The Planet Simulator:
A Coupled System of Climate Modules with Real Time Visualization

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Abstract

The Planet Simulator is a **M**odel of **I**ntermediate **C**omplexity (MIC), suitable for climate and paleo-climate simulations and time scales up to ten thousand years or more. It runs on a wide range of hardware and operating systems including massive parallel cluster and workstations with UNIX, Solaris, Linux, MAC OS or any other UNIX style operating system. The priorities in development are set to speed, easy handling and portability. Its modular structure allows a problem dependent configuration. A graphical **Mo**del **St**arter (MoSt) can be used to select a model configuration from the repository, set its parameters, compile and run the model. The model can be run either in production mode for maximum performance or in interactive mode using a **G**raphical **U**ser **I**nterface (GUI). This GUI is both a real time visualization interface for all model variables and a tool for tuning and experimenting with the model.

Introduction

For more than two decades climate research centres have been developing comprehensive general circulation models (GCMs) of high complexity, mostly for their research interests. As the complexity of these models has been and still is growing considerably on their way to Earth system models, it is not surprising that, for both education and research, models simpler than those comprehensive models at the cutting edge of the development, are becoming more and more attractive: They run fast and can be used to simulate millennia and longer time spans in relatively short real time. They can use inexpensive hardware like workstations with no need to buy time on mainframes. They may be reconfigured for simulating environments that are far away from our present climate and even atmospheres of other planets or moons. The diagnostic of the simulation is easier with fewer interactions occurring in the model. Finally, the understanding of atmospheric or climate phenomena and the identification of mechanisms is enhanced. The Planet Simulator is:

- **modular** – problem dependent configuration
- **parallel** – parallel computer and networks
- **scalable** – horizontal and vertical resolution
- **portable** – hardware independent code
- **interactive** – graphical user interface
- **structured** – clearly arranged and commented
- **open source** – freely available source code
- **compatible** – supports standard data formats like NetCDF and SERVICE

Applying a model like the Planet Simulator in a university environment has various aspects: First, the code must be open and freely available and also the required libraries; it must be user friendly, inexpensive and equipped with a graphical user interface. Second, it should be a flexible and universal tool to be used by researchers designing their own experiments. Third, it should be suitable for teaching project studies in classes or lab, where students practice general circulation modelling, in contrast to technicians running a comprehensive GCM.

The Planet Simulator includes, besides an atmospheric GCM of medium complexity, other compartments of the climate system, for example, an ocean with sea ice, a land surface with biosphere, etc. The source code of the Planet Simulator is portable to many platforms ranging from personal computers to workstations and mainframes; massive parallel computers and clusters of networked machines are also supported. The system is scalable with regard to vertical and horizontal resolutions, provides experiment dependent model configurations, and it has a well readable and rich documented code.

Model Overview

GCMs consist of a dynamical core based on the first principles, parameterizations for the unresolved processes and representations of the climate subsystems. In the following these modules are briefly presented for the Planet Simulator. A more comprehensive description may be found at "www.mi.uni-hamburg.de/plasim".

Dynamical Core

The dynamical core of the Planet Simulator is based on the moist primitive equations representing the conservation of momentum, mass and energy, which are the:

- prognostic equations for the vorticity and the horizontal divergence
- first law of thermodynamics
- equation of state
- continuity equation
- prognostic equation for water vapour (specific humidity)

The equations are solved numerically on a terrain following σ -coordinate system (where σ is the pressure normalized by the surface pressure). In the horizontal direction, the conventional spectral approach with the spectral transform method is applied (Orszag 1970; Eliasen et al., 1970). Finite differences are used in the vertical with the vertical velocity being defined between the 'full' (temperature, moisture, vorticity and divergence) levels. The equations are integrated in time by a leapfrog semi-implicit time stepping scheme (Hoskins and Simmons, 1975; Simmons et al., 1978) with Robert/Asselin time filter (Robert 1981; Asselin 1972).

Parameterizations and Subsystems

The effect of unresolved processes is included by simplified parameterizations for boundary layer fluxes and diffusion, radiation and moist processes with interactive clouds. The interaction with other climate subsystems is enabled by adding modules for land-surface processes, vegetation, ocean and sea ice. The parameterization schemes are documented in detail in (Lunkeit et al. 2007).

Graphics

The graphical user interfaces simplify the task of setting up experiments, modifying boundary values and resolution, setting essential model variables, and running the simulation.

The Graphical Model Starter

The Planet Simulator may be used in the traditional fashion with shell scripts, batch jobs, and network queuing systems. This is usually done for long running simulations on complex machines and mainframes, like vector-computers, massive-parallel-computers and workstation clusters. There is now, however, a much more convenient method by using a graphical user interfaces. The Planet Simulator is configured and setup by the tool MoSt

(Model Starter, screenshot in Figure 1). MoSt is the fastest way to get the model running. It gives access to the most important parameters of the model preset to the most frequently used values. The model can be started by a mouse click on the button labelled 'Save & Run' either with the standard parameter setting or after using the built-in parameter editor in the MoSt window. These parameters set horizontal and vertical resolution, select modules and choose boundary conditions. Depending on all settings MoSt generates a run script for the simulation. The user has the choice of leaving MoSt and continue with the simulation under control of the runtime GUI, or exiting MoSt for further work on the simulation setup within the run directory.
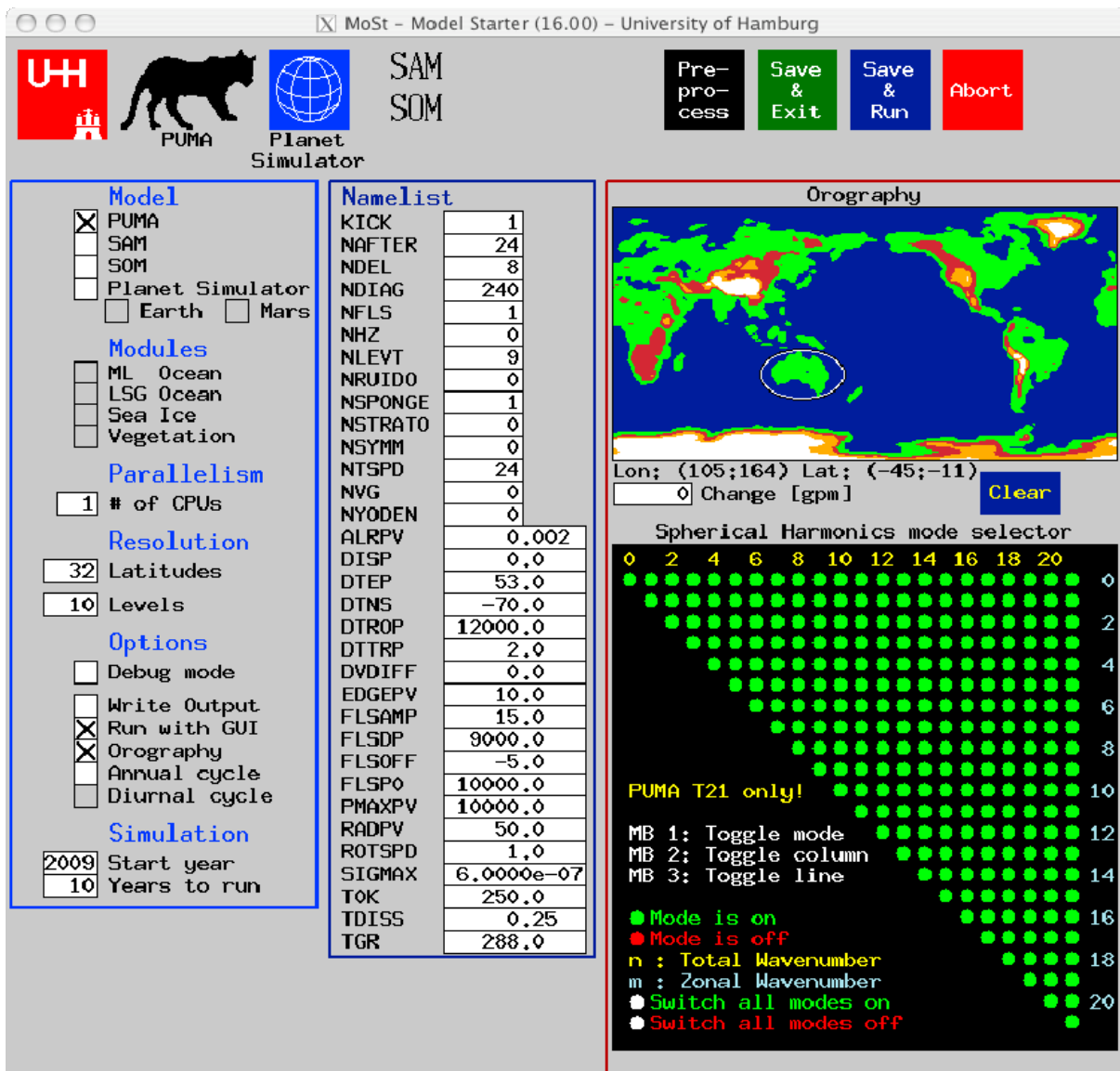

Figure 1. Screenshot of the Model Starter (MoSt) with model and parameter editor, orography editor, and mode selector for enabling/disabling modes of Spherical Harmonics.

The Graphical User Interface

The Planet Simulator can use a two-way interactive GUI (screenshot in Figure 2). The state of the model variables and arrays are displayed in common representations, like:

- zonal mean cross sections
- horizontal fields in cylindrical or polar projection

- time-longitude (Hovmoeller) diagrams
- longitude-height diagrams
- particle tracer moved by the horizontal wind components
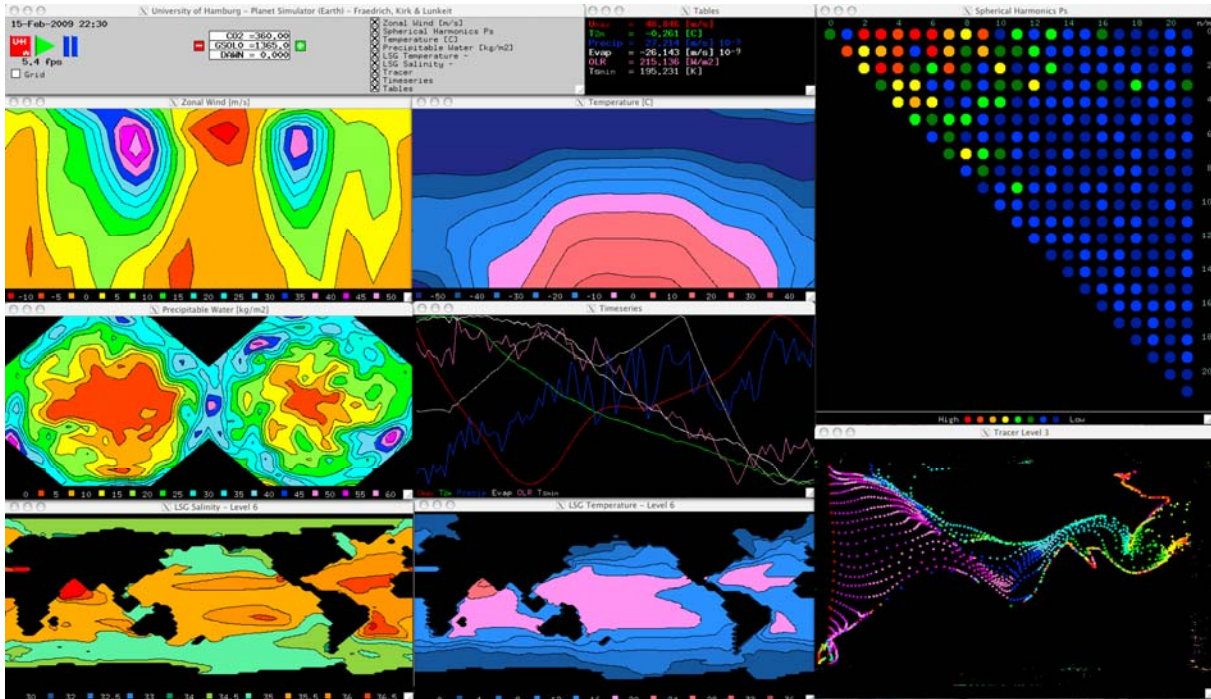- time series
- numerical values

Figure 2. Screen shot of an example layout of the graphical user interface with: a Control window (upper left), b Numerical display of scalar variables(upper middle), c Amplitudes of modes of spherical harmonics for surface pressure (upper right), d Zonal mean cross section of zonal wind (2nd. row left), e Zonal mean cross section of temperature (2nd. row middle), f Precipitable water in polar projection (3rd. row left), g Time series of scalar variables (3rd. row middle), h Salinity of the ocean model (bottom left), i Temperature of the ocean model (bottom middle), j Particle tracer.

Every window can be switched on or off and placed and zoomed by the user. Figure 3 shows a zoomed particle tracer window as an example.

The second purpose is the interaction part of the GUI, which allows the user to change selected model variables during model run. That is, it is not necessary, though possible, to pause the model while changing variables. All model fields or even fields received via coupling from other models can be put on the GUI display.
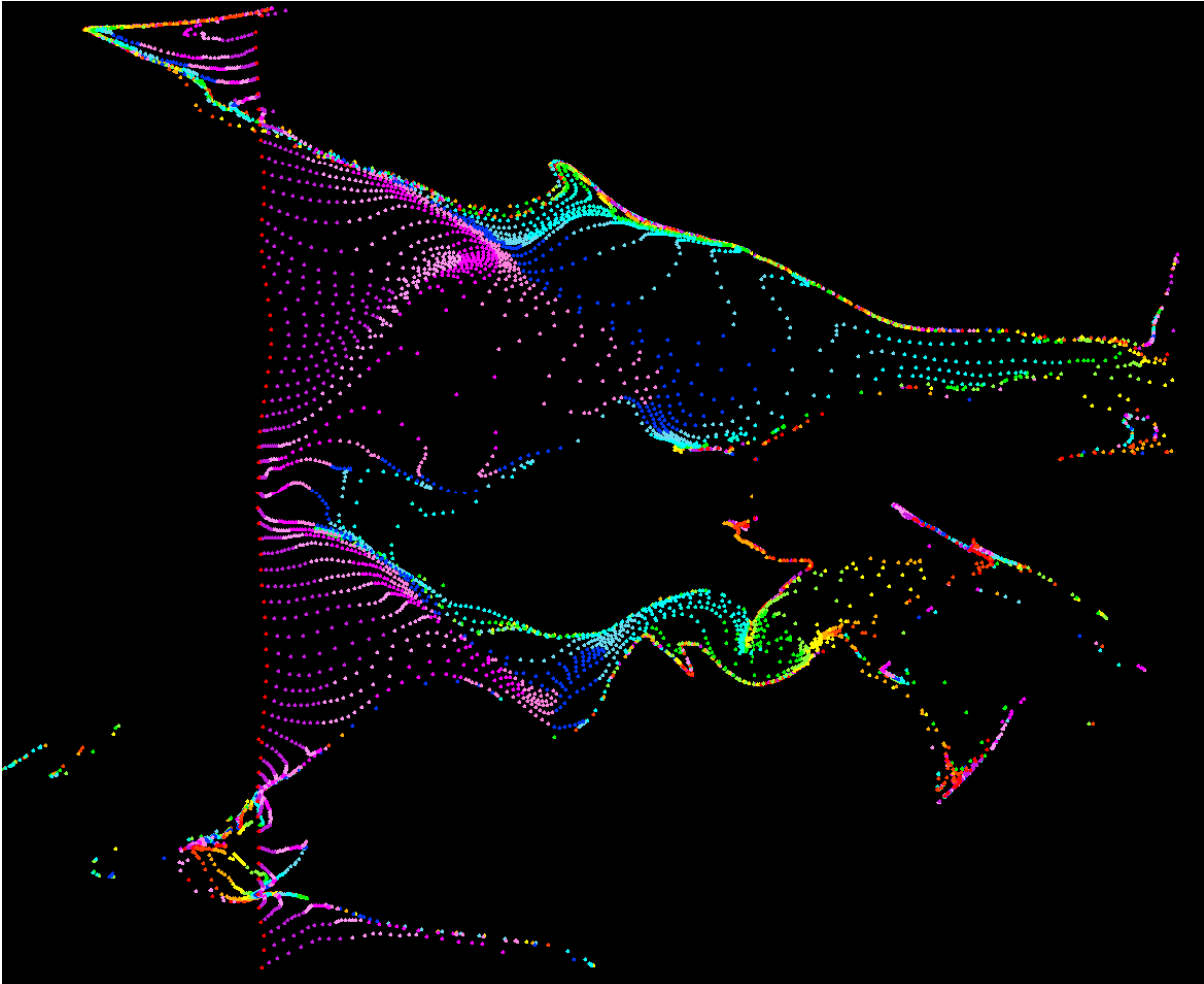
Figure 3. Screenshot of the GUI window "Particle Tracer" showing the movement of particles during the first month after starting the model from a state of rest. The particles are inserted at longitude 180 degrees and the height of 300 hPa. Westerly winds displace particles eastward to the right.

Graphics Library and Networking

Both MoSt and GUI are implemented using the Xlib (X11R5), which is a library of routines for graphics and event communication. As this library is part of every UNIX/Linux operating system and base of all desktop environments, there is no need to install additional software for running MoSt and GUI. Another important property of Xlib is the full network transparency. The display of MoSt and GUI is not locked to the machine running the programs or the model. In fact, the best performance is obtained in running the Planet Simulator on several cores of a remote server while displaying the GUI on the user's workstation. The MoSt and GUI programs automate many tedious tasks, minimize the time to become familiar with the Planet Simulator, and make testing and parameter tuning much easier.

Diagnostics and Offline Visualization

The output of the model is compatible to common data standards, which allows choosing from a huge base of diagnostic programs and visualization tools. Figure 4 shows a screenshot of an offline animation done with the software Avizo. The complete animation can be downloaded or viewed at http://www.mi.uni-hamburg.de/6472.0.html.
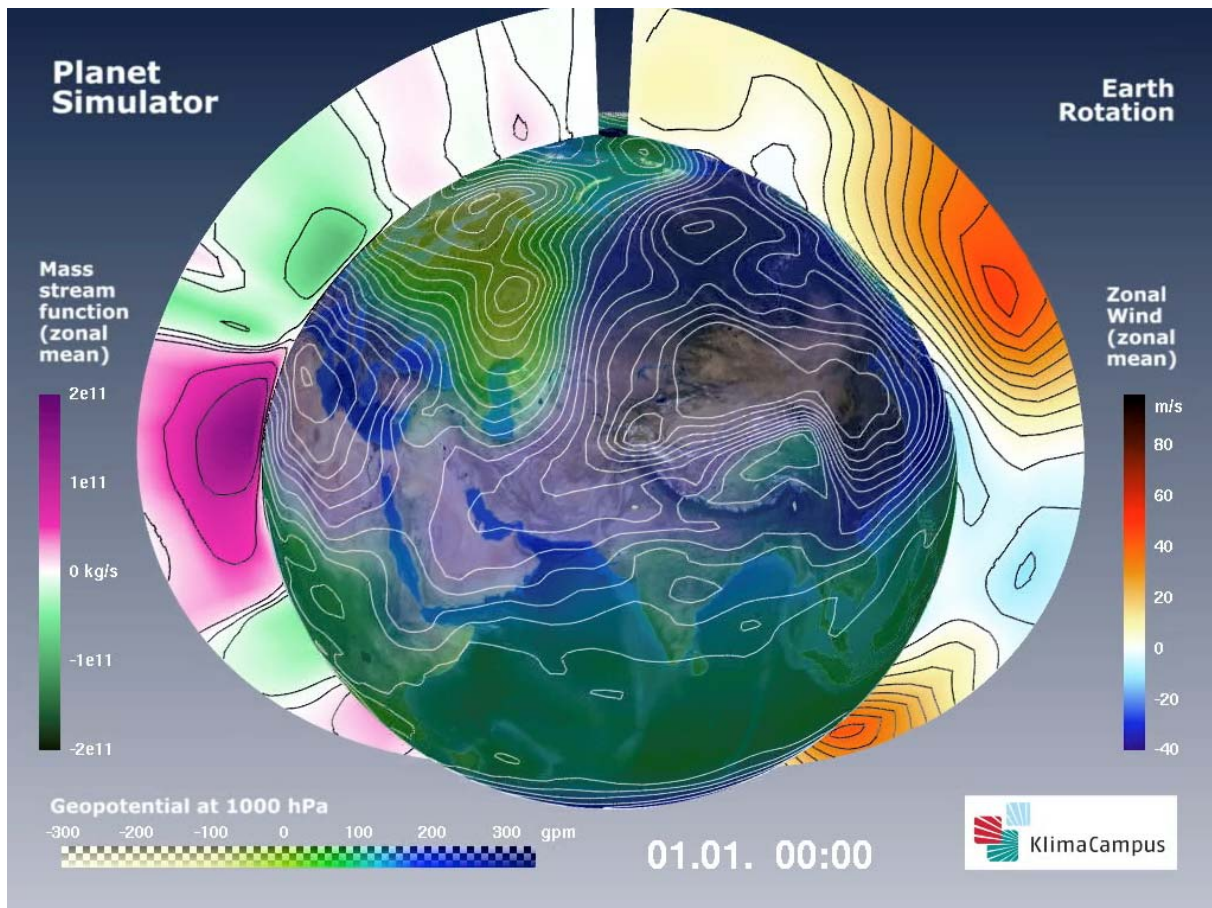
Figure 4. Screenshot from a movie created from model output showing three variables (geopotential height, mass stream function, and zonal wind) in one animation. This is an example of visualization that is not done in real time, but after completion of the simulation.

Summary and Outlook

The Planet Simulator represents the top model in a hierarchy of global spectral circulation models; other members of this hierarchy are the Portable University Model of the Atmosphere (PUMA), the Shallow water Atmosphere Model (SAM), and the Spectral Ocean Model (SOM) see http://www.mi.uni-hamburg.de/6.0.html. The Planet Simulator supports numerical experiments for understanding the dynamics of the climate of the Earth and Earth-like planets and moons of the solar system. In this sense the Planet Simulator can be used as a simplified virtual laboratory to study the fundamental dynamical and thermo-dynamical issues, to identify feedbacks responsible for the long-term stability of the climate, and explore the causes of sudden losses of stability or abrupt change, like the impact of volcanic eruption, the consequences of a thermohaline circulation breakdown, long-term variability, extremes, etc. Unique features of the Planet Simulator are the graphical user interface and the Model Starter. The Planet Simulator should be considered as an open system in transit based on a dynamical core of the primitive equation atmosphere in the traditional spectral form and sigma coordinates. Given the set of modules, a basic platform for the Planet Simulator is achieved but, more modules are certainly needed to complete it, including, for example, continental ice sheets, more realistic land and marine biospheres, geo-chemical cycles, etc. To test sensitivities or to create super ensemble forecasts, different modules of the same processes may also be useful. Fundamental research in atmospheric physics and dynamics, non-linear analysis and stochastic dynamics may be performed, now allowing for a more complete

model hierarchy approach. A first application, comparing a green planet with a desert world, is presented in (Fraedrich et al. 2005).

Acknowledgements

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Biography

The authors of this paper are scientists at KlimaCampus, University of Hamburg.
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1977:Diploma at the University of Kiel (major: Meteorology, minor: Oceanography).
1984: PhD at the University of Cologne (major: Meteorology, minor: Computer Science).
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2000–today: Development team member of the "Planet Simulator".