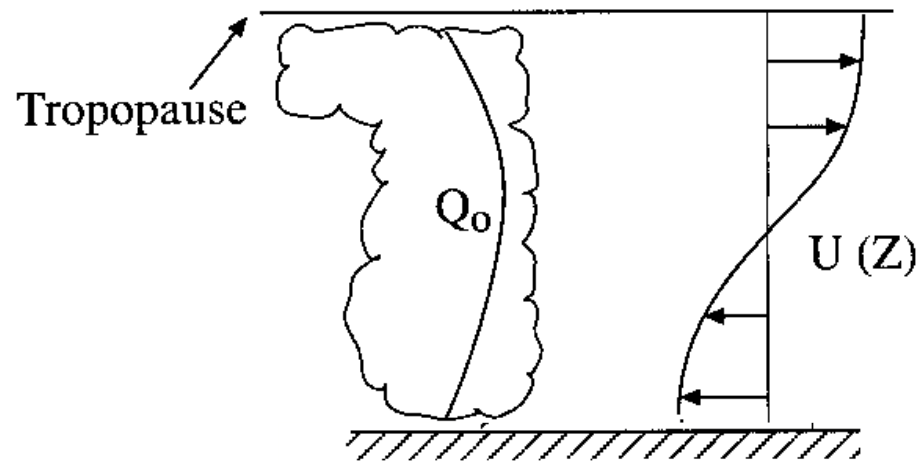


Gill (1980) response to heating Q_0



$$Q_0 = Q_{\text{evap}} + Q_{\text{conv}}$$

A. E. GILL

the buoyancy equation.
 psonse to steady forcing, dissipative processes must be included
 ent is the so-called 'Rayleigh friction' and 'Newtonian cooling'
 rator $\partial/\partial t$ by $\partial/\partial t + \epsilon$. The mathematics is simplest when the
 ne as the one for cooling, so the steady-state versions of Eqs.

$$\epsilon u - \frac{1}{2} y v = -\frac{\partial p}{\partial x}, \quad . \quad . \quad . \quad (2.6)$$

$$\epsilon v + \frac{1}{2} y u = -\frac{\partial p}{\partial y}, \quad . \quad . \quad . \quad (2.7)$$

$$\epsilon p + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = -Q, \quad . \quad . \quad . \quad (2.8)$$

$$w = \epsilon p + Q. \quad . \quad . \quad . \quad (2.9)$$

This model was used by Matsuno (1966).

Gill (1980) response to heating Q_c

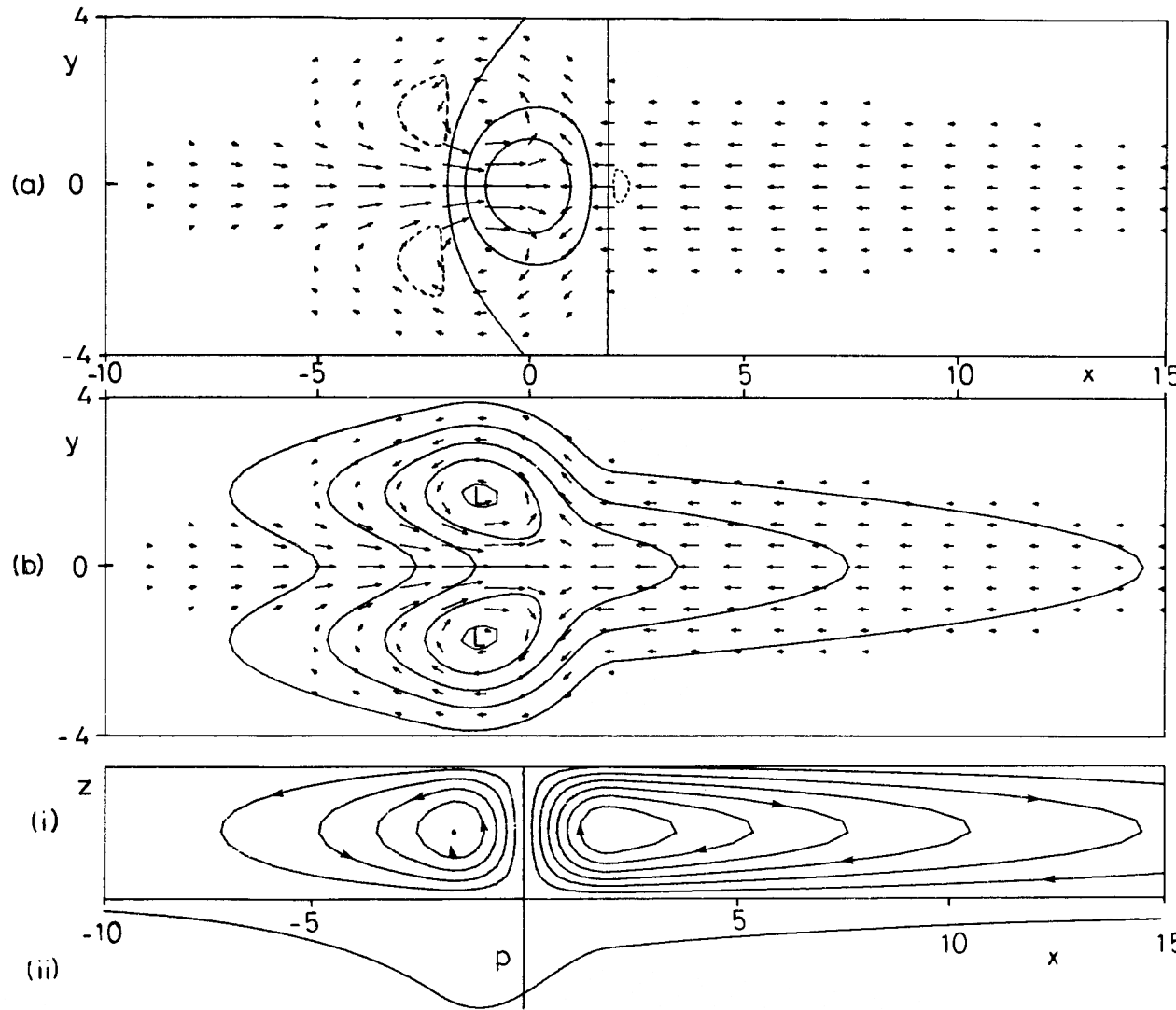


Figure 1. Solution for heating symmetric about the equator in the region $|x| < 2$ for decay factor $\varepsilon = 0.1$.

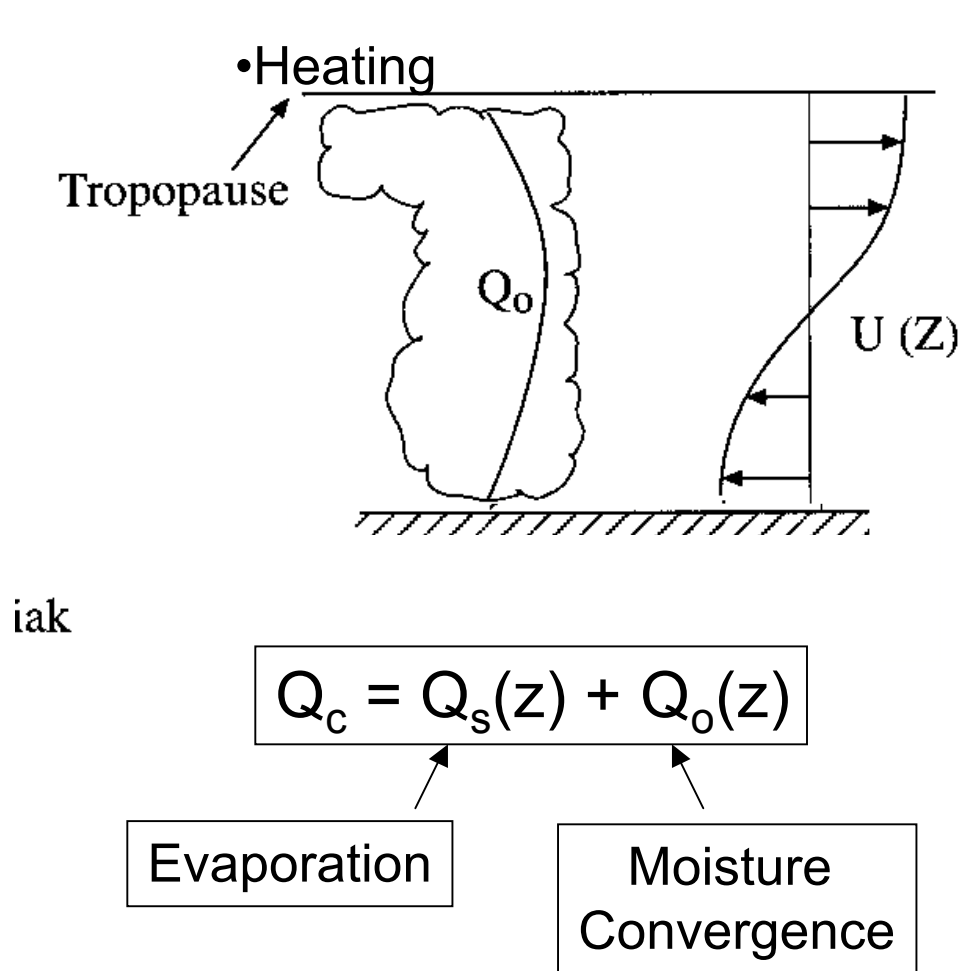
(a) Contours of vertical velocity w (solid contours are 0, 0.3, 0.6, broken contour is -0.1) superimposed on the velocity field for the lower layer. The field is dominated by the upward motion in the heating region where it has approximately the same shape as the heating function. Elsewhere there is subsidence with the same pattern as the pressure field.

(b) Contours of perturbation pressure p (contour interval 0.3) which is everywhere negative. There is a trough at the equator in the easterly regime to the east of the forcing region. On the other hand, the pressure in the westerlies to the west of the forcing region, though depressed, is high relative to its value off the equator. Two cyclones are found on the north-west and south-west flanks of the forcing region.

(c) The meridionally integrated flow showing (i) stream function contours, and (ii) perturbation pressure. Note the rising motion in the heating region (where there is a trough) and subsidence elsewhere. The circulation in the right-hand (Walker) cell is five times that in each of the Hadley cells shown in (c).

Zebiak's (1986) heating Q_c of the Gill model

- Forcing is due to the canonical SST anomaly at the of the warm phase of ENSO



$$Q_o(z) = \left\{ \begin{array}{l} P = H\{ E - \text{div}(uq) \} dp \\ L P = \int Q_o dp \end{array} \right.$$

$$Q_s(z) = \left\{ \begin{array}{l} \text{Evaporation} \end{array} \right.$$

Zebiak's (1986) heating Q_c of the Gill model

- Forcing is due to the canonical SST anomaly at the of the warm phase of ENSO

- Heating $Q_c = Q_s(z) + Q_o(z)$ $P = H\{E - \text{div}(\vec{u}q)^* dp\}$

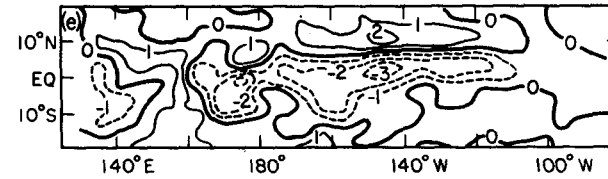
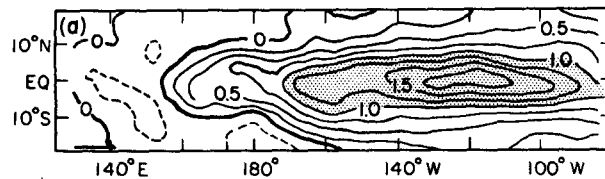
$$L P = \int Q_o dp$$

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MONTHLY WEATHER REVIEW

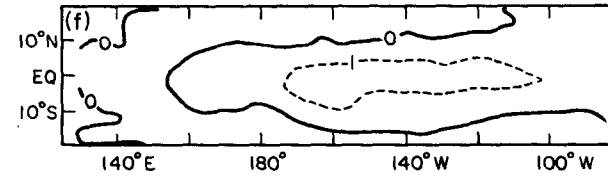
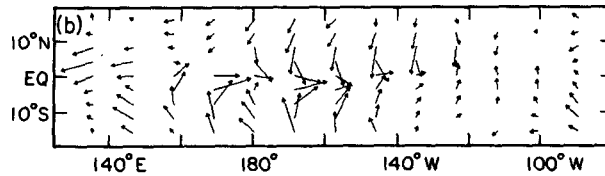
VOLUME 114

SST
(observed)



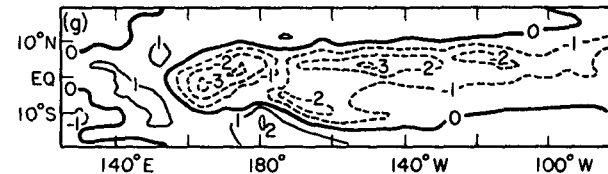
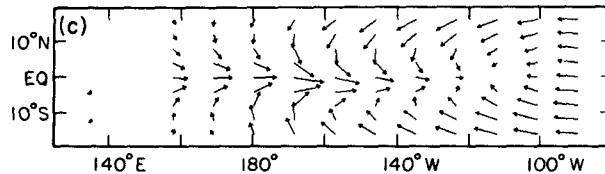
$\nabla \cdot \vec{u}$
(observed)

Winds
(observed)



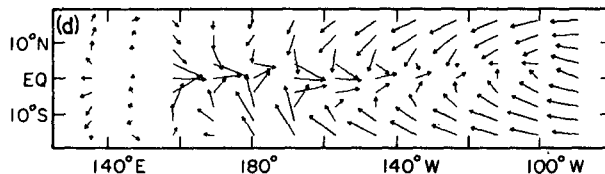
$\nabla \cdot \vec{u}$
(evap only)

Winds
(evap only)



$\nabla \cdot \vec{u}$
all Q_c

Winds Q_c



Nb: easterlies problem in eastern half of Pacific

Problems w/ Gill/Zebiak (1980) and LN (1987)

OCTOBER 1999

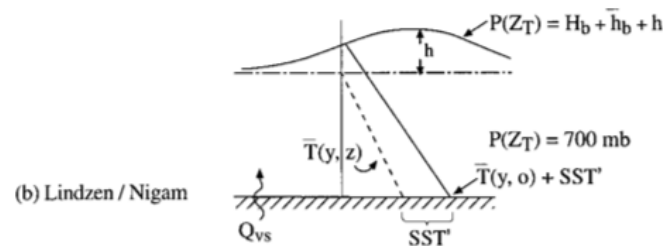
BATTISTI ET AL.

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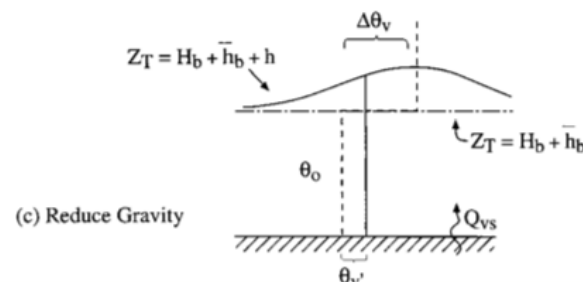
TABLE 1. Values for the constants used in various steady-state tropical atmosphere models. The values that are in bold are qualitatively inconsistent with the observations. The * indicates a wave speed given by Eq. (12). The typical forcing values denote anomalies that are observed during a standard deviation one ENSO.

Model type	Model source	Mechanical damping ϵ_D^{-1} (days)	Venting or thermal damping ϵ_T^{-1}	Wave speed $m s^{-1}$	Typical forcing ($W m^{-2}$)
Convective (full troposphere)	Gill-Zebiak	1–2	1–2 days	60	75
	observations	≈ 10	≈ 15 days	≈ 40	15–20 (evaporative)
Boundary layer	Lindzen-Nigam	$\approx 1–2$	30 min	$\approx 16^*$	5–10 (virtual sensible)
	Reduced gravity (section 2b)	$\approx 1–2$	8 h	≈ 18	5–10 (virtual sensible)
	Observations	$\approx 1–2$	$\approx 3–12$ h	≈ 18	5–10 (virtual sensible)

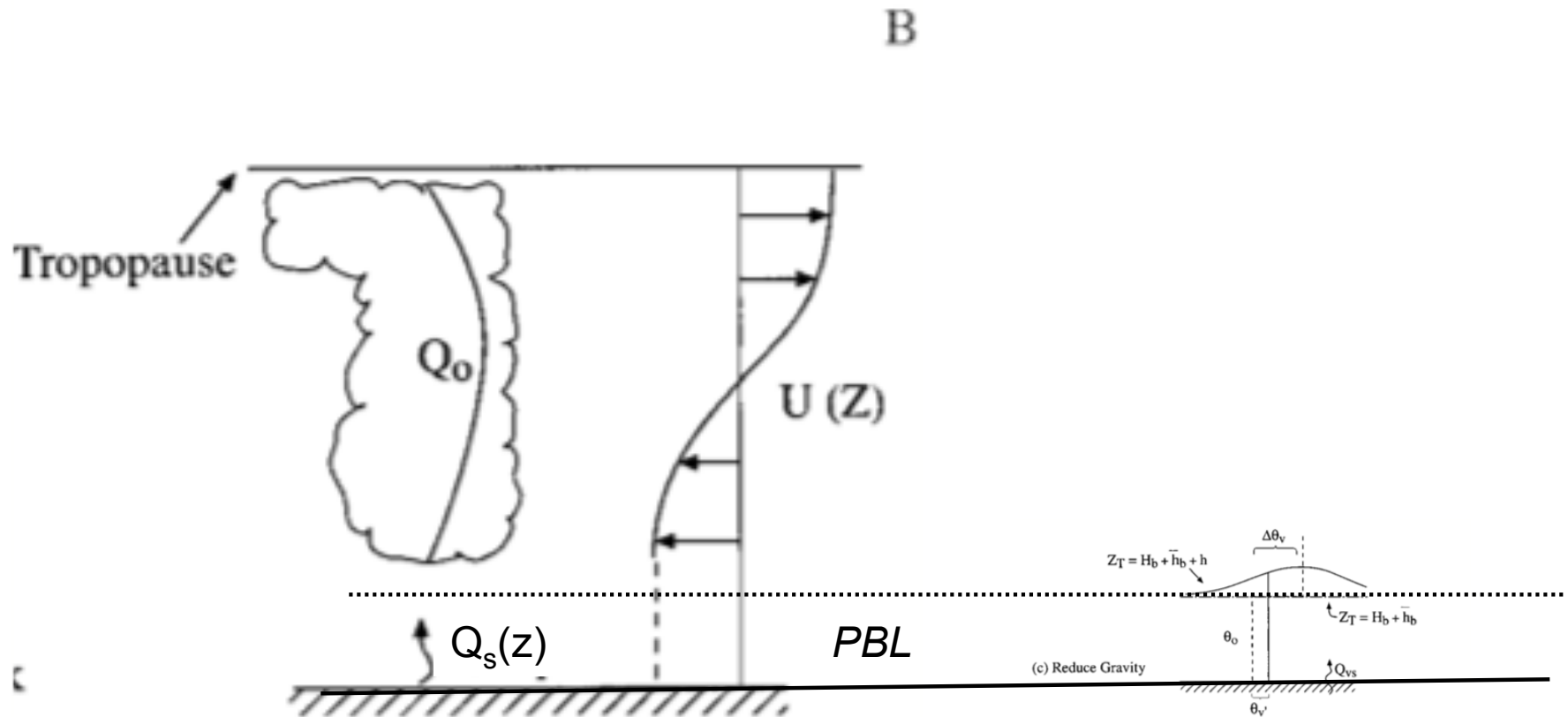
Lindzen/Nigam



Reduced Gravity
(BHS 1990)



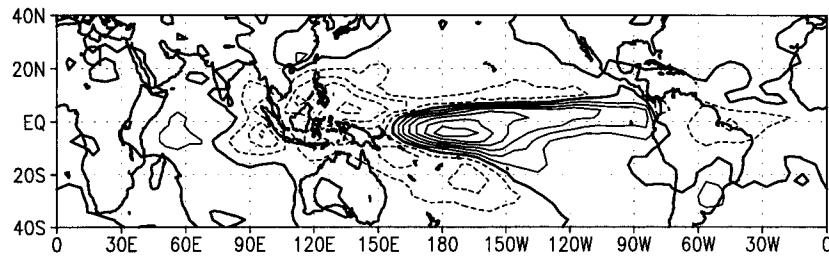
Chiang (2001) response to heating $Q_s + Q_o$



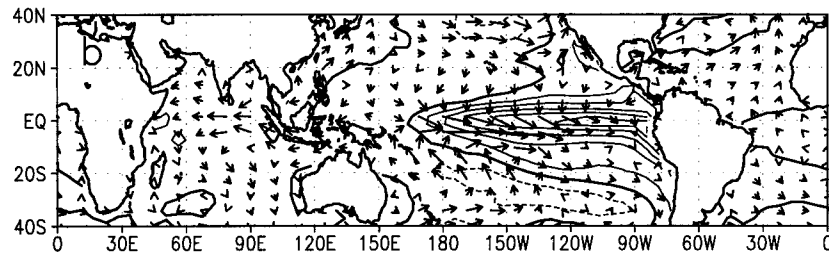
$$Q = Q_s(z) + Q_o(z)$$

$$P = H\{ E - \text{div} (uq)^* dp \}$$

$$L P = \int Q_o dp$$



Precipitation
(forcing)



SST (forcing)
975mb Wind

Fields are the
first EOF of the
combined SST,
wind vector and
precipitation
anomalies in
the tropics

Zonal Wind
Component

Meridonal
Wind

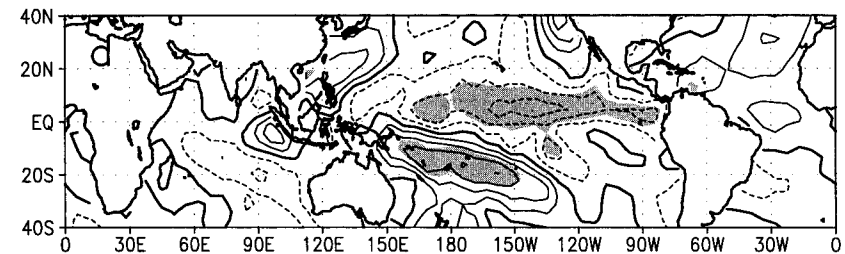
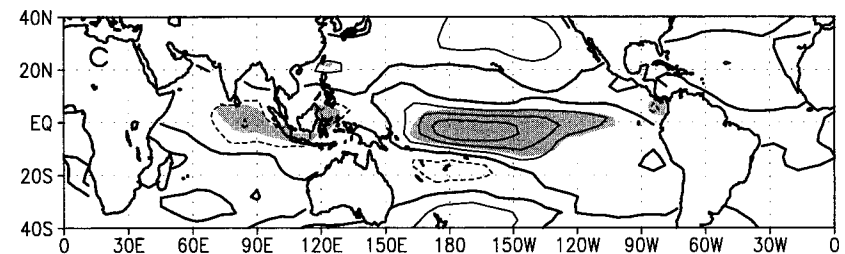
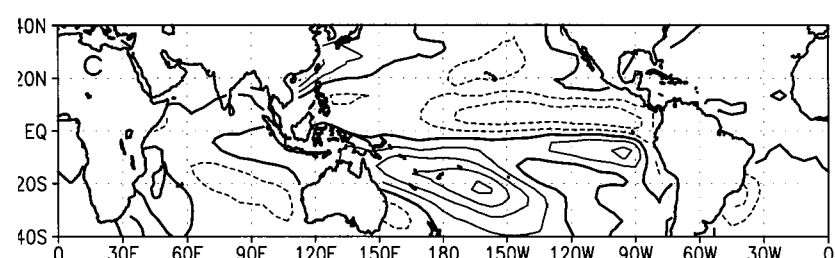
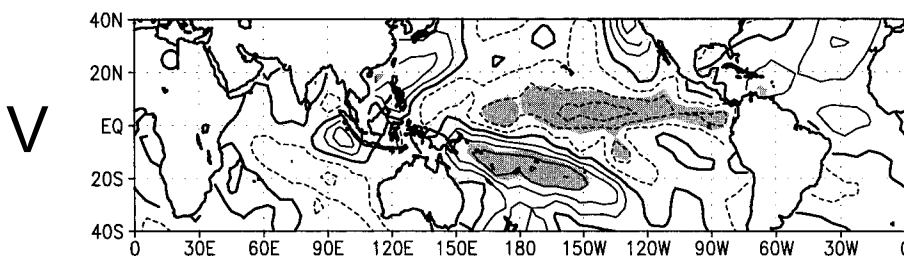
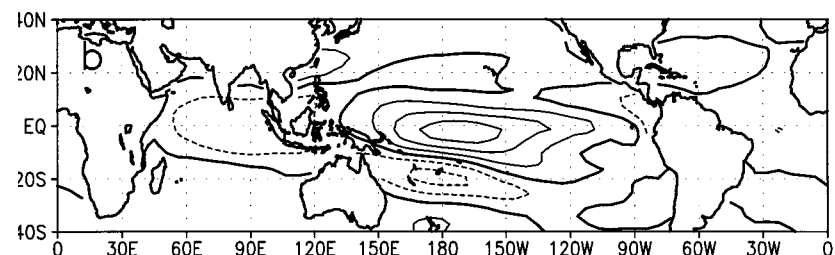
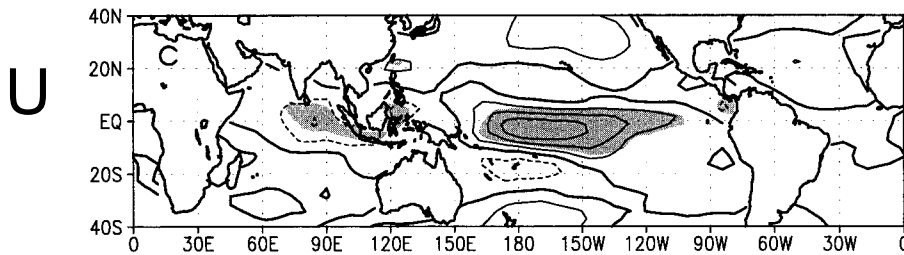
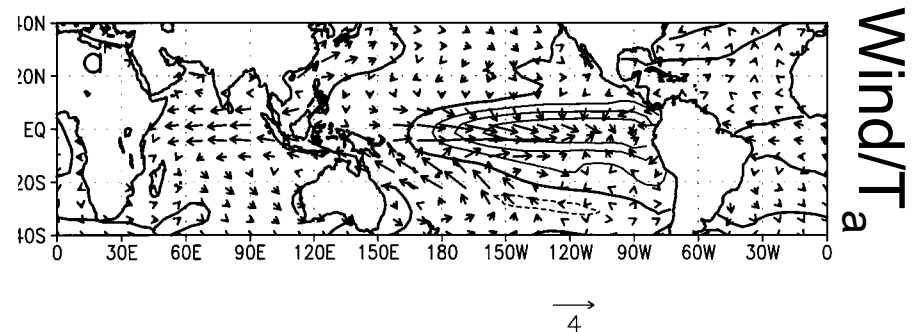
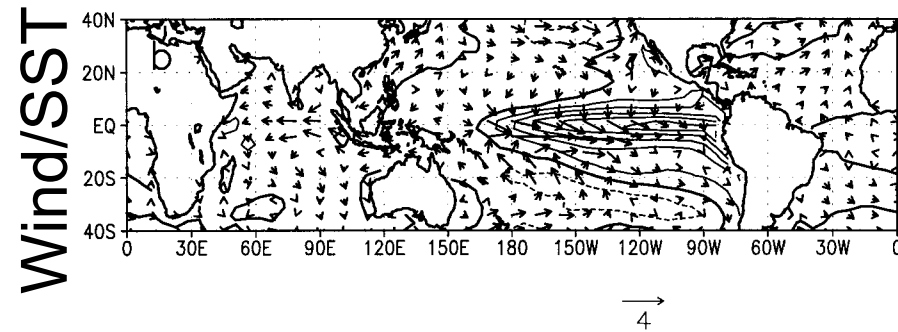


FIG. 1. Fields derived from the multivariate EOF for the tropical Pacific. (a) Precipitation [contour interval (CI) 1 mm day^{-1}]. (b) The 975-mb winds (reference wind is 4 m s^{-1}) and SSTA (CI 0.5 K). (c) Zonal wind (CI 1 m s^{-1}); shaded regions are where magnitude of the correlation exceeds 0.4 (d) Same as (c) but for meridional wind (CI 0.4 m s^{-1}). For all contour plots, the thick line represents zero and dashed lines represent negative values.

Simulated using *total* heating Q_c and Q_s

Observed

Simulated



Wind and T_a at 975mb

Simulated using *elevated* heating Q_c only

Observed

Simulated

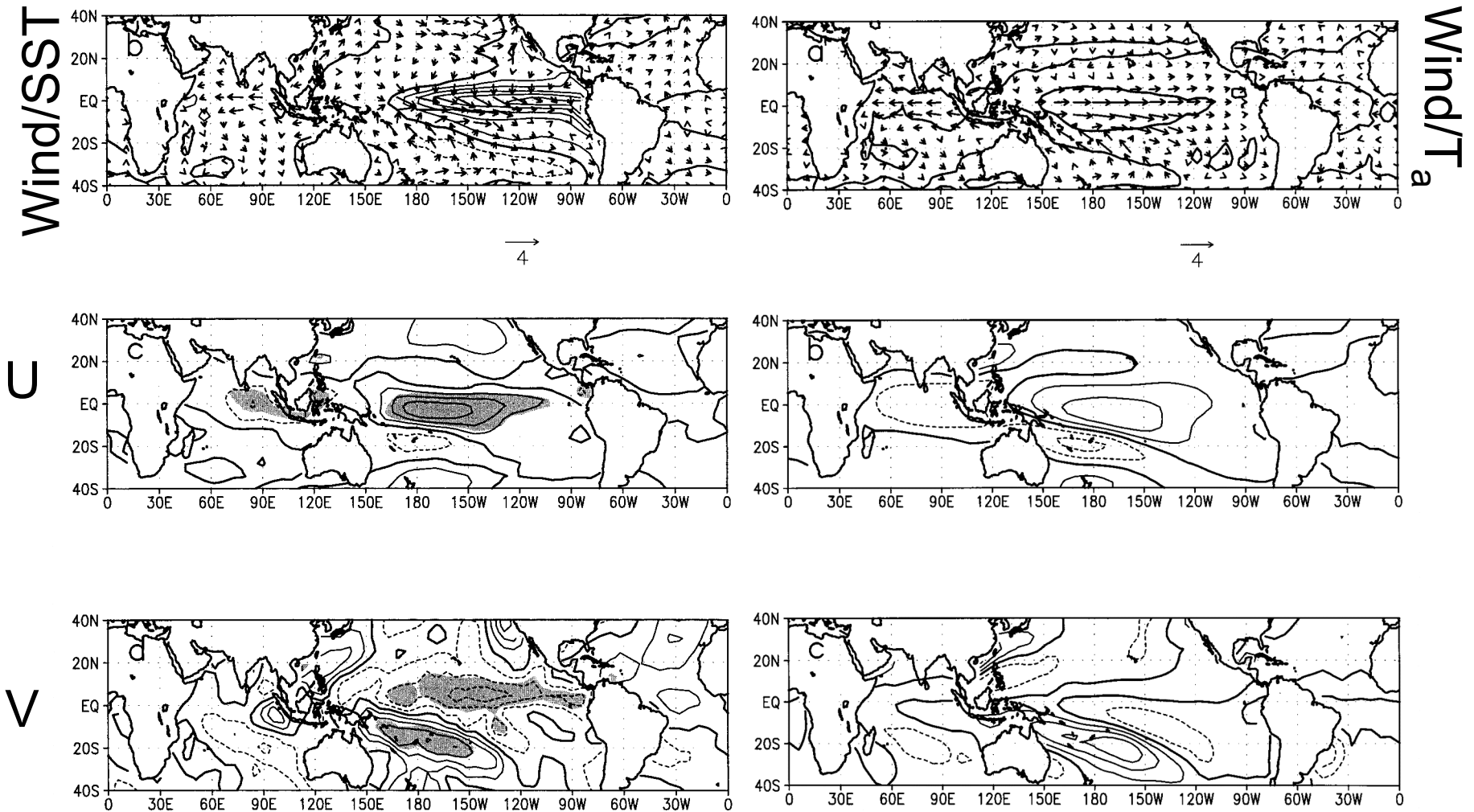


FIG. 4. Same as Fig. 3 but for elevated heating only.

Wind and T_a at 975mb

Simulated using *surface* heating Q_s only

Observed

Simulated

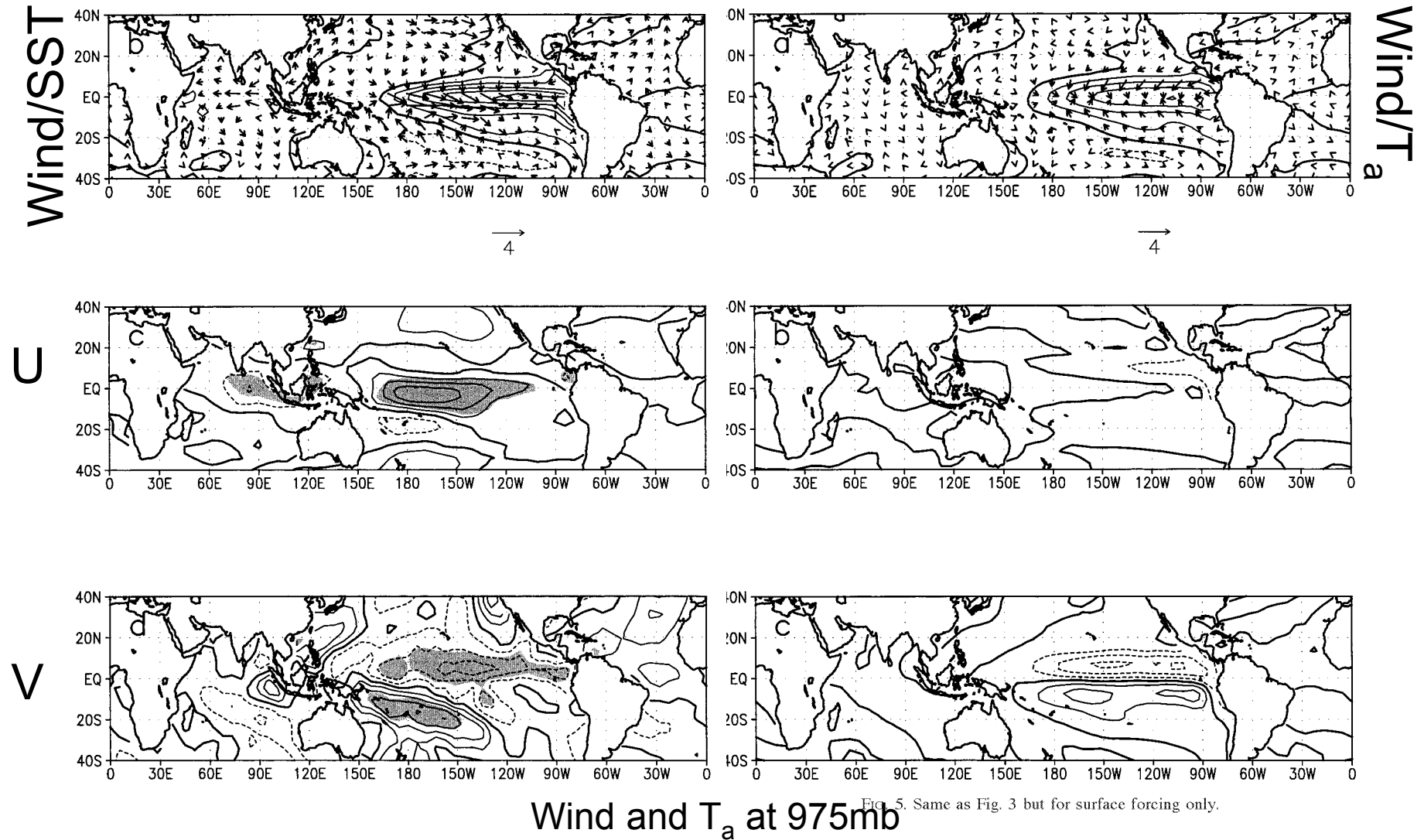
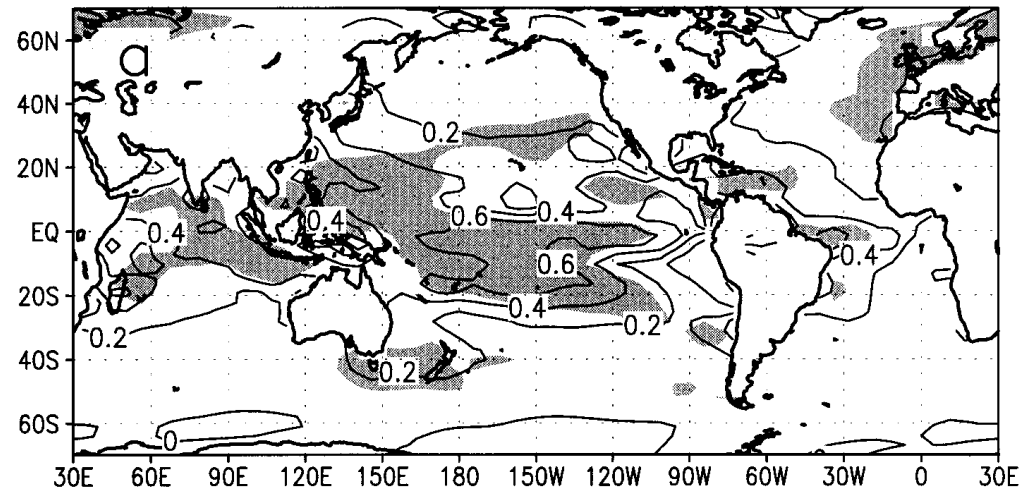
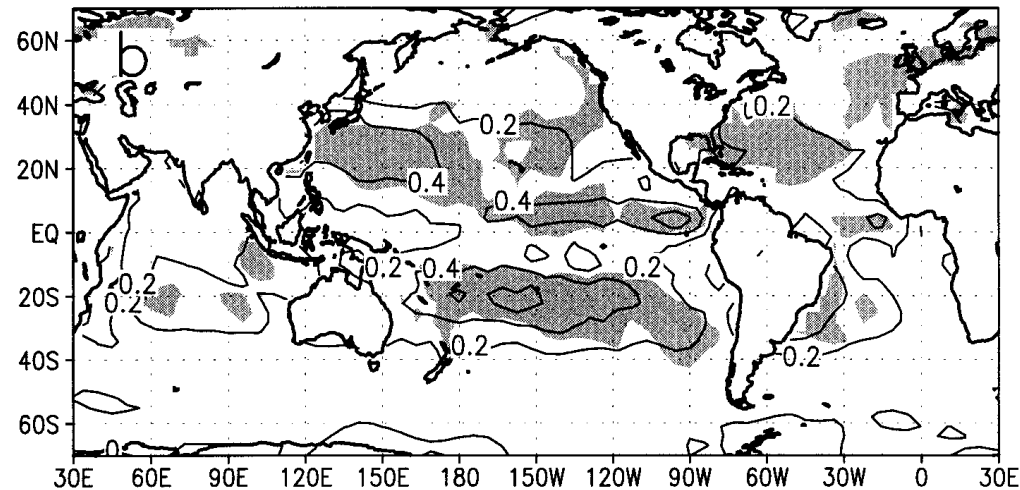


FIG. 5. Same as Fig. 3 but for surface forcing only.

Correlation of Model vs Observed Monthly Anomalies (1979-99)



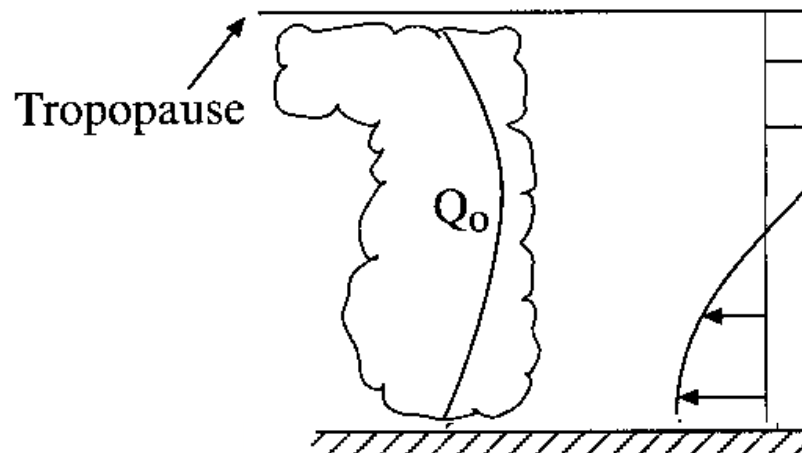
Zonal Wind



Meridional
Wind

FIG. 11. Regression and correlation maps of the model monthly anomalous 975-mb wind (Jan 1979–Dec 1998) with NCEP–NCAR anomalous 975-mb winds. (a) Zonal wind. (b) Meridional wind. For each figure, the shading indicates regions where correlation exceeds 0.4, and contour values are a regression of the model winds on the NCEP–NCAR anomalous winds (CI 0.2).

Gill/Zebiak heating Q_c



iak

$$Q_c = Q_s(z) + Q_0(z)$$

Evaporation

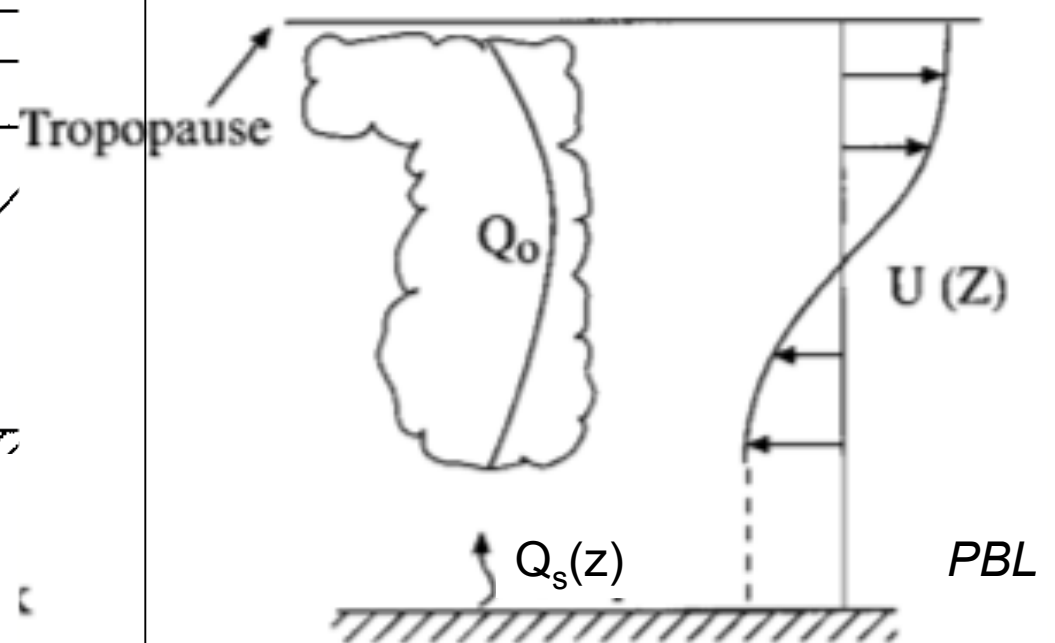
Moisture
Convergence

$$Q_0(z) = \begin{cases} P = H\{E - \text{div}(uq) \cdot dp\} \\ LP = \int Q_0 dp \end{cases}$$

$$Q_s(z) = \begin{cases} \text{Evaporation} \end{cases}$$

Chiang Q_c

B



$$Q_c = Q_s(z) + Q_0(z)$$

Evaporation

Turbulent

$$Q_0(z) = \begin{cases} P = H\{E - \text{div}(uq) \cdot dp\} \\ LP = \int Q_0 dp \end{cases}$$

$$Q_s(z) = \begin{cases} \text{Turbulent } (T, q) \end{cases}$$