Exploration of time-dependent paleoceanographic flow data in virtual reality

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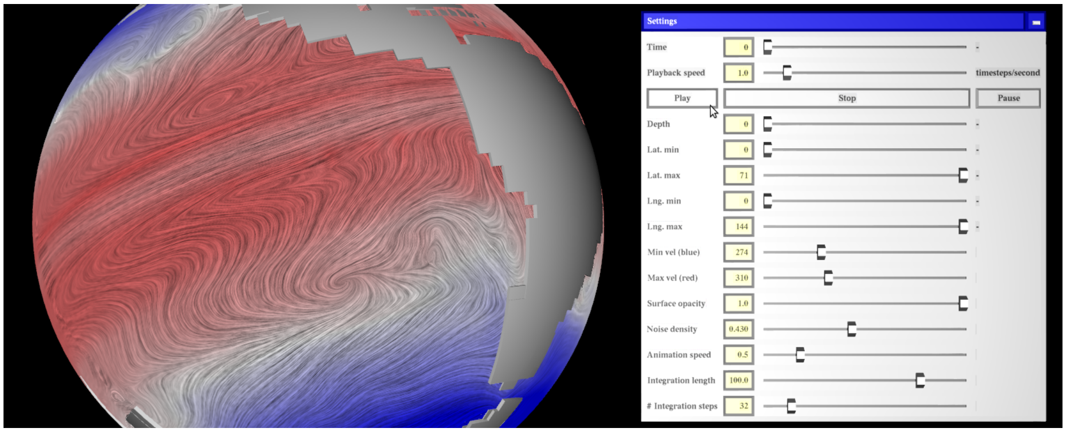

Fig. 1. Visualization of surface currents using line integral convolution and color coded temperature. The user interface supports VCR-style controls for time navigation as well as spatial cropping functionality.

Abstract—Palaeoceanography is the study of the history of the oceans, including the evolution of ocean currents. Sediments which are transported along these currents eventually settle on the ocean floor, forming a deposition record which can be sampled using drill experiments. By studying the composition of these samples, scientists attempt to infer the historical flow patterns which have produced these observations, which is a challenging inverse problem with a set of uncertain parameters and boundary conditions. We have developed a virtual reality visualization system for interactive exploration of such global, time-dependent flow datasets which combines simulation data with observation records using stereoscopic visualization. The software enables domain experts to explore the output of their simulations in order to support the development of the numerical methods and the validation of parameter choices.

1 Introduction

The flow patterns of the Earth's oceans change over large time scales. Sediments are transported along with the flow and subsequently deposited on the ocean floor where they accumulate to create layered depositions. Geoscientists perform drill experiments to extract core samples at select points and analyze their composition in order to better understand these processes.

Recovering the history of flow patterns based on these sparse samplings of the deposition record is an ill-posed inverse problem, however. Consequently, there is no unique solution unless one selects values for additional constraints and boundary parameters which are uncertain.

Due to this uncertainty, scientists require visualization tools to support the analysis of the simulation results to determine whether they agree with the original observations. We have developed an interactive visualization system which produces spherical renderings of time-varying simulated global flow data using a virtual reality (VR) environment. Line-integral convolution (LIC) is used to visualize flow direction on surfaces of constant depth, latitude or longitude or any combination thereof, allowing the user to obtain cross-sectional views of flow behaviour.

In addition, particles can be interactively injected at any point in the flow field to analyze the advection and dispersion behaviour of sediments as they are transported along the flow field. Scalar quantities such as temperature or the experimentally gathered deposition quantities can be visualized simultaneously using heatmaps. Stereoscopic rendering in the VR environment enhances the depth perception of these particles traces which helps domain experts in understanding three-dimensional flow behaviour.

The system was developed to support development and validation of a numerics kernel for a project with the goal of producing more accurate historic flow models. As a reference dataset, we used simulation results produced by Timm and Timmermann [5] which cover the last $21,000$ years at a resolution of 10 years per timestep. The flow field at each timestep is given on a uniform latitude/longitude grid with a resolution of 2.5 degrees. In the vertical dimension, 20 depth layers are provided.

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2 Related work

Nations [3] et al. have presented a VR-integrated in-situ visualization system for ocean flow simulations. Specifically, their system generates a low-resolution 2D model of the Sea of Japan, allowing the user to change simulation parameters on a front-end VR system and obtain an updated solution on the fly from a cluster. In our application, however, any change of parameters would require a re-computation of the whole time-dependent 3D flow field, making interactive parameter space exploration infeasible.

Line-integral convolution [1] (LIC) is a well-established technique for visualizing flow on surfaces. By integrating a noise texture along the flow direction, a dense texture is computed which indicates flow direction at any point of the surface. We apply a GPU-based version of the algorithm, using 3D textures to represent both the flow field and the (constant) noise texture. Since static LIC does not convey flow orientation, we apply an animated variant described in [6].

Interactive particle tracing in VR environments using GPGPU techniques has been demonstrated by Schirski et al. [4].

3 Visualization System

Our system uses the Vrui toolkit [2] as an abstraction layer to enable transparent interoperability between different VR environments. The user interface supports VCR-style playback controls for navigation along the time axis as well as a set of sliders for chosing a depth layer and a region of interest for the visualization.

The chosen depth layer is rendered as a sphere which is textured on the fly using a GPU-based animated LIC algorithm (Figure 1). When a region of interest is selected, additional LIC-textured boundary planes are inserted along the limits of the corresponding latitude or longitude intervals (Figure 2).

The grayscale image produced by the LIC is colored to indicate either velocity magnitude or an arbitrary user-defined scalar data set such as temperature or measured sediment concentrations. The data set contains cells with undefined values, which correspond to land masses and bathymetry. These are rendered as opaque geometry to provide context for orientation.

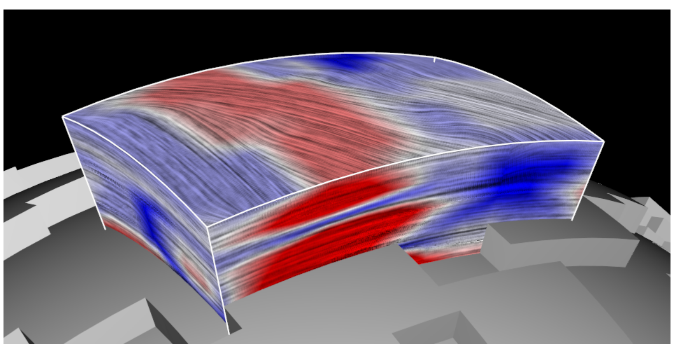

Fig. 2. Constraining the visualization to a region of interest reveals flow behaviour in depth. Color indicates velocity magnitude (blue $<$ white $<$ red).

To gain insight into sediment transport pathways, users can interactively inject particles at any point in the flow field using a pointing device such as a mouse or a flystick. These particles are advected in real time and their trails (so-called pathlets) are shown (Figure 3). The lengths of the trails indicate flow velocity.

4 Future Work

Development on our visualization system is ongoing while keeping in mind the demands of domain scientists working on the numerical models. Work is being done to create a forward-simulation model for sediment transport which advects scalar quantities along a flow field, producing a global scalar field of predicted sediment concentrations.

We plan to apply this advection model to hypothetical flow solutions to help experts understand how well they agree with the original observations. For this purpose, we want to visualize the drill experiment data (measured concentrations) as discrete glyphs on the sphere surface.

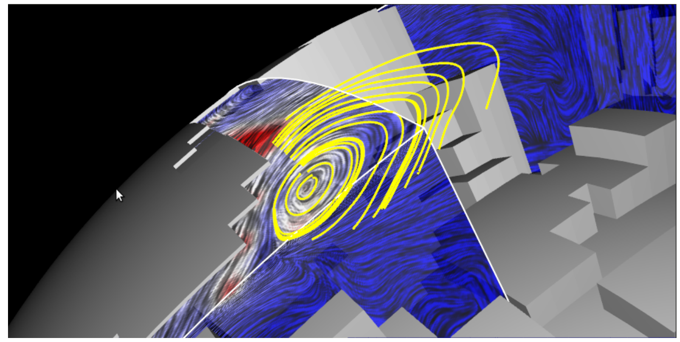

Fig. 3. Interactive particle injection in the vicinity of an eddy/vortex. As the particles are advected by the flow, their trails (pathlets) are visualized in yellow.

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