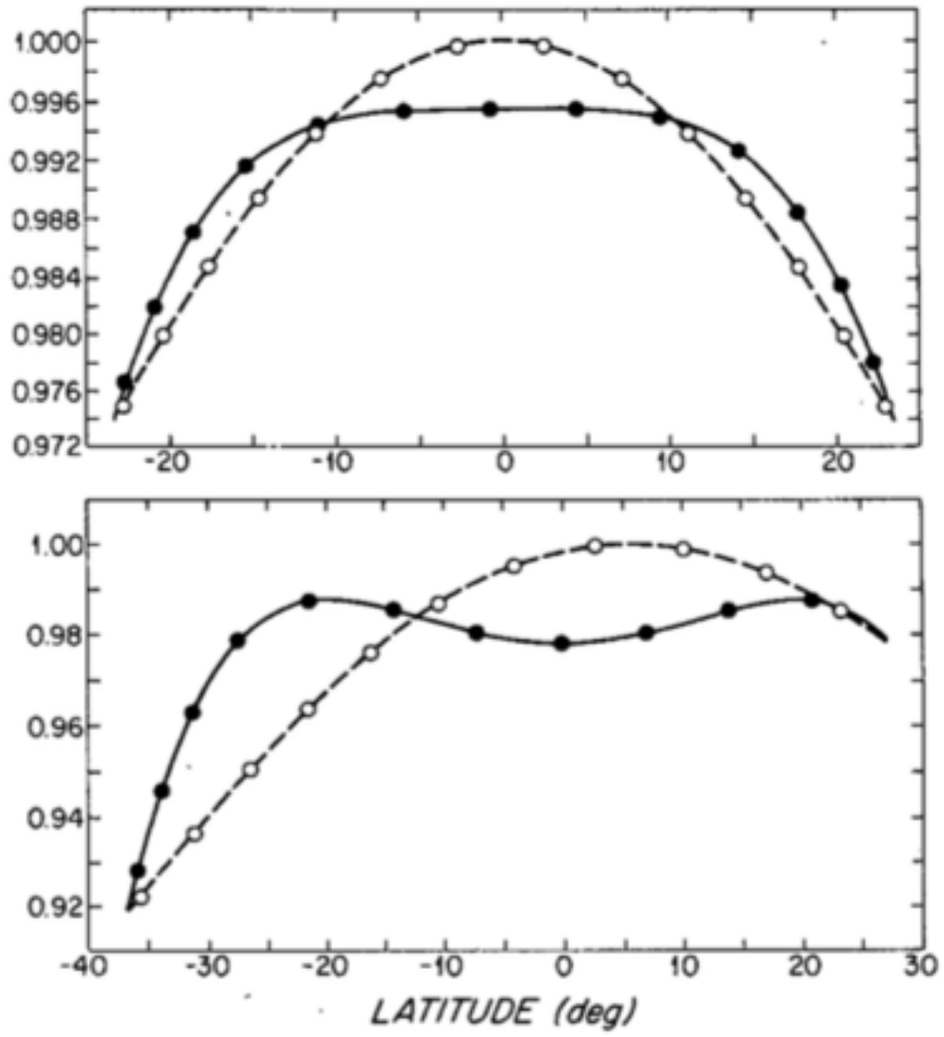
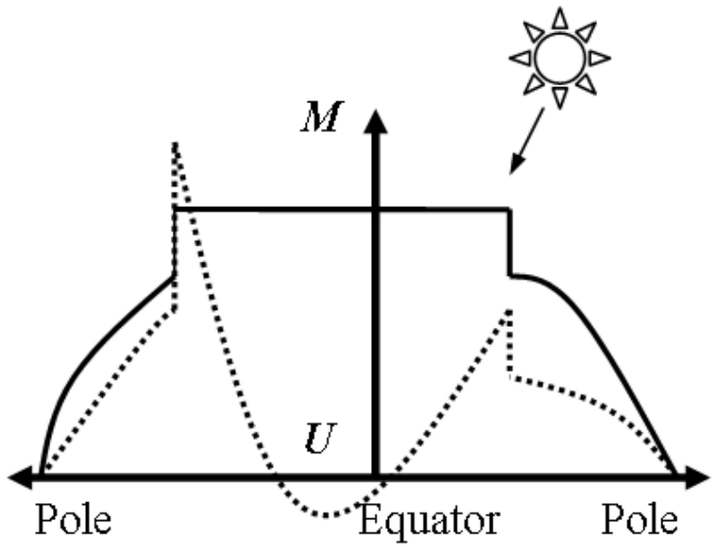
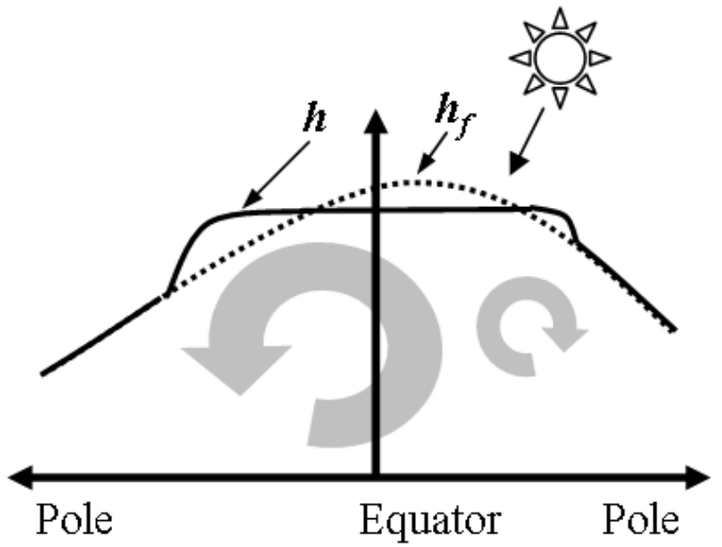


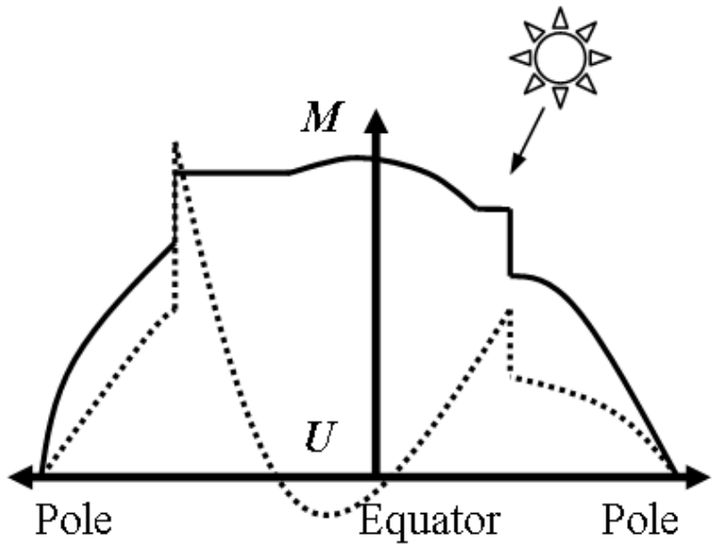
FIG. 5. $\bar{\theta}/\theta_0$ (solid line) and $\bar{\theta}_E/\theta_0$ (dashed line) as functions of ϕ using the simple model. (a) $\phi_0 = 0$. (b) $\phi_0 = 6°$.

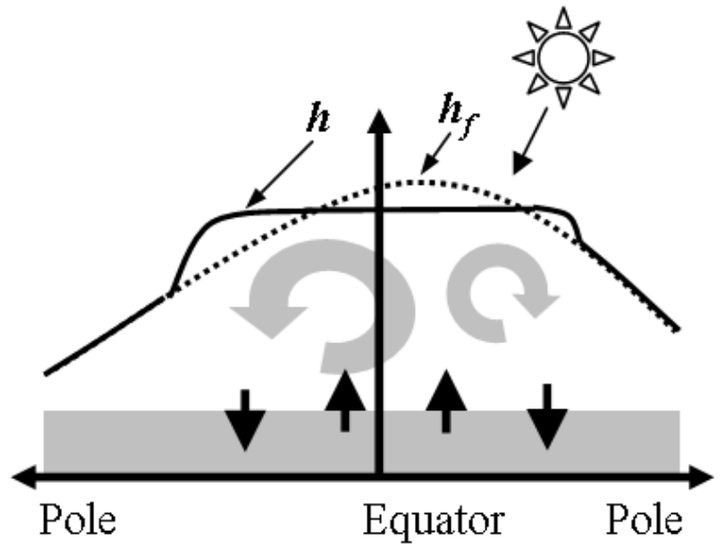
inviscid





nearly inviscid
vertical advection
of momentum





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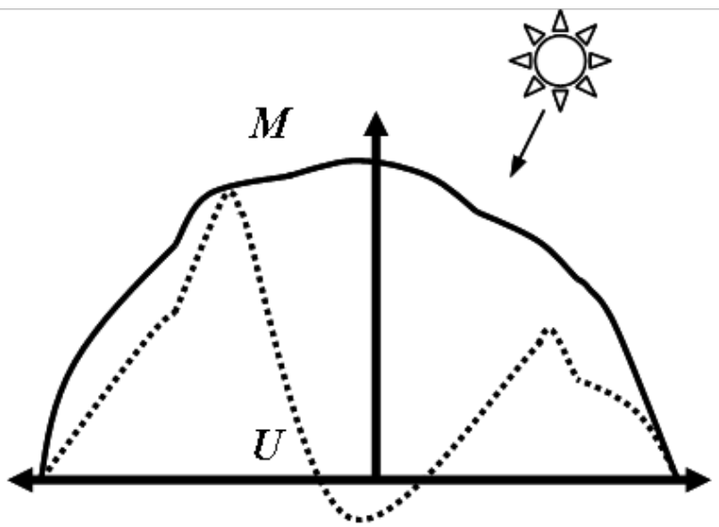

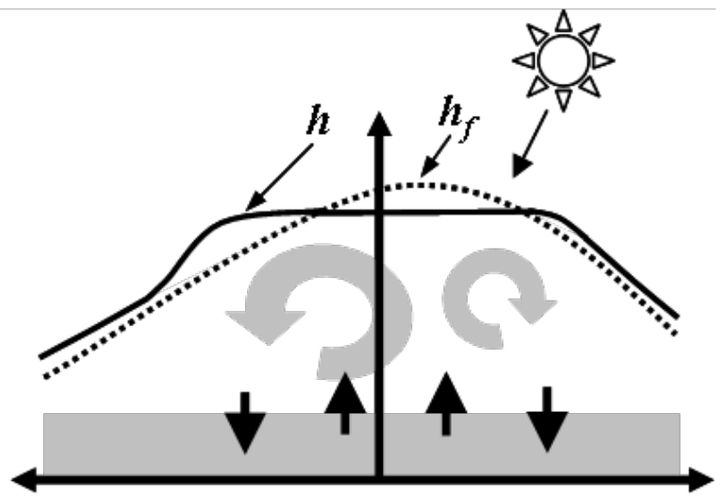

key points

Equinoctial (Held and Hou 1980):

- mean circulation accounts for about half of the heat transport

- thermally direct circulation must exist at the deep tropics.

- radiative equilibrium can exist only outside the tropics

Off equatorial heating (Lindzen and Hou 1988)

- strong winter Hadley cells and negligible summer cells

- (too strong) easterlies at the equator.