Detection of Melt Ponds on Arctic Sea Ice with Optical Satellite Data (Hamburg Studies on Maritime Affairs Book 25)

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Anja Rösel Hamburg Studies on Maritime AffairsInternational Max Planck Research School for Maritime Affairs at the University of Hamburg Detection of Melt Ponds on Arctic Sea Ice with Optical Satellite Data2013 10.1007/978-3-642-37033-5 © Springer-Verlag Berlin Heidelberg 2013 Volume 25 Hamburg Studies on Maritime Affairs International Max Planck Research School for Maritime Affairs at the University of Hamburg For further volumes: http://www.springer.com/series/6888 Anja Rösel Detection of Melt Ponds on Arctic Sea Ice with Optical Satellite Data Anja Rösel Institute of Oceanography, University of Hamburg, Hamburg, Germany ISSN 1614-2462 e-ISSN 1867-9587 ISBN 978-3-642-37032-8 e-ISBN 978-3-642-37033-5 Springer Heidelberg New York Dordrecht London Library of Congress Control Number: 2013939063 Erstgutachter: Prof. Dr. Lars Kaleschke Zweitgutachter: Prof. Dr. Detlef Stammer Tag der möndlichen Pröfung: 28.06.2012 Printed on acid-free paper Springer is part of Springer Science+Business Media

(www.springer.com) Dedicated to Mats and Jens

Preface

This book is based on my dissertation which I wrote at the Institute of Oceanography of the University of Hamburg under the supervision of Prof. Dr. Lars Kaleschke. The dissertation was accepted by the Department of Geosciences in 2012.

I started my work in November 2008 with the intention to use the now freely accessible huge Landsat satellite imagery archive to detect melt ponds on the Arctic sea ice surface. It turned out that this archive consists mainly of scenes covering landscape and not the ocean surface. Additionally, most of the few available scenes were not usable for a multispectral classification due to over-saturation of the sensor. Therefore I had to look for alternative sensors. I decided to use aquisitions of the MODIS sensor—they have a coarser spatial resolution than those from the Landsat sensor, but provide a full coverage of the Arctic region on a daily basis.

Despite the technical problems at the beginning of my studies, I was able to submit my dissertation in March 2012. My work was enabled by a scholarship of the International Max Planck Research School for Maritime Affairs.

Anja Rösel Hamburg, Germany December 2012

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Finally, I want to give special thanks to my family and to my husband for their love and encouragement.

Abstract

The Arctic sea ice is characterized by profound changes caused by surface melting processes and the formation of melt ponds in summer. Melt ponds contribute to the ice-albedo feedback as they reduce the surface albedo of sea ice and hence accelerate the decay of Arctic sea ice. To quantify the melting on the entire Arctic sea ice, satellite-based observations are necessary.

Due to different spectral properties of snow, ice, and water multi-spectral optical sensors like Landsat 7 Enhanced Thematic Mapper plus (ETM +) or Moderate Resolution Image Spectroradiometer (MODIS) are theoretically applicable for the analysis of these distinct surface types. In this study the potential of both mentioned sensors to detect melt ponds on Arctic sea ice is demonstrated.

To analyze Landsat 7 ETM + scenes, we have developed an algorithm based on principal component analysis (PCA) of two spectral channels for achieving the melt pond fraction. PCA allows differentiation of melt ponds and other surface types like snow, ice, or water. We use spectral bands 1 and 4 with central wavelengths at 480 and 770 nm, respectively. They represent best the differences in the spectral albedo of melt ponds. Due to problems caused by saturation of the sensor, it is only possible to analyze a few selected Landsat scenes which are not affected from over-saturation. A case study on a Landsat 7 ETM + scene from July 19, 2001 using PCA was successfully performed.

For the analysis of MODIS data, we derived the melt pond fraction by using a spectral unmixing algorithm. This algorithm consists of a system of linear equations and was solved by an approximation method. Additionally, an artificial neural network was trained to reduce computational costs. Arctic-wide melt pond fractions and sea ice concentrations have been derived from the level 3 MODIS surface reflectance product. The validation of the MODIS melt pond data set has been conducted (i) with aerial photos from the MELTEX campaign 2008 in the Beaufort Sea, (ii) with very high resolution satellite data sets from the National Snow and Ice Data Center (NSIDC) for the years 2000 and 2001 representing four sites spread over the entire Arctic, and (iii) with ship observations from the trans-Arctic HOTRAX cruise in 2005. The root mean square errors (RMSE) range from 3.8 % for the comparison with HOTRAX data and 10.7 % for the comparison with NSIDC data to 10.3 % and 11.4 % for the comparison with MELTEX data with coefficients of determination ranging from $R^2 = 0.28$ to $R^2 = 0.45$, respectively. For the first time, we have used satellite observations to analyze how melt pond fractions in the Arctic have developed spatially and temporally in the years 2000–2011. During this period the total melt pond area exhibits a significant negative trend of −16.4 %, corresponding to a declining sea ice extent, whereas the annual average of the relative melt pond fraction remains constant with 25.1 ± 1.7 % through the twelve melt cycles. Looking more into detail, a significant anomaly of the relative melt pond fraction at the beginning of the melt season in June 2007 followed by above-average values throughout the entire summer are documented. In contrast, the increase of the melt pond fraction at the beginning of June 2011 is within average values, but from mid-June 2011, relative melt pond fraction exhibits values up to two standard deviations above the mean values of 30.0 ± 1.2 % which are even higher than in summer 2007. Furthermore, the influence of surface melting on sea ice concentration retrievals from passive microwave sensors is pointed out. The sea ice concentrations calculated from passive microwave data are up to 40 % lower compared to the results of the MODIS sea ice concentration.

Acronyms

- ANN — Artificial neural network
- AWI — Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany— http://www.awi.de/
- BFGS — Broyden–Fletcher–Goldfarb–Shanno algorithm
- BRDF — Bidirectional reflectance distribution function
- CALIPSO — Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations
- CliSAP — Integrated Climate System Analysis and Prediction
- CRREL — Cold Regions Research and Engineering Laboratory
- ETM + — Enhanced Thematic Mapper Plus
- gdal — Geospatial Data Abstraction Library— http://www.gdal.org/
- HDF — Hierarchical Data Format— http://www.hdfgroup.org/
- HOTRAX — Healy-Oden Trans-Arctic Expedition 2005
- MELTEX — Impact of melt ponds on energy and momentum fluxes between atmosphere and sea ice
- MODIS — Moderate Resolution Imaging Spectroradiometer
- NetCDF — Network Common Data Form
- NSIDC — The National Snow and Ice Data Center, Boulder, Colorado— http://nsidc.org/
- PCA — Principal component analysis
- RMSE — Root Mean Square Error
- SLC — Scan line corrector
- SPOT — Satellite Pour l'Observation de la Terre
- TOA — Top-of-the-atmosphere
- UTM — Universal Transverse Mercator coordinate system

Contents

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