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Contribution of Amazon's Evapotranspiration To The Moisture Flux Over South America

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Introduction

There has been an interesting scientific debate about the importance of the Amazon forest to the precipitation south of it, notably to central and southeastern Brazil and even to subtropical south American regions such as northern Argentina, Paraguay, Uruguay and southern Brazil. In this study this question is tackled with a modeling approach. A semi-Lagrangian atmospheric global circulation model (AGCM) developed in Brazil is used to track the moisture evaporated and transpired (ET) from the Amazon forest as it travels over South America. The contribution of Amazon's evapotranspiration to the large scale moisture flux is evaluated by comparing the total moisture flux and precipitation with their ET-only counterparts.

Methodology

Some preliminary results (Barbosa and Nobre, 2008) have shown that even during the dry season it was not possible to simulate the ET-vapor dispersion over South America without including the boundary layer and deep convection vertical mixing. Hence, the model had to be further developed and now includes:

Advection

The semi-lagrangean dynamical core calculates the trajectories and advects any number of conserved passive tracers. ET-vapor can be considered a passive tracer because, as most models do, the Brazilian Model of the Global Climate Systems (BMGCS) uses an operator-split approach to numerically solve the equations of the atmosphere which separates the solution of Navier-Stokes equation from those of the sub-grid scale processes represented by physical parameterizations.

Dry turbulent transport

Vertical mixing of the ET-vapor due to dry turbulent transport is considered by solving the diffusion equation implicitly:

$$\frac{\partial q}{\partial t} = \frac{\partial}{\partial z}\left(K\frac{\partial q}{\partial z}\right)$$

where the turbulent diffusion coefficient is estimated using the Mellor Yamada 2.0 planetary boundary layer scheme. The set of equations can be arranged in a tree-diagonal form coupling the surface flux (source term) to the vertical profile of moisture tendency:

$$\begin{pmatrix} a_1 & c_1 & 0 & & & & & \cdots & 0 \\ b_2 & a_2 & c_2 & 0 & & & & & \vdots \\ 0 & \ddots & \ddots & \ddots & & & & & \\ & & b_{k-1} & a_{k-1} & c_{k-1} & & & & \\ & & \ddots & b_k & a_k & c_k & \ddots & & \\ & & & & b_{k+1} & a_{k+1} & c_{k+1} & & \\ & & & & & \ddots & \ddots & \ddots & \\ \vdots & & & & & 0 & b_{m-1} & a_{m-1} & c_{m-1} \\ 0 & \cdots & & & & & 0 & b_m & -a_m \end{pmatrix} \begin{pmatrix} q_1^{n+1} \\ q_2^{n+1} \\ \vdots \\ q_k^{n+1} \\ \vdots \\ q_{m-1}^{n+1} \\ q_m^{n+1} \end{pmatrix} = \begin{pmatrix} q_1^{n-1} - \frac{2\Delta t}{\Delta_1} F_s \\ q_2^{n-1} \\ \vdots \\ q_k^{n-1} \\ \vdots \\ q_{m-1}^{n-1} \\ q_m^{n-1} \end{pmatrix}$$

which solution gives q^{t+1} as a function of q^{t-1} and the surface boundary condition.

Convective transport

We have not yet implemented an explicit transport of the ET-vapor using the mass flux equations. For these preliminary results we have considered that in a quasi-equilibrium regime the vertical profiles of total water vapor and ET-only-vapor will be in equilibrium. Hence we estimate the transport and removal of ET-vapor as a fraction of the total humidity tendency calculated by the three convection schemes: deep, shallow and large scale:

$$\left.\frac{\partial q_{ev}}{\partial t}\right|_{convec} = \left\{ \left.\frac{\partial q_t}{\partial t}\right|_{deep} + \left.\frac{\partial q_t}{\partial t}\right|_{shallow} + \left.\frac{\partial q_t}{\partial t}\right|_{large} \right\} \frac{q_{ev}}{q_t}$$

The amount of ET-vapor that precipitates on the ground is calculated from the conservation equation, i.e., by numerically integrating the vertical tendency:

$$\mathrm{ET\_Prec} = \int_{Ps}^{0} \frac{\partial q_{ev}}{\partial t} \rho dz$$

Discussion and Future Work

Our results for the rainy season (Nov – Mar) show that 30% of the moisture flux leaving the Amazon region (70-50W 15S-EQ) southward is due to the forest's evapotranspiration. The ratio of ET to total moisture flux shows a maximum of about 40% over Bolivia with a secondary maximum of about 30% over southern Brazil.

The contribution to precipitation follows the same pattern but should be taken with extra care as it intrinsically depends on the model's deep convection scheme. Our coarse resolution preliminary results indicate that 40% of the precipitation over Bolivia and 30% of that over southern Brazil comes from moisture recycled by the Amazon forest at least once. However, at this resolution the Kuo (1965) deep convection scheme fails to represents the observed precipitation field.

A high resolution model integration (~80km) is currently underway. Future work include the introduction of a moist turbulent parameterization based on a mass flux approach, such as Grell & Deveni (2002), which has been shown to substantially improve the distribution of summer precipitation over South America (Figueroa et al, 2006).

Numerical Experiment

The atmospheric model was integrated for 5 years starting at September 1st 2002 with a spatial resolution of about 250km (T42 L18). Observed sea surface temperature from NOAA OI.v2 was used as boundary conditions. Physical parameterizations included: Kuo (1965) deep convection and Tiedke (1973) shallow cumulus, planetary boundary layer following Mellor & Yamada (1982) and Ssib surface scheme (Xue et al, 1991). This is the standard configuration of BMGCS which is used regularly at CPTEC-INPE for seasonal forecast and which was shown to reproduce South American climate reasonably well (Cavalcanti et al, 2002).

All following results are averages of 5 rainy (Nov-Mar) periods between 2002 and 2007).

Results

Fig 1 shows the time series of precipitation, evaporation and vertical profiles of total water vapor and Amazon's evapotranspiration over western Amazon (65W 5S) for the first rainy season (NDJFM) . ET-vapor is properly transported and removed reaching values between 6-10 g/kg near the surface, while the total water vapor is around 14 g/kg.

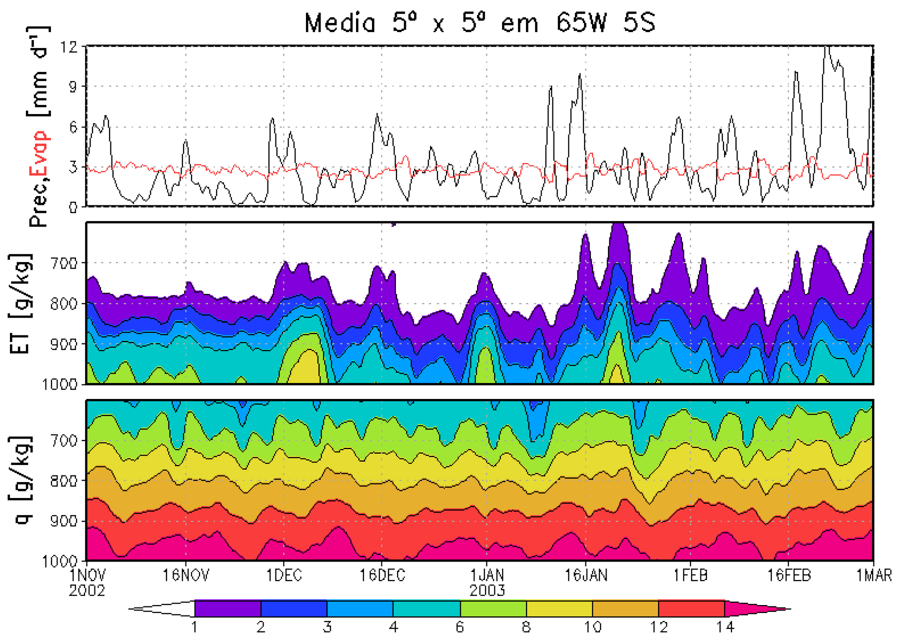

Fig. 1 – Time series of precipitation, evapotranspiration and vertical profiles of total vapor and ET-vapor over region 1 (5x5 degrees centred at 65W 5S, see fig.2).

Left panel of fig. 2a shows the vertically integrated moisture transport averaged during the rainy season (Nov-Mar, ave 2002-07) for both total and ET-vapor. Contribution from Amazon's ET to the total southward transport at 20S is very important and reaches about 30% at 62W (fig. 2b). This transport is more intense over Bolivia, Paraguay and southern Brazil.

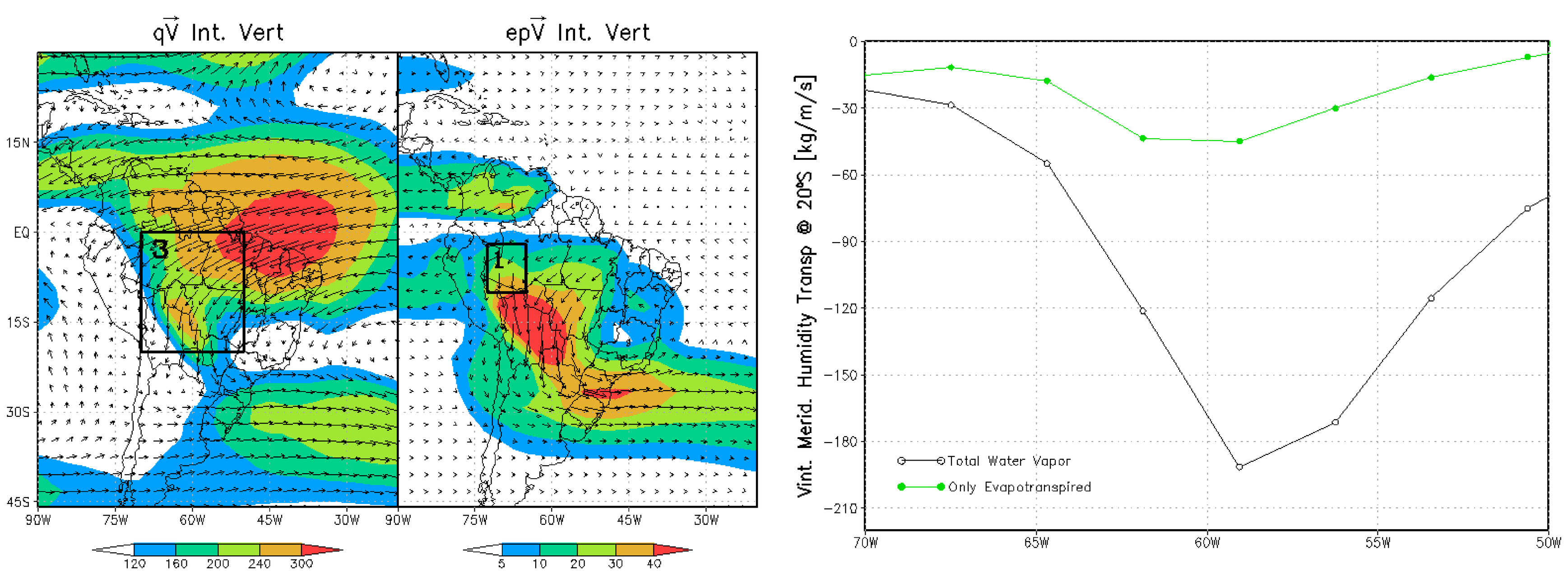

Fig. 2 – (A) Vertically integrated humidity transport (kg/m/s) for total water vapor (left) and only that evapotranspirated from the Amazon (right). **(B)** Meridinal humidity transport at 20ºS (southern edge of region 3).

How much of the southern transported moisture will be converted into precipitation in the subtropics is what is shown in fig. 3. These preliminary results indicate that 40% of the summer precipitation of Bolivia and 30% over southern Brazil stems from Amazon's evapotranspiration. These figures must be considered carefully, however. The deep convection scheme used (Kuo, 1965) has systematic errors over South America which are exacerbated at the low spatial resolutions used in this preliminary investigation.

In fact, fig. 3 shows both simulated and observed precipitation fields. The low resolution integrations fail completely in reproducing the observations. There is an super estimation over Bolivia and northeastern Brazil, and a sub estimation over the Amazon, south Atlantic and tropical convergences zones. This is different from the finds of Cavalcanti et al (2002), using the same "physics" but a higher spatial resolution, where the BMGCS systematically super estimated the precipitation in the SACZ and ITCZ. The reduced number of vertical atmospheric levels used in our study have not allowed tropical deep convection to be represented adequately.

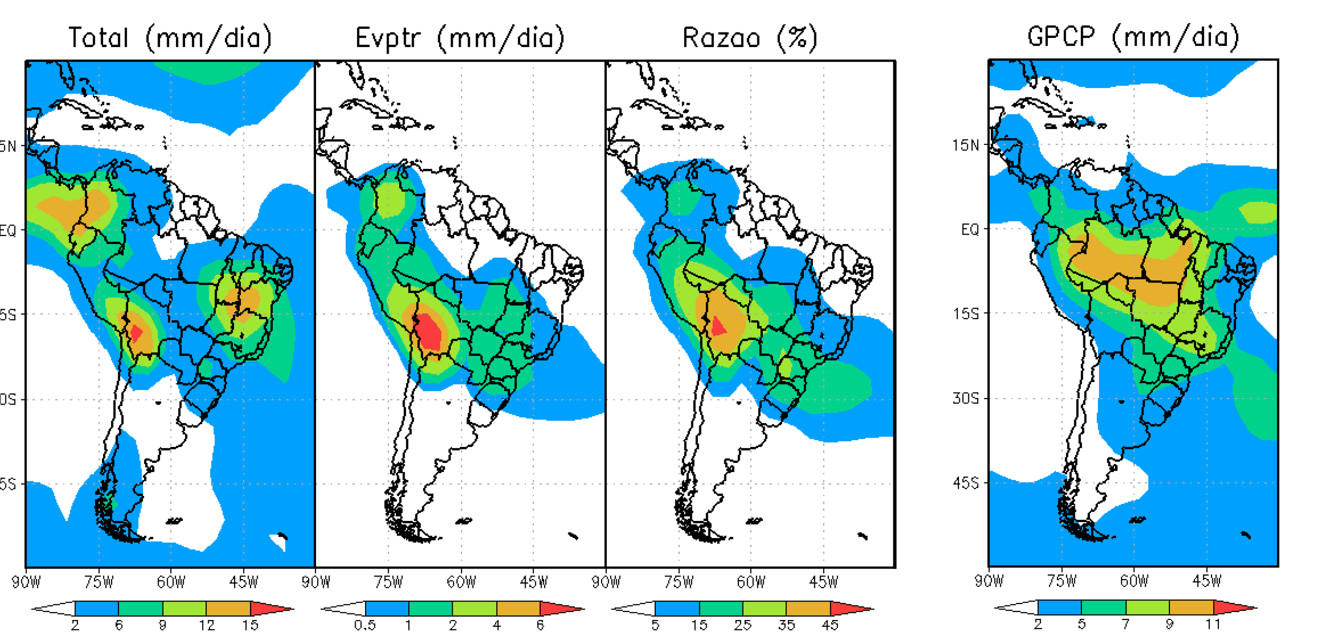

Fig. 3 – Precipitação de verão (NDJFM) média de 2002 a 2008. (A) Modelo CPTEC-INPE with low resolution T42L18: Total, ET e razão; (B) Observação por satélite, Global Precipitation Climatology Project.

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