The Estimation of Mesoscale Ocean Eddies Change Based on CBR

Yunyan Du [a], Chenghu Zhou [a] Lijing Wang [a, b], Guangya Qi [a], Xinzhong Yang [a, b]
[a] State Key Laboratory of Resources and Environmental Information System, Institute of Geographic Science and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101
[b] Geomatics College, Shandong University of Science and Technology, Qingdao 266510

KEY WORDS: Artificial Intelligence, Case-based Reasoning (CBR), Mesoscale Ocean Eddies, Spatial Relationships, Rough set

ABSTRACT:

Case-based reasoning (CBR) method has been widely used to study geographical problems during the past two decades. However it is still not perfect particularly when employed to solve complicated geographical problems. Urgently needed improvement includes development of geographic data representation modeling and design of algorithm for spatial similarity computation and reasoning. This paper reports an improved CBR-based method for studying the spatially and temporally complex Mesoscale Ocean Eddies (MOEs). After summarizes the basic advantages and challenges of current existing quantitative methods, the paper first proposes that CBR approach, with support of GIS, can be employed to study variation of MOEs. Representation model was constructed to describe the case, i.e., MOEs. This paper then provides an algorithm to retrieve the inherent spatial relationships among cases, as well as a CBR similarity reasoning algorithm to predict change of MOEs. The method was finally tested by examining the MOE in the South China Sea and yields an average estimation accuracy of 80%. In summary, the CBR-based approach proposed in this study provides an effective and explicit solution to quantitatively analyze and predict the change of MOEs.

1. INTRODUCTION

A variety of methods have been widely used to study change of MOE. These approaches can be categorized into either static or dynamic analysis. The first method indirectly studies ocean eddies by examining variations in marine water masses. The latter one studies characteristics of ocean eddies by analyzing the flow direction and velocity of ocean currents, either by using conventional analysis methods to study data derived from field survey or remote sensing, or by numerically simulating the ocean current and eddy(Du et al., 2004). Specifically, methods used to study MOE include numerical simulation, mathematical statistics, remote sensing information extraction (Hough change, multi-fractal), and the P vector (P-Vector) method. Numerical simulation method mainly uses the Princeton model (POM) to examine the characteristics of ocean eddy（Yang et al.,2000; Li et al.,2003）. Statistical methods study the spatial and temporal distribution pattern of ocean eddy by quantitatively examining long sequence of marine data derived from remote sensing techniques (TOPEX / Poseidon, altimeter, MODIS, NOAA and SeaWiFS)(Qian e tal.,2000; Lin, 2005). Remote sensing methods mainly focus on extracting quantitative information of MOE from different platforms (Wang et al., 2001, 2004; He et al., 2001; Ge et al., 2007).

Although these studies achieved valuable results in regarding to the developing mechanism and distribution pattern of MOE, as well as their own self parameters. However, some limitations still exist in these methods. The numerical simulation approach can provide continuous time series data to describe change of MOE. Unfortunately, time consuming is a big issue for this method as the parameters must be retuned and simulation must be rerun due to change of the boundary conditions when different regions are studied. Statistical methods, to somewhat extent, can present the spatial and temporal distribution patterns and movement trend of MOE. However, there is no way for these methods to quantitatively predict the occurrence of ocean eddy. While remote sensing is able to quantitatively extract the local spatial information and parameters of MOE, it is unable to analyze and predict its evolution trend. Therefore, a new method is in great of need. If the new method can absorb the advantages of those above-mentioned methods, it will serve better to study the MOE.

CBR is a method used to solve current geographical problems based on reasoning from historical similar cases. This method is capable to quantitatively analyze and predict geographic phenomena by examining enough existing historical data, even without any knowledge about their developing mechanism. CBR is a comprehensive problem-oriented analysis approach. CBR has already been widely used to study geographical problems since 1990s and yielded quite a few promising results (Jones et al., 1994; Du et al., 2002; Li, 2004). However, majority of these studies either focus on the direct application of traditional CBR approaches to solve geographical problems, or only consider the spatial attributes of geographical problems. Current CBR methods are not perfect enough to solve complicated geographical problems, particularly those with significant zonal and territorial differentiation. Therefore, research is necessary to develop improved case representation modelling and enhanced algorithms for similarity computation and reasoning]. This paper, from a new methodological perspective, uses CBR methods to quantitatively analyze and estimate the MOE change.

2. CBR FOR ESTIMATION OF MOE CHANGE

2.1 Case Representation Model

To better describe spatial distribution characteristics and relationships of the geographical problems, this paper proposed a three-component representation model by adding a new component, “geographical environment” into the traditional dual-mode model. As a result, case in this paper consists of three components, including “problem”, “geographical environment”, and “outcome”. By adding the “geographical environment” component, case representation model is able to consider the influence of marine environmental variables on the development of eddy. Spatial information of ocean eddy is also integrated into the “outcome” component.

2.1.1 Conceptual definition of three-mode representation model: The “problem” component of an ocean eddy case refers to “the situation of an eddy after a certain time interval”. The “geographical environment” refers to those ocean physical environments that influence the development and variation of MOE, usually including eddy’s spatial position, seabed terrain characteristics, water features (such as the ocean temperature, salinity, ocean current, density), and some other spatial-temporal information. The geographical environment can be described by 1- or n-dimensional GIS spatial feature layers or simply by some spatial indicators. The “outcome” component is defined as the situation of a MOE after a certain time interval, for instance, the variations in its travel speed, direction, and intensity.

2.1.2 Case representation and organization: In this research, the “problem” is described by some quantitative attributes of an ocean eddy, including, but not limited to, its travel direction, speed and intensity. The “geographic environment” component is represented by a series of quantitative indicators of MOE attributes and its spatial relationships (e.g., the relationships of direction, topology, and distance) to the adjacent ones. The last component, the “outcome”, is the attributes of the successive eddy after a certain time interval. As a result, case can be described using equation (1):

$$Case_i = \left\{ \begin{array}{l} S_i, SA_{1i}, SA_{2i}, \ldots, SA_{ji}, SR_{1i}, SR_{2i}, \ldots, \\ SR_{li}, Vortex_{t1i} \rightarrow Vortex_{t2j} \end{array} \right\}$$

$$i = 1,2,..K; j = 1,2,..M; l = 1,2,..N; \tag{1}$$

$$S_i = \{(x_i^1, y_i^1), (x_i^2, y_i^2), \ldots, (x_i^m, y_i^m)\}$$

Where i is the case number; Si is a set of spatial shape attributes of case i, i.e., the coordinates collection of polygonal boundary of an eddy; SA_{1i}, SA_{2i}, …,SA_{ji} are the attributes (totally M) of case i; SR_{1i}, SR2i, …,SR_{li} refer to the spatial relationships (totally N) between case i and the geographical environment factors; Vortex t1i → Vortext2i is the case “outcome”, i.e., the situation of an ocean eddy after a certain time interval.

2.2 Extracting Spatial Characteristics of MOE

Rough set is an approach used to study the data representation, learning, and induction from incomplete knowledge and data with certain uncertainty. No prior information other than data set itself is required. This method is able to extract the decision-making or classification rules by knowledge simplifying while maintains enough classification accuracy (Ding, 2004). This paper uses rough set theory to extract the decision-making rules from historical cases of MOE. Specific algorithm used in this study includes three basic steps:

(1) Description of the prior spatial relationships among eddies based on rough set theory

As shown in Figure 1, several specific spatial relationships impacted MOE change, such as topological relationships, the distance to the Kuroshio axis, and the distance to shoreline and so on, were selected based on previous research results or experiences. These spatial relationships were then converted into quantitative indicators by using GIS spatial analysis methods. Spatial decision-making table is then constructed, with row representing historical cases and column showing attributes. The first part of column records conditional attributes, including indicators of spatial relationships while the other part of column documents decision-making attributes, i.e., the ”result” of case.

(2) Discretizing continuous variables in the spatial decision-making table using different methods based on different conditional attributes.

(3) Simplifying spatial relationships in the decision-making table using attribute simplifying algorithm. Decision-making spatial relationships which determine the case outcome are extracted and decision-making rules are finally retrieved.

2.3 Case Similarity Calculation and Reasoning

Nearest neighbourhood method was usually used in traditional CBR approach to compute the similarity among cases based on the assumption that two cases have similar but completely independent attributes. As spatial relationships among cases, as well as between cases and environment, were all considered in the representation model proposed in this study, nearest neighbourhood method cannot be used to calculate the similarity among cases. In this study, general similarity among ocean eddy cases was calculated by equation (2).

$$Similarity_{Case(i,j)} = w_1 \times S_{r(Case(i,j))} + w_2 \times S_{a(Case(i,j))} + w_3 S_{s(Case(i,j))} \tag{2}$$

Where w_1, w_2, and w_3 are weights assigned to different similarity coefficients and $w_1 + w_2 + w_3 = 1$. $S_{a(Case(i,j))}$, $S_{r(Case(i,j))}$, and $S_{s(Case(i,j))}$ are the similarity coefficients between case *i* and *j*’s attributes, spatial relationships, and shapes respectively. In equation (2), $S_{a(Case(i,j))}$ was calculated same as the traditional CBR using Euclidean distance algorithm.

In equation (2) $S_{r(Case(i,j))}$ was calculated using equation (3):

$$S_{r(Case(i,j))} = w_{dir} \times S_{dir(Case(i,j))} + w_{top} \times S_{top(Case(i,j))} + w_{dis} S_{dis(Case(i,j))} \tag{3}$$

Where w_{dir} 、 w_{top} and w_{dis} are weights assigned to different similarity coefficients and $w_{dir} + w_{top} + w_{dis} = 1$. $S_{dir(Case(i,j))}$, $S_{top(Case(i,j))}$, and $S_{dis(Case(i,j))}$ are the similarity coefficients between case *i* and *j* in relationships of spatial direction, topology, and distance respectively. They can be calculated by the traditional GIS spatial relationship algorithm (Goyal, 2000).

Usually different similarity calculation methods are used to compute $S_{s(Case(i,j))}$ in equation (2) based on the geometric shape. For example, if the geographical cases are linear features, a “similarity calculation algorithm of Radius Vector Serial Analysis Model Based on Barycentre (RVSAMB)” can be used to calculate the $S_{s(Case(i,j))}$,(Du et al., 2002), while “an approach to similarity measures for polygonal shapes based on mechanics" is used for polygonal cases(Fan et al., 2003).

Case reasoning was then performed once similarity coefficients were calculated. Historical cases with similarity coefficients greater than an arbitrarily-set threshold were first selected. "Outcomes" of these cases were then screened and different weights were assigned to the "outcomes" based on different values of similarity. Weighted average was then calculated and accepted as the "outcome" of current case.

3. CASE STUDY

3.1 Study Area

Method proposed in this paper was tested by studying the MOE developed in the SCS (0°-23°N, 99°-12l°E) from November 2003 to February 2009. The study region has an area of 3.5 million square kilometres. The SCS is a semi-enclosed basin with complex seabed topography, usually showing unique mesoscale variations in marine environmental conditions due to the influence of East Asia Monsoon and the Kuroshio. Many researches have provided valuable historical experiments and solid basis for employing CBR approach to study MOE in the SCS (Lin et al.,2007).

Raw data used in this study include stratified numerically simulated global sea surface height abnormity (SSHA), sea surface temperature (SST), and marine current. These data have a spatial resolution of 1/32x1/32 degree and provided by Navy Research Laboratory (NRL). The data are substantiated by multiple satellite images. For instance, SSH is substantiated by ENVISAT, GFO and JASON-1 while SST by IR satellite-derived data. Cases (MOE) studied in this paper are identified by expert based on three data groups. As shown in Figure 1, Typical ocean eddy is identified as those with a diameter no less than 100 km, height difference between eddy centre and the outmost closed contour no less than 8 cm, life span no less than 20 days, visible annular flow on the current map of MOE, and a current speed more than 0.5m/s in the eddy centre.

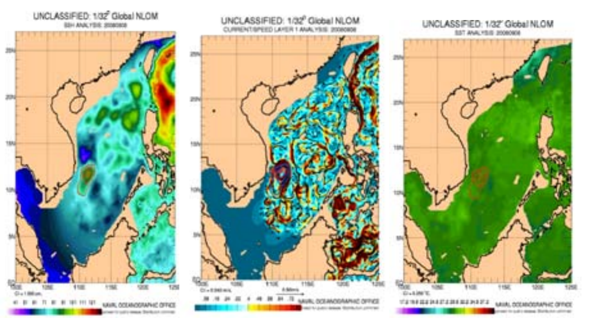

Figure 1 Example of a MOE in the SCS case. Data used to identify the eddy are also shown in this figure.

3.2 Estimation of Eddy Variation in the SCS

3.2.1 Representation and organization of cases: For this study, cases are represented by three components: "problem", "geographical environment", and "outcome". These three components are then quantitatively described. The "problem" is described by the shape and related spatial-temporal attributes of a specific eddy at a certain time, including the vortex number (ID), perimeter(P)，area(A), type(A_1), intensity(A_2), condition of the vortex at this time(A_3), horizontal scale(A_4), major axis length(A_5), minor axis length(A_6), time(A_8), and duration(A_9). Current research results indicate that development of ocean eddy in the SCS is significantly affected by the physical marine environment and the occurrence of other mesoscale phenomena in the same region. As a result, this paper uses four ocean environmental indicators and two spatial direction indicators to quantitatively describe the "geographic environment" component, including sea surface temperature in the vortex centre (F_1), temperature difference (F_2) between eddy centre and periphery, geographical longitude (Lo) and latitude (L_a) of the eddy centre, geographic azimuth of eddy opening (Dir_1), movement direction of eddy's main axis (Dir_2), and the eddy's movement velocity (S_p). The "outcome" refers to the eddy's intensity, direction, and movement speed at next moment. In summary, case of MOE can be represented by equation (4):

$$Case_i = \begin{Bmatrix} ID_i, P_i, A_i, A_{1i}, A_{2i}, \ldots, A_{8i}, F_{1i}, F_{2i}, \\ L_{oi}, L_{ai}, Dir_{1i}, Dir_{2i}, S_{pi}, \\ Vortex_{t1}(A_2, Dir_2, S_p) \rightarrow \\ Vortex_{t2}(A_2, Dir_2, S_p) \end{Bmatrix} \quad (4)$$

3.2.2 Extracting spatial relationships and case library construction: Indicators used in equation (4) must be calculated before establishing case library. The four ocean environmental indicators are determined by GIS grid analysis while the two spatial direction indicators are calculated by examining direction relationships among polygonal objects [18]. All indicators are calculated by executing a VBA- algorithm in ArcMap. Fifty typical MOE were selected and imported into the case library to test the CBR approach. As the MOE usually lasts a long time, its formation process is divided into 5 stages (birth, development, stabilization, weakening and extinction) for the purpose to reduce the number of case in the library while maintaining related information about eddy's evolution. One historical case was identified to match each of these 5 stages respectively. Table 1 illustrates an example of the case library, with each row showing one case, i.e., one of the 5 development stages of an ocean eddy. As a result, information of one eddy is described in 5 rows. Columns in Table 1 show the indicators used to quantitatively describe case in the representation model. Ten eddies were randomly selected as test cases (not showing in this paper) to test the estimation accuracy of CBR method proposed in this research.

Tab.1 The case library of MOE in the SCS from 2003 to 2009

OID	*ID*	A_1	A_2	…	F_1	…	Dir_1	…	*P*
1	1	Warm	11.22	…	29	…	none	…	984352
2	1	Warm	13.26	…	29.45	…	W	…	1835143
3	1	Warm	28.48	…	30.66	…	E	…	2559812
4	1	Warm	20.77	…	29.08	…	W	…	4395433
5	1	Warm	12.37	…	30.16	…	none	…	1887941
6	2	Cold	12.31	…	23.49	…	none	…	1066029

7	2	Cold	15.50	…	23.07	…	SE	…	903146
8	2	Cold	17.86	…	22.77	…	none	…	980633
9	2	Cold	20.61	…	21.74	…	S	…	1415178
10	2	Cold	20.96	…	22.04	…	S	…	1347750
…	…	…	…	…	…	…	…	…	…
246	50	Warm	15.46	…	29.27	…	E	…	1049085
247	50	Warm	14.98	…	28.82	…	W	…	1566574
248	50	Warm	15.35	…	28.48	…	SW	…	2713391
249	50	Warm	15.97	…	28.65	…	SW	…	2814450
250	50	Warm	15.69	…	29.41	…	SW	…	3034540

Note: Unit of each field in this table varies. Intensity (A_2), surface temperature in eddy centre(F_1), eddy polygon perimeter (P), eddy polygon area(A) are measured in centimetre, degree, meter, and square meter respectively. "None" in the field of eddy opening direction (Dir_1) suggests a closed eddy while the other value showing its opening azimuth.

3.2.3 Similarity Calculation and Reasoning: Once the case library is constructed, equations in section 2.3 are used to calculate similarity among historical cases and predict the "outcome". Equation (5) plays a more important role in this study as it describes the direction relationship. Different weights are determined and then assigned to different attributes and spatial relationships before the general similarity among cases was calculated. Based on previous research results, following weights are directly assigned to different indicators: P: 0.05, A: 0.05, A1: 0.1; A2: 0.1; A3: 0; A4: 0.15; A5: 0.05; A6: 0.05; A7: 0.05; A8: 0.15, F: 0.05; F2: 0.05; Lo: 0.05: La: 0.05: and Sp: 0.05.The threshold value for similarity extraction is set as 70% in this test. After obtaining similar historical cases, algorithm in section 2.3 is used to perform the reasoning with different weights assigned to different extracted historical cases based on the similarity value. Weights of 0.2, 0.3, and 0.5 were respectively assigned to similarity values falling within the range of [0.7, 0.8), [0.8, 0.9), and [0.9, 1].Calculation results were shown in Tables 2, 3. Each row in the table represents one ocean eddy, while the "predicted value" columns correspond to the forecast outcome of the eddy direction and movement velocity. The predication accuracy in the table shows that how well the forecast result matches the actual value.

Table 2 Predication result and accuracy of movement direction

Case No.	Value(development)		AC. (%)	Value (stabilization)		AC.(%)	value (weakening)		AC. (%)	value (extinction）		AC. (%)	Average AC(%)
	Estimate	Actual		Estimate	Actual		Estimate	Actual		Estimate	Actual		
11	North 76.51	N.E 55.35	94.12	North 77.76	North 97.35	94.56	North 90.58	North 78.95	96.77	North 107.95	N.W 125.73	95.06	95.13
16	North 74.67	North 111.44	89.79	North 78.76	N.E 39.37	89.06	North 98.12	N.W 143.24	87.47	North 95.47	N.E 45.57	86.14	88.12
20	N.W 112.53	N.W 120.48	97.79	North 70.62	North 91.51	94.20	North 89.29	N.W 152.48	82.45	N.E 57.77	N.E 55.79	99.45	93.47
27	North 69.97	North 111.33	88.51	North 80.07	North 80.61	99.85	North 92	East 15.1	78.64	North 99.07	West 169.37	80.47	86.86
33	North 87.18	N.E 44.99	88.28	North 83.74	N.W 146.34	82.61	North 83.45	N.W 114.09	91.49	North 112.32	N.W 128.41	95.53	89.48
59	N.W 121.05	N.E 56.32	82.02	North 84.24	N.W 139.63	84.61	N.E 65.51	N.E 33.91	91.22	North 89.99	N.E 62.89	92.47	87.58
62	*	N.W 146.92	*	*	N.W 113.26	*	North 83.08	East 18.64	82.10	*	N.W 128.31	*	82.10
73	N.E 49.69	North 84.13	90.43	N.E 45.59	N.W 131.58	76.11	North 110.92	East 22.1	75.33	North 81.89	North 72.71	97.45	84.83
77	East 14.27	North 103.03	75.34	N.E 155.02	North 108.9	87.19	N.W 136.31	N.E 35.79	72.08	West 174.92	N.E 46.64	64.37	74.75
80	North 92.94	N.W 129.54	89.83	North 73.71	East 21.87	85.60	North 74.12	N.W 119.12	87.50	N.W 112.5	North 83.4	91.92	88.71
Average Accuracy			88.46			88.20			84.51			89.21	88

Note: ＊indicates that no similar historical case can be identified in the case library under the given condition. As a result, no further attempts were made to predicate the movement velocity of this specific case. Direction is measured in angular degree. AC.means accuracy.

Table 3 Predication result and accuracy of movement speed

Case No.	Value (development)		AC (%)	Value (stability)		AC (%)	value (weakening)		AC (%)	value (extinction）		AC. (%)	Average AC.(%)
	P	Actual		Predicted	Actual		Predicted	Actual		Predicted	Actual		
11	10246.9	11961.7	92.9	8004.93	5154.61	88.16	6185.82	4145.33	91.52	10425.08	2358.33	66.49	84.76
16	11298.9	10027.2	94.7	9395.16	10587.7	95.05	6794.27	11462.74	80.61	10120.6	7577.43	89.44	89.96
20	6267.8	7226.6	96.0	5339.2	10978.3	76.58	5536.51	7941.14	90.01	5190.02	1685.5	85.44	87.01
27	10755.	10984	99.0	9323.92	6938.11	90.09	7230.63	4970.61	90.61	9765.13	7838.52	92	92.94
33	7111.8	5908.8	95	5541.57	8427.23	88.01	5969.03	5642.08	98.64	9512.17	6747.93	88.52	92.54
59	10520.1	942.4	60.2	8100.46	4002.56	82.98	5855.83	7465.94	93.31	7926.51	12293.4	81.86	79.59
62	*	2661	*	*	3263.79	*	5659.01	4748.39	96.22	*	15448.9	*	96.22
73	4525.4	5041.4	97.8	3191.43	2947.18	98.99	5589.74	1269.45	82.05	11959.4	1509.93	56.60	83.88
77	4726.7	618.4	82.9	1398.33	8695.48	69.69	1932.07	14675.5	47.07	2598.57	5322.16	88.69	72.10
80	5491.7	17164.2	51.5	5872.82	2751.12	87.03	5685.1	3204.71	89.70	9770.96	4529.37	78.23	76.62
Average accuracy			85.6			86.29			85.97			80.81	84.66

Note: ＊indicates that no similar historical case can be identified in the case library under the given condition. As a result, no further attempts were made to predicate the movement velocity of this specific case. Velocity is measured in m/day.

3.2.4 Results: Test results suggest that estimation accuracy of majority of these 10 cases is over 80% with an average of 86.6%. Estimation accuracy of eddy's movement direction and velocity is slightly low. No similar historical cases were found for some cases when the threshold was set at 70%. However, for those cases with corresponding similar historical cases, estimation accuracy is above 80%. Average estimation accuracies of movement direction and velocity are 88% and 84.6% respectively. Due to limited number of ocean eddy case in the case library, not all cases have similar historical cases and thus the predication accuracy is very low. Once more cases are added into the library increases, this problem can be easily solved and estimation accuracy can be improved significantly.
Type subheadings flush with the left margin in bold upper case and lower case letters. Subheadings are on a separate line between two single blank lines. The blank line after is added automatically when using the provided Word template file.

4. CONCLUSIONS

A new "geographic environment" component was introduced into case representation model of the traditional CBR approach, which was then used to study the change of MOE in the SCS. Experiment result indicates that the method proposed in this paper is simple, flexible, and practical in studying MOE change with satisfactory estimation accuracy. As the case study indicates, the CBR method is able to provide solutions to some application-oriented problems and hence is capable to perform quantitative simulation and complex analysis to study change of MOE. In addition, case library built using CBR method can be dynamically updated. Self-training is also possible as more cases were accumulated. Continuously absorption of the high-quality data and improved research results will further boost estimation accuracy. In summary, this method shows great potentials in predicting rapid change of MOE.

5. REFERENCES

Ding H. 2004. the study of space Similarity theory and the calculation model. Doctoral Dissertation of Wuhan University.

Du YY, Su F Zh,, Zhang T Y,Yang X M,Zhou Ch H. 2005. Research of case-based reasoning on Marine information space vortex characteristics similar. *Journal of Tropical Ocean*, pp. 24(3):1-9.

Du YY, Zhou CH, Sh QQ. 2002. Theoretic and Application Research of Geo-Case Based Reasoning. *Geography Journal*, pp. 2(57): 151-158.

Fan LT, Wu SY, Chen J. 2003. Tthe similarity measure based on the mechanics of polygon. *Journal of Shanghai Jiao tong University*, pp. 37(6):874-877.

GeY, Du YY, Cheng Q M, Li C. 2007. the Application of Multifractal methods in remote sensing information processing and Extraction of eddies. *ACTC Oceanologica Sinica*, pp. 9(29) : 40-47.

Goyal P K. 2000. Similarity Assessment for Cardinal Directions Between Extended Spatial Objects: [Ph. D Dissertation] . Orono: The University of Maine.

He ZG, Wang DX. et al. 2001. the vortex structure of the South China Sea in Satellite tracking buoys and satellite remote sensing of sea surface height. *Journal of Tropical Ocean*, pp. 20(1), 27-35.

Ji GR, Chen X, Jia YZ. et al. 2002. An Automatic Detecting method of the marine mesoscale eddy in remote sensing image, *Oceanologia et limnologia Sinca*, pp. 33(2), 139-144.

Jones, E.K, Roydhouse, A. 1994. Intelligent retrieval of historical meteorological data. *Artificial Intelligence Appl*, pp. 8(3): 43-54.

Lan J, Hong JL, Li PX. 2006. the seasonal variation characteristics of cold vortex of the western South China Sea in summer. *Progress in Earth Science*, pp. 11(21):1145-1152.

Li L. 2002. The Research Overview of Mesoscale ocean phenomena in the South China Sea.

Lin PF. 2005. Statistical analyses on mesoscale eddies in the South China Sea and the Northwest Pacific .Chinese Academy of Sciences Institute of Marine Research.

Lin PF ,Wang F, Chen YL, Tang X H. 2007. Temporal and spatial variation characteristics on eddies in the South China Sea. *ACTC Oceanologica Sinica*, pp. 5(29):14-21.

Li X, Xie JA, Liao QF. 2004. The use of case-based reasoning (CBR) method of radar images for land use classification. *Journal of Remote Sensing*, pp. 8(3):246-252.

Li Y Ch, Cai W L, Li L, Xu D. 2003. The seasonal and inter-annual change of MOE in the northeastern South China Sea. *Journal of Tropical Ocean*, pp. 5(22): 61-70.

Qian YF, Wang QQ, Zhu BC. 2000. the Numerical simulation of the cold and warm eddies formed by the South China Sea wind. *Atmospheric Sciences*, pp. 9(24): 625-633.

Wang DX, Chen J. et al. 2004. the ocean temperature ,salinity and circulation features of the central and southern South China Sea in August 2000. *Ocean logia et limnology Sinca*, pp. 35(2), 97-109.

Wang DX, Shi P. et al. 2001. The mixed assimilation experiment on TOPEX sea surface height data in the South China Sea. *Ocean logia et limnology Sinca*, pp. 32(1): 101-108.

Wang GZ. 2001. Rough Set Theory and knowledge acquisition. Xi'an: Xi'an Jiao tong University, pp.1-25.