UK NERC sea ice FSD workshop

“Bringing modelling, observation and image processing together”

Venue & Date: SAMS, Oban, Scotland, July 6-7, 2015 (http://www.sams.ac.uk/)

Scope of the workshop: The workshop has been funded from UK NERC to stimulate national and international collaborations to study physical processes governing changes in sea-ice floe size distribution (FSD). This includes a wide range of research areas such as modelling, observation, remote sensing and image processing. In this workshop we will have ocean/sea ice/wave modelling scientists, satellite and field-based observational scientists, and image processing experts.

Workshop coordinators:

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Monday 6 July

08:20-08:30 Bus-Railway Station
08:30-08:45 Corran Halls

09:00 Welcome/Logistics - Phil Hwang

Modelling - Tim Williams/Phil Hwang

09:20 Agnieszka Herman
09:40 Arnold J. Song
10:00 Chris Horvat
10:20 Tim Williams
10:40 Break
11:00 Yevgeny Aksenov
11:20 Lucia Hosekova
11:40 Jean Bidlot
12:00 Discussion

12:20 Lunch

13:20 Discussion

Observation - Phil Hwang/Tim Williams

14:20 Wolfgang Rosenthal
14:40 Susanne Lehner
15:00 Break
15:20 Alexandra Arntsen
15:40 Phil Hwang

16:00 Discussion

18:00 Bus to Dinner
18:30 Dinner
21:00 Bus to Oban
Tuesday 7 July

08:20 - 08:30 Bus-Railway Station
08:30 - 08:45 Corran Halls

*Image processing - Jinchang Ren/Xiuping Jia*

09:20 Jinchang Ren
09:40 Paul Murray
10:00 Steve Marshall
10:20 Xiuping Jia
10:40 **Break**
11:00 Erhan Abdullah
11:20 Mauro Dalla Mura
11:40 Erfu Yang

12:00 **Lunch**
13:00 **Discussion**
14:00 **Break**
14:20 **General discussion - eg special issue?**

16:00 Bus to Oban
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Possibilities and challenges of using discrete-element models in studies of sea ice dynamics, fragmentation and floe formation

At geophysical scales, sea ice is commonly modeled as a continuum, with various versions of the viscous-plastic rheology. This approach, well established and relatively efficient computationally, gives satisfactory results at large spatial and temporal scales, but has important limitations regarding reliable reproduction of certain physical processes, including fracture and fragmentation of ice, or dependence of its mechanical strength and other properties on the floe size distribution (FSD). Although progress has been made recently in parameterizing some of FSD-related effects in continuum models (e.g., Zhang et al. 2015), our limited understanding of many important aspects of processes related to the “granular” nature of sea ice hinders development of such parameterizations. Until recently, only few attempts to directly account for the granular effects in sea ice models have been made (e.g., Gutfraind and Savage, 1997; Hopkins et al., 2004; Herman, 2013a,b; see also review in Herman, 2015). The goal of this work is to investigate possibilities and problems associated with the application of discrete-element models (DEM) to the analysis of sea ice dynamics in general, and to FSD-related aspects of that dynamics in particular.

The DEM sea ice model used in this work (Herman, 2015) describes the motion and interactions of two types, or classes, of objects: ‘grains’ (disk-shaped sea-ice blocks moving within a two-dimensional space representing the sea surface) and ‘bonds’ (representing new, usually thinner ice filling cracks, leads and other open spaces between thicker ice blocks). There are two essentially independent mechanisms of interactions between neighboring grains. The first requires that they are in a direct contact with each other (nonlinear Hertzian contact model, taking into account polydispersity). The second requires that the grains are connected with an elastic bond. Crucially, whereas forces are transmitted in both cases, bonds are also able to transmit momentum; they also have certain tensile strength. The model is two-dimensional, but it takes into account wave-induced flexural moments related to the curvature of the sea surface – one of the most important mechanisms of sea ice breaking in the marginal ice zone.

Numerically, the model is based on the LAMMPS (Large-scale Atomic/Molecular Massively Parallel Simulator; http://lammps.sandia.gov/) and LIGGGHTS (LAMMPS Improved for General Granular and Granular Heat Transfer Simulations; http://www.cfdem.com/) libraries. It has a form of a toolbox that enables calculation of external forces acting on the ice (wind, ocean currents, etc.) and sea-ice-specific interactions between the grains and bonds. It is freely available together with a technical documentation and example input files.

This work presents selected examples of application of the model to analysis of sea ice dynamics, deformation and fragmentation. The examples concentrate on processes that are poorly or not at all reproduced in continuum sea ice models, but are crucial for sea ice dynamics in certain conditions. Two aspects of FSD-related problems are considered: first, the influence of the FSD on sea ice response to the oceanic/atmospheric forcing, including spatial and temporal variability of the internal stress; and second, ice deformation and breaking as processes shaping the FSD. The analysis concentrates, on the one hand, on the unique possibilities offered by DEM models to monitor very fine, small-scale details of the motion of individual ice floes and interactions between them, and on the other hand on typical challenges and problems, in particular those related to the model calibration and to validation of the modeling results against observational data.

REFERENCES

Herman, A., 2013a: Numerical modeling of force and contact networks in fragmented sea ice, Annals Glaciology, 54, 114-120.
Arnold J. Song  
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An examination of how heterogeneities affect floe break up patterns using a discrete element method sea ice model.

![Discretization of Arctic Basin](image1.png)  ![Detailed view](image2.png)

Demonstration DEM sea ice configuration initialization using the MASIE ice extent mask with an ACNFS thickness distribution overlay for July 1, 2014. In the DEM model, the ice cover is represented as a collection of discrete polygonal elements. Each element. This capability to initialize and discretize the sea ice cover using a raster mask is easily extended to any raster or vector polygon defined mask that delineates open water and ice.

**Background:** The goal of this work is to evaluate the utility of the discrete element method (DEM) in (a) advancing the understanding of the dynamic and thermodynamic processes governing the seasonal evolution of the marginal ice zone (MIZ) and (b) forecasting conditions in the MIZ in support of an anticipated increase in operational requirements.

**Methods:** The DEM is a numerical approach to describe the dynamics of systems that contain large numbers of discrete elements and for which the effects of element-to-element interaction significantly influence the mechanical behavior of the bulk material. The DEM has been successfully applied to model sea ice processes such as pressure ridging (Hopkins 1998), aggregation due to wave-ice interaction (Hopkins & Shen 2001), and the mesoscale evolution of the floe size distribution (Hopkins & Thorndike 2006). The DEM treats sea ice as a collection of discrete pieces of ice, thus affording the method certain advantages over the continuum approach for high-resolution, high-fidelity modeling of sea ice dynamics. Using the satellite-borne high-resolution imagery, we define the initial spatial distribution of open water, ice cover and ice thickness in the DEM model’s simulation domain. Weather and ocean circulation models from several sources can be used to force the DEM sea ice dynamics.

**Results:** We will present simulation results that examine how the spatial variation in the ice thickness and strength due to the presence of linear inclusions and melt ponds influence the break up pattern and, therefore, the floe size distribution.
Knowledge of the evolution and influence of the joint distribution of sea-ice floe sizes and thicknesses (FSTD) is important in seasonal or marginal ice zones, due to the possible effects of the FSTD on air sea fluxes, on sea ice melting and freezing, and on ocean state and climate.

To understand the manner in which the FSTD evolves, we developed a model that simulates its evolution subject to thermodynamic forcing, mechanical forcing, and fracture by ocean surface waves, as a function of atmospheric and oceanic forcing fields, and have coupled this to a basic mixed-layer model of the ocean in order to evaluate feedbacks between ocean waves and ice thermodynamics.

In an effort to understand how the FSTD influences climate, we have used an ocean GCM to simulate the response of the ocean to a variety of idealized distributions of ice "floes", examining the influence of the lateral distribution of these floes on stratification, air-sea exchange, and dynamics on scales comparable to climate model grid-scales. We find so far little influence on the steady-state, but a potentially pronounced influence on the transient state of the upper ocean.
In this talk we will discuss interactions between a wave-ice model that includes break-up of sea ice and wave attenuation, with the elasto-brittle (EB) sea-ice rheology. EB is the dynamical core of the neXtSIM sea ice model that is being developed at NERSC, which involves cascading of damage due to repeatedly large internal stresses. When the damage parameter $d$, is 1, the ice is totally damaged and has no internal stress, and will consequently be in a state of free drift.

A correspondence between $d$ and the floe size distribution is non-trivial, but for now we simply set $d=1$ when the sea ice is broken by waves. While this neglects a lot of effects – for example dissipation due to collisions between floes – we use this as a starting point to investigate the impact that waves might have on sea ice dynamics. In particular, we investigate the effect of momentum transfer between the waves and the ice at the ice edge when this is done.
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**Modelling Sea Ice Dynamics in the Changing Arctic**

Rapid decline of Arctic summer sea ice in the last decade has resulted in decreasing close summer pack ice, while the area of open sea ice has grown. Exposure of large, previously ice-covered, areas of the Arctic Ocean to the wind and surface ocean waves leads to the Arctic pack ice cover evolving into the Marginal Ice Zone (MIZ), increases ocean turbulence and speeds up ocean currents. We present initial results from a version of the global coupled sea ice-ocean model NEMO (Nucleus for European Modelling of the Ocean). The model implements a novel rheological formulation for sea ice dynamics, accounting for ice floe collisions and offering a seamless framework for pack ice and MIZ simulations. In the decadal-long model integrations we examine basin scales sea ice and oceanic responses to the changes in ice rheology and floe size distribution. We analyse model sensitivities and attribute them to key sea ice and ocean dynamical-thermodynamical mechanisms. The results suggest, that to make accurate sea ice predictions in the changing Arctic, the models need to include MIZ dynamics and physics.
Sea-ice – wave interactions in a global ocean model

The surface waves, sea ice and ocean interact in the Marginal Ice Zone through multiple complex feedbacks and processes which are not accounted for in any of the present-day global climate models. To address this issue, we present a model development which implements surface ocean wave effects in the global Ocean General Circulation Model NEMO, coupled to the CICE sea ice model. Our implementation takes into account a number of physical processes specific to the MIZ dynamics. Incoming surface waves are attenuated due to reflection and energy dissipation induced by the presence of ice cover, which is in turn fragmented in response to external stresses. This process generates a distribution of floe sizes and impacts the dynamics of sea ice by the means of combined rheology that takes into account floe collisions and allows for a more realistic representation of the MIZ.

We present results from the NEMO OGCM at 1 degree resolution with the wave-ice interaction module described above. The module introduces two new diagnostics previously unavailable in GCMs: surface wave spectra in sea ice covered areas, and floe size distribution (FSD) due to wave-induced breakup. We will discuss the extension of the FSD definition from MIZ to pack ice in order to realistically describe the ice fragmentation in global models, and show the comparison between our wave-generated floe size diagnostics and a parameterization derived only from sea ice concentration. We will also present the impact of our FSD implementation on sea ice thermodynamics due to lateral melting.

The study contributes to the EU FP7 project 'Ships and Waves Reaching Polar Regions (SWARP)', aimed at developing techniques for sea ice and wave modelling and forecasting in the Arctic MIZ Arctic.
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Abstract

Up to now, the impact of sea ice on waves has been limited to the specification of a fixed threshold in sea ice cover over which it is assumed that no waves exist. Recent developments of how waves are affected as they propagate into the Marginal Ice Zone (MIZ) have resulted in an attenuation model for wave energy that can be used to represent the impact of sea ice in a spectral wave model (Kohout and Meylan 2008). We have applied that model to the wave model used at ECMWF, even though the details of the sea ice field are not known. Results will be compared to observations. Work is on-going to test alternative parametrisations of the impact of sea ice on the wave field and on obtaining a better parametrisation of the floe size distribution that enters into the wave attenuation model.

When used to produce operational forecasts, the wave model is fully coupled to the atmospheric model. The presence of sea ice alters the spectral distribution of the waves which in turn will impact the wind above as will be shown. ECMWF is currently developing a fully coupled atmosphere-wave-ocean-sea-ice model. In that system, an active ice model will be used to supplement the basic information about the sea ice condition to the other components of the system. The impact of the sea ice on the wave field will be revisited in the context of the coupled system. Waves also affect the sea ice. Impact of the waves on the sea ice distribution will be explored.
Swell Waves travelling into Sea Ice by TerrsSAR-X Satellite Imagery

The penetration of water waves into sea ice has various implications. Their range of influence extends from heat fluxes and water mixing at the ocean surface to land erosion, etc. This leads to the issue of potential feedback processes between waves and ice, e.g. the break-up of ice by waves leads to a larger water/air interface. This, in turn, may be connected with enhanced absorption of solar radiation and less ice formation. All this is of particular relevance in the context of a changing ocean wave and sea ice climate.

Over the last few decades, the propagation of ocean waves into the marginal ice zone (MIZ) was extensively studied with in situ measurements from field campaigns, remote sensing methods, and laboratory experiments using ice tanks being utilized. The focus of these studies ranged from waves in frazil and pancake ice to those encountering ice floes. Based on different theoretical approaches, models were developed to describe the wave ice interaction. For details, see the review paper of Squire (2007) and references therein.

The potential of synthetic aperture radar (SAR) instruments to reveal effects of wave refraction in ice floe covered areas was already pointed out by Wadhams et al. (1986). Subsequently, considerable insight into ocean waves in sea ice was gained from SAR satellite images. Subsequent studies such as Wadhams et al. (2002, 2004) address the behavior of sea state in frazil, pancake, and brash ice. As follow-on application, first attempts of retrieving the thickness of pancake ice from wave patterns evident from SAR images are made. The aforementioned publications involve case studies on different conditions of the sea state in the MIZ comprising local wind sea to long swell waves.

Based on TerraSAR-X (TS-X) satellite images, the present study focuses on ocean waves penetrating into the MIZ off the coast of Eastern Greenland in February 2013. A high and complex sea state given by swell waves of 300 to 350 m length travelling to North East through the Denmark Strait together with a younger swell with wavelength up to somewhat less than 200 m propagating North of Iceland roughly in the West direction into sea ice is analyzed. The high resolution imaging quality of the TerraSAR-X satellite is demonstrated. Peak wavelength and direction are retrieved without inversion. The TS-X images which are the basis for this investigation are available as a sequence extending from the open ocean through to solid ice. An interesting insight into the abilities of TS-X to monitor the sea state under ice conditions is provided.
Investigating the potential of dual-pol TerraSAR-X for sea ice classification and floe size distribution analysis

ABSTRACT

Synthetic Aperture Radar (SAR) data of the high resolution TerraSAR satellite are used to investigate sea ice in the Marginal Ice Zone. Resolution and Coverage of the images are compared to the freely available Sentinel-1 images. In contrast to SAR single-pol data, which allow only classical image analysis, TerraSAR dual-pol imagery can be analyzed by means of complex polarimetry. Our work investigates the potential of dual-pol data (co-pol) delivered by TerraSAR-X for automatic sea ice classification and subsequent computation of floe size distribution. The first step of our analysis comprises the extraction of polarimetric features. To enrich the information content of image segments, second order statistics on these polarimetric features are additionally computed. The discriminative power and relevance of the different features are ranked by utilizing the concept of mutual information. Different selections of the most relevant features are then fed into a neural network classifier. For the computation of the floe size distribution, we utilize the results of the classification (i.e., the different polarimetric features) to separate open water or small flow type from ice types consisting of distinct, larger floes. Based on this prior analysis, we perform a segmentation and subsequent particle analysis to compile the floe size histogram. Examples from different parts of the Arctic and from different seasons are shown.
Observations of the Summer Breakup of a Sea Ice Cover

The Arctic sea ice cover evolves dramatically through the summer melt season. Floe size distribution (FSD) is a critical parameter used to examine this change as a region of interest transitions from large rectilinear plates in spring to an ensemble of discrete rounded floes by mid-summer. The FSD at a given time impacts both dynamic and thermodynamic behavior of the ice cover. Additionally, the realized FSD itself is a manifestation of past dynamic and thermodynamic processes and events. Focusing on the seasonal marginal ice zone (MIZ) in the Beaufort and Chukchi Seas from May until September 2014, we present qualitative and quantitative results derived from National Technical Means (NTM) high resolution imagery and supported by ice mass balance buoy 2014C. Findings indicate that as melt accelerates, floe breaking pattern, and therefore FSD, is heavily influenced by the distribution of melt ponds. Preferential melt, pond formation, and subsequent failure at features created by pre-melt dynamic events is also observed.
Observation of sea ice floe size distribution from SAR: algorithm, effects of scale, and physics

Satellite data have been revealing rapid changing “new” Arctic, as more and more permanently sea-ice covered area turning into seasonally sea-ice covered area. It has been long anticipated that ocean waves have significant role in sea-ice floe breakup and consequent changes in FSD. However, questions are being raised; how much the role actually do the waves have in early summer floe breakup?, what are the other factors causing floe breakup?

Recently there have been efforts to implement sea-ice floe breakup into numerical sea-ice models, as well as a intensive in-situ buoy observation program. Along with these efforts, the accurate measurement of changing FSD is of key importance in addressing fundamental questions we have. This talk presents collaborative works that include a) brief introduction to the algorithm for FSD retrieval from satellite images, b) scale effects of the derived FSD, c) model comparison, and d) a case study on 2014 summer.
Effective Segmentation of SAR sea ice images using Multi-stage hybrid approaches

Abstract: Accurate sea-ice segmentation from satellite synthetic aperture radar (SAR) images plays an important role for understanding the interactions between sea-ice, ocean and atmosphere in the Arctic. Processing sea-ice SAR images are challenging due to poor spatial resolution and severe speckle noise. In this talk, multi-stage hybrid approaches are discussed for the sea-ice SAR image segmentation, which includes edge-preserved filtering for pre-processing, preliminary pre-segmentation using watershed and graph cut, and post-processing using rule based validation and/or local active contours based fine segmentation. As such, the effect of noise has been suppressed and the under-segmented regions are successfully corrected. The efficacy of the proposed approaches are benchmarked with other well-known image segmentation algorithms such as level set and k-means clustering.
Addressing the challenge of separating small ice floes in under segmented SAR sea-ice imagery

Automated techniques capable of accurately segmenting sea-ice and water regions from SAR (Synthetic Aperture Radar) imagery would be extremely useful to researchers and scientists aiming to analyse such images to better understand sea-ice dynamics at different times of the year.

Unfortunately, developing these methods is not trivial, particularly when SAR images themselves tend to be noisy and are generally suffer from low spatial resolution. This means that the boundaries between touching sea-ice regions and water boundaries are often not clear in the data, hence, extracting this information is hard. In this talk, an initial segmentation of SAR sea-ice imagery - based on K-means clustering and Watershed segmentation - is presented. Then, we explain our approach known as Dynamic Directional Conditional Morphology (DDCM) and show how it can be used to address the problem of under-segmentation of small sea-ice floes in the data. DDCM first identifies under-segmented regions of the image by analysis of the distance transform of the initial segmentation. Then, morphological structuring elements are generated for each under-segmented region and applied in turn to improve the segmentation accuracy of the initial approach. Before concluding, we also demonstrated a morphological approach for detecting so called “melting ponds” in the segmented sea-ice regions. All techniques will be presented by example and an extensive set of results will be shown.
HSI in manufacturing and the laboratory

Hyperspectral imaging cameras can determine if objects being viewed are hot or cold, wet or dry, their fat and sugar content and the presence of certain chemical elements. Therefore, it has a diverse and growing range of applications in areas such as pharmaceuticals, food technology and other inspection processes.

Typically HSI finds application in two main areas: Where the subject has a spatial variation and; where HSI provides a rapid alternative to wetlab work.

This talk will cover a range of application of HSI in market sectors including Food and Drink for assessing moisture of cakes and eating quality of beef. It will also cover pharmaceutical applications in which chemical changes which are not perceptible to the human eye can be visualised through hyperspectral image processing. Finally an application using HSI to assess the authenticity of artwork will be described.

Imaging of baked products

Classified Images of Tablet dissolution
Spatial-spectral based feature extraction and remote sensing image classification

Optical and microwave remote sensing collects data at various wavelength to identify different land cover materials. Spectral information, either reflected solar radiation, Earth emission or backscattered radar signals, is the main source used in pixel-wise pattern recognition. In terms of image classification, relationships between the neighboring pixels and spatial properties, such as edges and shapes, textures, and morphological structures, become important information to employ. The current trend of research is to adopt big data approach and combine multisource data for reliable knowledge mining. In this talk, an overview of contextual based image classification techniques will be provided, including the application of Markov Random Fields model, superpixel approach, and spatial feature generation as derived new measurements. Feature extraction and fusion will be discussed to combine the multisource data for hard and soft classification. Mapping of the sea-ice floe size distribution (FSD) using a SAR image will be illustrated and discussed.
Remote sensing image retrieval with morphological texture descriptors

The remote sensing scene has witnessed dramatic changes in the last couple of decades. For one, both spatial and spectral resolution capacities of image acquisition devices have increased significantly. Spectral-wise, with the advent of hyper-spectral sensors, every pixel can now be described with its spectral response across not just a few, but hundreds of narrow contiguous spectral bands. And as far as spatial resolutions are concerned, they have improved from tens of meters down to a few tens of cm's per pixel. Moreover, the rate of image acquisition has also reached higher levels, thus leading to the formation of very large, remotely sensed data warehouses in private or public establishments.

The aforementioned changes have had profound effects on the processing of remote sensing images. On one hand, the availability of images containing a significantly higher amount of spatial and spectral detail, has paved the way for new applications and has enabled the use of a wider range of image analysis methods. On the other hand, the rapid accumulation of gigabytes worth of remote sensing data on a daily basis, has rendered robust and automated tools, designed for their management, search and retrieval, as essential for their effective exploitation. Consequently, the interest of the remote sensing community on how to adapt the existing body of knowledge about content-based image retrieval to this context, has been increasing in the last years.

This talk will provide an overview of the issues surrounding the content-based retrieval of remote sensing images. It will concentrate on the particularities of this context with respect to the data, casually manipulated by computer vision specialists, and on the need to adapt the existing amount of know-how on retrieval. We will elaborate on the state of the art of content-based description and retrieval, with a particular focus on what mathematical morphology has to offer in this regard.
A joint work with
M.A. Veganzones1,3, M. Dumont2, I. Zin3, J. Chanussot1,4
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Monitoring Seasonal Snow Cover based on Spectral unmixing

Abstract
The snow coverage area (SCA) is one of the most important parameters for cryospheric studies. The use of remote sensing imagery can complement field measurements by providing means to derive SCA with a high temporal frequency and covering large areas. Images acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) are among the most widely used data to retrieve SCA maps. Some MODIS derived algorithms are available for subpixel SCA estimation, as MODSCAG and MODImLab. Both algorithms make use of spectral unmixing techniques using a fixed set of snow, rocks and other materials spectra (endmembers). In this talk, we explore advanced spectral unmixing techniques for SCA estimation. Specifically, we make use of endmember induction algorithms to obtain the endmembers from the data itself instead of using a fixed spectral library. Experiments considering the proposed approach are conducted on a case study in the mountainous region of the French Alps.
Visual Attention Model-Based Multiple Target Detection in Synthetic Aperture Radar Images for Autonomous Surveillance Systems

Visual surveillance is an attempt to detect, recognize and track certain objects from image sequences, and more generally to understand and describe object behaviors. Future’s visual surveillance systems for outdoor (including security) applications will require mission platforms that are autonomous, asynchronous, adaptive and highly sensitive in complex, time-varying and possibly hostile environments.

One fundamental problem in autonomous surveillance systems is how to detect multiple targets, sense and percept the world/environment in extreme outdoor conditions in which the presence of dust, fog, rain, changing illumination can dramatically degrade conventional stereo and laser sensing. Thus, radar-based imaging in autonomous surveillance systems has attracted extensive research attention in recent years since radar also allows for multiple targets detection within a single beam, whereas other range sensors are limited to one target return per emission. The main challenge arising from radar-based autonomous visual surveillance systems is always linked to radar image information processing and utilization, i.e., how to quickly and efficiently extract and analyse the information of interest for multiple targets from consecutive images acquired by radar imaging sensors.

In this talk, a visual attention model-based algorithm is proposed to detect multiple targets from SAR (synthetic aperture radar) images. The algorithm extends the well-known Itti model according to the requirements of multiple target detection in SAR images. It locates salient regions in SAR images and reduces false alarms significantly by using an efficient top-down process. The performance of the proposed algorithm is demonstrated by using real SAR images with 20 vehicle targets.