Energy and Moisture Budget in Tropical Convective Systems

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Abstract

One of the objectives of the Megha-Tropiques project is to understand the energy and moisture budget in the tropical convective systems. In this paper it is shown that when the energy and moisture budget in the tropics are combined, a diagnostic equation to estimate rainfall is obtained. This equation shows that the parameters that determine rainfall in tropics are the net radiation at the top of the atmosphere, integrated water vapour, evaporation and a parameter that depends upon the vertical profile of temperature and water vapour. The Megha-Tropiques satellite can be used to measure most of the parameters necessary to evaluate the combined mass and energy budget in the tropical convective systems.

1. Introduction

The Tropical Convective Systems (TCS) transport moisture and energy from the surface of the ocean and continent to the upper troposphere. The moistening of the upper troposphere occurs primarily on account of deep clouds in the Tropical Convective systems. Hence it is important to understand the energy and moisture budget of these systems. Neelin and Held (1987) proposed a simple model for TCS based on the conservation of moisture and moist static energy. They showed that monthly mean rainfall in the TCS in continents is governed by the net radiation at the top of the atmosphere and the difference in the mean moist static energy between the upper and lower troposphere. This model showed that the amount of moisture that can converge in TCS in continents is constrained by the net radiation at the top of the atmosphere. Hence TCS cannot be sustained in continental regions wherein the net radiation at the top of the atmosphere is negative in summer. In the regions north of 20^{o} N in Africa, the net radiation at the top of the atmosphere is small or negative during summer. Hence TCS are rarely seen in the region north of 20^{o} N in Africa during summer. Srinivasan (2001) has shown that a simple diagnostic model can be developed for monsoon rainfall based on the ideas proposed by Neelin and Held (1987) and some simple assumptions regarding the vertical structure of tropical atmosphere. The moist static energy and moisture budget of TCS is discussed in section 2. The simple diagnostic model proposed by Srinivasan(2001) is discussed in section 3. In section 4, the parameters that can be measured by the various instruments proposed in the Megha-tropiques project is discussed

2. Moisture and Energy Budget

The moist static energy balance on a monthly mean scale in a column of the atmosphere can be written as

$$M_{uv} + M_w = g\,[F_B - F_T]\ \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where

$$M_{UV} = \int_0^1 u\,[\partial m/\partial x]\,\partial p^* + \int_0^1 v\,[\partial m/\partial y]\,\partial p^*$$

$$M_w = \int_0^1 \omega\,[\partial m/\partial p^*]\,\partial p^*$$

where

u,v = meridional and zonal winds

ω = vertical velocity

m = moist static energy

$p^* = p/p^o$

p^o = surface pressure

The moisture balance on a monthly mean scale in a column of the atmosphere can be written as

$$Q_{uv} + Q_w = [E - P]\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where

$$Q_{UV} = \int_0^1 u\,[\partial q/\partial x]\,\partial p^* + \int_0^1 v\,[\partial q/\partial y]\,\partial p^*$$

$$Q_w = \int_0^1 \omega\,[\partial q/\partial p^*]\,\partial p^*$$

Where

q = specific humidity

The energy and moisture balance indicated by the above equations has been shown for India in figure 1 . The left panel shows the balance based on NCEP reanalyses data while the right panel shows the balance in NCAR AMIPII simulations. We find that the energy and moisture balance is more accurate in the GCM simulations than in NCEP reanalyses. This could be on account of errors in the NCEP reanalyses estimate of evaporation or error in the rainfall estimated by Xie and Arkin(1997).

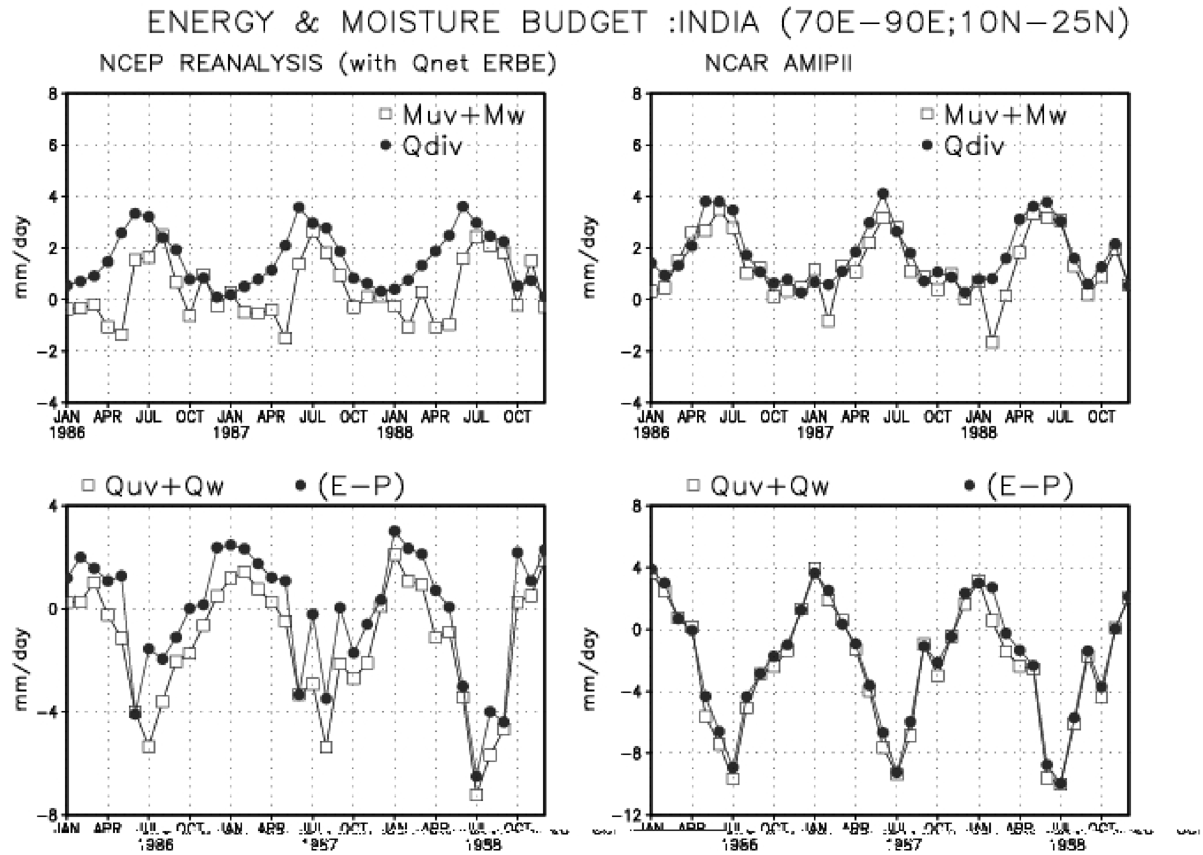

Figure 1 Moisture and Energy Balance over the Indian region using NCEP renanlysis data (left panel) and NCAR AMIP II data (right panel)

3. A Diagnostic Model based on moist static energy budget

In the tropical convective systems, the value of M_{uv} and Q_{uv} are small compared to M_w and Q_w respectively. . Hence the equations (1) and (2) can be simplified to

$$M_w = g\,[F_B - F_T] \qquad \ldots\ldots..(3)$$

$$Q_w = L\,[E - P] \qquad \ldots\ldots...(4)$$

Where,

ω = vertical velocity , m = moist static energy =dry static energy + latent energy , s = dry static energy = enthalpy + potential energy, q = specific humidity,

$p^* = p/p_O$

p = pressure ,

p_O = surface pressure ,

g =acceleration due to gravity ,

L = the latent heat of condensation,

E = the evaporation from the soil,
F_B =sum of radiative , sensible, and evaporative heat fluxes at the surface ,
F_T = radiative flux at the top of the atmosphere and
P =precipitation.

The above two equations can be combined to obtain an expression for precipitation.

$$P = E + \{ F_B - F_T \} / \{ \delta - 1\} \quad \ldots\ldots\ldots\ldots..(5)$$

Where

$$\delta = - \{ M_w / Q_w - 1\}$$

The value of δ is always greater than 1 and hence the denominator of the second term in equation 5 is always positive.
Fortelius and Holopainen(1990) have shown that on monthly mean scales the energy stored in the soil in the continents is small and hence net flux at the bottom of the atmosphere (i.e., F_B) is close to zero. The net flux at the top of the atmosphere (F_T) is purely radiative. This flux is measured by satellites and is know as net radiation at the top of the atmosphere (Q_{net}). By definition,
$Q_{net} = - F_T$.
Hence in the tropical continental regions, the above equation can be simplified to

$$P = E + Q_{net} / \{ \delta - 1\} \quad \ldots\ldots\ldots\ldots\ldots(6)$$

In the above equation, P, E and Q_{net} can be expressed in terms of mm/day or W/m^2. The second term in the right-hand side of the above equation represents the moisture convergence. Note that the moisture convergence term has been obtained from the constraints imposed by the moist static energy budget and not from the equations governing the dynamics of the flow. Since the magnitude of δ is always greater than 1 and hence the sign of this term is determined by the sign of Q_{net}. In regions of the tropics wherein Q_{net} is negative the amount of rainfall is less than evaporation. In regions wherein Q_{net} is positive , the magnitude of the second term is determined by how close δ is to 1. Srinivasan(2001) obtained a simple expression for δ based on simple assumptions regarding the variation of vertical velocity , temperature and specific humidity with pressure. He showed that δ depends upon surface temperature, surface humidity ,temperature lapse rate and water vapor scale height. He demonstrated that δ depended strongly upon the vertically integrated water vapor(P_W) and weakly upon other parameters such as surface temperature and temperature lapse rate. He showed that δ can be expressed as C/P_w where C is approximately a constant. The value of C was found to be around 85 based on NCEP reanalyses data. Hence equation 6 can be simplified to

$$P = E + Q_{net} / \{ 85/p_w - 1\} \quad \ldots\ldots\ldots\ldots\ldots(7)$$

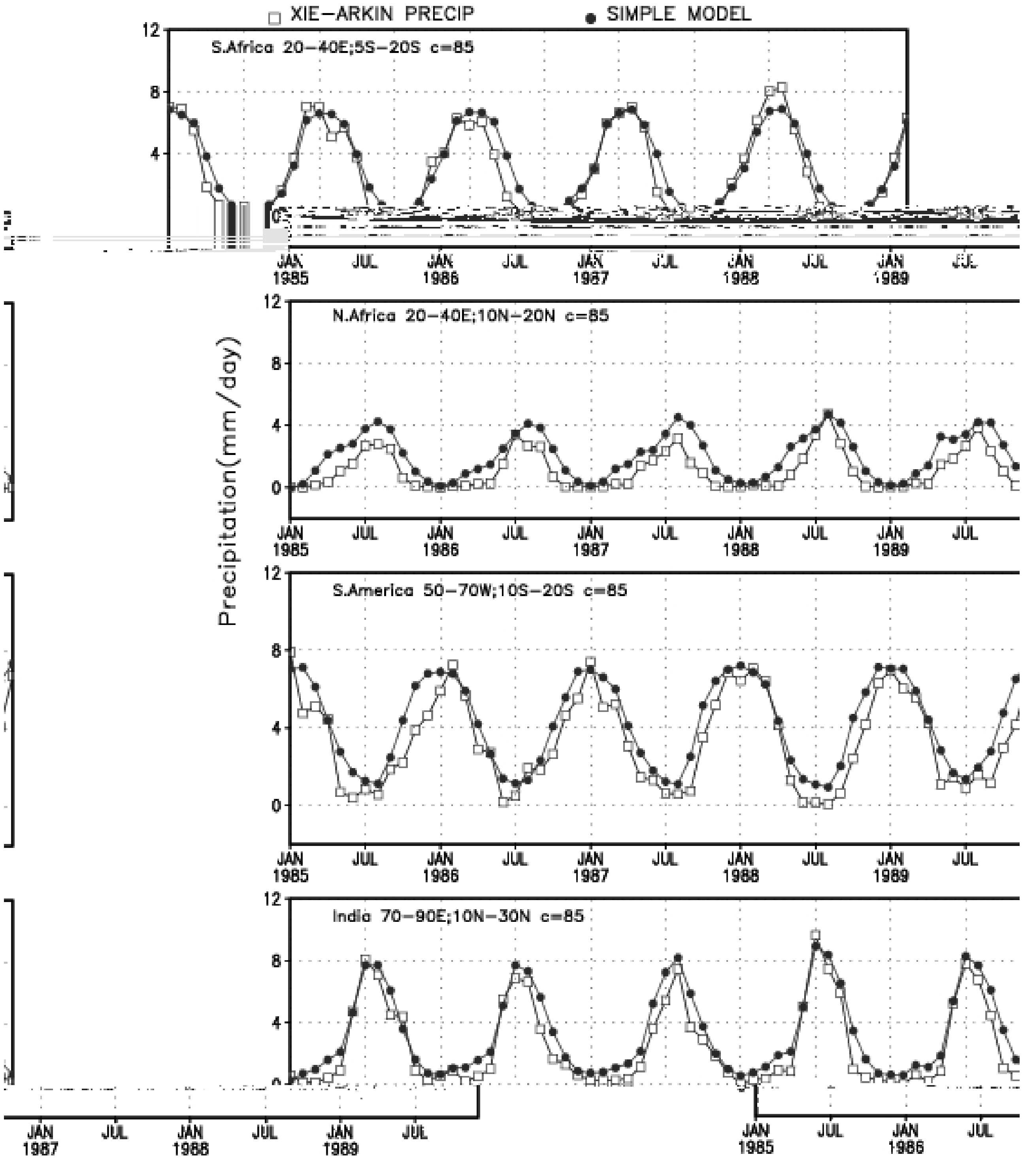

Figure 2 Comparison of rainfall estimated from simple model based on energy and moisture balance with observed rainfall from Xie and Arkin(1997)

The monthly mean precipitation can estimated using equation 7, if the three parameters in the right hand side of that equation can be estimated accurately. They are evaporation (E) , net radiation at the top of the atmosphere (Q_{net}) and vertically integrated water vapor P_W. The net radiation at the top of the atmosphere was measured accurately by the Earth Radiation Budget Experiment (ERBE). This data is available on 2.5^o by 2.5^o grids for the period 1985-1989(Barkstrom et al 1989). The other two quantities can be estimated from the National Centre for Enviromental Prediction (NCEP) reanalyses(Kalnay et al 1996) .

In figure 2, the seasonal variation of precipitation (in large tropical continents) estimated from equation 7 has been compared with observations obtained from Xie and Arkin(1997). We find that the simple model based on moisture and energy budget is able to simulate the seasonal variation of rainfall in tropical regions quite well.

4. Conclusions

The combined energy and moisture budget in tropical convective systems is useful to understand the factors that influence the monthly mean rainfall in these systems. Many of the parameters appearing in equation 5 or equation 7 will be measured in the proposed Megha-Tropiques mission. The net radiation at the top of the atmosphere, Q_{net} , can be measured by the ScaRaB instrument. Rainfall can be measured using the 85 Ghz channel in the MADRAS instrument. Integrated water vapour can be measured over the oceans using the 23 Ghz channel in MADRAS. The vertical profile of water vapour plays an important role in the evaluation of the constant C. The variation of water vapour with height can be measured using the SAPHIR instrument. The wind speed obtained from the 18 Ghz channel in MADRAS can be used to estimate the evaporation over oceans. The net flux at the surface of the ocean (F_B) is not zero. The net solar flux at the surface of the ocean can be estimated indirectly using the Outgoing Longwave Radiation(OLR) data from ScaRaB The latent heat and sensible heat flux can be estimated using the wind speed from 23 Ghz channel in MADRAS. The net longwave flux at the surface of the ocean cannot be estimated easily but this term is usually small in warm tropical oceans on account of strong absorption of infrared radiation by water vapour. Hence the meausrements made in the Megha-Tropiques mission will provide new information about the factors that control rainfall in tropical convective systems.

5. References

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