An Application-Oriented Framework for Feature Tracking in Atmospheric Sciences

Daisuke Sakurai* — Zuse Institute Berlin
Hans-Christian Hege† — Zuse Institute Berlin
Alexander Kuhn‡ — NVIDIA
Henning Rust§ — Freie Universität Berlin
Bastian Kern¶ — Deutsches Zentrum fuer Luft- und Raumfahrt e.V. (DLR)
Tom-Lukas Breitkopf‖ — Zuse Institute Berlin

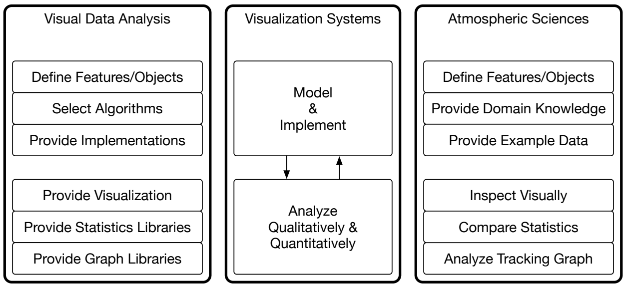

Figure 1: In a tight collaboration with atmospheric researchers we develop a framework for extracting and tracking objects that is especially suited for large data.

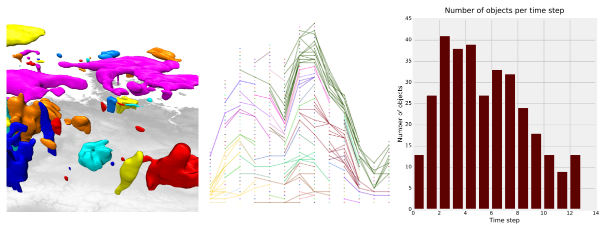

Figure 2: We compare diverse atmospheric data sets by extracting objects (left), tracking them over time (center) and finally deriving object statistics, abstracting from spatial information in order to compare fields with chaotic properties (right).

Abstract

In atmospheric sciences, sizes of data sets grow continuously due to increasing resolutions. A central task is the comparison of spatiotemporal fields, to assess different simulations and to compare simulations with observations. A significant information reduction is possible by focusing on geometric-topological features of the fields or on derived meteorological objects. Due to the huge size of the data sets, spatial features have to be extracted in time slices and traced over time. Fields with chaotic component, i.e. without 1:1 spatiotemporal correspondences, can be compared by looking upon statistics of feature properties. Feature extraction, however, requires a clear mathematical definition of the features – which many meteorological objects still lack. Traditionally, object extractions are often heuristic, defined only by implemented algorithms, and thus are not comparable. This work surveys our framework designed for efficient development of feature tracking methods and for testing new feature definitions. The framework supports well-established visualization practices and is being used by atmospheric researchers to diagnose and compare data.

Index Terms: I.3.8 [Computing Methodologies]: Computer Graphics—Applications

1 Introduction

Atmospheric research deals with a diverse range of data. Data sources include radar, satellites and computer simulation, representing phenomena such as clouds, rain areas, cyclones and hurricanes [10]. This diversity is particularly problematic when diagnosing and comparing them for various tasks [6, 10]. A useful approach is to extract spatial or spatiotemporal features, aka (meteorological) objects, and to compare their statistics [6]. Atmospheric researchers deal with a rich variety of conceptualizations, representing meteorological objects in space-time. They also implemented algorithms to extract such objects and track them in time. However, the results are difficult to compare due to the still lacking mathematical definition of features and the heuristic nature of the algorithms. For example, when comparing a simulation results with radar output, the specifics of the algorithms can bias the evaluation.

This led to the present and ongoing collaboration of the authors from visual data analysis and atmospheric sciences. On one hand, the visualization community has accumulated knowledge in feature extraction and tracking that is considerably generic [7] and thus applicable to diverse analysis questions in atmospheric sciences. On the other hand, new developments in feature extraction and tracking are needed to suit the specific needs in the discipline.

We aim at establishing a feature tracking strategy for research questions in the atmospheric sciences and applying it exemplarily. We target at a scheme that can compare various atmospheric data sets qualitatively and quantitatively. Our primary target simulation [6] outputs typically 40 TB of data, which is not the full resolution – only on-line algorithms may access all data. The challenge therefore is to extract and trace suitable objects in $O(10\text{-}100)$ TB data sets offline, and in even larger data sets online. If objects are not mathematically defined, we help to establish such a definition; alternatively, we provide means that help researchers in atmospheric sciences to establish such definitions. This will enable us to objectively compare small-scale phenomena that are visible in data from different sources.

2 Related Work

Atmospheric sciences have their own tracking algorithms. One of the oldest known computes motion vectors [8] for grid cells. Since we deal with large data involving small scale features, our interest is a more efficient and flexible approach to extract objects and establish

*e-mail: d.sakurai@computer.org
†e-mail: hege@zib.de
‡e-mail: akuhn@nvidia.com
§e-mail: henning.rust@fu-berlin.de
¶e-mail: bastian.kern@dlr.de
‖e-mail: breitkopf@zib.de

their correspondence across time steps. The object definition can be as simple as a level set [4]. As such a simple definition differs from experts' expectations, refinements are proposed that resemble persistency analysis [5] or convolving close regions [3]. Definitions of objects differ from algorithm to algorithm.

Tracing objects means establishing links between objects in adjacent time slices that correspond to each other. While the spatial resolution determines the size of the smallest objects that can be identified and the finest shape details that can be resolved, the temporal resolution determines the degree of similarity (in position, shape and physical properties) of corresponding objects. The simplest correspondence criterion is spatial overlap; it works for data with high temporal resolution [3, 10]. If the temporal resolution required for this criterion is not available, e.g. in off-line tracking (due to I/O and storage limitations) or in on-line tracking (due to too much computing effort), more sophisticated correspondence criteria need to be applied. In the simplest case, also volume differences [4] or distances between objects in relation to their speed [5] can be considered.

In comparison, visualization community has tracked predefined spatiotemporal features [7, 13]. Region-based tracking [11] often does not rely on a specific definition of a feature. Tracking methods that are similar to aforementioned atmospheric approaches are also found [7], while sophisticated global analysis based on topology and statistics is also available [9]. Recent progress in parallelization of topological analysis [2] makes such an approach attractive.

3 Feature Extraction Framework

In our collaboration (Fig. 1), each of the two parties focuses on its contribution, while the results achieved are accessible for each side through the visualization system. At the *Model & Implement* stage, both visualization and atmospheric researchers propose a feature tracking method. Visual Data Analysis researchers (left box) provide the mathematical definition of objects and suitable implementations of extraction and tracking algorithms. Atmospheric sciences have a long history and arrived in a long discourse at certain conceptualizations which they use to formulate their science. Simple examples are clouds, rain cells, rain bands, and circulation cells. Reviewing the literature and discussion with domain experts showed that almost all such objects can be defined in terms of (combinations) of level sets, potentially with suitable refinements. We are currently evaluating topological simplifications based on contour tree [1]. As a first step, we started with available data sets using off-line analysis (Fig. 2). The future development of a distributed system for on-line feature tracking will be based on this step. Although these data sets exhibit different characteristics, like coarser time and space resolution, they can be used to explore and test mathematical definitions of features.

In parallel, in *Analyze Qualitatively & Quantitatively* we evaluate our feature extraction and tracking algorithms. Object extraction and tracking are done in *Amira* [12] with instant visual feedback.

The quantitative analysis boils down to statistical analysis in the framework. In addition, we expose the tracking graph to the atmospheric researchers. This is mainly for allowing them to extract statistics flexibly; another advantage is that they can investigate the tracking results of individual data sets in more depth. The significance of this latter usage has yet to be assessed.

4 Feedback and Discussion

Overall, the efficiency of algorithms tends to be a secondary concern for atmospheric researchers, while they prefer as much information as possible in the output. Visual interaction provides an intuitive understanding of feature definitions. Our collaborators from atmospheric science also started topological analysis for multi-scale analysis of small data sets. We aim at analyzing large-scale data using a distributed system; the major issue there is scalability.

5 Conclusion and Future Work

We presented a collaboration framework for feature tracking in atmospheric research. Feature tracking helps to abstract from details of the data, to focus on relevant topological-geometric properties of the field under consideration and to reduce the amount of information significantly. Using feature statistics, also fields affected by chaotic processes can be compared. A major challenge is to base the approach on solid mathematical definitions of the features, in order to achieve objective, comparable results.

The next steps are (1) further development of the offline method to a scalable, distributed online method, (2) extension of the feature definitions based on multivariate fields, and (3) defining objects in multi-fields, which is easier to be related to atmospheric knowledge.

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