# 15B.5 A Moist Model of the Hadley Circulation with Wind Dependent Surface Fluxes

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## 1. Introduction

The Quasi-Equilibrium Tropical Circulation Model (QTCM) (Neelin and Zeng, 2000) is used to study the moist axisymmetric (Hadley) circulation. The model is solved for an aquaplanet domain with a zonally symmetric equatorial SST distribution and globally uniform insolation. The QTCM calculates moisture explicitly, has a Betts-Miller type convection scheme, and projects the vertical structure of atmospheric variables on a set of basis functions (one each for temperature and moisture, and two for momentum) that are designed to optimize the model's representation of tropical convection. The QTCM exploits the idea of statistical quasi-equilibrium, in which the factors that influence small scale convection are assumed to be in near equilibrium on the timescale of the large scale dynamics. This assumption allows the the equations of motion and the complexity of the model to be simplified while still producing realistic atmospheric circulations.

A goal of this study is to determine the nature of the feedback between the wind-dependent surface fluxes and the strength and width of the Hadley cell. This feedback has not been systematically examined in previous studies.

## 2. Axisymmetric Tropical Circulation with Wind Dependent Surface latent Heat Fluxes

The modelling of the axisymmetric circulation was studied by Schneider and Lindzen (1977), Schneider (1977) and Held and Hou (1980) in idealized steady-state models without moisture but with relaxtion towards a set thermal equilibirium. The next step in complexity is to include moisture expicitly which is the focus of the GCM studies by Satoh (1994) and of Numaguti (1993). In Satoh (1994) a convection scheme is included but the evaporation from the sea surface is independent of the surface winds and so there is no feedback between the strength of the Hadley cell and the evaporation. In Numaguti (1993) wind dependent evaporation is included and is found to play a significant role in the location of precipitation, but the overall role of surface fluxes in determining the Hadley cell strength was not addressed. In this study we use an intermediate scale model (QTCM) to address the latter issue. We vary the bulk exchange coefficient in the surface latent heat flux and see how the circulation changes, both under fixed SST and with a slab ocean mixed layer conditions.

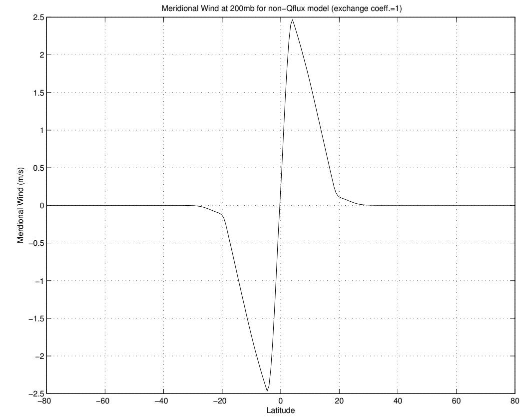


Figure 1: Merdional Winds at 200mb for the no Qflux run

In order to use the QTCM to study the sensitivity of the wind dependent surface evaporation, we have retained the standard domain size of $78.75^0$N to $78.75^0$S, but we changed the resolution with the interest of studying a zonally symmetric solution. The model is run with 256 grid points in the latitudinal direction and 3 grid points in the zonal direction. The model was run with no land (aquaplanet mode) and with uniform insolation and albedo set to reasonable tropical ocean values. The runs were performed for 12 months in perpetual March. The fixed SST runs used an SST field defined by

$$SST(\theta) = \begin{cases} A[\cos(\frac{\pi}{\theta_0}\theta + 1)] + SST_0 & , -\theta \geq \theta \leq \theta_0 \\ SST_0 & , -\theta_0 > \theta > \theta_0 \end{cases}$$

In the fixed SST runs $\theta_0$ was set to $15^0$, $SST_0$ was set to $25^0 C$ and $A$ was set $3.5$. Runs were first performed with a dynamically passive slab ocean mixed layer. Then runs were made in Q flux mode, where the SST is computed by the mixed layer model, with a prescribed surface heat flux (the Q flux) imposed. The Q flux is the ocean surface heat flux which would reproduce the SST field of the control simulation performed with the SST field described above and the default values of the model parameters (in particular the surface exchange coefficients).

The bulk formula for the surface latent heat flux in the QTCM has the form.

$$E = \alpha_{exch} \rho C_D |V_s| (q_{sat}(SST) - q_s)$$

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Where $\rho$ is the density, $C_D$ is the bulk exchange coefficient, $V_s$ is the surface wind, $q_s$ and $q_{sat}(SST)$ are the surface air specific humidity and saturation specific humidity at the SST, and we have multiplied the exchange coefficient by a nondimensional multiplier $\alpha_{exch}$. With $\alpha_{exch} = 1$ in Figure 1 the meridional winds at the top of the model (200mb) gives a Hadley circulation structure with a cell width of approximately $20^o$ N/S.

We performed a series of model runs, in both fixed SST and Q flux mode (keeping the Q flux fixed in the latter) in which we varied $\alpha_{exch}$ over a large range. Our results show that the strength of the Hadley circulation is sensitive to these variations. The fixed SST model has a significantly greater sensitivity to $\alpha_{exch}$ than does the Q flux model. This may be expected, since there is an implied infinite energy source in the fixed SST mdoel. A larger $\alpha_{exch}$ means a larger evaporation, hence larger precipitation in the convective region over the warmest SST, hence a stronger Hadley cell. In the Q flux model, in the absence of radiative feedbacks we expect zero sensitivity to $\alpha$, since the surface turbulent fluxes have to balance the surface radiation plus the Q flux. The Q flux and the insolation are both held constant. Thus the modest, but non-negligible sensitivity to $\alpha$ that we do see indicates that radiative feedbacks are active. These may be either atmospheric radiative feedbacks involving the water vapor or (highly parameterized) clouds, or perhaps a surface radiative feedback involving the dependence of surface longwave emission on SST. We are currently further exploring the nature of this result with further simulations and analysis of the results, and with further reduced semi-analytic models derived from the QTCM equations.

## References


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