

A NOVEL VECTOR FIELD DATA MINING APPROACH: EXTRACTION OF FRONT BASED ON PHYSICAL FEATURES OF TARGET

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ABSTRACT:

The explosive growing of earth observing data needs to have relative efficient data processing methods. This paper aims at the processing and analysis of large volume of vector field data acquiring from satellite derived, or model assimilation, an approach of fronts extraction from vector field data was proposed. The study is based on the assumption that the distribution of feature vectors for front and non-front are significantly different. A front is represented as a multi-dimensional feature space composed by a set of physical features acts as feature vectors. On the basis of the characteristics analysis of vector field data and the physical feature of fronts, a five-step front extraction process was illuminated in detail, including physical feature abstraction of target, physical features spatialization and multi-dimensional feature space construction, feature space segmentation, identification of possible front and post-processing. By expert knowledge, speed, vorticity, and the direction variation of vector field were chosen as feature vectors, Fuzzy Clustering method is used to segment the feature space into several regions, and get the possible front. For the filtering of the candidate regions and the identification of possible front, principal components analysis and the domain knowledge were used, followed by a hierarchical threshold technique and other post processing techniques for the removing of false regions. To illuminate the application of the approach, the extraction of ocean front from ocean current field data was taken as an example. Experimental results show that the extracted fronts are in good agreement with the ones identified by Sea Surface Temperature (SST) image. Furthermore, the approach is universal for all kinds of front extraction from vector field data, including the extraction of air front system from wind field.

1. INTRODUCTION

With the development of earth observing technology, more and more scientific data are acquired by earth observing instruments onboard polar orbiting satellites, model assimilation and model reanalysis. These data provide rich information related to the properties and dynamics of the earth's land, oceans, and atmosphere. Moreover, they are characterized by large volumes, high dimensionality, and possess Spatio-Temporal attributes. Vector field data with the property of dynamic both over spatial and temporal, and changing over time in intensity and direction is one of the most popular and useful kind. As most of them are closely related to phenomena in physics, oceanography, and meteorology, it's one of gigantic subjects to explore novel scientific knowledge and features from such mass, multi-dimensional, dynamic, and heterogeneous data scientific data sets. Data mining technique which is a valuable and effective way in the processing and analysis of large volumes and heterogeneous data is helpful in finding the knowledge hiding behind amount of data, and have some application in scientific data mining area (Ertöz, L., *et al.*, 2003; Steinbach, M., *et al.*, 2003; Jiang, M. *et al.*, 2003).

A front is a narrow transition zone where two masses with significant different properties meet, The masses can be air, water, sound and other dynamic matters. According to the

causing masses, it can be divided into thermal front, salinity front, density front, sound front and so on. Fronts have distinct shapes but vary depending on their types. Generally, they appear as elongated stripes or comma-like curve regions, and covering a bewildering range of scales: from 100 m to 10,000 km along-front; from 10 m to 100 km across-front; from 1 m to 1 km down-front (Belkin, I., 2002); They can be permanent large-scale features, or transient mesoscale features usually occurring seasonally with more diffuse boundaries (Valavanis, V.D. *et al.*, 2005). Fronts are significant geographical phenomena. They are always accompanied by current jets, convergencies, eddies, subsurface intrusions and lenses, and are associated with strong mixing and stirring, elevated bioproductivity and ecotones, acoustical wave guides, marginal ice zones and atmospheric boundary layer fronts (Belkin, I., 2002). Lots of studies show that fluids have significant relationship with the evolving of fronts, the front is always evolves at the regions with high vorticity, and high velocity of fluid. Moreover, the intensity of fronts is determined by the values which induce their development. The shape, location are also have significant relationship with these factors (Li, X., *et al.*, 2005; He, Z.G., 2005). The objective of this study is front extraction from huge amount of vector field data. The rest of this paper is organized as follows. Firstly, in Section 2, characteristics of vector field data, as well as related works on vector field data mining and front

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extraction approaches are introduced. Section 3 is the principle of vector field data mining approach, the extraction method of front based on physical features of target is presented in detail. Section 4 is a case study of extraction oceanic front from current field. Conclusions and ongoing work were given in the end of the paper.

2. RELATED WORKS

2.1 Characteristics of Vector Field Data

Vector field is defined as each point in the field which has associated with it a vector which represents the flux in the field at that point (Boker, S.M., 1995), namely, the values and orientation of each point in the vector space form the vector field. Wind field, magnetic field, gravitation field, and current field are the general fields, while Gradient, Curl, Divergence are the basic physical measures of vector field. As to the geosciences data, vector field data like wave, tide, wind, current are valuable spatial data. They are always the force of geophysical phenomena which are closely related to human life, like storms, tornados, hurricanes, etc. They are usually obtained from in-situ observation, satellite derived or model reanalysis. The characteristics of these data are as follows:

1. High dimension

Because of the orientation characteristic of vector field data, they are always stored or represented in vector or scalar quantity, like U and V fields or intensity and directions in two dimensional space or U, V and W fields in three dimensional space.

2. Dynamic

Evolving at times, the vector field data owns the dynamic nature over spatial and temporal, and changing over time in intensity and direction.

3. Large volumes

The high dimensional and dynamic characteristics, leading to the volumes of vector field data rather complex and large. Furthermore, the advances in technology also make the data volumes in the terabyte and petabyte range. So it is extremely a big challenge for the analysis of these data.

2.2 Vector Field Data Mining Approach

The typically used vector field data mining approach can fall into four categories: (1) Methods based on data statistics. These methods are based on the assumption that the region of interest is homogeneous and distinct from background. The normally used thresholding and segmentation methods, as well as Phenomena Extraction Algorithm (Ramachandran, R., *et al.*, 2006) are included. The PEA used KD-tree data decomposition strategy to segment the original image into sub-regions hierarchically, and statistical tests were used to determine if the region contains data points with abnormal intensities or large variations of intensities compared to the data statistics of the global image. The algorithm was used in the extraction of tropical cyclones, surface frontal system and troughs. (2) Machine learning/image processing algorithms. The hybrid object-based/pixel-based classification approach (Li, X., *et al.*, 2005) which is a specialized machine learning and image processing method. It was used for the extraction of frontal systems. (3) Domain knowledge based heuristic algorithms. Spencer *et al.* (2001) used domain knowledge about temperature, wind speed and other physical parameters to detect tropical cyclones from the Advanced Microwave Sounding Unit-

A(AMSU-A).(4) Multi-scale theory. Due to discrete wavelets transform can extract major dominant factors from data, it is applied for compressing the image data and extracting the major characteristics from magnetic vector field data which are variable in space and time. (Sawa, M., 2005).(5) Using current velocity data. After analyzing the relationship between the oceanic fronts in the southeast Indian Ocean and the strong geostrophic currents, He, Z.G. (2005) used the Acoustic Doppler Current Profiler (ADCP) current velocity data for the identification of the main fronts in the southeast of Indian Ocean for the first time. The locations, velocity, width and possible variations of fronts were also analyzed.

It can be included that though with plenty of information evident or potential, since the restriction of complication and large volumes, vector field data have not been sufficiently used for potential knowledge discovering in geosciences, even though some preliminary researches have been done in geophysical phenomenon extraction, like front systems, cyclones, troughs and so on.

2.3 General Frontal Extraction Approach

General fronts extraction approach uses satellite imagery of sea surface temperature (SST), height, colour, as well as chlorophyll (CHL), and fronts are always considered as regions where the gradient of SST and CHL changed a lot, or the peak value appears (Belkin, I., 2002; Andrey, G., *et al.*, 2004). Nevertheless, the results of the gradient and histogram methods depend on the targeted scale of fronts, thus some spatially small or weak fronts may not be detected in a mesoscale level. Time series of satellite data were also used for the identification of fronts (Bonatti, J.P., *et al.*, 1999), Ullman and Cornillon (2000) considered this method provide acceptably accurate statistics on front occurrence. Valavanis V.D. (2005) proposed a "sink" method for the identification of mesoscale transient thermal fronts. Thermal fronts are handled as data value sinks in SST lattice data arrays. Automated edge-detection, the histogram and gradient algorithm were used for the processing of SST satellite. This method can even detect the weakest thermal discontinuities. Shaw, A.G.P. *et al.* (2000, 2001) suggested a front-following algorithm for the extraction of front from AVHRR SST imagery. It utilizes a hyperbolic tangent function in a surface-fitting technique to follow an oceanic front. The algorithm has the advantage of describing the characteristics of an oceanic thermal front (including mean SST, SST difference, width and gradient across the front) and extracting information on the position and characteristics of the front into parameter form. Moreover, it can record the changes in the characteristics of the thermal front as it tracks along the front. Xue C.J. *et al.* (2007) made use of the characteristics of weak edge of ocean front, and used Harr wavelet to detect the edge of temperature fronts in Mexico Gulf.

The common characteristic of these methods is the using of satellite imagery of SST, height, and colour. The relative vector field data from numerical assimilation or observation were rarely used. Furthermore, most of these methods are pixel-based, the physical features of targets were rarely considered.

3. METHODOLOGY

The objective of this paper is extracting front (including front system in the meteorology and ocean front in hydrology) from vector field data. The approach involves five main steps: (1)

physical feature abstraction of target; (2) physical feature spatialization and multi-dimensional feature space construction; (3) feature space segmentation; (4) identification of possible fronts and (5) post-processing. A Flow diagram of the whole extraction procedure is shown in Figure 1. Data and images are plotted in round rectangle, while the processing methods are in rectangle.

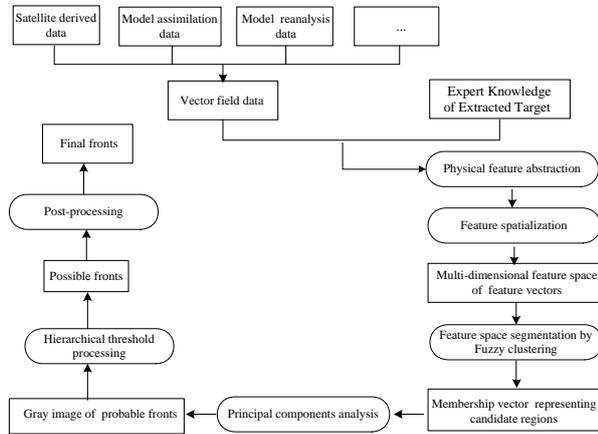


Figure 1 Flow diagram of vector field data mining

3.1 Physical Feature Abstraction of frontal by Expert Knowledge

A feature is a pattern occurring in a dataset that is of interest and that manifests correlation relationships between various components of the data (David, S., Thompson *et al.*, 2002). Physical features are those features can determine their evolving, growing and perishing. Physical feature abstraction is the preliminary task and vital step for front extraction. Due to the characteristics it owns, a front can be represented as a multi-dimensional feature space composed by a set of physical features acts as feature vectors. Domain knowledge was used for the selection of these physical features. A frontal system is normally characterized by moderate to high values in these values (Li, X., 2005), through analysis, speed (speed), vorticity (vor), and the direction variation of vector field (vdir) were chosen, for these factors determine the evolving of fronts well. Among these vectors, vorticity is a significant feature to represent the spatial variation of flow field, and the variation of direction characterizes the direction change of flow. These physical features chosen all can be derived from vector field data.

3.2 Feature Spatialization and Construction of Multi-dimensional Feature Space

Before analysis, the physical features need to be spatialized at first. The multi-sources vector field data which may come from satellite derived, observation station, or model assimilation, resulted in the data formats are rather different, e.g. HDF, NetCDF, NC, Binary, ASCII, Text and so on. So the basic vector field values of horizontal and vertical value of fluid u , v , or intensity and angle needs to be abstracted from these data with diverse formats, and form a grid space at the very beginning. On account of the absence of some vector field data because of the weather influence, resolution of satellite sensor, or the limitation of observation sites' location, it is necessary to

interpolate the data at times, nearest neighbor interpolation, linear interpolation, spline interpolation are the general method. For each grid, Vorticity can be estimated by calculating some numerical schemes, like Stokes theorem represented in formula (1), Least Squares Schemes represented in formula (2), as well as Richardson Extrapolation Scheme. The other two physical features can be calculated by the following formula:

$$vor_{i,j} = \frac{1}{8 \times \Delta x \times \Delta y} [\Delta x \times (u_{i-1,j-1} + 2u_{i,j-1} + u_{i+1,j-1}) + \Delta y \times (v_{i+1,j-1} + 2v_{i+1,j} + v_{i+1,j+1}) + \Delta x \times (u_{i+1,j+1} + 2u_{i,j+1} + u_{i-1,j+1}) + \Delta y \times (v_{i-1,j+1} + 2v_{i-1,j} + v_{i-1,j-1})]$$

where $vor_{i,j}$ = the vorticity of point (i,j)

Δx = the length of latitude for each grid

Δy = the length of longitude for each grid

$u_{i,j}$ = the flow value in x direction

$v_{i,j}$ = the flow value in y direction

$$vor_{i,j} = \frac{1}{10 \times \Delta x} (2v_{i+2,j} + v_{i+1,j} - v_{i-1,j} - 2v_{i-2,j}) - \frac{1}{10 \times \Delta y} (2u_{i,j+2} + u_{i,j+1} - u_{i,j-1} - 2u_{i,j-2})$$

$$vdir_{i,j} = \frac{1}{N} \sum_{k,l} \Delta dir_{k,l}$$

$$\Delta dir_{k,l} = \begin{cases} |dir_{k+i,l+j} - dir_{k,j}|, |dir_{k+i,l+j} - dir_{k,j}| \leq 180 \\ 360 - |dir_{k+i,l+j} - dir_{k,j}|, |dir_{k+i,l+j} - dir_{k,j}| > 180 \end{cases}$$

where $dir_{i,j}$ = the fluid direction of point (i, j).

$k = \{p \mid p \in Z, -1 \leq p \leq 1\}$,

$l = \{q \mid q \in Z, -1 \leq q \leq 1\}$,

$N=8$.

Each physical feature represents one dimension feature vector of a grid, and the three physical features construct a three dimensional vector feature space, shown in Figure 2. The first two steps can be seen as data pre-processing, which provides a good foundation for the following analysis.

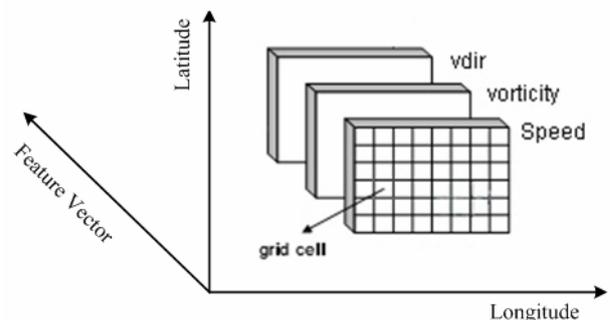


Figure 2 Three-dimensional feature space

3.3 Segmentation of Feature Space

The following process is based on the assumption that the distribution of feature vectors of front and non-front are significantly different, thus they clusters at different regions in the space. The Fuzzy Clustering method is used to segment the feature space into several regions. It is an unsupervised classification wherein each data point belongs to a cluster to some degree that is specified by a membership grade, rather than a certain value represents whether a point belongs to the object. By iteratively updating the cluster centers and the membership grades for each data point, we can get a list of cluster centers and several membership grades for each data point. It can be represented by formula (5) and formula (6).

$$D_j = \sqrt{\sum_{i=1}^N (V_i - C_{i,j})^2} \quad (5)$$

$$P_j = \left(\sum_{k=1}^K \frac{D_j}{D_k} \right)^{-1} \quad (6)$$

Where C = the center of each class

V = the physical feature vector

D = the distance of each point to each cluster

P = the membership vector representing the distance of the feature vector to each of the cluster centers.

$N=3$

K = the number of cluster

Due to this method is sensitive to the initial cluster center, so the choice of initial cluster center is fatal to the precision of clustering result. The following heuristic approach (Li,X., *et al.*, 2005) or iterative approach can be used for the identification of initial cluster center.

3.4 Identification of Possible Front

From step (3), candidate regions of fronts are obtained from the membership grades. For the filtering of the candidate regions and the identification of possible front, principal components analysis and the domain knowledge are used. As it is known that a front is characterized by moderate to high values in speed, vorticity, and variation of direction. The possible fronts are those with high score in the membership grades. For the filtering of regions with lower scores, a hierarchical threshold technique is used to avoid the influence posed by uniform threshold values too big or too small. Possible frontal regions are only those identified at each threshold level. It should be pointed out that since the units of the three vectors are different, the normalization processing is necessary before analysis.

3.5 Post processing

The possible frontal regions obtained are not all the real fronts, since some false regions may be also extracted. Therefore it is necessary to filter the noise and spurious information. Due to fronts always have large temperature gradient except for the characteristics of high velocity, variation of direction, as well as vorticity, the temperature gradient was used for the filtering of the false information. The regions whose horizontal gradient is smaller than 0.04° C/Km are seen as non-fronts regions.

4. CASE STUDY

To illuminate the application of the approach, the extraction of oceanic front from ocean current field data was taken as an example in the following section. With high salinity and temperature, oceanic fronts often associated with high productivity levels (Valavanis, V.D. *et al.*,2005). Its study is significant and meaningful in marine fisheries, environmental protection, offshore dumping, and marine perils. For the filtering of the false information of the possible fronts and the evaluation of extraction result, the Sea Surface Temperature (SST) image was used.

4.1 Data and Study Area

Current field data used in this study is from Archiving, Validation and Interpretation of Satellite Oceanographic (AVISO) which is a satellite altimetry product from Topex/Poseidon, Jason-1, ERS-1 and ERS-2, EnviSat, and Doris precise orbit determination and positioning. The data field has a resolution of (1/3) ° Mercator grid resolution. The u and v current fields data were provided every two months from October 1992 to July 2001, and daily later on.

The study area covers Northern Gulf Stream area from 34° N~44° N latitude and 64° W~76° W longitude. The Gulf Stream is the western boundary current of the N. Atlantic subtropical gyre. It begins upstream of Cape Hatteras, where the Florida Current ceases to follow the continental shelf. The position of the Stream as it leaves the coast changes throughout the year. It shifts north in the fall, while in the winter and early spring it shifts south (Gyory, J. *et al.*). The current data of 1 May 2003 was used for the analysis of fronts. Figure 3 is the Oceanic Current field plot of North Gulf Stream, where the color and length of the arrow represent the intensity of the current. The orientation of the arrow represents the direction of the current. It is clearly that the stripe region in the middle of the plot is in high velocity, and veering greatly. The region in white color in the left-top of the plot is the land area without current data. Figure 4 is the Sea Surface Temperature (SST) image from AVHRR for a time interval of 2.67 days ending in 2 May 2003. The region with gray color in the left-top of the image is land area of Florida. Since Gulf Stream system is strong enough and with evident thermal gradients to be readily seen, the Gulf Stream Front can be easily identified from SST image, namely, the stripe region in deep orange color.

4.2 Results and Discussion

The oceanic current data used is in NC format, the horizontal and vertical values of U and V were extracted and interpolated. Vorticity value is calculated using the least squares scheme. A iterative approach is used for the identification of the cluster numbers and the choosing of initial cluster centers. By performing the approach proposed step by step, the possible and final front is obtained. Figure 5 is the gray image of the possible fronts, the whiter the region looks, the more likely it belongs to a front; Figure 6 is the binary image of possible front after hierarchical threshold processing and the holes filling in the front regions. Regions of a, b, c, d, e, f in Figure 6 are the six possible frontal regions. Figure 7 is the final front after post-processing. Region b and e were filtered because of their low gradient values in SST image.

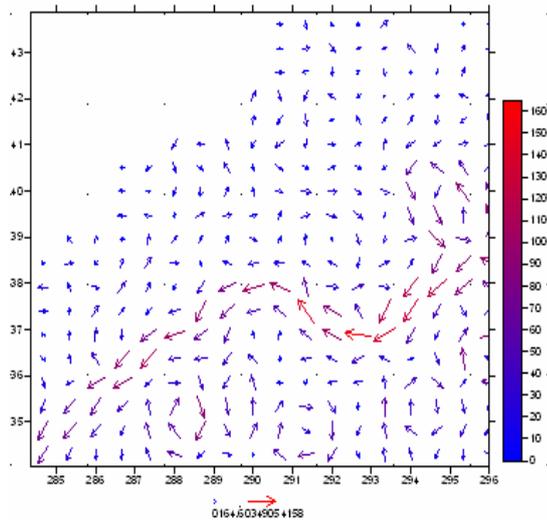


Figure 3 Oceanic current plot

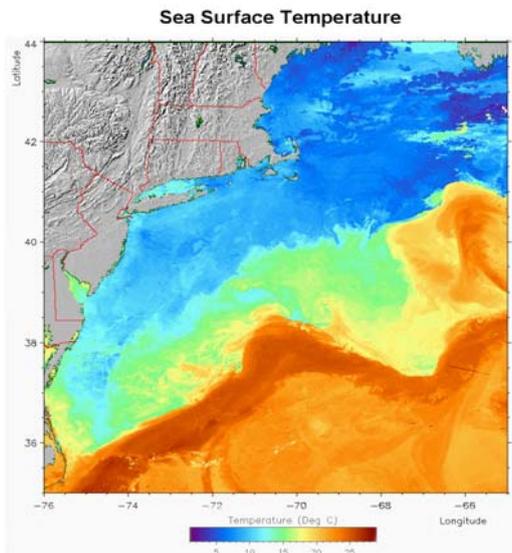


Figure 4 Sea Surface Temperature(SST) image from AVHRR for a time interval of 2.67 days ending in May 2,2003

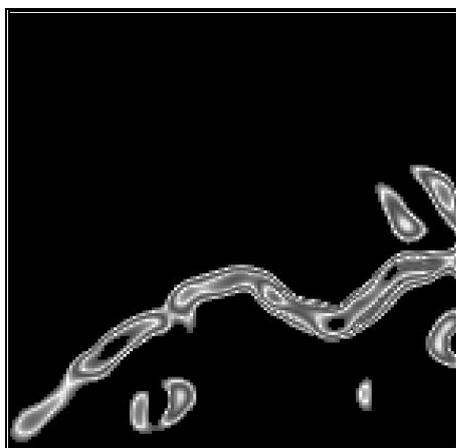


Figure 5 Gray image of possible front

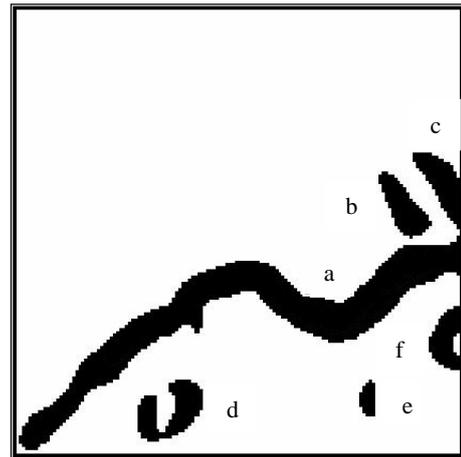


Figure 6 Binary image of possible fronts after filling the holes.

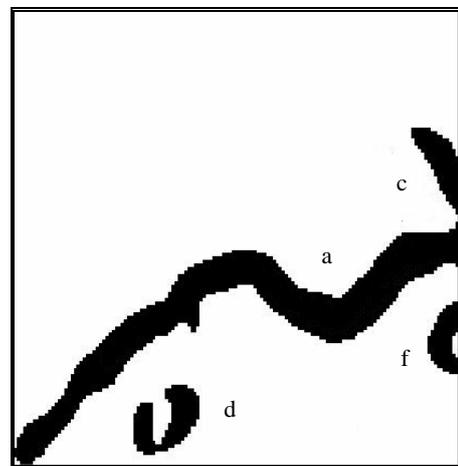


Figure 7 The final fronts

From SST image series, it is clearly that the identified fronts c, d, f are eddies around front a. They were also extracted because they possess nearly the same physical characteristics with fronts, and they are always accompanied with fronts. By comparison with the SST image, it can be concluded that except for the eddies, the location and shape of Gulf Stream Front extracted by the approach proposed in this paper is generally coincide with that identified from the SST image.

Since the precision of the current data used in this paper is a little bit low, the extraction precision may be depend on the interpolation method to some degree.

5. CONCLUSION AND ONGOING WORK

The explosive growing of earth observing data needs to have relative efficient data processing ways. The vector field data mining approach proposed in the paper is based on the physical feature of object, and is not only suited for large-scale fronts, but also mesoscale ones. It is a good attempt for the vector field data mining approach for multi-source data, not only the normally used remote derived data, but also model assimination data, and observation data, and thus to be an effective way for target extraction from vector field data. Experimental results show that the extracted oceanic fronts from current field data are generally in good agreement with the ones identified from

SST images. Furthermore, the approach is universal for all kinds of front extraction from vector field data, including the extraction of air front system from wind field. Nevertheless, some field knowledge is needed in the identification of real front, and eddies may be also interrupted. Additional studies are required to take the shape of fronts into account in the extraction process to avoid the influence of eddies. Moreover, further analysis of the shape and location change rules discovery of fronts using the mining results of current data in a long time series is also challenge and meaningful, and is planned as part of future work.

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