Enhancing Efficiency of the RRTMG Radiation Code with Graphics Processing Units in the Weather Research and Forecasting Model

Michael J. Iacono¹, David Berthiaume¹, Eli Mlawer¹, John Michalakes²

(¹) Atmospheric and Environmental Research (miacono@aer.com)   (²) NOAA – National Centers for Environmental Prediction

RRTMG, Radiation Calculations in GCMs

- Accurate calculations of radiative fluxes and cooling rates are key to accurate simulations of climate and weather in GCMs
- Radiative transfer (RT) calculations in GCMs constitute a significant fraction of the model’s computations
  - As much as 30-50% of execution time
- **RRTMG** is an accurate and fast RT code relative to RRTM,LBLRTM and measurements
  - (Iacono et al., JGR, 2008; Mlawer et al., JGR, 1997)
- RRTMG is used in many dynamical models:
  - **WRF-ARW**: LW and SW implemented as physics options in v3.1 in 2009
  - NCAR CAM5 and CESM1 (LW in 2010, SW in 2010)
  - NASA GEOS-5 RRTMG to be next operational RT code
  - ECMWF IFA (2000,2007) and ERA40
  - ECHAM5 (2002)

Computational savings will allow introduction of more sophisticated physics packages elsewhere in WRF.

Restructuring RRTMG to Run Efficiently on the Graphics Processing Units (GPUs)

- In order for every profile to be run in parallel, arrays were padded to be multiples of 32, the size of a warp on a GPU, and reordered so that the fastest changing dimension would coincide with the thread layout to enable efficient memory coalescing.
- Algorithms were restructured so that g-points can be run in parallel, ensuring that even with a relatively low number of profiles, the GPU is always busy and therefore running efficiently.
- Look-up tables were removed and calculations were implemented within the main loop to avoid scattered memory access and enable more efficient execution on the GPU.
- Profile partitioning was implemented using the MPI API and multiple streams for running RRTMG on multiple GPUs in parallel.
- The main loop was restructured so that, instead of running a single profile at a time, the various subroutines for all of the profiles were run in parallel.
Test Environment: NCAR Caldera

- **System Configuration:**
  - Compiler: PGI_v13.3 (LW), PGI_v13.9 (SW) with CUDA Fortran and openACC
  - Caldera CPU: 2.6 GHz Intel Xeon E5-2670 (SandyBridge)
  - Caldera GPU: NVIDIA Tesla M2070-Q
  - Compiler Flags (CPU): -O3 -r4 -i4
  - Compiler Flags (GPU) –O3 -r4 -i4 -Kieee -acc -Mcuda -ta=nvidia,fastmath,cuda5.0

- **Radiation Configuration:**
  - RRTMGPU_LW/SW running offline on CPU and GPU
  - CMAKE compile build system used with PGI_v13.3 and v13.9
  - Input data generated for 1250 to 40000 clear and cloudy profiles

- **Radiation Timing Performance:**
  ![Graph showing GPU vs. CPU speed-up for LW and SW](image)

### Summary
- RRTMGPU_LW/SW are working both offline and within WRF_v3.51 at NCAR,
- Running the radiation codes on the GPU presently requires the PGI compiler (v13.9), a recent version of CUDA Fortran (e.g. v5.0), and NVIDIA GPU hardware,
- An initial speed-up of a factor of 12 from RRTMG to RRTMGPU has been achieved within a one-day WRF forecast on a single regional grid relative to a single processor,
- Additional speed-up is expected with further configuration refinement,
- WRF grid size is a significant factor in the potential speed-up; faster results are expected on larger forecast grids than used here,
- Specific performance improvement is also dependent on the GPU hardware available; faster GPUs are available than the NVIDIA Tesla M-2070Q in use in Caldera

### Future Work
- Timing improvement reported here is a preliminary result; it will be essential to perform a fair comparison between the optimal CPU and GPU environments,
- Dependence of timing improvement on WRF grid size will be quantified,
- Further refinement of GPU application will be completed to determine optimal configuration,
- Version of RRTMGPU in use here is a transitional model; under separate funding (ONR) the radiation codes will be completely redesigned to further enhance their parallel processing capability and generalized application,
- Current RRTMGPU or a later version will be made available to NCAR for application to a future WRF release

---

**Acknowledgment:** This work is supported by the DOE Office of Science Earth System Modeling (ESM) SciDAC Program under grant DE-SC0007038.