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## TURBULENT PARAMETERIZATION FOR CCATT-BRAMS BY GPU

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### ABSTRACT

A strategy to increase the computer code performance is to employ of hybrid computing, combining CPU with GPU or/and FPGA. Two turbulent parameterizations, Smagorinsky and Mellor-Yamada, were codified on GPU for the CCATT-BRAMS code, using the CUDA standard. The results show a good speed-up for the model.

### RESUMO

Uma estratégia para aumentar o desempenho de códigos computacionais é o uso de computação híbrida, que combina CPU com GPU e/ou FPGA. Duas parametrizações de turbulência, Smagorinsky e Mellor-Yamada, foram codificadas em GPU para o código CATT-BRAMS. O padrão CUDA foi usado na implementação. Os resultados mostram um aumento significativo no speed-up do modelo.

### 1. INTRODUCTION

The environmental prediction model CCATT-BRAMS (Freitas et al., 2009; 2013) is a complex computer code, and it is operationally employed by the CPTEC-INPE. This model allows atmospheric simulation with emission, transport, pollutant dispersion, and chemical reactions. The CCATT-BRAMS is already prepared to run on parallel machines. But, depending on the model resolution, this is a very expensive code. This motivates the research to improve its performance. Two parameterizations in the CCATT-BRAMS are codified on GPU: Smagorinsky (1963), and Mellor-Yamada (1982).

#### 1.1 Smagorinsky's parameterization

The turbulent fluxes are parameterized using the theory of gradient-flux. The Reynolds tensors are given as following:

$$\overline{u'_i u'_j} = -(K_m)_{ij} (D)_j \quad (1a)$$

$$(D)_j = \partial u_i / \partial x_j + \partial u_j / \partial x_i \quad (1b)$$

$$K_m = (cs_z \Delta z)^2 [ |D_v| + H(N) ] f(R_i) \quad (1c)$$

where  $cs_z$  is a fitting coefficient,  $\Delta z$  is the discretization for vertical grid, and  $|D_v|$  is the magnitude of the deformation tensor for vertical direction.  $H(N)$  and  $f(R_i)$  are given by

$$H(N) = \sqrt{\max(0, -N^2)} \quad (2a)$$

$$f(R_i) = \max \{ 0 ; 1 - (K_n / K_m) R_i \} \quad (2b)$$

with  $N$  being the Brunt-Väisälä frequency, and  $(K_h/K_m)$  is the ratio between the heat and momentum eddy diffusivities.

## 1.2 Mellor-Yamada's parameterization

This is a 2.5 closure scheme for turbulence, where the third order tensors are parameterized, with a prognostic equation for the turbulent kinetic energy ( $e$ ):

$$\frac{\partial \overline{\psi'_i \phi'_j}}{\partial t} = f(\overline{\psi'_i \phi'_j \zeta'_k}, \overline{\psi'_i \phi'_j}, \psi_m, t) \quad (3a)$$

$$\overline{\psi'_i \phi'_j \zeta'_k} \approx K_p \nabla \overline{\psi'_i \phi'_j} \quad (3b)$$

where  $\psi, \phi, \zeta = u, v, w, q, \theta$  (wind components, moisture, and temperature). Key parameters are a length scale  $l$ , and TKE ( $e$ ):

$$K_p = S_p l \sqrt{2e}, \quad l = \frac{\kappa(z+z_0)}{1 + \kappa(z+z_0)l_\infty}, \quad l_\infty = 0.1 \frac{\int_0^d z \sqrt{2e} dz}{\int_0^d \sqrt{2e} dz} \quad (4)$$

where  $S_p$  are constants suggests by Mellor-Yamada (1982).

## 2. CUDA PROGRAMMING ON GPU

CUDA (Compute Unified Device Architecture) (Nvidia: CUDA, 2012) was developed for the parallel processing for the GPUs produced Nvidia Corporation. The CUDA programming could be understood as an extension of languages like C, C++, and Fortran, adding qualifiers to functions and data, producing kernels for execution. The job on a kernel is to be divided among thousands of threads, organized into blocks, and grids, with dimensions *blockDim* and *gridDim*. The kernel uses indexes *blockIdx* and *threadIdx* for defining the job to a thread.

The turbulence routines were codified on Nvidia GPUs: Fermi GTX-580 (512 cores), and Kepler GTX-680 (1536 cores).

## 3. RESULTS AND FINAL COMMENTS

Two horizontal resolutions were evaluated: 40 km (grid points number: 95×48×38), and 20 km (194×100×40). Figure 1 shows the speed-up results to Smagorinsky's approach for both resolutions, and for Fermi and Kepler architectures.

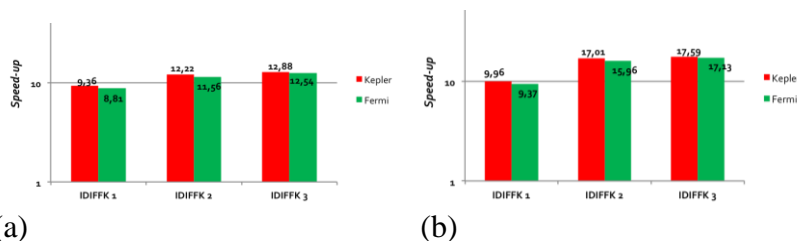
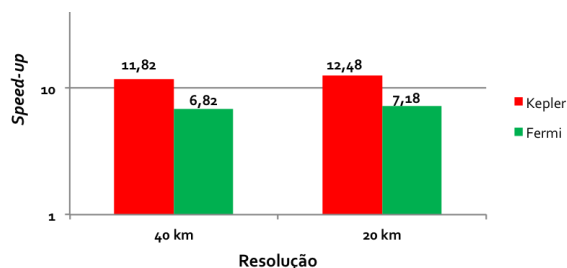


Figure 1: GPU execution for Smagorinsky's approach under two resolutions: (a) 40 km, (b) 20 km.

Similarly, the speed-up for the Mellor-Yamada scheme is presented in Figure 2, also considering two resolutions, and Fermi and Kepler architectures performance.



**Figure 2: GPU execution for Mellor-Yamada's approach under two resolutions: 40 km, and 20 km.**

For the lower resolution worked here, similar speed-up results were obtained for both GPU architectures – the gain for the Mellor-Yamada approach has superior speed-up than the Smagorinsky's parameterization. The results show a tendency to improve the speed-up for a finer resolution.

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