Visual Trend Analysis in Weather Forecast

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Abstract

Weather conditions affect multiple aspects of human life such as economy, safety, security, and social activities. Weather forecast significantly influences decision and policy making, construction planning, productivity, and environmental risk management.

Visualization of weather conditions and trends assists the anticipation of unexpected meteorological events and thus helps with appropriate actions and mitigation systems to minimize the impact of them on human life and activities.

In this work, we propose an interactive approach for visual analysis of weather trends and forecast errors in short-term weather forecast simulations. Our solution consists of a multi-aspect system that provides different methods to visualize and analyze multiple runs, time-dependent data, and forecast errors. A key contribution of this work is the comparative visualization technique that allows users to analyze possible weather trends and patterns.

We illustrate the usage of our approach with a case study designed and validated in conjunction with domain experts.

Index Terms: I.3.6 [Computer Graphics]: Methodology and Techniques—Comparative Visualization

I.6.4 [Simulation and Modeling]: Model Validation and Analysis—Weather Forecast Research Model

1 Introduction

Atmospheric processes can be described by physical laws expressed in mathematical equations, which are complex and do not have exact solutions. The state of the atmosphere can be described by several meteorological variables that can be predicted (to a certain degree of accuracy) by numerical weather prediction models. The Weather Research and Forecasting (WRF-Model) is an example of those models. Its optimum configuration and performance highly depend on the specific applications, including aspects such as geographical area, time of the year, and local forecast errors due to the regional model [6]. Therefore, it is essential to count on tools that facilitate the analysis of multiple runs, time-dependent data, and forecast errors, particularly in terms of identifying weather temporal patterns and identifying model error behaviour.

There have been many efforts in the analysis of temporal data and temporal patterns [2, 1, 4]. In particular, work of Coto et al [3] contributed an important background to our work. It described a classification based on "time-signal curve types" for early detection of breast cancer, each curve type represented a characteristic of that tumor. For example, curves with increasing values were identified as indicators of benign lesions.

Furthermore, work of Konyha et al [5] described the concept of families of curves. They defined a curve as an atomic data type representing a simulation run, or temporal measurements from engineering domain problems. In particular, they defined families of curves as an ensemble of multiple simulation runs, or measurements of a physical quantity, and provided a set of tools for the analysis of this type of data. We use a similar concept applied to weather forecast models.

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2 Exposition

2.1 Tasks and Workflow Analysis

This work is a result of a interdisciplinary collaboration with meteorologists from the CIMA (Research Center of the Sea and the Atmosphere). Our collaborators from the CIMA institute performed experimental short-term weather forecast using a specialized version of the WRF-Model.

Their task work-flow can be described by four main activities. The first task (W1) starts with a generation of new weather predictions that include a new forecast-cycle runs every twelve hours. Each run generates sixteen forecasts with time steps of three hour to cover the 48-hour cycle (W1). In the second task (W2), simulation outputs are post-processed to aggregate and derive new information for each one of the forecasted dates/hours. In the next task (W3), the specialists create 2D maps and plots. Finally (W4), the visualizations are presented on a website using 2D maps and plots.

Although the presented information is vast, it carries certain drawbacks. Visualizations use a static interface that makes interaction difficult, and different views cannot be linked or compared.

2.2 Solution

Our solution consists in a multiple-aspect visualization system structured as web-based Visual Interactive Dashboard (VIDa). Our main purposes are (G1) to maintain the key functionality of the current system accounting for the complete work-flow, and (G2) to support interactive exploration, data filtering, and visual analysis of time evolution, geographic distribution, and forecast errors.

Its dashboard is composed of an integrated map, a timeline, linked views, and filters, all of which allow users to visualize and compare forecast runs, and to analyze trends and errors (see Figure 1). The timeline provides a starting point for visual analysis of forecast runs, time evolution, and forecast errors. It presents a visual overview via geo-referenced mini-maps for all the runs that intersect at a given date. Along the timeline, it is possible to retrieve information about multiple runs and forecast time evolution.

The user can select a mini-map that represents a weather-forecast scalar field for a given date, and then visualize it in the map view. To compare two or more scalar fields, the user can select a subset of mini-maps from the timeline. A comparative visualization algorithm is applied to the scalar fields resulting in a new color coded layer. Then, an overview of the resulting layer is shown on the

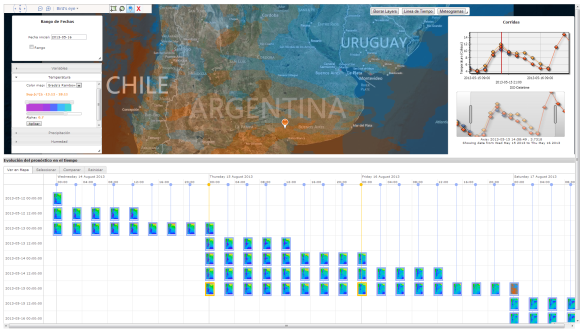

Figure 1: VIDa System.

timeline as a mini-map and visualized over the map view for further analysis.

2.3 Methodology

The purpose of our comparative visualization system is to provide a qualitative visual comparison of multiple 2D scalar fields aiming to identify patterns corresponding to, for example, extreme weather events like heavy precipitation or wind gusts.

Our approach compares an arbitrary number of scalar fields, which are represented as images, and creates a new single image with the resulting visualization. We assume the existence of an arbitrary number K of scalar fields for a given meteorological variable. They are represented as 2D georeferenced pixel grids, all of which have the same dimension of $N * M$. We want to compare those grids and represent the results in a new grid with the same dimensions.

Let I_t be a bi-dimensional real value pixel grid of size $N * M$ with $t \in [0, K)$, where t is the grid number in a grid array. We define $f(t) = g(i, j, t)$ as a real value function where i and j represent the pixel position at row i and column j respectively, as depicted in Figure 2.a. We define a curve as a function $f(t) = g(i, j, t)$ that

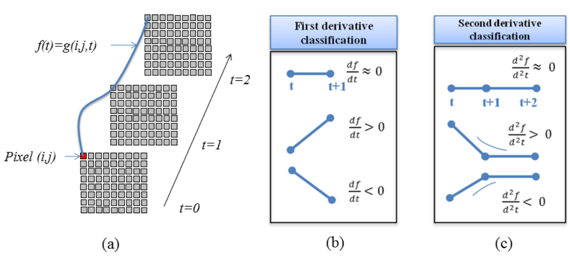

Figure 2: (a) The function $f(t)$ is defined in the pixel position (i, j) of each one of the grids that composes the grid array. (b) First derivative classification. (c) Second derivative classification.

can represent a weather temporal trend or an anomaly that appears in the predictions or a forecast error functions. We define a pattern as a curve type meaningful to the users. Among all possible curve types, the user selects a subset that is physically possible and meaningful to her or him. Our approach to identify patterns resides in the qualitative analysis of the first and second derivatives. To calculate the first derivative, we define a segment $s_t(u) = f(t + u)$ of a parametric function with $u \in [0, 1]$ and $t \in [0, K - 1)$, and a curve of $K - 1$ segments as $c_k = \{s_t(u)\}$ with $u \in [0, 1]$ and $t \in [0, K - 1)$. The first step is to classify the behaviour of a segment s_t based on its first derivative, $\frac{df}{dt}$. Possible values include approximately zero(e.g. constant with $\frac{df}{dt} \approx 0$), positive(e.g. increasing with $\frac{df}{dt} > 0$), or negative (e.g. decreasing with $\frac{df}{dt} < 0$) (see Figure 2.b). Next, we classify the behaviour of the curve c_k based on the behaviours of its member segments, e.g. c_k is a curve composed of $K - 1$ segments to give $3 * 3^{(K-2)}$ possible behaviours. The curve changes depending on the meteoreological variables, and only a few of the $3 * 3^{(K-2)}$ possible behaviours are meaningful to the users. To narrow down the classification, we analyze the second order derivatives. Let us define a segment $s_t^2(u) = f(t + u)$ of a parametric function with $u \in [0, 2]$ and $t \in [0, K - 2)$, and a curve $c = \{s_t^2(u)\}$ of $K - 2$ segments with $u \in [0, 2]$ and $t \in [0, K - 2)$. Consequently, we construct a new classification using $\frac{d^2 f}{dt^2}$, defining three basic behaviours: strict ($\frac{d^2 f}{dt^2} \approx 0$), monotonic accelerating ($\frac{d^2 f}{dt^2} > 0$), and monotonic decelerating ($\frac{d^2 f}{dt^2} < 0$). Then, the function behaviour can be classified based on its s_t and s_t^2, both of which are formed by its segments as illustrated Figure 2.c.

The resultant patterns are rendered using a YIQ color-space color-map, where I value is reserved to represent its first derivative (change rate), and Y value to represent its second derivative (strength rate). As a result, only a qualitative set of different variational patterns is represented in terms of, for instance, large negative variation, small negative variation, or no variation. Finally, the pixel grid is compared against the pattern subset. In the case that the curve matches one of the patterns, the color of this pattern is mapped onto a pixel in the position (i, j). Otherwise, the pixel is considered a glitch or an outlier, and rendered using a distinguishable color.

3 Conclusion

In our work, we propose a solution to address weather forecasts analysis by means of a multi-aspect visual interactive dashboard (VIDa). It allows users to visualize an overview of the short-term weather forecasts by means of a mini-maps timeline. From there, to narrow down the visual analysis of the meteorological variables into more details, we introduce a comparative visualization technique for the analysis of weather forecast trends and errors. Moreover, our solution has implemented a web front-end that runs on the Internet, which facilitates the broadcast and easy access of information. Our approach was received with high acceptance and positive feedback from the domain experts.

Future works will address the extension of our comparative visualization technique to ensemble of forecasts runs, allowing for statistical error analysis and uncertainty analysis.

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