Limited-area Geophysical Fluids Modeling Framework (L-GAME) Handbook

L-GAME Development Team

All physical quantities in this document are to be multiplied with their respective SI units.

Contents

Chapter 1

Overview

L-GAME is the application of the theory and numerics of GAME to a quadrilateral latitude-longitude grid in a regional domain. The spatial and temporal discretizations are identical, apart from the following differences:

1. The domain is regional and not global (as mentioned).
2. The grid is a quadrilateral (rotated) latitude-longitude grid.
3. The connections of the gridpoints in longitude direction are small circles instead of great circles.

This is only the handbook (manual) of L-GAME, it explains how to configure, compile and run (use) the model. For a scientific derivation of the model see [2] and the literature cited therein. The source code of the project is maintained on Github (`https://github.com/OpenNWP/L-GAME`).

Chapter 2

Code structure

The code of the model resides in the directory `src`.

2.1 Spatial operators

- Coriolis: [1] and [6] modified by [4]
- kinetic energy: [3]

2.2 Time stepping

A fully Eulerian time stepping is employed. The basic building structure is Runge-Kutta second order (RK2). In the vertical, at every substep, an implicit column solver is used, which makes it possible to violate the CFL criterion of vertically propagating sound and fast gravity waves. This has the cost of decreasing the accuracy of these modes, which is however a bearable trade-off, since these waves are of low meteorological relevance. Furthermore, a forward-backward scheme is used, where the divergence term is backward.

Chapter 3

Installation

3.1 Dependencies

The following dependencies must be installed before being able to successfully build the model:

- geos95 (`https://github.com/OpenNWP/geos95`)
- atmostracers (`https://github.com/OpenNWP/atmostracers`)
- Clone our fork of the RTE+RRTMGP repository: `git clone https://github.com/OpenNWP/rte-rrtmgp`
- Python and pip (only needed for the plotting routines): `sudo apt-get install python3 python3-pip`
- Python packages (only needed for the plotting routines): `pip3 install matplotlib numpy netCDF4`

3.2 Building

`CMake` is used for building `L-GAME`. Execute `./compile.sh` to build the model.

Chapter 4

Running the model

4.1 Grid generation

4.1.1 Vertical grid structure

The vertical grid structure is the same as in GAME, which is explained in [8].

4.2 Dynamics configuration

4.3 Physics configuration

4.3.1 Local thermodynamic equilibrium option

Assuming a local thermodynamic equilibrium in a heterogeneous fluid boils down to assuming that all constituents have the same temperature. This reduces the complexity of the simulation by about 40 %, since now internal energy densities are not prognostic variables anymore.

4.4 Coupling to the radiation field

L-GAME employs the so-called RTE+RRTMGP (Radiative Transfer for Energetics + Rapid and Accurate Radiative Transfer Model for Geophysical Circulation Model Applications-Parallel) [5], [7] scheme.

Chapter 5

Configuring Output

Chapter 6

Initialization

Chapter 7

Boundary conditions

Bibliography

[1] J. Thuburn et al. Numerical representation of geostrophic modes on arbitrarily structured C-grids. In: *Journal of Computational Physics* 228 (22 2009), pp. 8321–8335.

[2] M. H. Balsmeier. *Kompendium Theoretische Meteorologie*. 2021. URL: https://raw.githubusercontent.com/MHBalsmeier/kompendium/master/kompendium.pdf.

[3] Almut Gassmann. A global hexagonal C-grid non-hydrostatic dynamical core (ICON-IAP) designed for energetic consistency. In: *Quarterly Journal of the Royal Meteorological Society* 139.670 (2013), pp. 152–175. DOI: 10.1002/qj.1960. eprint: https://rmets.onlinelibrary.wiley.com/doi/pdf/10.1002/qj.1960. URL: https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/qj.1960.

[4] Almut Gassmann. Discretization of generalized Coriolis and friction terms on the deformed hexagonal C-grid. In: *Quarterly Journal of the Royal Meteorological Society* 144.716 (2018), pp. 2038–2053. DOI: 10.1002/qj.3294. eprint: https://rmets.onlinelibrary.wiley.com/doi/pdf/10.1002/qj.3294. URL: https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/qj.3294.

[5] Robert Pincus, Eli J. Mlawer, and Jennifer S. Delamere. Balancing Accuracy, Efficiency, and Flexibility in Radiation Calculations for Dynamical Models. In: *Journal of Advances in Modeling Earth Systems* 11.10 (2019), pp. 3074–3089. DOI: 10.1029/2019MS001621. eprint: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2019MS001621. URL: https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2019MS001621.

[6] Todd Ringler et al. A unified approach to energy conservation and potential vorticity dynamics on arbitrarily structured C-grids. In: *J. Comput. Physics* 229 (May 2010), pp. 3065–3090. DOI: 10.1016/j.jcp.2009.12.007.

[7] *RTE-RRTMGP github repository*. June 22, 2020. URL: https://github.com/earth-system-radiation/rte-rrtmgp.

[8] GAME Development Team. *Geophysical Fluids Modeling Framework Handbook*. 2021. URL: https://github.com/OpenNWP/GAME/blob/main/handbook/handbook.pdf.