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EULAG: high-resolution computational model for research of multi-scale geophysical fluid dynamics

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**CScADS Summer Workshops: ”Scientific Data Analysis and Visualization for Petascale Computing"
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What does the application do?

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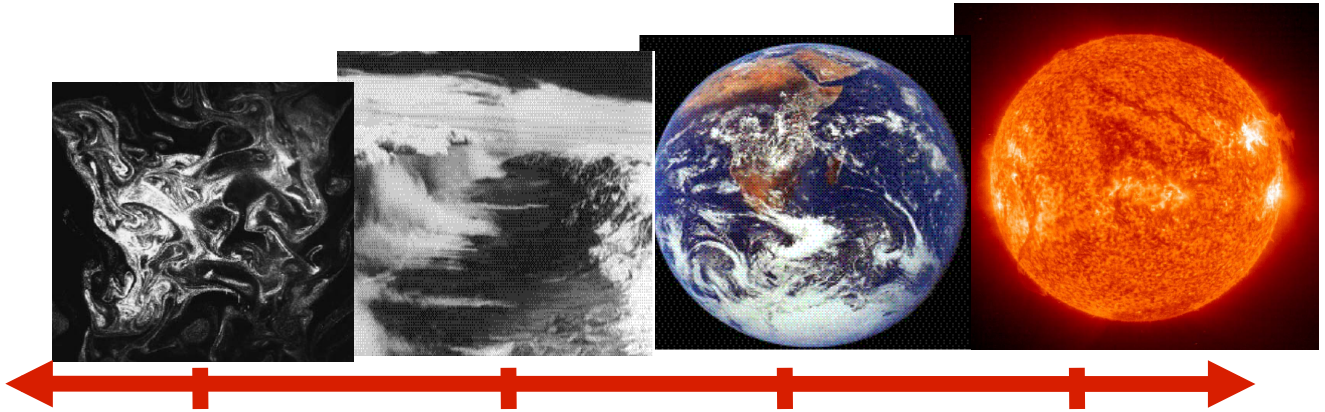
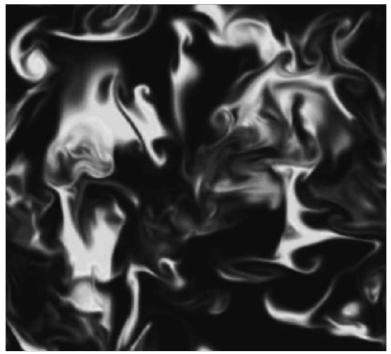
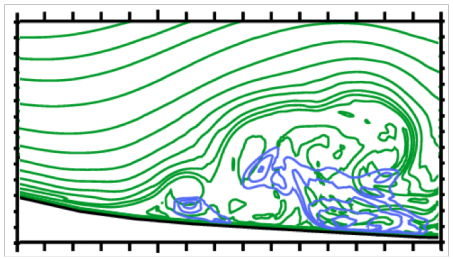
Simulating thermo-fluid flows across a range of scales and physics

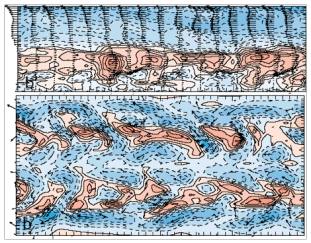




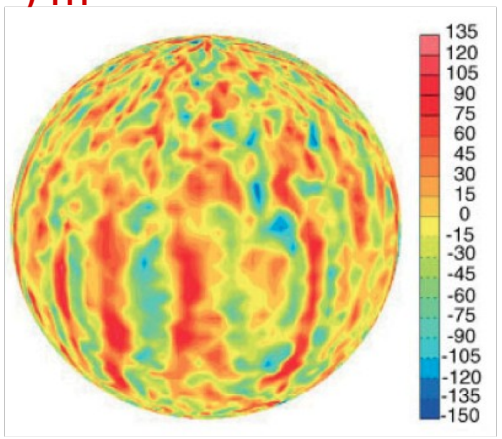
Cloud turbulence



Gravity waves



Global flows



Solar convection

Science Lesson – How?

Two optional modes for integrating fluid PDEs:

- **Eulerian --- control-volume wise integral**
- **Lagrangian --- trajectory wise integral**

Optional fluid equations (nonhydrostatic):

- **Anelastic,**
- **Compressible/incompressible Boussinesq,**
- **Incompressible Euler/Navier-Stokes'**
- **Fully compressible for high-speed flows**
- **Anelastic MHD**
- **Anelastic for unstructured grid formulation**

Available strategies for simulating turbulent dynamics:

- **Direct numerical simulation (DNS)**
- **Large-eddy simulation, explicit and implicit (LES, ILES)**

Parallel Programming Model

- MPI / Shmem
- Fortran 77
- Libraries in parallel mode: Netcdf, Vis5d
- Simple one-file construction
- Shell preprocesor
- Currently run on BG/L, IBM p575, Cray XT4 and XT5, Linux clusters, PC workstations, etc.
- In progress: vertical MPI parallelization, GPU, OpenMP/ hybrid, performance improvements and tuning for petascale

Computational Methods

Numerical algorithms:

- Nonoscillatory forward-in-time (NFT) advective/convective transport MPDATA
- Preconditioned non-symmetric Krylov-subspace elliptic solver GCR(k)

Parallelization:

- Parallel two-dimensional horizontal grid decomposition (vertical decomposition in progress, very promising !)
- Local domain contains inner processor grid and halo's (guard cells) to keep information from neighbor processors
- Global exchange of information for the purpose of iterative elliptic solver
- Aiming at petascale performance on BlueWaters

EULAG I/O

- Serial or parallel mode
- Fortran 77 tape read/write
- NetCDF, Parallel Netcdf
- Restart from Fortran tape or from Netcdf file
- Good scaling of Parallel Netcdf output tested up to O(1000) cores

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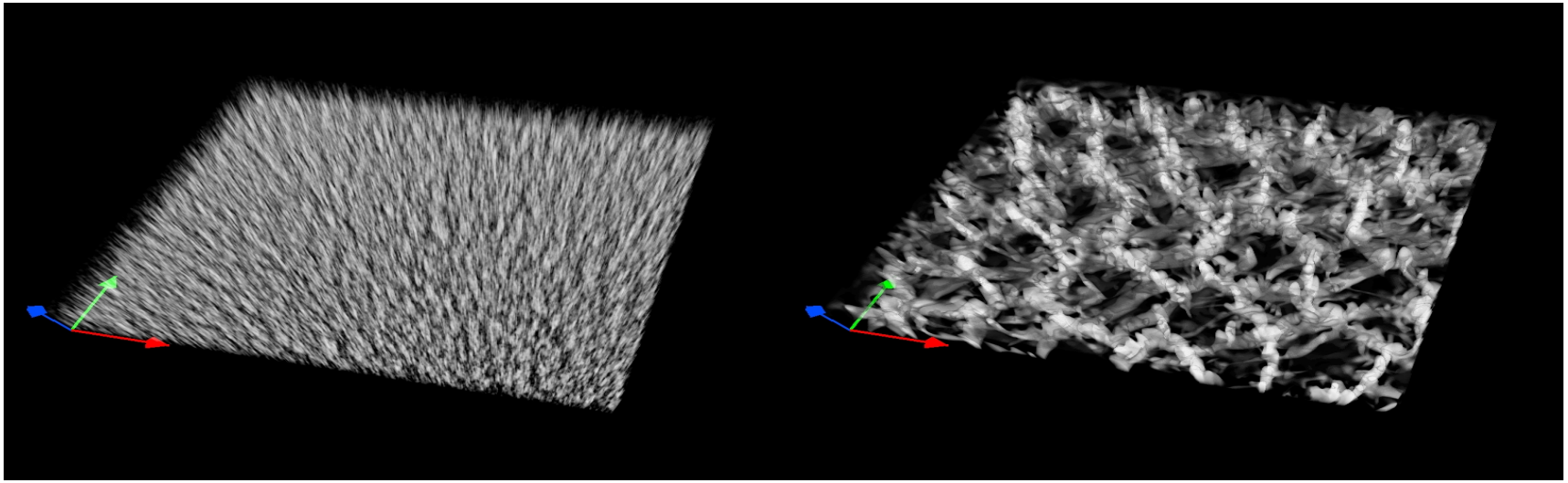
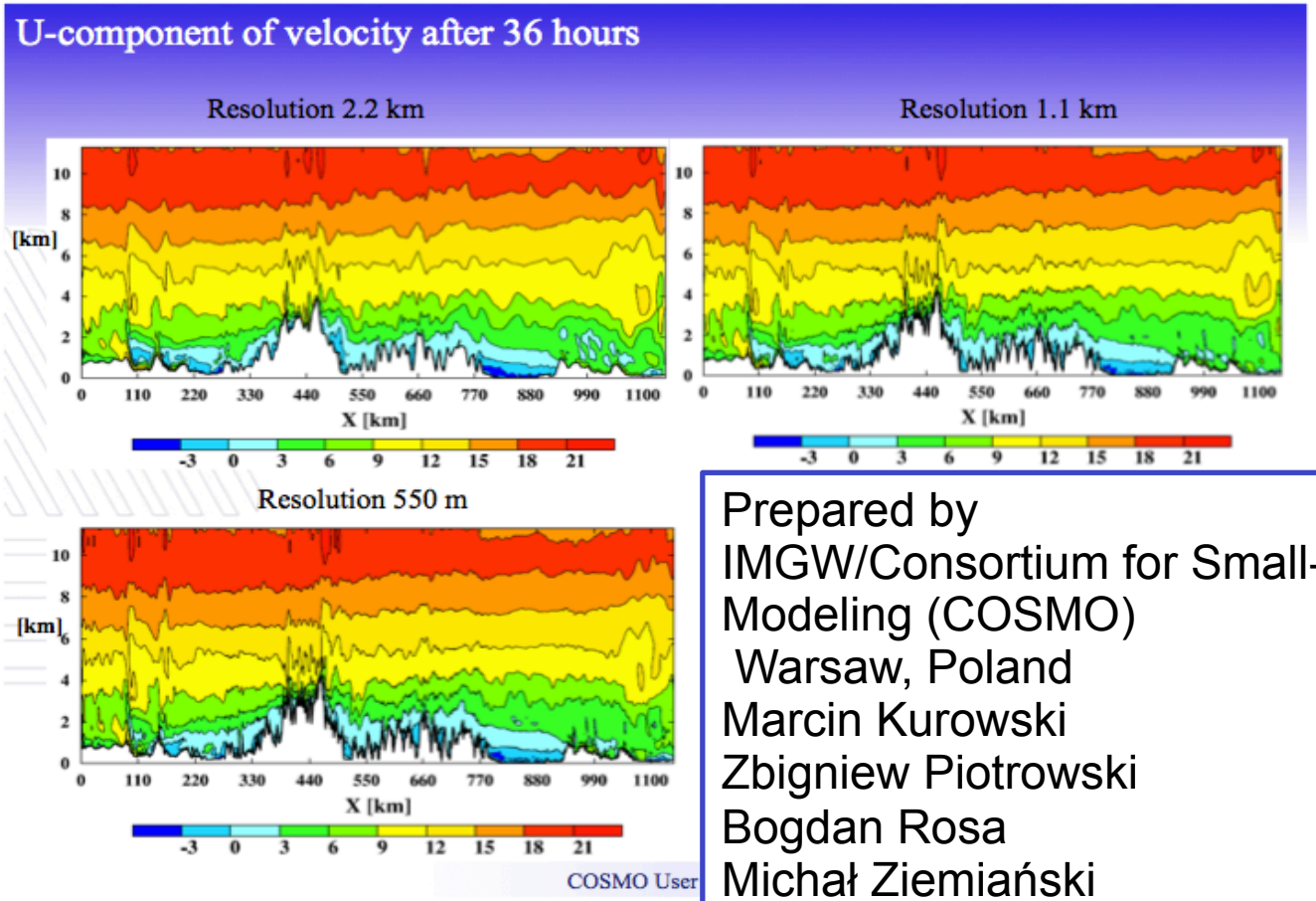
Visualization

- NCAR Graphics, NCL, Matlab, IDL, Python
- VIS5D, VAPOR



Realizability of convection research - 512x512x181 grid visualization positive vertical velocity over heated plane

Very high resolution numerical weather prediction research (mountains become steeper !)



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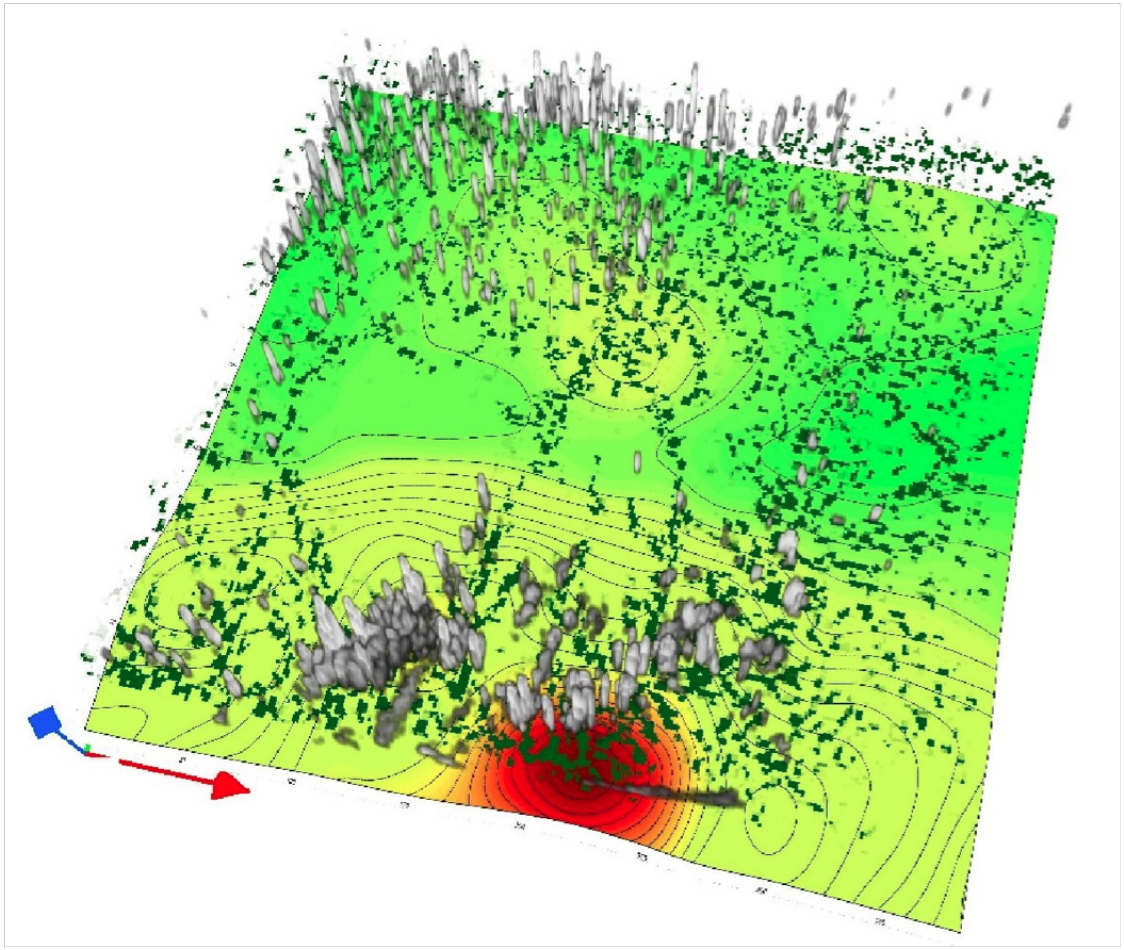
Crossection of wind component through NWP domain

NWP research cont.

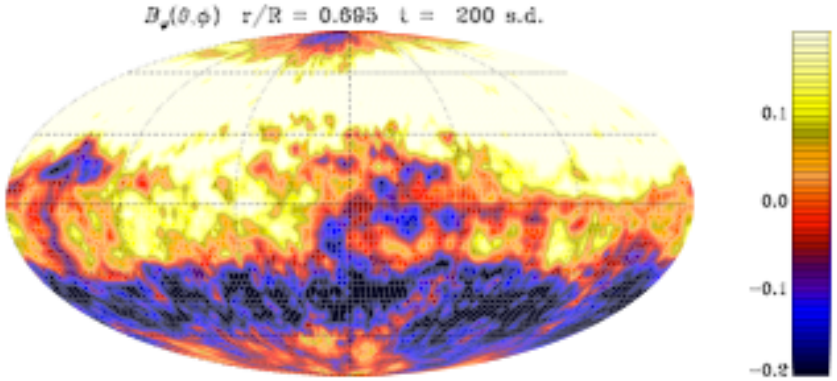


- Combine 3D rendering with 2D sections (prev. slide)
- Automatic topography coloring/ contouring could be useful.

NWP data specification

- 12 GB of data for routine mesoscale MeteoSwiss Cosmo 2.2 km run on 520x350x61 gridpoints
- We are investigating forecasts on similar domain with 1.1 km , 0.55 km and 0.275 km using EULAG as a dynamical core of Cosmo
- The amount of data increases considerably
- Data stored in Netcdf format (for research)

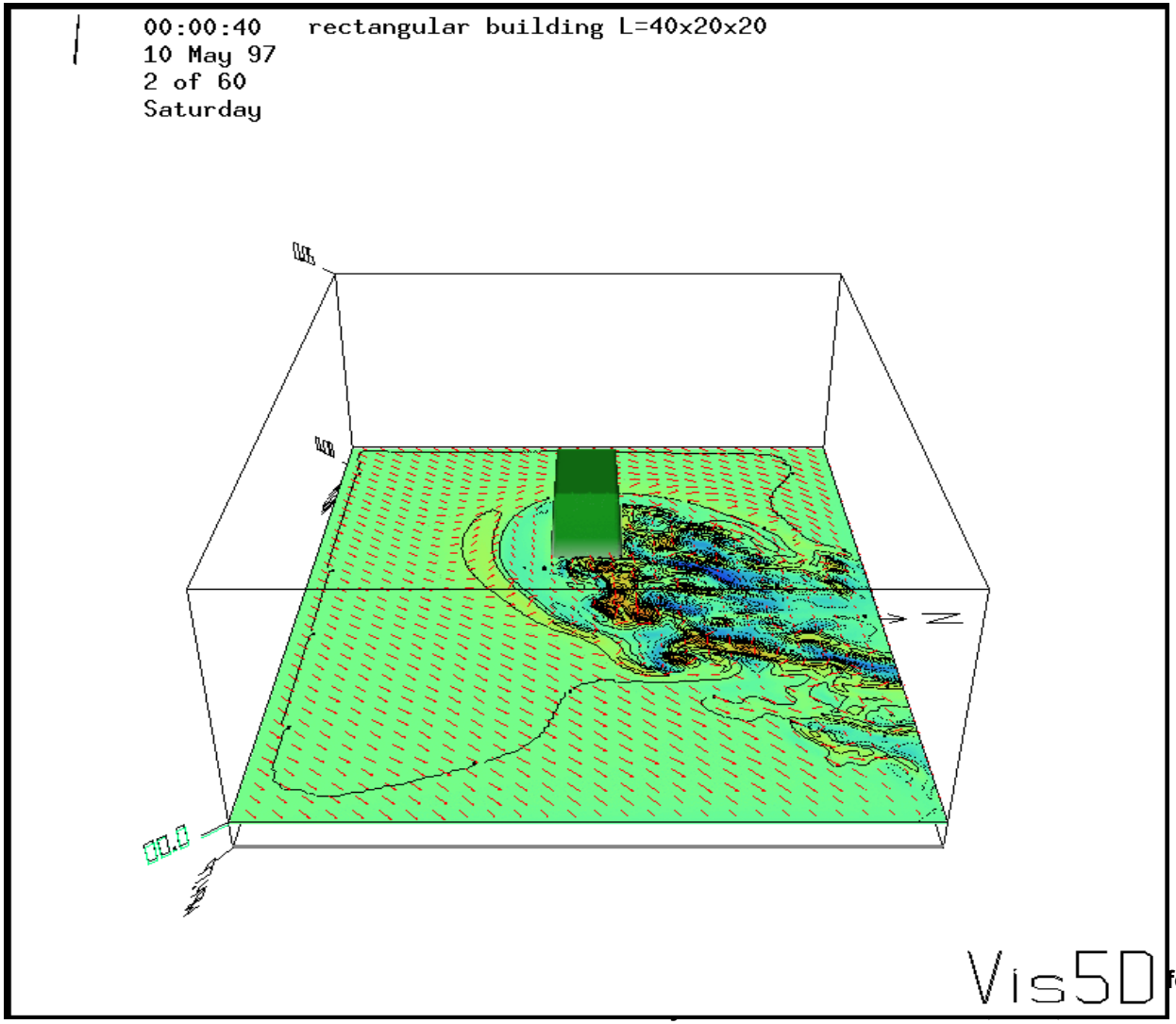
Solar convection



MAGNETIC CYCLES IN GLOBAL LARGE-EDDY SIMULATIONS OF SOLAR CONVECTION, M. Ghizaru, P. Charbonneau, and P. K. Smolarkiewicz, The Astrophysical Journal Letters, Vol. 715

- Next step: spherical data 3D visualisation of solar convective layer, velocity and magnetic field

Example of realizations with Vis5D



Prepared by
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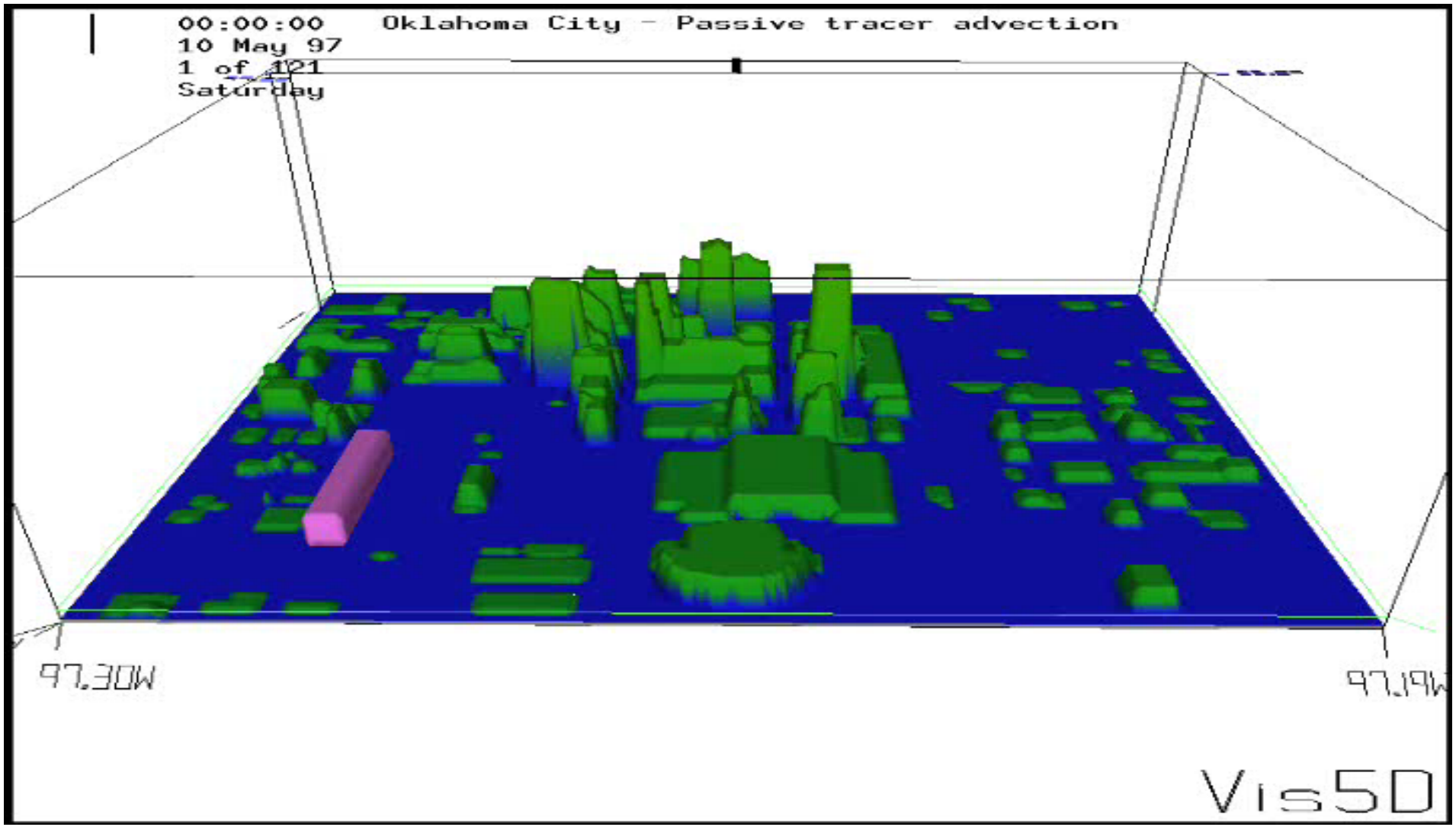
Example of realizations with Vis5D



Example of realizations with Vis5D

- Vis5D – great software, but obsolete and with many annoying bugs
- Large datasets troublesome or impossible to render, need to recompile the source code
- Combines topography, 3D rendering and 2D vector fields, sections analysis
- Looking for replacement suitable for petascale era simulations

Expectations – data analysis

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- Software that uses multicore on workstations (NCL is slow on data with topography)
- Since transmission of large datasets from remote computation sites is time-consuming, it would be nice to be able to perform analysis and 2D vis. remotely on regular ssh connection

Expectations - visualisation

- Possibility of mixing real time 3D rendering with
  - 2D crossections
  - 2D and 3D vector fields
  - Soundings
  - Contours
  - Isosurfaces
  - Streamlines / Pathlines