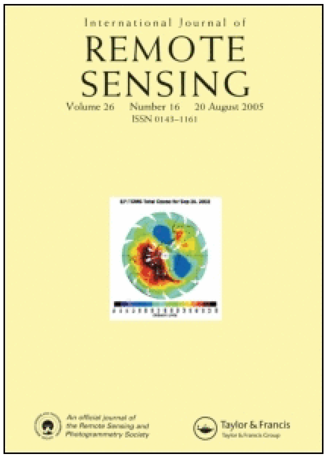

International Journal of Remote Sensing
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713722504

Application of the Active Learning Method for the estimation of geophysical variables in the Caspian Sea from satellite ocean colour observations

Taheri H. Shahraiyni [ab]; M. Schaale [a]; F. Fell [c]; J. Fischer [a]; R. Preusker [a]; M. Vatandoust [d]; Bagheri S. Shouraki [e]; M. Tajrishy [b]; H. Khodaparast [d]; A. Tavakoli [f]
[a] Institute for Space Sciences, Freie Universitaet Berlin, 12165 Berlin, Germany
[b] Department of Civil Engineering, Sharif University of Technology, Tehran, Iran
[c] Informus GmbH, 13355 Berlin, Germany
[d] Inland Waters Aquaculture Institute, Bandar Anzali, Iran
[e] Department of Computer Engineering, Sharif University of Technology, Tehran, Iran
[f] Department of Electrical Engineering, Amir Kabir University of Technology, Tehran, Iran

Online Publication Date: 01 January 2007
To cite this Article: Shahraiyni, Taheri H., Schaale, M., Fell, F., Fischer, J., Preusker, R., Vatandoust, M., Shouraki, Bagheri S., Tajrishy, M., Khodaparast, H. and Tavakoli, A. (2007) 'Application of the Active Learning Method for the estimation of geophysical variables in the Caspian Sea from satellite ocean colour observations', International Journal of Remote Sensing, 28:20, 4677 - 4683
To link to this article: DOI: 10.1080/01431160701442062
URL: http://dx.doi.org/10.1080/01431160701442062

International Journal of Remote Sensing
Vol. 28, No. 20, 20 October 2007, 4677–4683

Letter

Application of the Active Learning Method for the estimation of geophysical variables in the Caspian Sea from satellite ocean colour observations

H. TAHERI SHAHRAIYNI*†‡, M. SCHAALE†, F. FELL§, J. FISCHER†,
R. PREUSKER†, M. VATANDOUST¶, S. BAGHERI SHOURAKI||,
M. TAJRISHY‡, H. KHODAPARAST¶ and A. TAVAKOLI††

†Institute for Space Sciences, Freie Universitaet Berlin, Carl-Heinrich-Becker-Weg 6–10, 12165 Berlin, Germany
‡Department of Civil Engineering, Sharif University of Technology, Azadi Avenue, PO Box 11365-9313, Tehran, Iran
§Informus GmbH, Gustav-Meyer-Allee 25, 13355 Berlin, Germany
¶Inland Waters Aquaculture Institute, PO Box 66, Bandar Anzali, Iran
||Department of Computer Engineering, Sharif University of Technology, Azadi Avenue, PO Box 11155-9517, Tehran, Iran
††Department of Electrical Engineering, Amir Kabir University of Technology, Tehran, PO Box 15914, Iran

(*Received 27 January 2007; in final form 2 May 2007*)

Remotely sensed data inherently contain noise. The development of inverse modelling methods with a low sensitivity to noise is in demand for the estimation of geophysical variables from remotely sensed data. The Active Learning Method (ALM) is well known to have a low sensitivity to noise. For the first time, ALM was utilized for the inversion of radiative transfer calculations with the aim of estimating chlorophyll *a* (Chl *a*), coloured dissolved organic matter (CDOM), and suspended particulate matter (SPM) in the Caspian Sea using MERIS (MEdium Resolution Imaging Spectrometer) data. ALM training is straightforward and fast. The ALM inversion models revealed the most relevant variables and showed a short processing time in operational applications for the estimation of geophysical variables. The mean absolute percentage errors of Chl *a*, SPM, and CDOM estimation using ALM inversion models were 44, 70, and 73%, respectively. According to the ALM results, it can be introduced as a new method for inverse modelling of ocean colour observations.

1. Introduction

Monitoring of spatio-temporal changes of geophysical variables such as chlorophyll *a* (Chl *a*), suspended particulate matter (SPM), and coloured dissolved organic matter (CDOM) is necessary for water-quality or marine-ecosystem modelling and management. Space-borne measurements of the ocean colour provide a complementary tool for the monitoring of geophysical variables in various water types. Different approaches exist for the estimation of geophysical variables from remotely

---

*Corresponding author. Email: h_taheri@civil.sharif.edu

International Journal of Remote Sensing
ISSN 0143-1161 print/ISSN 1366-5901 online © 2007 Taylor & Francis
http://www.tandf.co.uk/journals
DOI: 10.1080/01431160701442062

sensed radiances. One of the most promising is based on inverse radiative transfer modelling (IOCCG 2000, Durand *et al.* 2000).

More than 80% of the signal measured by ocean colour sensors (e.g. MERIS) is 'noise' due to instrumental, adjacency, and atmospheric effects or air–sea interface contribution (Durand *et al.* 2000, IOCCG 2000). Operational atmospheric correction techniques based on the 'black ocean' assumption (water is black in the red and near-infrared) have been developed for the relatively clear open ocean (case 1) waters. These methods are not applicable over more turbid (case 2) waters often found in coastal areas (IOCCG 2000). The noise potentially deteriorates the performance of inverse modelling methods and subsequently affects their suitability for operational applications (Hughes *et al.* 2001). Hence, an inverse modelling method that has a low sensitivity to noise is needed.

It is well known that human perception has a low sensitivity to noise. Bagheri Shouraki and Honda (1997) suggested a fuzzy modelling technique similar to human perception. This method, entitled the 'Active Learning Method' (ALM), is a universal approximator. It is based on a simple algorithm and its accuracy increases with increasing number of iterations. ALM is similar to human modelling method, hence it is promising to be low-sensitive to noise. In addition, ALM has shown to have a very low sensitivity to noise for the estimation of in-water constituents from water-leaving remote-sensing reflectance data (Taheri Shahraiyni *et al.* 2007). ALM is described in detail in Bagheri Shouraki and Honda (1999) and Taheri Shahraiyni *et al.* (2006).

In this letter, ALM inversion models are developed for the estimation of Chl *a*, SPM, and CDOM from MERIS data acquired over the Caspian Sea in both case 1 and case 2 waters.

2. Investigation area

The Caspian Sea is a land-locked endorheic sea situated between Asia and Europe. It is the largest inland water body in the world. It covers a surface area of about 371 000 km^2 and reaches a maximum depth of about 1000 m. The average salinity is about 12 PSU (one-third of the average sea water salinity). Its major freshwater source is Volga River with an average annual discharge of 250 km^3. Our study area covers the southern parts of the Caspian Sea which are bordered by Azerbaijan, Iran, and Turkmenistan (figure 1).

There is relatively little information available on the inherent optical properties (IOPs) of the Caspian Sea, especially for the southern parts. CDOM concentration in the Caspian Sea is generally low, while high concentrations of other water constituents are observed mainly in the coastal regions. Moreover, the SPM concentration is generally very high in the south-eastern parts (figure 1).

3. Data sources

3.1 In situ *measurements*

In situ measurements of Chl *a* ($\mu g\,l^{-1}$), SPM ($mg\,l^{-1}$), and CDOM absorption at 443 nm (m^{-1}) have been performed in the Caspian Sea between July and October 2005. The *in situ* water samples were taken during 25 one-day campaigns at different distances to the coast using a motor boat as sampling platform (figure 1), covering the natural variability between the coastal and the open sea waters. The samplings were performed concurrent with MERIS imaging of the Caspian Sea, but with an

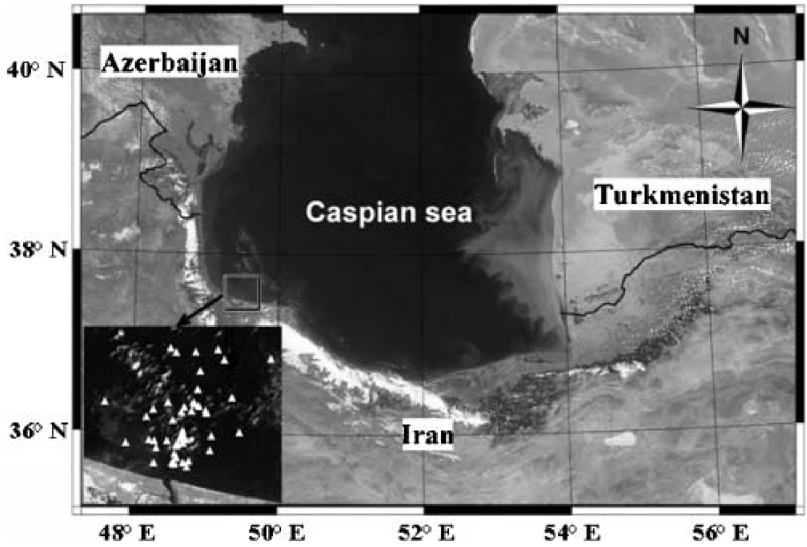

Figure 1. Grey-scaled colour composite MODIS image (11 June 2003) of the study area (southern parts of the Caspian Sea) and location of the *in situ* measurements (triangles) in a Landsat TM image (30 June 2000).

average lag of about +45 min (the systematic delay being caused by preceding sampling at another location, the Anzali Wetland) (table 1). The laboratory analyses of water samples acquired in the initial campaigns showed very high values of SPM concentration. Hence, these data were removed, and the SPM measurement instruments were replaced with new ones. Also, coincidence of the sampling stations and concurrent MERIS images revealed that some stations have been located in the Sun glinted regions of MERIS images, and so these stations were removed.

Finally, 37, 18, and 34 samples of Chl *a*, SPM, and CDOM remained, and these samples were utilized for the evaluation of ALM inversion models in the next section. The laboratory analyses of the water samples revealed the following concentration ranges in the sampling region (figure 1): Chl *a* 1.5–30.7 μg l^{-1}, SPM 6.3–21.3 mg l^{-1}, and CDOM absorption 0.17–0.75 m^{-1} at 443 nm.

3.2 *Satellite data*

A total of 25 Level 1B MERIS Full Resolution (300 m × 300 m) images acquired over the Caspian Sea between July and October 2005 were used in this study (table 1).

3.3 *Radiative transfer simulation data*

In this study, a database of synthetic top-of-atmosphere (TOA) reflectance data, generated by Schroeder (2005) was utilized for the training of the ALM inversion models. Schroeder (2005) used the MOMO code (Fell and Fischer 2001) based on the matrix-operator method to simulate the azimuthally resolved radiative transfer in a coupled ocean–atmosphere system. Adjacency effects and polarization were not taken into account. The COASTLOOC database (Babin 2000) was utilized to model the IOPs of the water constituents. The ranges of Chl *a*, SPM, and CDOM concentrations used for the simulations were 0.05–50 μg l^{-1}, 0.05–50 mg l^{-1}, and

Table 1. Characteristics of sampling campaigns in Caspian Sea between July and October 2005 and corresponding MERIS imaging time.

Campaign no.	Date of campaign and its corresponding MERIS imaging	Time of sampling (GMT)	Time of MERIS imaging (GMT)	No. of sampling stations
1	8 Jul.	08:30	07:27	1
2	9 Jul.	06:55–07:30	06:55	3
3	12 Jul.	07:55	07:01	1
4	18 Jul.	07:20–07:55	07:13	3
5	22 Jul.	08:15–08:45	06:47	3
6	24 Jul.	08:00–08:15	07:24	3
7	25 Jul.	07:37	06:53	1
8	28 Jul.	08:00	06:59	1
9	31 Jul.	07:00–07:30	07:04	3
10	6 Aug.	06:55–07:20	07:15	3
11	10 Aug.	06:30–06:57	06:50	3
12	13 Aug.	07:07:07:30	06:55	2
13	16 Aug.	07:15–07:30	07:01	3
14	19 Aug.	07:50–08:18	07:07	3
15	31 Aug.	08:26–08:42	07:30	3
16	1 Sep.	08:05–08:38	06:58	3
17	16 Sep.	08:10	07:27	1
18	20 Sep.	08:00	07:01	1
19	23 Sep.	08:46–09:35	07:07	3
20	2 Oct.	07:00–07:26	07:24	3
21	3 Oct.	06:39–07:08	06:53	3
22	15 Oct.	07:08–07:30	07:15	3
23	16 Oct.	07:46–08:11	06:44	3
24	18 Oct.	07:50	07:24	1
25	25 Oct.	8:24–8:52	07:01	3
			Total no. of stations	60

0.005–1.0 m^{-1} at 443 nm, respectively. These ranges cover the variability observed in the Caspian Sea (§3.1). Each dataset in the database consists of the TOA reflectance at 12 different wavelengths, auxiliary data (geometric variables, wind speed, and air pressure), aerosol optical thickness, as well as the matching Chl *a*, SPM, and CDOM concentrations. For further details, see Schroeder (2005) and Schroeder *et al.* (2007).

4. Methodology, results, and discussion

Figure 2 shows the flow chart for the algorithm developed in this study.

The ALM was trained with radiative transfer simulation data described in §3.3. The input variables to the ALM were the spectral reflectance at TOA as well as auxiliary data. The output values were Chl *a*, SPM, and CDOM. ALM does not need initial parameters to start the training, and so the training does not need to be repeated, thus saving computing time. Hence, its training is straightforward and fast.

ALM is a fuzzy method and generates fuzzy rules. The *in situ* data taken from the Caspian Sea (§3.1) and concomitantly acquired MERIS images (§3.2) were utilized to identify the number of rules that reproduces the best values for the *in situ* measured water constituents. These tests revealed that the appropriate number of rules for Chl *a*, SPM, and CDOM retrieval is eight. Hence, the ALM inversion models with eight rules were applied to MERIS images in order to estimate the

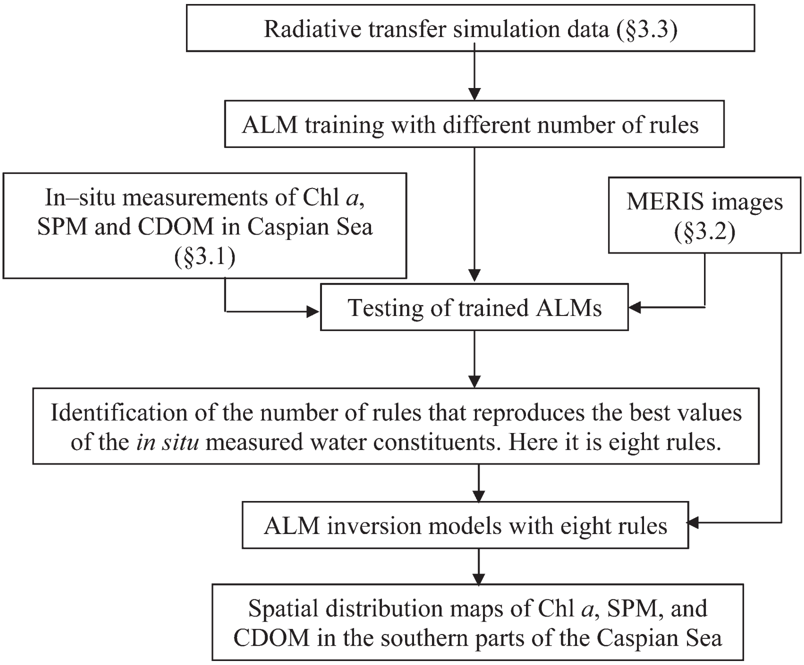

Figure 2. Flow chart for the algorithm developed in this study.

spatial distribution of Chl *a*, SPM, and CDOM. The processing time of fuzzy models is highly related to the number of rules, and this number of rules (eight rules) is small enough to allow for an appropriate processing time in operational applications.

ALM modelling is similar to human perception, can determine the necessary and important variables for modelling, and stringently removes the less relevant variables (Bagheri Shouraki and Honda 1999, Taheri Shahraiyni *et al.* 2007). TOA reflectance values at {490, 510, 560, 620, 865, and 885 nm}, {490, 510, 560, 620, 709, 754, and 885 nm}, and {490, 510, 560, 620, and 885 nm} were identified by ALM inversion models with eight rules as the relevant variables for the Chl *a*, SPM, and CDOM estimation in the Caspian Sea, respectively.

Evaluation of the results reveals that the Mean Absolute Percentage Error (MAPE) of Chl *a*, SPM, and CDOM estimation is 44, 70, and 73%, respectively. These results are reasonable and similar to the results of other studies on optically complex case 2 waters. For example, Schroeder *et al.* (2007) found that the MAPEs of Artificial Neural Network-based inversion models for Chl *a*, SPM, and CDOM estimation in the North and Baltic Sea from MERIS data were 50, 60, and 73%, respectively.

Figure 3 shows the spatial distribution of Chl *a*, SPM, and CDOM obtained by applying the ALM inversion models to a MERIS image acquired over the southern parts of the Caspian Sea.

5. Conclusions

ALM modelling is similar to human perception. It has a low sensitivity to noise and can identify the important input variables for inverse modelling and neglect the

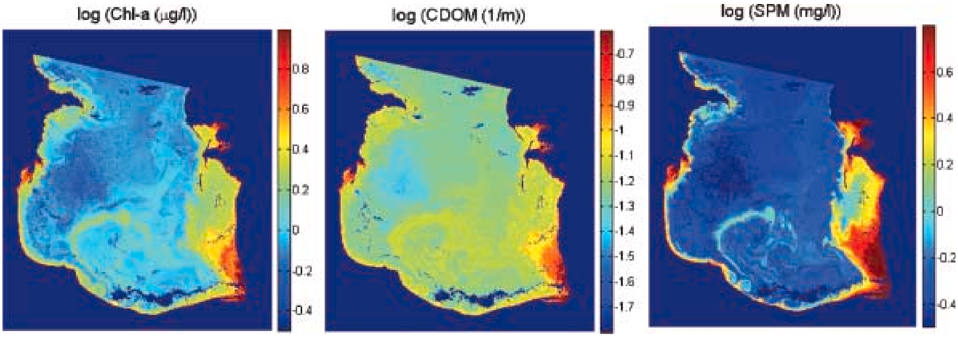

Figure 3. Estimated geophysical variables in the southern part of Caspian Sea by applying the ALM inversion models to a MERIS image (3 October 2005). Available in colour online.

unnecessary variables simultaneously. In addition, ALM training is straightforward and fast, and can achieve an acceptable accuracy and processing time. According to the results of this study, ALM can be introduced as a new appropriate inverse modelling method for the estimation of geophysical variables from ocean colour data.

Acknowledgements

We would like to thank the UNESCO for the financial support of this study through the UNESCO/KEIZO OBUCHI Research Fellowships Programme 2005. The ocean colour data (MERIS-FR) used in this study were provided by the European Space Agency (ESA) through the C1P2868 project.

References

Babin, M., 2000, *Coastal Surveillance through Observation of Ocean Colour (COASTLOOC). Final Report, Project ENV4-CT96-0310* (Villefranche-sur-mer, France: Laboratoire de Physique et Chimie Marines).

Bagheri Shouraki, S. and Honda, N., 1997, A new method for establishing and saving fuzzy membership functions. In *13th Fuzzy Symposium*, 4–6 June 1997, Toyama, Japan, pp. 91–94.

Bagheri Shouraki, S. and Honda, N., 1999, Recursive fuzzy modelling based on fuzzy interpolation. *Journal of Advanced Computational Intelligence*, **3**, pp. 114–125.

Durand, D., Bijaouni, J. and Cauneau, F., 2000, Optical remote sensing of shallow-water environmental parameters: A feasibility study. *Remote Sensing of Environment*, **73**, pp. 152–161.

Fell, F. and Fischer, J., 2001, Numerical simulation of the light field in the atmosphere–ocean system using the Matrix-Operator method. *Journal of Quantitative Spectroscopy and Radiative Transfer*, **69**, pp. 351–388.

Hughes, D.C., Holyer, R.J. and Lee, Z.P., 2001, Remote sensing algorithms by numerical inversion of radiative transfer models: neural network and optimization methods compared. In *International Conference on Current Problems in Optics of Natural Waters*, D. S. Rozhdestvensky Optical Society, St. Petersburg, Russia, 25–29 September.

IOCCG, 2000, *Remote Sensing of Ocean Color in Coastal, and Other Optically-Complex Waters. Report of the International Ocean-Colour Coordinating Group, No. 3*, S. Sathyendranath (Ed.), pp. 1–140, IOCCG, Dartmouth, Canada.

Schroeder, T., 2005, Fernerkundung von Wasserinhaltsstoffen in Küstengewässern mit MERIS unter Anwendung expliziter und impliziter Atmosphärenkorrekturverfahren.

PhD thesis, Freie Universität Berlin, Berlin, Germany. Available online at: http://www.diss.fu-berlin.de/2005/78/ (accessed 23 March 2005).

SCHROEDER, T., SCHAALE, M. and FISCHER, J., 2007, Retrieval of atmospheric and oceanic properties from MERIS measurements: A new Case-2 water processor for BEAM. *International Journal of Remote Sensing*, in press.

TAHERI SHAHRAIYNI, H., BAGHERI SHOURAKI, S., FELL, F., SCHAALE, M., FISCHER, J., TAVAKOLI, A., PREUSKER, R., TAJRISHY, M., VATANDOUST, M. and KHODAPARAST, H., 2007, Application of Active Learning Method to retrieve pigment from spectral remote sensing reflectance data. *International Journal of Remote Sensing*, in press.