96 Development and Implementation of MODE Time Domain Object-Based Verification

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1 INTRODUCTION

Researchers in the area of forecast verification have long seen the need for verification methods that incorporate the time dimension. For users of traditional verification statistics, doing time series and also stratifying verification results by lead time or valid time have been experimented with as approaches to this problem. In addition to these methods, users of object-based verification techniques would also like to be able to perform matching and merging of objects over time as well as space, and to do tracking of forecast and observed objects through time.

This paper describes a time-domain extension of the Method for Object-Based Diagnostic Evaluation (MODE) that will eventually become part of the Model Evaluation Tools (MET) verification software package—probably in next year's release.

2 DATA

Our forecast data is International H_2O Program (IHOP) data. For our observations we used Stage IV precipitation data.

3 METHODS

The approach adopted was to emulate as closely as possible the traditional (or 2D) MODE approach to both resolving objects in each data field and also matching and merging forecast and observed objects. This allowed us to remain close to a conceptual framework that we already had experience with, and that we knew worked fairly well. As will be seen, however, the fact that one of the dimensions is non-spatial introduced a few new wrinkles.

3.1 *Resolving Objects*

To get some idea of just what objects are in this context, see Figure 1. On the top we see a precipitation field, while on the bottom we see the field resolved into objects by MODE. The objects in this example represent the regions of hight precipitation that the human eye picks out automatically when looking at the raw field. MODE tries to mimic this shape-detection process that humans do so easily.

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Thus, objects are just regions of interest. For precipitation, regions of interest are high precipitation regions. For other fields, the regions of interest may be characterized differently.

In recent decades there has been much research devoted to computer vision, pattern recognition and classification, resulting in highly sophisticated approaches to these problems. MODE uses a simplified approach that has proved adequate in practice.

MODE performs object resolution in a data field by using a *convolution-thresholding* approach. This process involves several steps, First, the raw data field is convolved with a simple filter, which has the effect of smoothing the data. Due to the nature of the convolution process, the resulting field at each grid point is influenced by the field values at nearby points. For the time-domain version of MODE, we perform a convolution in both space and time, so that each point in the resulting field is influenced not only by *spatially* nearby points, but also by field values from it's immediate past and future.

Next, as in 2D MODE, the convolved field is thresholded to produce an on/off mask field which gives the object boundaries in space and time. Finally, the original raw field is restored to object interiors, so that we can look at distributions of data values inside the objects.

3.2 *Adding the Time Dimension*

How is the time dimension incorporated? To see this, imagine we have two dimensional data available at consecutive, equally spaced time intervals (see Figure 2). Furthermore, suppose there is a moving feature (indicated by the red dot in the figure) moving along some path. If we consider the time dimension to be vertical and stack the data plots as in the figure, we can get a mental picture of having two (horizontal) spatial dimensions and one (vertical) time dimension.

3.3 *Attributes*

Once the objects are in hand, various object *attributes* are calculated. A couple of examples will have to suffice due to our limited space here. *Centroid* is the geometric center of an object. It is illustrated by the blue

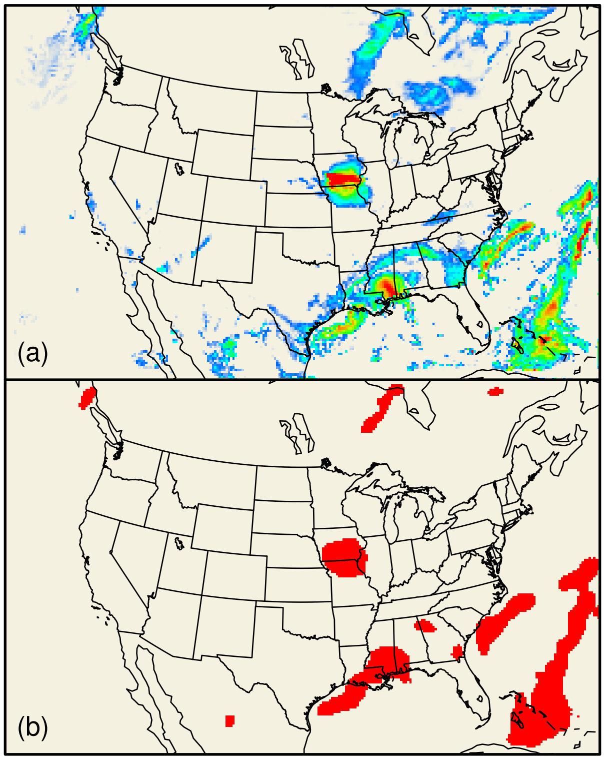

Figure 1

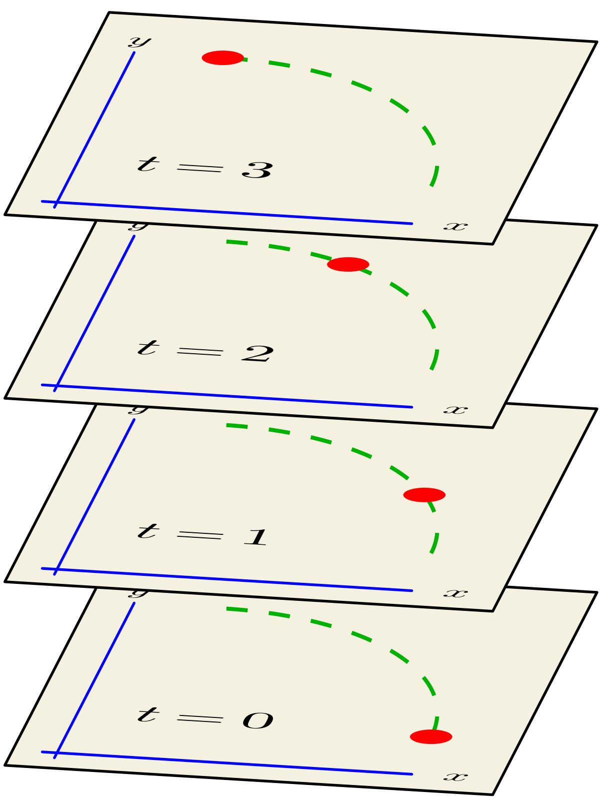

Figure 2

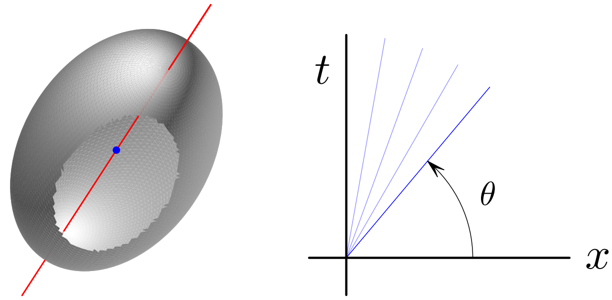

Figure 3

dot in the left half of Figure 3. It allows us to assign a single point location to what may be a large, complex object.

The *axis* is obtained by fitting a line to an object. This is shown by the red line in the left-hand side of the figure. In the two dimensional case, it allows us to define an overall spatial orientation for an object. In the 3D case, because one of the dimensions is nonspatial, the axis carries new information. In addition to spatial orientation information, the inclination of the axis from the vertical (see the right-hand side of the figure) gives information on average velocity for the object.

3.4 *Matching and Merging*

Attributes are used to answer the question of which objects "go together." There are two aspects to this: first, associating objects in the forecast field with objects in the observation field, and second, associating objects in the same field with each other, The first is called *matching*, and the second is called *merging*. A fuzzy logic engine is used for both.

In general, the two operations are done concurrently, information from one ongoing process being used to assist in the other.

4 RESULTS

In Figure 4 we see an example 3D object field—observed field on the left, and forecast on the right. The colors are a form of depth-cueing—useful when looking at a static image as opposed to an animation. The colors run through the spectrum from blue in the west to red in the east. Since we're looking at these objects from the west (roughly), blue things are close to us, and red things are far away.

We have noticed that in the 3D case, the forecast object field almost always has a more complicated structure than the observed field. We're looking for ways to describe and quantify the complexity of the object field so that we can turn that subjective interpretation into something objective. Also, we may want to stratify the verification statistics by complexity.

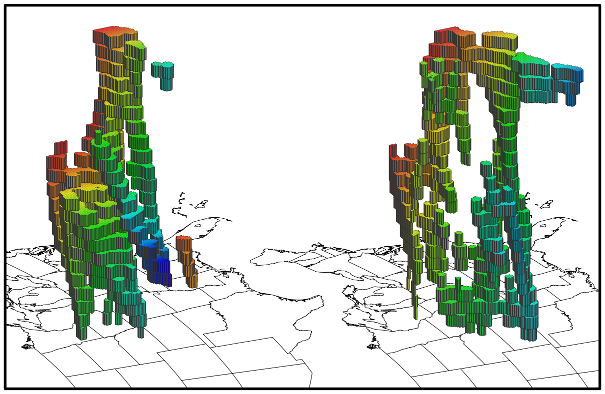

Figure 4

5 CONCLUSIONS & FUTURE WORK

This method has been under development for some time now, and is ready to be implemented in the next MET release. It offers a way to do verification over time, track objects through time, and visualize and quantify changes such as splitting and merging of features during their evolution.

6 ACKNOWLEDGEMENTS

NCAR is sponsored by the National Science Foundation. This research is in response to requirements and funding by the Air Force Weather Agency (AFWA). The views expressed are those of the author and do not necessarily represent the official policy of AFWA or NCAR.

The author would like to thank Barb Brown and Chris Davis, my co-workers on is project.

7 REFERENCES

Davis, C. A., B. G. Brown, R. G. Bullock and J. Halley Gotway, 2009: The Method for Object-based Diagnostic Evaluation (MODE) Applied to Numerical Forecasts from the 2005 NSSL/SPC Spring Program. *Wea. Forecasting*, 24 (5), 1416–1430, 24 (5), 1252–1267, DOI: 10.1175/2009WAF2222241.1.