

Examination of Historical Data on Maritime Search and Rescue Incidents

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Abstract

The Canadian Coast Guard has maintained a database of maritime search and rescue (SAR) incidents involving response personnel and assets since the 1980s. This information is stored in a national system known as the Search and Rescue Program Information Management System (SISAR). The SISAR database records all major incidents that occur within Canada's coastal SAR regions, documenting them with both spatial and temporal details. As a result, it serves not only as a record of response operations but also as a valuable historical dataset that analysts can use to support various decision-making processes. This paper shows how SISAR incident data can be used to identify and visualize temporal and spatial patterns in maritime SAR incidents. Temporal trends were examined using annual, monthly, and hourly time scales, while spatial patterns were analysed by considering the location and density of incidents. Several visualization techniques are presented to help explore and interpret the SISAR dataset effectively. In addition, the chapter briefly discusses several important topics related to the analysis of SAR incidents. These include underreporting within incident databases, the sharing of national SAR incident data, and the integration of environmental factors with accident data. Incorporating environmental information can provide greater context for historical SAR incidents and contribute to more accurate estimates of SAR response times.

Keywords Data analytics · Incident analysis · Search and rescue and Visualization

I. INTRODUCTION

Search and rescue (SAR) operations represent one of the primary responsibilities of the Canadian Coast Guard (CCG) in Canada. The importance of this program is largely due to the immense size of Canada's coastal search and rescue area, which covers approximately 5.3 million km² and includes both open ocean regions and extensive inland waterways (Government of Canada 2019c). To address emergencies within this vast area, the CCG manages around 6,000 maritime incidents each year, deploying SAR resources in an efficient and coordinated manner (Government of Canada 2019a). Like many other emergency response services—such as police and fire departments—incident reporting and record management play a critical role in SAR operations. After every response activity, the event details are recorded in the Search and Rescue Program Information Management System (SISAR) database. SISAR is a web-based national system that consolidates response data from all regions into a single centralized platform. Information stored in the SISAR database serves as a key source for the Government of Canada (2019a) when compiling statistics on SAR incidents. These statistics are used to assess the demand for SAR services and evaluate program outcomes. This chapter provides a brief background on the CCG SISAR database, along with an overview of the spatiotemporal analysis of SAR incident data. It also presents several interactive web visualizations designed to explore and analyse spatial and temporal patterns within the SISAR incident dataset. Section 3.2 reviews previous work and research related to the spatiotemporal analysis of SAR incidents. Section 3.3 introduces the main components used in developing the visual analytics presented later in the chapter and describes the SISAR database in greater detail. The visual analytics developed in Section 3.4 are then applied in Section 3.5 to examine SAR incident patterns. The results of this analysis and possible directions for future research are discussed in Section 3.6, while Section 3.7 concludes the chapter with final remarks.

Spatiotemporal Analysis of Search and Rescue Incident Data

Multivariate spatiotemporal data from Search and Rescue (SAR) incidents can support a wide range of analytical applications. Temporal attributes enable time-series analysis to examine trends and patterns over time (Malik et al. 2012), whereas spatial attributes allow the use of geo-referenced data processing techniques and spatial statistical methods (Shahrabi 2003). Both the Canadian Coast Guard (CCG) and academic researchers have widely used such datasets to investigate issues related to maritime SAR planning and evaluation. Examples include determining appropriate staffing levels (Marven et al. 2007; Government of Canada 2019b) and identifying key locations for permanent SAR resources (Akbari et al. 2017; Akbari et al. 2018; Pelot and Plummer 2008).

Using the available SISAR dataset, Shahrabi (2003) conducted an early spatial and temporal examination of fishing and marine traffic accidents along the Nova Scotia coastline. The study aimed to better understand where fishing incidents occur and when they are most likely to happen. By applying a geographic information system (GIS) together with spatial statistical techniques such as kernel density estimation and hierarchical clustering, Shahrabi identified high-risk zones for fishermen off Nova Scotia. In addition, analysis of temporal attributes made it possible to determine specific periods of the year when the probability of SAR incidents increased.

Pelot and Plummer (2008) later expanded this research by providing a comprehensive risk assessment of the Atlantic coastal region, primarily based on maritime traffic modelling and historical SAR incident records. A comparable analysis was carried out by Goerlandt, Venäläinen, and Siljander (2015), who studied SAR incidents in the Finnish sector of the Gulf of Finland. Their approach integrated historical incident data with GIS-based information to conduct a risk-informed capacity assessment of voluntary SAR services. The methodology incorporated SAR incident records, meteorological information, and Search and Rescue Unit (SRU) data to generate several quantitative risk indicators, which were then used to evaluate SAR response performance in recreational boating incidents.

Beyond supporting spatiotemporal analysis, SAR incident data can also assist in decision-making processes. Marven, Canessa, and Keller (2007) demonstrated how such data could be applied to SAR resource planning. Through exploratory spatial data analysis (ESDA) techniques designed for point-pattern analysis, they proposed several resource allocation modelling approaches based on historical incident information, including linear programming, Monte Carlo simulation, and process simulation.

More recently, Akbari, Eiselt, and Pelot (2017) introduced a multi-objective goal programming model to determine the optimal placement and allocation of maritime SAR vessels. Their model addressed three key objectives in the location-allocation problem: (1) primary coverage, (2) backup coverage, and (3) average access or response time. By analysing historical SAR incidents together with the existing distribution of SAR vessels by type and location in Atlantic Canada, the study demonstrated that significant improvements in both coverage and response time could be achieved through the optimal solutions generated by the model.

Malik et al. (2012) also proposed a visual analytics framework designed to support maritime response planning, asset allocation, and risk assessment. The resulting system, Coast Guard Search and Rescue Visual Analytics (cgSARVA), was created to analyse the United States Coast Guard (USCG) historical response operations database, which includes records from the Great Lakes region between 2002 and 2011. cgSARVA enables analysts to interact visually with historical SAR incident data, facilitating the identification of data quality issues and improving data

exploration and analysis. In recent years, cgSARVA has been incorporated into the USCG's Station Optimization Process (US Department of Homeland Security 2018), an initiative aimed at evaluating USCG boat stations and identifying those that may be closed due to overlapping or redundant SAR coverage.

Finally, Sonninen and Goerlandt (2015) investigated the meteorological conditions surrounding maritime SAR missions in the Gulf of Finland by applying visual data mining techniques. Their objective was to better understand which types of SAR incidents occur during severe wind and wave conditions. To achieve this, the researchers linked wind and wave information with incident records obtained from a SAR operations database. The combined dataset was then used to examine variations among different SAR mission categories, as well as the activities of various SAR organizations operating under harsh weather conditions. Through the use of visual analytics, the authors were able to identify regions where strong wind and wave conditions were most concentrated, along with areas that experienced the highest density of SAR incidents.

Search and Rescue Program Information Management System

In Canada, three main Search and Rescue (SAR) regions exist, and each is linked to a Joint Rescue Coordination Centre (JRCC). These centres are jointly operated by personnel from the Department of National Defence (DND) and the Canadian Coast Guard (CCG). The JRCC is responsible for ensuring the effective organization of SAR services and coordinating SAR operations within its designated region (Government of Canada 2019a). When a distress report from a vessel is received, the JRCC assigns the most suitable SAR resource to provide assistance. After every SAR operation, a new entry is recorded in the SISAR database.

The SISAR database maintains a spatiotemporal record of serious incidents that required SAR responses within Canada's coastal search and rescue zones. It was developed to give CCG personnel convenient access to key information that supports SAR planning, management, and operational decision-making (Marven et al. 2007). The incident description fields in the SISAR database are mainly used for internal CCG documentation and event tracking. Each incident is given a unique identification number, which is used in all subsequent reports. Typical incident description attributes include the distress alert method used by the vessel, the incident location, the start and end date-time group (DTG), and a narrative summary written by the first responders. For this study, the incident description data utilized included the incident ID, location, start and end DTG, and incident severity.

The SAR resource usage fields describe the SAR assets deployed and the operational details of the response. These fields capture aspects of the mission, including incident severity, distance to the incident, alert time, on-scene time, and towing distance. In this research, the resource usage information considered consisted of incident severity, the distance of the incident from shore, and alert time.

The CCG rates incident severity on a four-level scale, where 1 represents the most critical incidents and 4 indicates a false alarm.

Another component of the database, the SAR resource deployment fields, records the region, base, and squadron associated with the responding SAR asset. Canada's SAR system is divided into three major regions: Eastern, Pacific, and Central and Arctic, and each region is further subdivided into smaller SAR areas. These smaller areas are primarily used to aggregate and report marine incident statistics, which helps guide resource allocation and planning decisions (Marven et al. 2007). However, the SAR resource deployment information was not included in the analysis conducted in this study.

The final category, known as the unit assisted field, contains details about the vessel involved in the incident. This includes characteristics such as vessel dimensions, flag state, vessel type, vessel class, and the number of people on board. Such information helps the JRCC determine the most appropriate SAR asset to deploy during an emergency. It is also useful for analysing issues related to asset suitability and operational capacity based on the expected vessel characteristics. In this study, the only information from the unit assisted fields that was used was the vessel length measured in metres.

Visual Analytics for SISAR Data Analysis

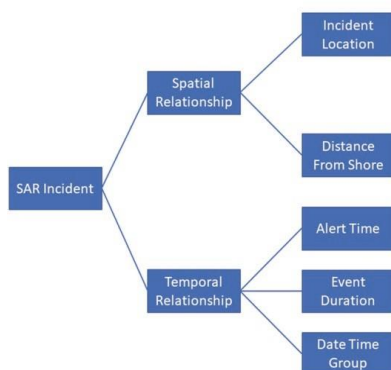
This section presents several useful visualizations developed using Data-Driven Documents (D3) to examine a SISAR dataset containing roughly 36,000 SAR response records. The dataset spans the years 2005 to 2013, with the exception of 2007, for which data is unavailable. It includes incidents that occurred within Canada's coastal Search and Rescue (SAR) areas and required a physical response from a Canadian Coast Guard (CCG) SAR asset. A dataset covering multiple years was necessary to support the visualizations discussed in Section 3.4.2. The selected time period was chosen arbitrarily because the main objective of this study is to demonstrate the development and possible application of visual analytics for analysing historical SAR incidents, rather than emphasizing the specific analytical outcomes derived from the dataset.

D3 is an open-source JavaScript library that allows developers to create and manipulate web-based visualizations such as charts and graphs using underlying data (David and Tauro 2015). It works by offering a declarative framework that links data directly to visual elements within a web page. Through this mapping, users can inspect and interact with the data representation directly through a web browser (Bostock et al. 2011). Additionally, Bostock (2019) provides publicly accessible documentation for D3 along with a large collection of visualization examples contributed by the D3 user community.

When using D3 in this study, each SAR incident is considered an entity with a set of related attributes. These attributes make it possible to visualize both temporal and spatial relationships present in the dataset. To analyse temporal patterns, ordinal categories were applied to group temporal attributes by year, month, day, and hour, enabling the creation of multiple visualizations. Figure 1 illustrates a basic hierarchical structure showing how SAR incidents relate to the attribute data utilized in this research.

Fig. 1
Hierarchical view of entity relationship model

ENTITY ▶ RELATIONSHIP ▶ ATTRIBUTE



Interactive SAR Incident Dashboard

The interactive SAR incident dashboard offers a web-based visualization tool for examining the temporal patterns of SAR incidents recorded in the SISAR database. Through a standard web browser, users can quickly explore how incidents are distributed across months and days. The dataset displayed in this section corresponds to the 2013 calendar year and includes a total of 4,062 SAR incident records. Monthly incident totals for 2013 are presented in a bar chart, while the distribution of incidents by weekday is illustrated using a pie chart. The pie chart is divided into seven segments, with each segment representing one day of the week. Initially, the chart displays the total number of incidents recorded on each weekday during the 2013 calendar year. Figure 3.2 illustrates the dashboard in its initial state using the 2013 SAR incident data. Interactive features within the dashboard enable users to explore the temporal characteristics of the SISAR incident data. These elements allow rapid sorting and filtering of information by simply hovering the mouse pointer over specific parts of the visualization. When the cursor is placed over a bar in the bar chart, a particular month is selected, while hovering over a segment of the pie chart highlights a specific weekday. Selecting these elements automatically updates the related visualization on the web page. For example,

hovering over a bar in the bar chart prompts the pie chart to display the distribution of incidents by weekday for the selected month. Conversely, hovering over a sector in the pie chart causes the bar chart to update and show the yearly distribution of incidents corresponding to the chosen day of the week.

Fig. 2

SISAR interactive monthly/weekday SAR incident dashboard for calendar year 2013 (all data for figures and tables in this chapter from Canadian Coast Guard 2017)

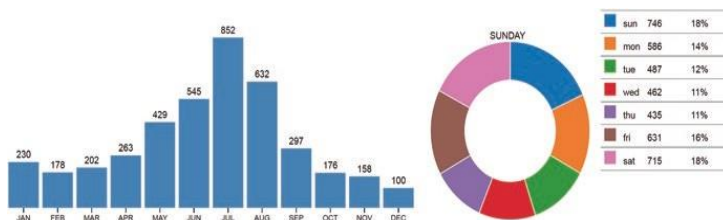
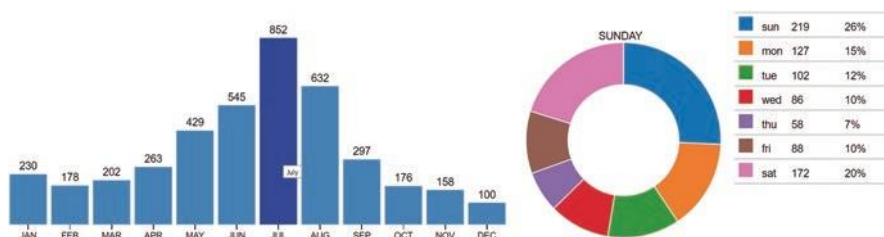


Fig. 3

Interactive dashboard result showing the weekday distribution of the total number of incidents that occurred during July 2013

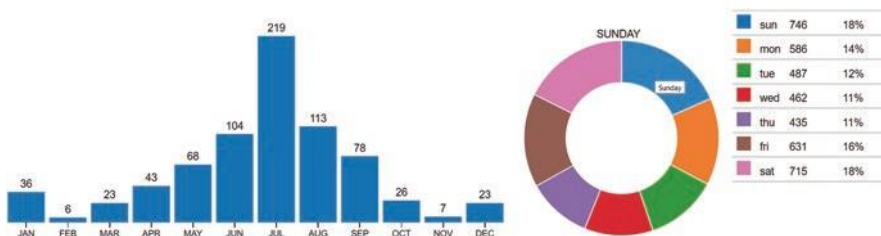


Figures 3 and 4 demonstrate how the interactive features of the SAR incident dashboard can be used. Figure 3 presents the same monthly distribution of SAR incidents displayed in Figure 2. In this example, the month of July is selected in the bar chart by hovering the mouse pointer over the corresponding bar, which appears as a highlighted column. As a result of this interaction, the pie chart automatically updates to display the distribution of incidents by weekday for the month of July.

Figure 4 illustrates the monthly distribution of total SAR incidents that occurred on Sundays. In this case, Sunday is selected by hovering the mouse pointer over the sector of the pie chart representing that day. This interaction causes the bar chart to update automatically, showing the monthly distribution of all SAR incidents that took place on Sundays.

Fig. 4

Interactive dashboard result showing the monthly distribution of total incidents that occurred on Sunday during 2013



Multi-year Monthly Incident Analysis

The incident dashboard described earlier enables users to view the monthly and weekday distribution of SAR incidents for only a single calendar year. To address the need for examining longer-term patterns in the SISAR incident dataset, three types of multi-year visualizations were developed: (1) a multi-year monthly incident time-series graph, (2) a multi-year monthly incident time-series chart, and (3) a multi-year monthly incident heat map. Although each visualization presents the same underlying data, they differ in the way the information is displayed and interpreted. An extensive discussion of calendar-based visualization techniques for time-series data, similar to those used in this chapter, is provided by Van Wijk and Selow (1999).

Multi-year Monthly Incident Time Series Graph and Chart

The date and time associated with each SAR incident allow the data to be visualized as a time series. In this approach, each month is paired with the corresponding number of incidents and plotted accordingly. A line connecting the points representing the monthly incident totals is created using simple linear interpolation. Generally, continuous lines are not considered appropriate for categorical data, where bar charts are typically preferred. However, an exception applies when the categories follow a natural order. In this case, the data are arranged by calendar month, as illustrated in Figures 3.5 and 3.6, making the use of a line graph acceptable. By overlaying data from multiple years, it becomes possible to compare several line plots and identify long-term trends. Figure 3.5 presents a multi-series line chart showing monthly total incident data from 2005 to 2013. For comparison, Figure 3.6 displays the same dataset in the form of a multi-year time series graph. This representation more effectively highlights the cyclical pattern of monthly SAR incident totals across multiple years and also emphasizes the absence of data from 2007, which was mentioned earlier in the section.

Fig. 5

Multi-series line chart of monthly incident totals (2005–2020)

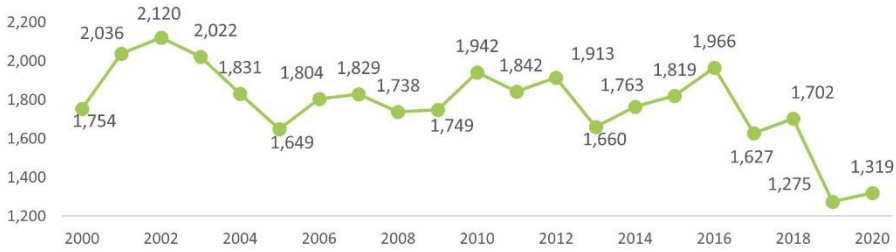
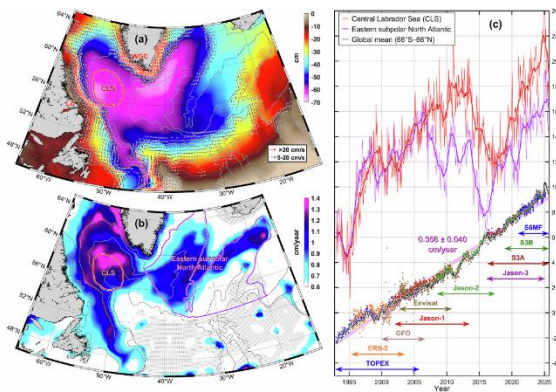


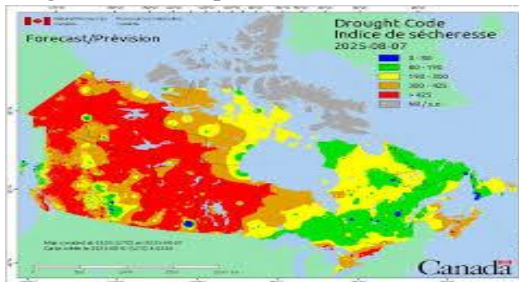
Fig. 6

Multi-Year Time Series Graph of Monthly Incident Totals (2005–2025)



Multi-year Monthly Incident Heat Map

A heat map is a two-dimensional method of data visualization in which colour is used to indicate the value of a specific attribute. In this study, the attribute represented is the total number of SAR incidents. The two dimensions of the heat map correspond to month (y-axis) and year (x-axis). Patterns and trends can be identified by observing regions that share similar colour intensities across these two dimensions. In Figure 7, darker shades of blue indicate months with a higher number of incidents, whereas lighter shades represent months with fewer recorded incidents.



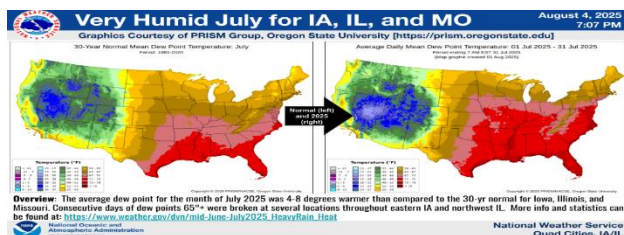
The Drought Code, a key component of the Canadian Forest Fire Weather Index (FWI) August 7, 2025

Hourly Total Incident Heat Map

The hourly total incident heat map enables users to examine the 24-hour distribution of SAR incident alert times through a circular heat map representation. In this visualization, the chart is divided into 24 sectors, with each sector corresponding to one hour of the day. Colour is used to indicate the total number of SAR incident alerts received during each hourly period. Dark red represents the hour with the highest number of incidents, while dark blue indicates the hour with the lowest number of incidents. This colour scheme allows users to quickly identify the times of day when SAR alerts are most likely to occur. Figure 8 presents the aggregated hourly distribution of SAR incident alerts for the period from 2005 to 2025.

Fig. 8

Aggregate hourly total incident heat map of SAR incident alerts from 2005 to 2025 these visual analytics will be discussed in the next section. Equation 3.1 describes how opacity is derived using SAR incident severity data



Spatial Analysis Map

The spatial analysis map enables users to visualize the geographic locations of SAR incidents. This type of visualization allows users to take advantage of the spatial proximity and similarity of events in order to interpret patterns and extract meaningful insights (Ware 2004). Figure 3.9 includes a coastline contour so that incident locations can be referenced against recognizable geographic regions. Two main components of the spatial analysis map are discussed: the analysis map itself and the SISAR data layer.

The analysis map was created using a GeoJSON representation of the Canadian coastline together with the default map projection library available in D3 (Murray 2013). Selecting an appropriate map projection depends largely on the size and shape of the geographic area being represented. Because the SISAR dataset used in this study spans the entire Canadian search and rescue region, choosing a projection that accurately displays all incident locations is challenging. Maps representing very large countries such as Canada often experience distortion due to the curvature of the Earth. While such distortion is minimal over short distances, it becomes more pronounced in maps that include the Canadian Arctic. Since most of

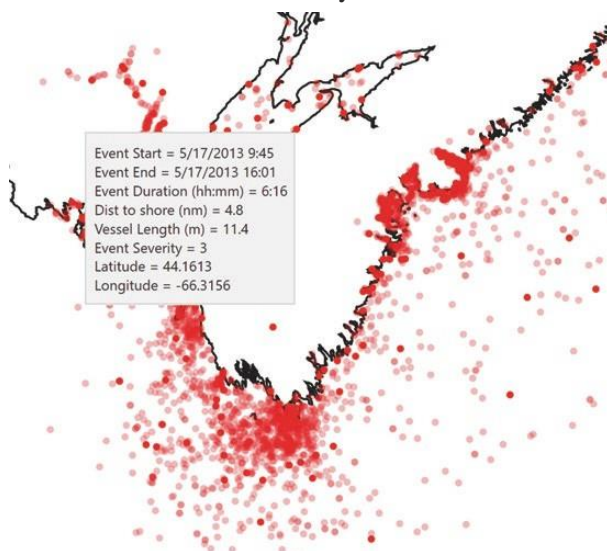
the SISAR incident data lies below 60° North latitude, a standard Albers projection was selected. The Albers projection is commonly applied to landmasses that extend primarily in an east–west direction, such as Canada and the United States (ESRI n.d.). Figure 9 presents a zoomed-in view of the Atlantic Canada region.

The SISAR dataset used in this research includes incidents from the entire Canadian coastal search and rescue area and contains approximately 36,000 records, each associated with a geo-referenced location. By plotting each incident on the analysis map, the spatial distribution of SAR events becomes visible. Observing the proximity between incidents makes it possible to identify regions where incidents are more concentrated. Shahrabi (2003) demonstrated how such information, when combined with techniques such as kernel density estimation and hierarchical clustering, can be used to detect high-risk areas.

In this study, the approach focused on utilizing attribute information from the SISAR dataset to create a visual analytic tool capable of highlighting and localizing areas of higher risk. Specifically, the severity level of each incident was used to determine the opacity of the plotted SISAR data points. As a result, more severe incidents appear as bright, opaque red points, while false alarms are displayed as nearly transparent markers (Fig. 10). The application of these visual analytics techniques is discussed further in the following section. Equation 3.1 outlines the method used to calculate opacity based on SAR incident severity data.

Fig. 3.10

Zoomed-in map view showing the geo-referenced position of incidents plotted as bright red circles with the opacity determined by Eq. 3.1. Hovering the mouse pointer over each geo-referenced data point provides the detailed summary of the incident



SISAR Data Analysis and Results

This section showcases a few potential use cases for the visualizations presented in this chapter. Visualizations have been selected that allow an analyst to explore both temporal and spatial trends in the SISAR dataset using a standard web browser. Specifically, three questions are addressed:

1. What was the temporal (by hour, month, and day of week) distribution of the 2013 SAR incidents?
2. Based on the historical data for all SAR cases, what was the expected annual response case demand broken down by month?
3. Based on the historical data for all SAR cases, what regions show a high concentration of most severe incidents?
4. What Is the Temporal Distribution of the Response Case Load?

The interactive incident dashboard introduced in Sect. 3.4 allows the user to quickly identify monthly and weekday trends in the SISAR data. For any given calendar year in the study period, the user can quickly examine the total number of incidents responded to in a month or on a given weekday. Figure 3.2 showed the 2013 monthly distribution of incidents. A distinct peak in the total number of incidents is easily observed during the summer months (June–August). The peak during the summer months is observed during every year in the SISAR data and was best illustrated by the multi-year time series line chart of monthly incident totals shown in Fig. 3.6. This was likely due to the increase in pleasure boat activity associated with the summer months, previously observed and reported by Malik et al. (2011), Sonninen and Goerlandt (2015), and the Government of Canada (2019a).

To support this claim through a visual analytic approach, the available SISAR data was processed to create a bar chart illustrating the monthly distribution of the average vessel length involved in SAR incidents between 2005 and 2025. As shown in Figure 3.11, the average vessel length decreases during the summer months, which is likely the result of a higher number of smaller recreational boats being involved in incidents.

Figure 12 further indicates that the average distance of SAR incidents from shore also declines during the summer period. This pattern is similarly attributed to the increased presence of pleasure boats operating closer to the coast during these months. In addition to the rise in the overall number of incidents during summer, a larger proportion of incidents was found to occur on weekends (Saturday and Sunday). For instance, when July is selected, the data shows that weekend incidents account for approximately 46% of the total number of cases. In contrast, during January, weekend incidents represent only about 24% of the total. Figure 3.13 provides a comparison of the weekday distributions of SAR incidents for July and January.

Finally, the hourly distribution of SAR incidents was examined. By aggregating all incidents recorded in the SISAR database, the hourly total incident heat map described in Section 3.4.3 and illustrated in Figure 3.8 was produced. The analysis revealed a noticeable increase in incidents between 6 p.m. and 11 p.m. This reporting pattern is commonly linked to recreational boating activities, where individuals undertake day trips without plans for overnight travel (Government of Canada 2003). In such situations, SAR incidents are often initiated when a vessel fails to reach its intended destination, does not return to port at the expected time, or is otherwise reported overdue. A similar hourly distribution of SAR incident workload has also been documented by Malik et al. (2012) for the United States Coast Guard (USCG) in the Great Lakes region.

Fig. 12
Average SAR incident distance from shore (kilometers) by month (2005–2025)

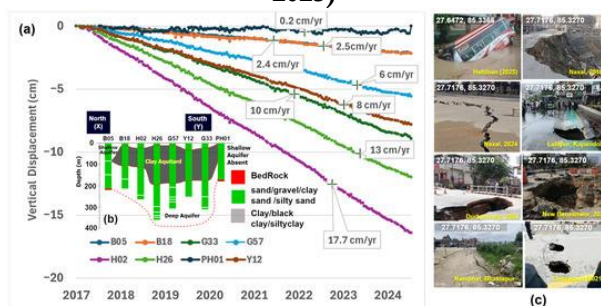
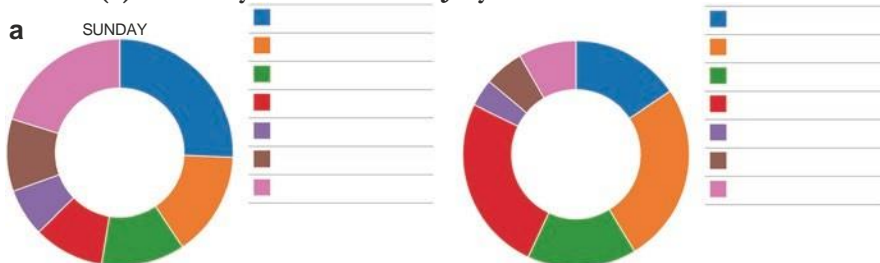


Fig. 3.13

(a) Weekday distribution of July 2025 total SAR incidents



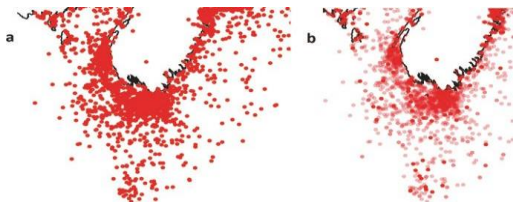
What is the expected annual response case demand?

Response case demand shows a pronounced seasonal pattern. As discussed earlier, the number of incidents rises considerably during the summer months, while incident levels remain relatively stable throughout the rest of the year. Figure 3.7 presented a multi-year heat map of SISAR incidents, illustrating this trend clearly. Across several years of data, incident frequency increases substantially between May and September and declines noticeably outside this period. The Canadian Coast Guard (CCG) records the highest number of SAR incidents in July, with an average

of 829 ± 121 incidents, while the lowest level occurs in January, with an average of 227 ± 29 incidents.

Fig. 3.14

(a) Spatial distribution of SAR incidents, (b) Spatial distribution of SAR incidents with opacity determined using incident severity (Eq. 3.1)



What areas show a high concentration of most severe incidents?

Understanding how incidents are spatially distributed is essential for planning emergency response activities and allocating resources effectively (Marven et al. 2007; Akbari et al. 2017; Malik et al. 2011). Emergency resources are typically positioned in areas where SAR incidents occur more frequently in order to reduce response times and lower the overall cost of delivering lifesaving services. The SISAR database offers a valuable collection of historical, geo-referenced SAR incident records. However, the main challenge lies in developing visualizations that clearly communicate the importance of locations with high incident concentrations.

To address this issue, a visual analytic method was developed that incorporates incident severity to help interpret the spatial distribution of incidents. As illustrated in Figure 3.14, adjusting the opacity of incident markers based on their severity enhances the visibility of areas with more serious incidents. In this visualization, severe incidents appear opaquer, which improves the identification of clusters and helps highlight hotspots where serious incidents occur close together.

Discussion

Under-reporting in historical SAR incident databases can significantly influence the results of quantitative analyses and may lead to poor decision-making outcomes (Psarros et al. 2010). In the case of the SISAR database used in this study, under-reporting could potentially affect the findings discussed in Section 3.5. The Canadian Coast Guard (CCG) acknowledges the existence of under-reporting in SISAR, which is believed to result mainly from technical limitations and human error during the creation of the database (Government of Canada 2019a).

The CCG has estimated the percentage of missing cases by region for the period between 2006 and 2010: Quebec (0.9%), Newfoundland and Labrador (2.9%), Central and Arctic (2.7%), Maritimes (4.6%), and Pacific (30.9%). To address concerns about bias caused by missing data, a CCG evaluation team examined a sample of these cases and concluded that the missing incidents were not

systematically biased. Because the proportion of missing cases has been quantified and shown to be unbiased, the SISAR database continues to serve as a primary source for SAR incident analysis in Canada.

Throughout this chapter, reference has also been made to the US Coast Guard visual analytics tool cgSARVA (Malik et al. 2011), which analyzes historical response operation data for the Great Lakes region between 2002 and 2011. The Great Lakes represent a major inland waterway where search and rescue responsibilities are shared by Canada and the United States. Both countries have a long history of providing cross-border SAR support in this region. Therefore, a comprehensive evaluation of maritime response, resource allocation, and risk assessment should ideally incorporate the cooperative nature of SAR operations in the Great Lakes.

Including Canadian SAR station information and incident data in the cgSARVA system would likely influence the risk profiles produced by the tool and reported in Malik et al. (2012). Updated risk assessments incorporating Canadian data could offer valuable insights into the benefits of stronger cross-border SAR coordination. More broadly, maritime search and rescue in the Arctic also requires extensive international cooperation. The importance of collaboration among Arctic nations is highlighted in the *Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic* (Arctic Council 2011). Combining historical incident data, SAR resource locations, and operational capabilities from all participating countries could enable a more comprehensive evaluation of SAR capacity in the region and potentially improve service delivery.

Recent research has also focused on integrating environmental conditions with accident data to better contextualize historical SAR incidents. Wu, Pelot, and Hilliard (2009), for example, examined the impact of weather conditions on the relative incident rate of fishing vessels in Atlantic Canadian waters. Their study analyzed several environmental variables, including wave height, sea surface temperature, air temperature, ice concentration, fog, and precipitation. Among these factors, ice concentration had the strongest influence on relative incident rates for fishing vessels. In areas where ice levels were low, higher wave heights were associated with increased incident rates. Conversely, fog and precipitation were found to have little effect on incident frequency.

Building on this work, Rezaee, Pelot, and Ghasemi (2016) extended the analysis and found that the effect of weather conditions on incident rates in Atlantic Canadian waters also varies depending on vessel size. Similar investigations have been conducted in other maritime regions. For example, Goerlandt et al. (2017) studied navigational accidents in the northern Baltic Sea by integrating accident records with environmental data. Using atmospheric and sea ice information, the researchers reconstructed the navigational conditions present at the time of each accident, providing valuable context for improving winter maritime transportation

risk assessments.

Finally, estimating SAR response time has become an increasingly important topic in research, as it plays a critical role in determining optimal SAR station locations and the assignment of response units. Siljander, Venäläinen, Goerlandt, and Pellikka (2015) used GIS-based tools to evaluate SAR response times while considering environmental conditions. Their analysis incorporated both the operational capabilities of SAR units and prevailing wave conditions during incidents, leading to more accurate response time estimates for strategic planning. Response times can be particularly long in remote areas such as the northwest Atlantic and the Arctic. These regions not only present geographical challenges but also experience harsh environmental conditions that further delay response operations. Consequently, new methods are needed to improve estimates of vessel speed in adverse conditions—such as sea ice—to enhance the accuracy of SAR response time predictions.

II.CONCLUSION

Since the 1980s, the Canadian Coast Guard (CCG) has gathered data and information related to SAR incidents involving its assets and personnel. This dataset provides CCG staff with essential information to support SAR planning, management, and operational activities. The extensive SAR incident records also offer researchers and analysts a rich multivariate dataset that can be applied to a variety of analytical and visualization tasks. In this chapter, SISAR incident data was used to examine temporal and spatial patterns through interactive web-based visualization techniques. The most noticeable trends identified include a rise in SAR incidents during the summer months, particularly on weekends and during evening hours between 6 p.m. and 11 p.m.

Along with temporal patterns, the spatial distribution of SAR incidents was also analysed. By mapping the geographic coordinates of each SAR event onto a projection of Canada's eastern coastline, areas with high concentrations of incidents could be identified. One notable example highlighted in this chapter is the cluster of incidents located off the southern tip of Nova Scotia (see Fig. 3.14). In addition to displaying incident locations, incident severity was incorporated into the visualization by adjusting the opacity of the location markers (represented as red circles). This use of opacity proved useful in better distinguishing regions where severe incidents are concentrated.

Overall, these interactive visualizations successfully revealed several important temporal and spatial patterns within the SISAR dataset. Such visual tools can assist analysts in making informed decisions related to SAR station staffing, station placement, and employee shift scheduling at monthly, daily, and hourly levels. Continued use of SISAR data to guide decision-making within the CCG will help

ensure that SAR services are delivered efficiently, reduce response times, and ultimately contribute to saving more lives.

III. REFERENCES

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