SEA SURFACE SALINITY RETRIEVAL BASED ON LEVENBERG MARQUARDT ALGORITHM USING SATELLITE DATA

NOORLIDA BINTI ABD RAHIM

UNIVERSITI TEKNOLOGI MALAYSIA

SEA SURFACE SALINITY RETRIEVAL BASED ON LEVENBERG MARQUARDT ALGORITHM USING SATELLITE DATA

NOORLIDA BINTI ABD RAHIM

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Science (Remote Sensing)

Faculty of Geoinformation and Real Estate
Universiti Teknologi Malaysia

AUGUST 2014

Dedicated to my beloved mother and father,

My beloved one

My beloved siblings....

And Special Appreciation to

All lecturers from Department of Remote Sensing

Thanks for all the support...

ACKNOWLEDGEMENT

In the name of ALLAH SWT, I would like to express my gratefulness and most heartfelt thanks to Him for giving me strength to successfully complete my study. First and foremost, I wish to express my gratitude to my academic supervisors Dr. Mohd Nadzri bin Md Reba and Prof. Dr. Mohd Ibrahim Seeni Mohd for their guidance, support and encouragement during my study.

I would like to thank my parents, Abd Rahim bin Mohd Amin and Zalekha binti Endut to whom I dedicate this work for their love and constant support. My special thanks to my husband, Aminuddin bin Mohd Noor whose patient and love enabled me to complete this work. Thanks to other individuals who have contributed to the success of this report whether directly or indirectly.

ABSTRACT

Soil Moisture Ocean Salinity satellite exploits the frequency of 1.4 gigahertz which represents the best conditions for salinity retrieval. The new challenge is to interpret the observed brightness temperature into the salinity. The main objective of this study is to measure the sea surface salinity in the South China Sea using the Levenberg Marquardt algorithm. The methodology of this study involves the mapping of this algorithm to solve the non-linear least squares in order to obtain the salinity. The salinity was estimated based on the comparison between brightness temperature measured and brightness temperature simulated value of the successive iteration. The difference between both brightness temperature values is compared to the desired threshold at each iteration, this recursive process either updates the brightness temperature simulated or finally terminated if the brightness temperature difference is lower or higher than that threshold respectively. The salinity values estimated from the designed of Levenberg Marquardt algorithm tools were assembled, thus maps of sea surface salinity were produced. Some accuracy analyses were carried out to identify the appropriateness of a Levenberg Marquardt algorithm for the salinity retrieval. The results of the regression analysis and Pearson Correlation Coefficient indicate that sea surface salinity measured performs high correlation with the sea truth data, which is 0.9042 and ±0. 9509 psu, respectively. The analysis of variance by testing the hypothesis indicates that there is no substantial difference between the mean of sea surface salinity from the satellite and sea truth data. The root mean square error of measured sea surface salinity is smaller compared to the sea truth data values. In conclusion, the appropriateness of Levenberg Marquardt algorithm in inverting the salinity in the non-linear technique proved as a solution for ill-posed inversion that estimates the sea surface salinity from the Soil Moisture Ocean Salinity brightness temperature.

ABSTRAK

Satelit Kelembapan Tanah Kemasinan Laut mengaplikasi frekuensi sebanyak 1.4 gigahertz di mana ia merupakan jalur yang terbaik bagi penganggaran kemasinan. Cabaran baru ialah untuk mengadaptasi suhu kecerahan yang dicerap kepada kadar kemasinan. Objektif utama kajian ini adalah untuk menentukan kemasinan permukaan laut di Laut China Selatan menggunakan algoritma Levenberg Marquardt. Kaedah digunapakai dalam kajian ini melibatkan penggunaan algoritma tersebut untuk menyelesaikan kuasa dua terkecil tidak langsung dalam menentukan kadar kemasinan. Nilai kemasinan dianggar berdasarkan perbandingan di antara cerapan suhu kecerahan dan simulasi suhu kecerahan untuk lelaran berterusan. Perbezaan di antara kedua-dua suhu pencerahan dibandingkan dengan nilai ambang yang dikehendaki pada setiap lelaran dan proses rekursif ini samada akan mengemaskini semula nilai simulasi suhu kecerahan atau prosesnya ditamatkan sekiranya perbezaan suhu kecerahan lebih rendah atau lebih tinggi daripada nilai ambang masing-masing. Penganggaran kadar kemasinan daripada algoritma Levenberg Marquardt yang direka telah dikumpul, seterusnya menghasilkan peta kemasinan permukaan laut. Beberapa analisis ketepatan dijalankan bagi menilai kesesuaian algoritma Levenberg Marquardt terhadap penentuan kadar kemasinan. Hasil bagi analisis regresi dan Pekali Hubungan Pearson menunjukkan kadar kemasinan laut memberikan perkaitan yang paling hampir dengan data lapangan, iaitu masing-masing merekodkan 0.9042 dan ±0.9509 psu. Analisis kepelbagaian dengan menguji hipotesis menunjukkan tiada perbezaan yang ketara di antara purata kadar kemasinan laut daripada data satelit dan data lapangan. Ralat punca min kuasa dua bagi kadar kemasinan yang dicerap adalah lebih kecil berbanding nilai data lapangan. Kesimpulannya, kesesuaian algoritma Levenberg Marquardt dalam penyongsangan kadar kemasinan bagi teknik tidak langsung terbukti sebagai satu kaedah penyelesaian untuk menentukadar kemasinan laut daripada suhu kecerahan Kelembapan Tanah Kemasinan Laut.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

B	-	Radiance [Wm-2sr-1]
F_t	-	The Power Flux Emitted [W.sr-1]
A_t	-	Unit of Surface [m^2]
A_r	-	The Effective Area of the Antenna [m^2]
R	-	The Distance between the Antenna and the Radiating Target [m]
Ω_t	-	The Transmitting Antenna [.]
P	-	Power [Watts]
Δf	-	Bandwidth of the Receiver [Hertz]
f	-	Frequency [Hertz]
h	-	Constant of Planck ($6.63x10^{-34}$ Js)
T	-	Absolute Physical Temperature [K]
c	-	Speed of Light [ms^{-1}]
B_{bb}	-	Brightness of a Blackbody [K]
e	**-**	Emissivity [.]
R	-	Fresnel Power Reflection Coefficient Dependent on the Polarization. [.]
T_b	-	Brightness Temperature [K]
$T_{b,flat}$	-	Brightness Temperature of a Flat Sea Surface [K]
$T_{b,rough}$	-	Contribution of Sea Surface Roughness [K]
θ	-	Incidence Angle [degree]
SST	-	Sea Surface Temperature [°C]
SSS	-	Sea Surface Salinity [psu]
P_{rough}	-	Parameter Used To Characterize the Roughness
Γ	-	Reflectivity [.]
R_p	-	Fresnel Reflection Coefficient At Polarization p

ε	-	Dielectric Constant of Seawater [.]
ε_∞	-	The Dielectric Constant at Infinite Frequency [.]
ε_s	-	The Static Dielectric Constant [.]
ω	-	Radian Frequency [Hertz]
τ	-	The Relaxation Time [seconds]
i	-	Imaginary Number [.]
σ	-	The Ionic Conductivity [mhos/meter]
ε_0	-	The Permittivity of Free Space [farads/meter]
W_{10}	-	Wind Speed Below than 10 m/s [m/s]
χ^2	-	The Sum of Squared Difference between T_b meas and T_b sim
$T_{b,meas}$	-	Measured Brightness Temperature [K]
$T_{b,sim}$	-	Simulated Brightness Temperature [K]
N	-	Number of SMOS Measurements along a Dwell Line
σ_p	-	Variance of The Expected Error of the Reference Values

LIST OF ABBREVIATIONS

AMSR-E	-	Advanced Microwave Scanning Radiometer for EOS
CCSDS	-	Consultative Committee for Space Data Systems
CDOM	-	Color Dissolved Organic Matter
CEOS	-	Committee on Earth Observation Satellites
DGG	-	Discrete Global Grid
ECS	-	East China Sea
EEZ	-	Exclusive Economic Zone
EMR	-	Electromagnetic Radiation
ENSO	-	El-Nino Southern Oscillation
E-P	-	Evaporation minus Precipitation
ESA	-	European Space Agency
FOV	-	Field of View
ISEA	-	Icosahedral Synder Equal Area
L1C	-	SMOS Level 1C data
MIRAS	-	Microwave Imaging Radiometer Using Aperture Synthesis
SMOS	-	Soil Moisture and Ocean Salinity
SSS	-	Sea Surface Salinity
SSA	-	Small Slope Approximation Model
SST	-	Sea Surface Temperature
SWH	-	Significant Wave Height
W	-	Wind Speed
WISE	-	Wind and Salinity Experiments

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Study on ocean becomes significant as the ocean covers almost 71 percent of the earth's surface and it has larger influence and capability in transporting energy. As a result, this imposes knowledge on coastal characteristics and climate to be improved. Salinity is dissolved salt or literally defined as the total amount of dissolved solids in the units of 1000 grams. Interaction between lattices and water molecules induces salinity to form the ion which is the charged molecules. By the presence of molecule charges, salinity can be determined by seawater's conductivity. The main salt ions contributed to the seawater element are chlorine, sodium, sulphate, magnesium, calcium, and potassium. Seawater also contains some types of dissolved gases such as carbon dioxide, nitrogen, and oxygen.

In the climatological aspect, salinity observation becomes an integral part of global ocean observations designed ultimately to monitor interannual to interdecadal processes as of the idea is to understand uncertainties of El-Nino Southern Oscillation (ENSO) forecasting, global warming and other climate variations (Lagerloaf *et al*., 1995). In fisheries, the lower salinity level that originated from the fresh water end turns sea grass blades to yellow and thus this adversely impacts the breeding ground for fish, prawns and other aquatic lives (Thorhaug *et al*., 2006).

Salinity plays an important role in the earth's water cycle in which it subsequently affects the weather and climate by means of temperature salinity that drives the ocean currents. The change in salinity is mainly caused by the additional or removal of freshwater from land. The salinity of sea water is normally about 30 to 35 psu (practical salinity unit) in open ocean but tends to be variable in coastal water coming from the fresh water output, tidal fluctuations and etc (Thorhaug *et al*., 2006). Several studies have reported that the reflectance spectra of certain seagrass species indicating the physiology of the seagrass are strongly and significantly affected by low salinity level (Thorhaug *et al*., 2006). Level of salinity in water can be classed in different types based on the electrical conductivity and salt concentration tabulated in Table 1.1.

Table 1.1: Class of salinity level in water (Rhoades *et al*., 1992).

Water class	**Electrical conductivity (dS/m)**	**Salt concentration (mg/l)**	**Type of water**
Non-saline	<0.7	<500	Drinking and irrigation water
Slightly saline	0.7 - 2	500-1500	Irrigation water
Moderately saline	2 - 10	1500-7000	Primary drainage water and groundwater
Highly saline	10-25	7000-15 000	Secondary drainage water and groundwater
Very highly saline	25 - 45	1 5 000-35 000	Very saline groundwater
Brine	>45	>45 000	Seawater

Sea water or ocean is strongly related to hydrologic water cycle in the context of providing sustainability of the origin of the sea water. The water vapor evaporates from the ocean surface and gaseous are released from the molten igneous rocks which provide functionality in cooling the earth. Later, the earth's surface becomes cool until reaching the level below the boiling point temperature. Rain takes part in the continuous process to gain the humidity of the ground and flows to the watershed and the ocean.

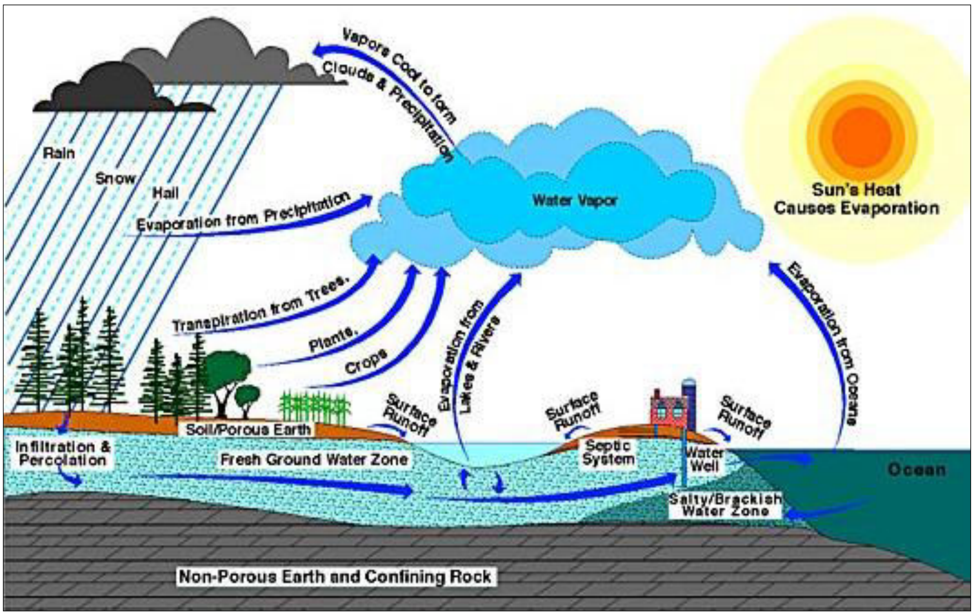

Figure 1.1: The hydrologic water cycle (from http://www.Greenewatersheds.Org/Cycle.Html).

The sun heat distils pure water from the sea surface and keeps the salt remains in the ocean that later contributes to the oceans salinity. All these processes are schematically presented as hydrologic water cycle in Figure 1.1. The hydrologic water cycle is the continual exchange of water between the Earth and the atmosphere which explains the existing of oceans water and sources of the salts.

Conventional methods to observe sea surface salinity (i.e., by means of hydrolab taken in the excursion by vessel) are very time consuming, expensive and limited to small area. On the other hand, remote sensing technique has proved as an efficient technique in mapping the sea surface salinity at regional or global scale. Several algorithms have been introduced to measure the sea surface salinity by space-borne data.

1.2 Problem Statement

Traditional methods that extract salts directly from the ocean are very time consuming, expensive and limited to small area coverage. For instance, the estimation of net Evaporation minus Precipitation (E-P) has high correlation with sea surface salinity and therefore is used to relatively estimate the sea surface salinity. Even though the net E-P provides better understanding of the thermohaline circulation and later this technique helps to improve the estimation of latent heat flux, E-P measurement imposes massive manpower, high time consuming and very costly.

Sea surface salinity retrieval by remote sensing technique proved as an efficient technique in mapping the salinity at regional or global scale. In the context of Malaysian coastal waters, focus more on the sea-truthing than satellite-based measurements are mainly reported. The satellite derived sea surface salinity was majorly formulated by means of optical bands at which interferences by weather, cloud covers and atmospheric induced error are regularly encountered. There is also concern on the impact of seasonal monsoon towards the sea surface salinity particularly at the east coast of Malaysia where the study on impact is necessary for biological production and ocean ecology studies.

Most of the satellite derived sea surface salinity was obtained by optical remote sensing data though this approach has disadvantages of interferences produced by atmospheric condition, weather and cloud covers. This is not a case for the microwave radiometer type satellite called Soil Moisture and Ocean Salinity (SMOS) which has been deployed in space in 2009 by which high degree of ocean salinity and soil moisture are retrieved using microwave sensor. Yet, the salinity product estimated from the Microwave Imaging Radiometer Using Aperture Synthesis (MIRAS) have yet been calibrated and validated as this 1.4GHz L-band sea surface salinity variant is ill-pose solution. As a result, high order non linear solution is needed and provides complicated solution.

1.3 Objectives

The aim of this study is to measure the sea surface salinity using the SMOS data over the South China Sea. Therefore, the objectives of this study are:

1. To develop a tool for the SMOS sea surface salinity retrieval based on a non-linear inversion algorithm using the ocean surface brightness temperature data.
2. To validate the SMOS sea surface salinity retrieval over the coastal water of Malaysia using the corresponding in-situ measurements.
3. To map the ocean salinity distribution of South China Sea from SMOS data.
4. To determine the impact of seasonal monsoon on the estimated SMOS sea surface salinity.

1.4 Scope of Study

The scopes of this study are as follows,

1. Soil Moisture and Ocean Salinity (SMOS) data providing sea surface salinity information within large area of 35 kilometre and revisiting time of 3 days with accuracy between 0.5 to 1.5 psu for a single observation is used as the primary data. Level 1C data is projected on an Icosahedral Synder Equal Area (ISEA 4H9) grid provides a uniform inter cell distance of 15 km.

2. Klein and Swift model (1977) and semi-empirical models are considered to compute the brightness temperature in both conditions of flat sea surface and rough sea surface as those models provide systematic and straight ward estimation procedures.

3. Levenberg Marquardt technique is chosen to solve for the non-linear optimization and inversion on the SMOS brightness temperature pixels because the technique provides simultaneous estimation of sea surface salinity, sea surface temperature and wind speed.

4. Sea truth data of sea surface salinity and sea surface temperature were used for algorithm validation and the fieldwork was carried out in the coastal water of east coast of Peninsular Malaysia on June 2008 and June 2009. Besides that, some sea truth data were obtained from the related agencies namely Universiti Malaysia Terengganu (UMT) and Southeast Asian Fisheries Development Center (SEAFDEC).

5. For calibration and validation of the SMOS data, regression analysis provides better overview on the accuracy of SMOS derived sea surface salinity.

1.5 Significance of Study

This is the first study of SMOS data application in the Malaysia coastal water that involves extensive data processing (i.e., SMOS data acquisition, brightness temperature estimation and validation) and development of iterative non-linear inversion algorithm. The SMOS mission is dedicated to continuously measure the ocean salinity and soil moistures over the globe at the higher degree of accuracy in space and time. This study would serve to the salinity mapping over coastal water in east coast Peninsular Malaysia and give benefit to fisheries, aquaculture and habitats for coral reef and sea grass. Salinity affects water density that controls the sinking of water and the patterns of evaporation over the ocean. This would therefore improve the knowledge of the water cycle and thus gives better understanding of climate change. Salinity information helps to constrain the hydrological cycle and by incorporating high degree of accuracy of salinity may improve ocean circulation modelling and data assimilation (Yueh *et al*., 2000).

Validation and calibration of SMOS salinity product may serve to local satellite mapping in order to improve the accuracy of data product. In this case, discrepancy of satellite salinity product is reduced so that increases its data reliability in space and time. As result, high accuracy remote sensing data offer more effective salinity mapping technique and more cost efficiency covering large ocean areas than that of conventional ones. Study on the impact of seasonal monsoon to the salinity distribution give significance overview for the ocean bio geochemical identification namely shellfish productivity, aquaculture, ice melt process, major river run-off events and fish location dependent parameters (Castillo *et al*., 1996; Morita *et al*., 2001).

1.6 Study Area

The study area is in the South China Sea as shown in Figure 1.2. The area covered from 2°30'N and 103°00'E to 6°00'N and 105°00'E that governs open seawater with low and high salinity range. There are various surrounding marine resources and habitats that rich with coral reefs, sea grass and seaweeds and therefore this area is also known as the Exclusive Economic Zone (EZZ). The change in salinity in turn affects the coral reefs, sea grass and seaweed habitats that eventually intervenes the growth and life of fish, prawns, sea cucumber and other marine resources. The South China Sea is the marginal sea and connects to the East China Sea (ECS), the Pacific Ocean in northern and also links with the Java Sea and the Sulu Sea in the south. The South China Sea is one of the busiest ocean routes and networks for ships.

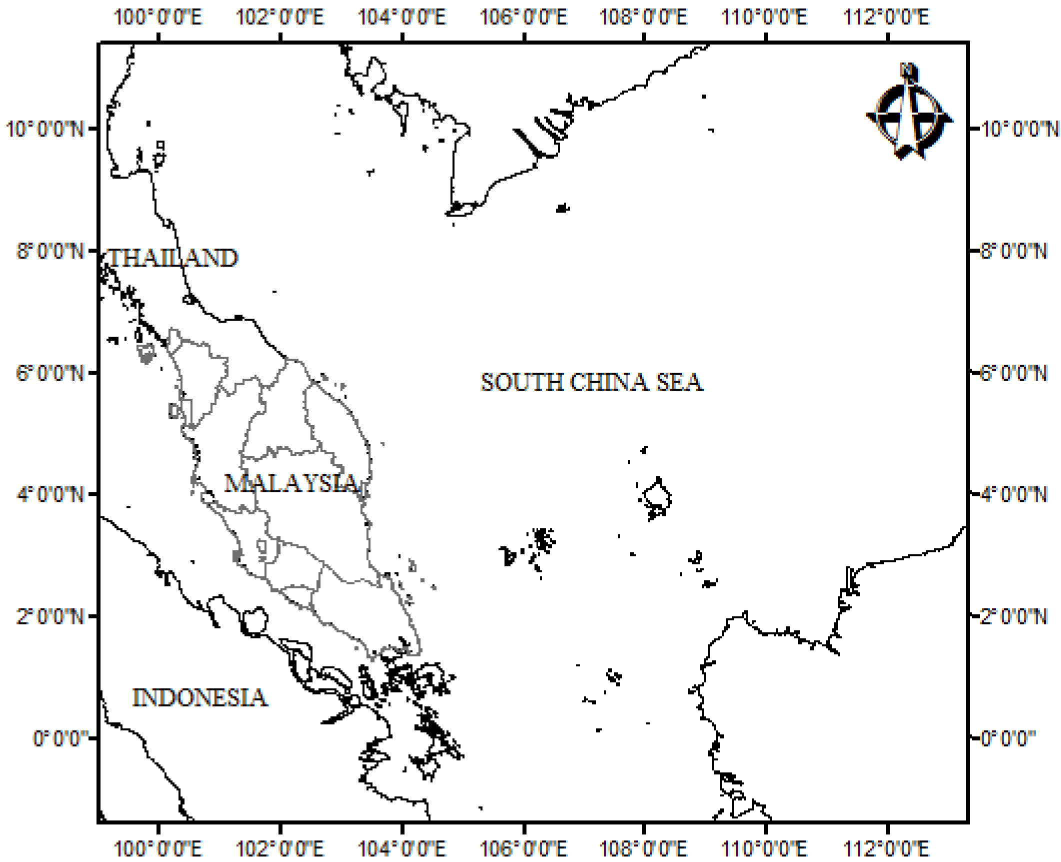

Figure 1.2: Location map of the study area.

REFERENCES

Ahn Y. H., Shanmugam P., Moon J.E.and Ryu J.H. (2008). Satellite Remote Sensing of a Low-Salinity Water Plume in the East China Sea. *European Geosciences Union 2008: 2019-2035.*

Altman D.G. and Schulz, K.F., (2001). Statistics Notes: Concealing treatment allocation in randomized trials. *British Medical Journal* 323: 446-447.

Ammar A., Labroue S., Obligis E., Mejia C. E., Crepon M. and Thiria S. (2008). Sea Surface Salinity Retrieval for the SMOS Mission Using Neural Networks. *IEEE Transaction on Geoscience and Remote Sensing*, Vol. 46, No. 3, March 2008.

Binding C.E., Bowers D.G. (2003). Measuring the Salinity of Clyde Sea from Remotely Sensed Ocean Color. *Elsvier Science. Estuarine, Coastal and Shelf Science 57* (2003) 605-611.

Blanch S. and Aguasca A. (2004). Seawater Dielectric Permittivity Model From Measurements at L-Band. *Proceedings of IGARSS 2004, Alaska*.

Burrage D., Wesson J. and M., (2008). Deriving Sea Surface Salinity and Density Variations From Satellite and Aircraft Microwave Radiometer Measurements: Application to Coastal Plumes Using STARRS. *IEEE Transactions on Geosciences and Remote Sensing*, 46 (3), pp: 765- 785.

Camps A., Corbella I., Vall llossera M., Duffo N., Torres F., Villarino R., Enrique L., Julbe F., Font J., Julia A., Gabarro C., Etcheto J., Boutin J., Weill A., Rubio E., Caselles V., Wursteisen P., Martin-Neira M. (2003). L-Band Sea

Surface Emissivity: Preliminary Results of the Wise-2000 Campaign and Its Application to Salinity Retrieval in the SMOS Mission, *Radioscience,* 38 (4), MAR 36-3.

Camps A., Font J., Vall-llossera M., Gabarro C., Corbella I., Duffo N., Torres F., Blanch S., Aguasca A., Villarino R., Enrique L., Miranda J.J., Arenas J.J., Julia A., Etcheto J., Caselles V., Weill A., Boutin J., Contardo S., Niclos R., Rivas R., Reising S.C., Wursteisen P., Berger M. and Martin-Neira, M. (2004). The WISE 2000 and 2001 Campaigns in Support of the SMOS Mission: Sea Surface L-band Brightness Temperature Observations and their Application to Multi-Angular Salinity Retrieval, *IEEE Trans. Geosci. and Remote Sens.*, 42(4), 804-823.

Castillo J., Barbieri M.A., and Gonzales A. (1996). Relationship between Sea Surface Temperature, Salinity and Pelagic Fish Distribution off Northern Chile. *ICES Journal of Marine Science* 53(2):139-146.

Corbella I., Torres F., Duffo N., Gonzalez V., Camps A. and Vall-llossera, M. (2008). Fast Processing Tool for SMOS Data. *International Geoscience and Remote Sensing Symposium (IGARSS) 2008. IEEE International*. 2 (1), art no. 4779204, pp II-1152 - II-1155.

Debye, P. (1929). *Polar Molecules. Dover Publication*. New York: Reinhold Publishing Corp.

Delwart S., Petitcolin F., and SMOS Team (2006). SMOS SSS L2 Algorithm Theoretical Baseline Document ICM-*CSIC LOCEAN/SA/CETP IFREMER*, 2006.

Dinnat E. P., Boutin J., Caudal G. and Etcheto J. (2003). Issues Concerning the Sea Emissivity Modeling at L Band for Retrieving Surface Salinity. *Radio Sci.*, Vol. 38, no. 4, 8060, 2003, DOI:10.1029/2002RS002637.

Droppelman, J.D., Mennella R.A. and Evans D.E. (1970). An Airborne Measurement of the Salinity Variations of the Mississippi River Outflow. *J. Geophys. Res*., 75, 5909 5913.

Durden S. L., and Vesecky J. F. (1985). A Physical Radar Cross-Section Model for a Wind Driven Sea with Swell. *IEEE J. Oceanic Eng.,* 10, 445–451.

D' Sa E.J, Hu C, Muller-Karger F. E. and Carder K. L. (2002). Estimation of Colored Dissolved Organic Matter and Salinity Fields in Case 2 Waters using SeaWIFS : Examples from Florida Bay and Florida Shelf. *Proc. Indian Acad. Sci. (Earth Planet. Sci.),* 111, No 3, September 2002, pp. 197-207.

Elfouhaily T., Chapron B., Katsaros K., and Vandermark D. (1997), A Unified Directional Spectrum for Long and Short Wind-Driven Waves, *J. Geophys. Res*., 102(C7), 15,781– 15,796.

Ellison W., Balana A., Delbos G., Lamkaouchi K., Eymard L., Guillou C. and Prigent, C. (1998). New Permittivity Measurements of Sea Water. *Radio Science,* 33(3):639–648.

Font J., Camps A., Borges A., Martín-Neira M., Boutin J., Reul N., Kerr Y. H., Hahne A., and Mecklenburg S. (2010). SMOS: The Challenging Sea Surface Salinity Measurement from Space. *IEEE* Vol. 98, No. 5, May 2010.

Gabarro C., Vall-Ilossera M., Font J. and Camps A. (2003), Determination of Sea Surface Salinity and Wind Speed by L-band Microwave Radiometry from a Fixed Platform*, Int. Journal Remote Sensing*., 25(1), 111-128.

Hertz, J., Krogh, A., and Palmer, R. G. (1991) *Introduction to the Theory of Neural Computation.* Addison-Wesley.

Ho W., Love A. W. and Van Melle M. J. (1974). *Measurements of the Dielectric Properties of Sea Water at 1.43 GHz.* NASA Contractor Report CR-2458, Dec. 1974.

Hu, C., Chen Z.,, Clayton T., Swarnzenski P., Brock J. and Muller-Karger F.(2004). Assessment of Estuarine Water-Quality Indicators using MODIS Medium-Resolution Bands: Initial Results from Tampa Bay. *Remote Sensing of Environment,* 93:423-441.

Jorda G., Gomis D., and Talone M. (2011). The SMOS L3 Mapping Algorithm for Sea Surface Salinity. *IEEE on Geoscience and Remote Sensing*, Vol. 49, No. 3, March 2011.

Kerr Y. H., Fukami K., Skou N., Srokosz M. A., Lagerloef G. S. E., Goutoule J. M., Vine D. M. L., Martin-Neira M., Marczewski W., Laursen B., Gazdewich J., Bara J. and Camps A. (1995). *Proceedings of the Consultative Meeting on Soil Moisture and Ocean Salinity Measurement Requirements and Radiometer Techniques (SMOS),* Noordwijk, The Netherlands, 1995, ESA WPP-87.

Klein L.A. and Swift C. T. (1977). An Improved Model of the Dielectric Constant of Seawater at Microwave Frequencies. *IEEE Transactions Antennas and Propagation,* Vol. AP-42, pp. 104-111, 1977.

Le Vine D.M., Lang R. Utku C. and Tarkocin Y. (2011). Remote Sensing of Salinity: The Dielectric Constant of Sea Water. *IEEE.* 978-1-4244-5118-0/11/.

Liu K. K., Chen Y.J., Tseng C.M., Lin I.I., Liu H.B. and Snidvongs A. (2007). The Significance of Phytoplankton Photo-Adaptation and Benthic–Pelagic Coupling to Primary Production in the South China Sea: Observations and Numerical Investigations. *Deep-Sea Research II* 54 (2007) 1546–1574.

Lagerloef G.S.E., Swift C. F. T. and Vine D. M. L. (1995). Sea Surface Salinity: The Next Remote Sensing Challenge. *Oceanography.* Vol. 8, No.2 1995,pp 44-50.

Lerner. R.M. and Hollinger J.P. (1977). Analysis of 1.4 GHz Radiometric Measurements from Skylab. *Remote Sensing Environment*, 6, 251-269.

Lourakis M.I.A. (2005). A Brief Description of the Lavenberg- Marquardt Algorithm Implemented by Levmar. *Unpublished Note.* Institute Of Computer Science

Foundation for Research and Technology - Hellas (FORTH) Vassilika Vouton, Greece.

Maged Marghany (2010). Examining the Least Square Method to Retrieve Sea Surface Salinity from MODIS Satellite Data. *European Journal of Scientific Research*. ISSN 1450-216X Vol.40 No.3 (2010), pp.337-386.

Martin- Neira M., Font J., Srokosz M., Corbella L. and Camps A. (2000). Ocean Salinity Observations with SMOS Mission. . *IEEE Transaction on Geoscience and Remote Sensing* 0-7803-6359-00/00.

Monerris A. (2009). *Experimental Estimation of Soil Emissivity and Its Application to Soil Moisture Retrieval in the SMOS Mission.* Doctor of Philosophy Thesis. Dept. Teoria Del Senyal I Comunicacions Universitat Politècnica De Catalunya, Barcelona.

Morita S.H, Morita K. and Sakano H. (2001). Growth of Chum Salmon (Oncorhynchus keta) Correlated with Sea-Surface Salinity in the North Pacific. *ICES Journal of Marine Science* 58(6):1335-1339.

Philips S., Boone C. and Obligis E. (2007). The Role of Averaging for Improving Sea Surface Salinity from the Soil Moisture and Ocean Salinity (SMOS) Satellite and Impact of Auxiliary Data, American Meteorological Society, *Journal of Atmospheric and Oceanic Technology* vol. 24, February 2007.

Pinori S., Crapolicchio R., Mecklenburg S. (2008). Preparing the ESA-SMOS Mission- Overview of the User Data Products and Data Distribution Strategy. *IEEE Transaction on Geoscience and Remote Sensing* . 978-1-4744-1987-6/08.

Prats G. (2004). 5.1 Inversion Algorithm doc. Available: tdx.cat/bitstream/handle/10803/6390/02Cgp2de02.pdf?sequence=2

Reul N. and Chapron B. (2003). A Model of Sea Foam Thickness Distribution for Passive Microwave Remote Sensing Applications, *J. Geophys. Res*., Vol. 108, No. C10, 3321, 2003, DOI: 10.1029/2003JC001887.

Reul N. and Chapron B. (2003). A Simple Algorithm for Sea Surface Salinity Retrieval from L-Band Radiometric Measurements at Nadir. *IEEE Transaction on Geoscience and Remote Sensing,* pp 2783-2785.

Reul N., IFREMER,CLS,MERCATOR-OCEAN, ICM, UPC,NERSC, SOC, STARLAB (2005). Synergetic Aspects and Auxiliary Data Concepts for Sea Surface Salinity Measurements from Space. *ESA Contract* 18176/04/NL/CB

Reul N., Chapron B., Mevel S., Le Traon P.-Y., Obligis E., Boone C., Bahurel P., Brasseur P., Testut C.-E., Tranchant B., Font J., Gabarro C., Srokosz M., Snaith H., Gommenginger C., Camps A., Vall-llosera M., Miranda J., Sabia R., Germain O., Soulat F., Bertino L., Le Vine D. M., and Lagerloef G. S. E. (2006). Synergetic Aspects and Auxiliary Data Concepts for Sea Surface Salinity Measurements from Space, *European Space Agency ESTEC Contract 18176/04/NL/CB, Final report,* 2006.

Rhoades J.D., Kandiah A. and Mashali A.M., (1992). The Use of Saline Waters for Crop Production. *FAO Irrigation and Drainage Papers*, Version 48. URL: http://www.fao.org/docrep/T0667E/T0667E00.htm

Sahr K., White D. and Jon Kimerlin A. (2003). Geodesic Discrete Global Grid Systems. *Cartography and Geographic Information Science*, Vol. 30, No. 2, 2003, pp. 121-134.

Saleh T. D., Shattri M., Rodzi A. M. and Pirasteh S. (2010). In-situ Measurements and Satellite Data for Sea Surface Salinity Monitoring. *International Geoinformatics Research and Development* Journal., Vol. 1, Issue 1.

Shirota A., Lim L.C. and Chong W.H. (1971). The relationship of Nutrient and Plankton Biomass Distribution in the South China Sea. *Second Congress of Singapore National Academy of Science.*

Stogryn A. (1971). Equations for Calculating the Dielectric Constant of Saline Water. *IEEE Trans. Microwave Theory Tech*., Vol. MTT-19, pp. 733-736.

Talone M., (2010). *Contribution to the Improvement of the Soil Moisture and Ocean Salinity (SMOS) Mission Sea Surface Salinity Retrieval Algorithm*. Doctor of Philosophy Thesis. Department de Teoria sel Senyal i Comunicacions, Universitat Politecnica De Catalunya, UPC.

Ulaby F.T., Moore R.K. and Fung A.K. (1981). *Microwave Remote Sensing: Active and Passive Volume I: Microwave Remote Sensing Fundamentals and Radiometry,* Addison-Wesley Publishing Company, 1981.

Ulaby F. T., Moore R. K. and Fung, A. K. (1986). *Microwave Remote Sensing: Active and Passive. Volume II: Radar Remote Sensing and Surface Scattering and Emission Theory.* Addison-Wesley Publishing Company, 1986.

Wang F. and Jun Xu Y. (2008). Development and Application of a Remote Sensing-based Salinity Prediction Model for a Large Estuarine Lake in the US Gulf of Mexico Coast. *Journal of Hydrology* (2008) 360, 184-194.

Weyl P. (1964). On The Change in Electrical Conductance of Seawater with Temperature. *Limnol. Oceangr*., Vol. 9, Pp. 75-78, 1964.

Wilson W., Yueh S., Dinardo S. and Li F. (2004). High Stability I-Band Radiometer Measurements of Saltwater. *IEEE Transactions on Geoscience and Remote Sensing*. 42(9): 1829-1835.

Wong M.S., Lee K. H., Kim Y. J., Nichol J. E., Li Z. and Emerson N. (2007). Modeling of Suspended Solids and Sea Surface Salinity in Hong Kong using Aqua/ MODIS Satellite Images. *Korean Journal of Remote Sensing*, Vol.23, No.3, 2007, pp. 161-169

Yueh S. H., Wilson W. J., Njoku E., Li F. K. and West R. (2000). Retrieval Modeling and Error Sources for Microwave Remote Sensing of Ocean Surface

Salinity. *IGARSS 2000, Hawaii, Honolulu, Proceedings*, Vol. VI, pp. 2546-2548.

Zhang B., Zhang Y., Song K. and Zhang B. (2004). Detection of Sea Surface Temperature (SST) and Salinity Using Thermal Infrared Data of AVHRR and MODIS in the Gulf Of Bohai Sea of China. *International Journal of Infrared and Millimeter Waves*, Vol. 25, No. 1, January 2004.

Zine S., Boutin J., Font J., Reul N., Waldteufel P., Gabarro C., Tenerelli J., Petitcolin F., L. Vergely J. and Talone M. (2008). Overview of the SMOS Sea Surface Salinity Prototype Processor.*IEEE Transaction on Geoscience and Remote Sensing*, Vol.46, No. 3, March 2008.

Zu T.T., Gan J. and Erofeeva S.Y. (2008). Numerical Study of the Tide and Tidal Dynamics in the South China Sea. *Deep-Sea Research* I 55 (2008) 137–154.

Title, date of access, http://Www.Greenewatersheds.Org/Cycle.Html

Title, date of access, http://www.smos-bec.icm.csic.es/smos_satellite_views