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Development of a Web-GIS based system for safer ship navigation in Antarctic region using open source technologies

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Abstract: Polar ecosystem plays a crucial role in global climate change processes. Antarctica is an ideal natural laboratory for advanced research related to climate change and polar ecosystem studies. Concerned global scientific community carries out various scientific experiments by organising expeditions to various research stations located in Antarctica. These stations are heavily dependent on outer world for their maintenance, logistic requirements as well as scientific needs. The number of vessels travelling to and from Antarctica; and between research stations are increasing every year. These vessels face adverse climatic conditions viz. high wind conditions, sea ice resistance, changing polar currents, sea ice deformations etc. Remote sensing data available through various satellites can provide relevant and needed information such as Sea Ice Thickness (SIT), Sea Ice Concentration (SIC) and Sea Ice Extent (SIE) which, when utilized rationally can provide a suitability map for safer ship navigation. Web-GIS acts as a low-cost modus operandi that brings GIS based system in public reach across the globe. Therefore, a need of Web-GIS enabled Earth Observation (EO) satellite data based safer ship navigation system is felt. This paper discusses development and dissemination of a rich Graphical User Interface (GUI) based Web-GIS application which inherits power of open source technologies for generation as well as geo-visualization of ship navigation suitability map in the Antarctic region. In backend, relevant data is automatically downloaded, ingested and processed using Python. VueJS framework is deployed for in-browser visualization experience at client's end. Users can pan, scale, get feature information at a given pixel by clicking on image and perform temporal pixel drilling. User can also download temporal profile in .csv format. The developed system has been used for Indian Scientific Expedition to Antarctica during 2018-19 and available at https://vedas.sac.gov.in/vstatic/ship_nav/.

Keywords: Ship navigation suitability map, Sea-ice, Antarctica, Remote Sensing, Web-GIS, VEDAS

1. Introduction

A polar ecosystem is unique and differs significantly from other ecosystems. It consists of atmosphere, ocean, sea ice, polynyas, ice shelf, ice sheet etc. In recent years, there has been increasing interest in polar studies to understand impact of climate change. Several studies suggest that ice cover, having growth and melting order of one year, captures climate signal and acts as an indicator, if integrated over short period (Rees, 2006).

These studies provided further curiosity and momentum to research related to polar ecosystem. Global scientific community carries out various scientific experiments by organising expeditions to various research stations located in Antarctica. However, frequent variability of atmospheric and oceanic conditions, such as high wind conditions, rapidly changing ocean waves, varying sea ice conditions etc. causes challenges for safer ship navigation. Therefore, accurate knowledge of sea ice conditions is crucial for ship navigation in polar region during various expeditions. In recent years, there have been news of vessels stranding in sea ice in Antarctic Ocean, e.g., stranding of a Russian vessel MV Akademik Shokalskiy in December 2013 (Pearlman, 2013). There are several vessels engaged in scientific expeditions from different countries in the Antarctic region. Some may have limited ice breaking capability. In such conditions, there is a need for an automated satellite data based web GIS integrated system to provide near real time navigation suitability map.

Safer navigation through Antarctic Ocean requires information on major sea ice parameters, viz., Sea Ice Thickness (SIT), Sea Ice Concentration (SIC), Sea Ice Extent (SIE) etc, which is primarily derived using Earth Observation (EO) satellite data. This information when combined with Web based Geographic Information System (WebGIS) results into a near real time information system for safer ship navigation. The Arctic Ice Regime Shipping System (AIRSS) provides a flexible framework for decision making along with minimum risk of pollution in the Arctic waters due to damage to vessels by sea ice (Anonymous, 2018). Space Applications Centre (SAC) has been providing regular sea ice advisories to the Indian Scientific Expeditions to Antarctica since 2012-13 using various sea ice products derived from EO data (Rajak et al., 2014 and 2015). Several attempts have been made to develop expedition specific navigation system (Hui et al. 2017). However, a more user friendly near real time Web-based GIS information system is lacking for Antarctica.

Web-based GIS is open source, distributed, standardized by OGC (Open Geospatial Consortium) system that brings GIS technology to the public at little or no cost (Caldeweyher et al., 2006). A web-GIS based system increases visibility of system and enhances effectiveness of system for decision making process as all related data is available at a single place. Today, only a reliable internet connection and compatible browser makes it possible for users to access such system.

In the study presented in this paper, a Web-GIS enabled satellite data based system for safer ship navigation is developed for Antarctic region. This system utilizes available sea ice related information viz. SIE, SIC, SIT derived using EO data to generate near real time navigation suitability map.

Table 1: EO satellite data products used in the study

Sr. No.	Input	Data type	Spatial Resolution	Temporal interval	Data Sensor / Source
1	Sea Ice Thickness (SIT)	Image	10 km	Daily moving 15-day composite	SARAL/AltiKa
2	Sea Ice Extent (SIE)	Image	~2.2 km	Daily composite	SCATSAT-1
3	Sea Ice Concentration (SIC)	Image	25 km	Daily composite	SSMIS

2. Study area

Study area covers entire oceanic region surrounding the Antarctica. It includes the ocean portion nearby Amery ice shelf (Prydz Bay), Brunt ice shelf & Larsen ice shelf (Weddell sea), Bellingshausen sea, Amundsen sea, Ross ice shelf (Ross sea) and Shackleton ice shelf as well ocean portions neighbouring Indian research stations viz., Maitri (70° 45' S, 11° 43' E) and Bharati (69° 24'S, 76° 11' E).

3. Data used

Table 1 summarizes information regarding input data used in this study.

3.1 Sea Ice Thickness (SIT)

The developed system uses a daily product of Sea Ice Thickness derived from SARAL/AltiKa. The SARAL/AltiKa program is a collaborative programme between ISRO, India and CNES, France. SARAL (acronym for "Satellite for ARgos and ALtiKa". SARAL/AltiKa), launched on 23 February 2013, is the world's first satellite equipped with a Ka-band (35.75 GHz) altimeter for measuring ocean sea-surface height (https://altika-saral.cnes.fr/en/home-20). Sea ice thickness is retrieved using SARAL/AltiKa radar waveforms (Joshi and Oza, 2018). Sea ice thickness retrieved as point data from satellite is later interpolated at grid size of 10 km.

3.2 Sea Ice Concentration (SIC)

The SIC information is obtained from Near-Real-Time NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration, Version 1 dataset (Meier et al. 2017). This dataset is a near real time version of final NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration which provides daily sea ice concentration estimates from two well established algorithms: the NASA Team algorithm (Cavalieri et al. 1984) and NASA Bootstrap (BT) algorithm (Comiso, 1986) on a 25 km x 25 km grid. This dataset is available in netCDF4 format and has been used in present study.

3.3 Sea Ice Extent (SIE)

The system utilizes data from Ku-band scatterometer on-board SCATSAT-1 instrument to extract information of sea ice extent (SAC, 2016). A multiple thresholds based classification algorithm comprising four parameters, namely Gamma naught (γ^0) and Brightness temperature (T_b) of H-pol and V-pol i.e. $\gamma_H^0, \gamma_V^0, T_{b_H}, T_{b_V}$ along with the polarization ratio of H-pol and V-pol data which are Normalized Difference Gamma Naught Index (NDGI) and Normalized Difference Brightness Temperature Index (NDBI), are used to discriminate sea ice from water and other classes. This product is available at 2.25 km spatial resolution on daily basis at VEDAS (Web portal of Space Applications Centre, ISRO, Ahmedabad).

4. Methodology

The development of Web-GIS based system can be divided into three subsystem or modules: (1) Data generation / download module, (2) Ship navigation suitability classification map generation, (3) Publishing and visualization of ship navigation suitability map.

4.1 Data download and generator module

The main functionality of this module is to download data automatically from data storage server and process it to bring it in common projection and spatial resolution. In order to develop a sustainable and operationalized system, automated scripts are used to download respective SIT, SIC and SIE data on daily basis. This module read incoming SIC and SIE data from given file format, georeference it from given metadata details, resample it to a common spatial resolution of 10 km. The unprocessed daily SIT data is available in ESRI shapefile format where sea ice thickness is given with its coordinates along with date of its retrieval from AltiKa daily data.

4.2 Ship navigation suitability classification map

Generator module

This module is back bone of the system which generates ship navigation suitability class map at a spatial resolution of 10 km. SIT values are spatially interpolated based on 17-day SIT composite data on one day temporal resolution. In order to eliminate daily processing of past 16-days thickness values from AltiKa, an incremental algorithm that processes same-day thickness values with last 16 days thickness values iteratively, designed and implemented. In this implementation, only daily incoming data is processed, and past 16-days processed thickness values are fetched from central database. Once incoming data is processed then it is stored in central database. This way duplication of processing AltiKa data for generating SIT values is avoided, resulting in faster processing.

Interpolated SIT image, along with SIC, is then processed to their weighted version with an indigenously developed individual weighting schemes. Weights are given in such a way that higher the weights, high suitability for ship navigation. The details of respective scheme are as shown in tables 2 and 3.

Table 2: Weighting scheme for Sea Ice Thickness (SIT) and Sea Ice Concentration (SIC)

SIT (in m)		Weighted SIT	SIC (in %)		Weighted SIC
> SIT	**<=SIT**		**> SIC**	**<= SIC**	
0	0.25	50	0	50	50
0.25	0.5	30	50	70	30
0.5	1	10	70	80	10
1	1.5	7	80	90	7
1.5	2	2	90	95	2
2	Any	1	95	100	1

Table 3: Criteria for ship navigation suitability classification (With enough ice floes points)

Suitability Class	**< TW**	**>= TW**
Low	0	50
Medium	50	100
High	100	2500

Table 4: Threshold range of SIC for ship navigation suitability classes in case of unavailability of SIT

Suitability Class	**SIC (in %) in case of "Ice" in SIE**
Low	80-100
Medium	60-80
High	<60

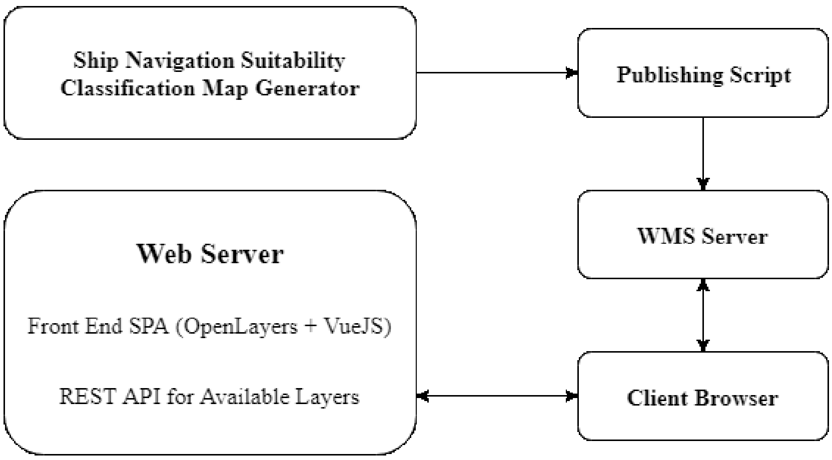

Figure 1: Web-GIS system architecture of ship navigation suitability

From Weighted SIC and SIT values, Total Weights (TW) are computed as:

$$TW = Weighted\ SIT * Weighted\ SIC$$

Once TW is calculated, Sea Ice Extent (SIE) data is finally used to mask out "No-Ice" pixels. In case of "No-Ice" pixels, highest value, 2500, is given as TW. After weights computation, ship navigation suitability classified image is generated based on conditions given in table 3. However, in cases when there will not be enough ice floes points such as during winter season, sea ice thickness at floes points cannot be computed. Therefore, in such case, sea ice concentration and sea ice extent are used in decision making related to ship navigation suitability. This modified criterion for suitability is tabulated in table 4.

4.3 Publishing and visualization module

The overall architecture of the system is illustrated in figure 1. All processes of the system from downloading of data to layer publishing is handled by automated scripts without any manual intervention. Each component of the system is described below.

4.3.1 Ship navigation suitability classification map generator

This component is responsible for generating ship navigation suitability map based on sea ice parameters. Output is then stored in a shared data storage location, which is accessed by the publishing script. This generator uses Python with GDAL library for generating map.

4.3.2 Publishing Script

This component reads the generated products from the shared data store and publishes the same on a WMS server. The publishing process comprises extraction of timestamp from the filename of the generated product file and loading the product file to the WMS server data store.

4.3.3 WMS server

The WMS server is responsible for serving images generated from the SIT product for client-side visualization. The client-side mapping scripts can consume OGC standard WMS services exposed by the WMS server for visualization of data in browser.

4.3.4 Frontend Single Page Application (SPA)

Frontend application is a Single-Page-Application (SPA) for in-browser visualization is developed using VueJS framework with OpenLayers as a mapping library. The SPA consists of static JavaScript and HTML files, which are served by a static web server. These are loaded and executed on the client browser.

4.3.5 REST API for available layers

The client SPA queries a REST API which returns a list of available published layers. This service relies on the shared data store to list the available datasets for visualization.

5. Results and discussion

A Web-GIS enabled system increases the scope and reach of developed system from a local to global scale. In this endeavour, the role of open source software/tools cannot be ignored to provide cost effective and interoperable system. The developed system uses open source technologies that assist system in geo-visualization on both web and mobile platform. Figure 2 shows ship navigation suitability map generated as per discussed methodology. This map classifies study area in three suitability classes, namely Low, Medium and High. In figure 2, different colours red and green, yellow and blue are given to low, medium or intermediate and high suitability classes respectively.

This developed system facilitates user by providing a web-based interactive satellite data based ship navigation suitability classification map, along with other overlaying layers viz. countries and continental boundary, Antarctica boundary, Average Antarctica Winter OSCAT backscatter mask etc. These layers give clarity on classification by giving geographic details as well as sea ice related details. The system overlays SCATSAT-1 daily False Colour Composite (FCC) providing visual appearance of sea ice variations. The SCATSAT-1 gamma0 HH (horizontal), vertical (VV) and polarization ratio were used to generate FCC. It also shows input parameters as layer which can be selected for a date at a click as shown in figures 3 and 4.

The developed system performs pixel drilling operation to extract temporal information which can be accessed by clicking at "Tools and Chart". This shows temporal charts related to SIT and SIC at one click by fetching data on-the-fly. Users can download charts through developed application in .png, .jpg and .pdf format. Users can also download temporal data in .csv format.

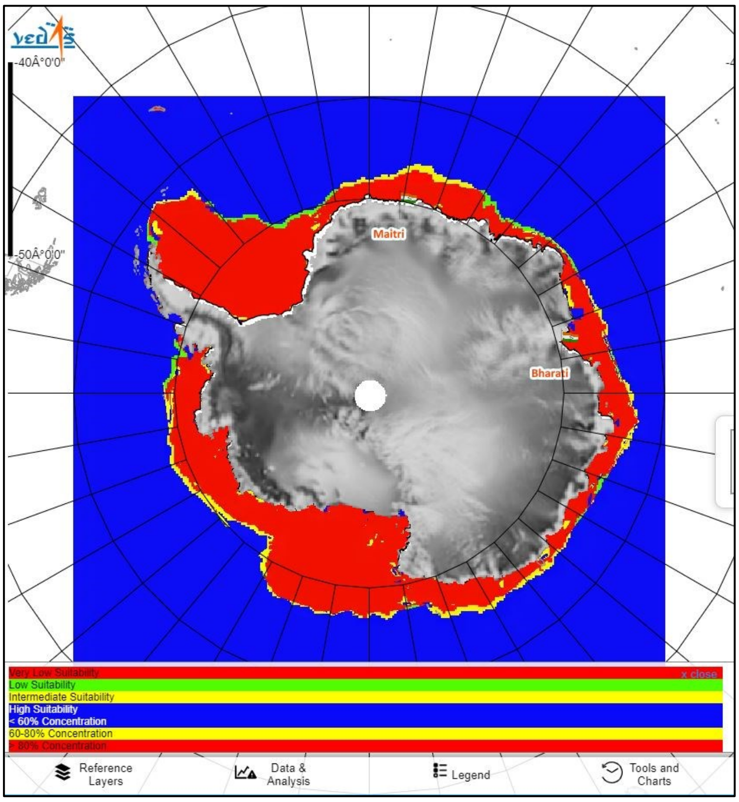

Figure 2: Safer ship navigation suitability map as per discussed methodology (Date: 05/05/2019)

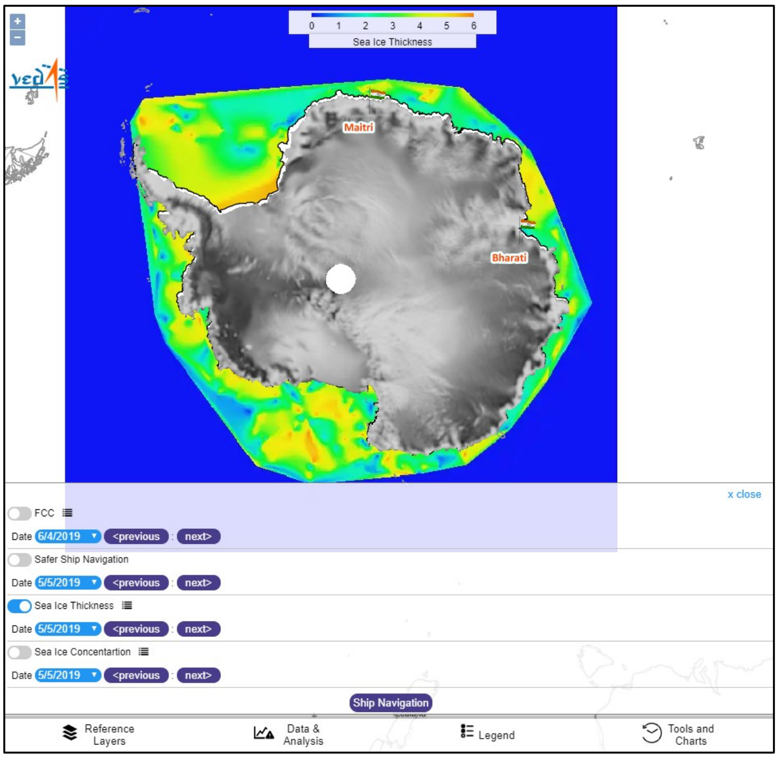

Figure 3: Sea ice thickness visualized through Web-GIS system (Date: 05/05/2019)

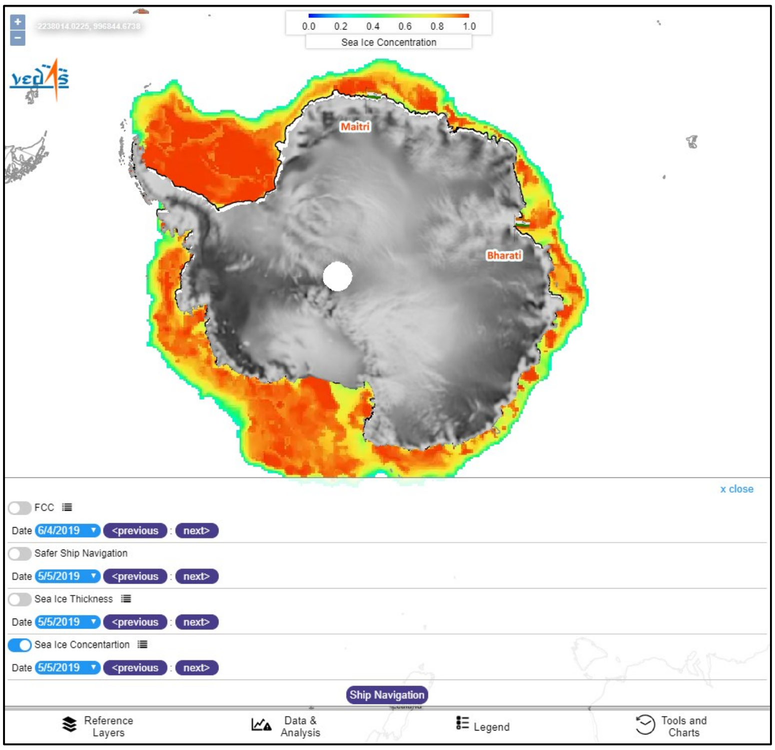

Figure 4: Sea ice concentration visualized through Web-GIS system (Date: 05/05/2019)

6. Conclusions

This paper presents details of a Web-GIS based system for safer ship navigation, based on satellite derived remote sensing data for the Antarctic. The proposed methodology uses important aspects of sea ice such as Sea Ice Thickness (SIT), Sea Ice Concentration (SIC), Sea Ice Extent (SIE) as inputs to generate ship navigation suitability classes. The developed Web-GIS based system can be accessed by user community, globally. However, current system lacks use of information related to vessel characteristics and route optimisation techniques, which are planned to be taken up in near future.

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