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# Use of fractal-based approaches in the assessment of the Canadian recognized maritime picture

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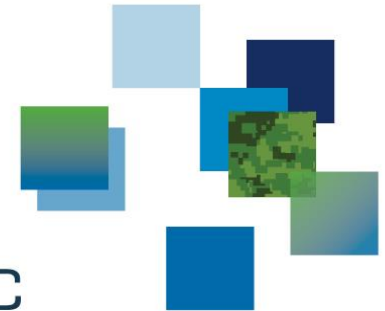
DRDC Centre for Operational Research and Analysis

Presented at 32 International Symposium on Military Operational Research

Royal Holloway, University of London

21-24 July 2015

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# Outline

- Motivation
- Fractal measures
  - Spatial entropy
  - Symmetry
  - Fractal Dimension
- Data sources
  - RS2
  - AIS
- Results
- Conclusions

# Motivation

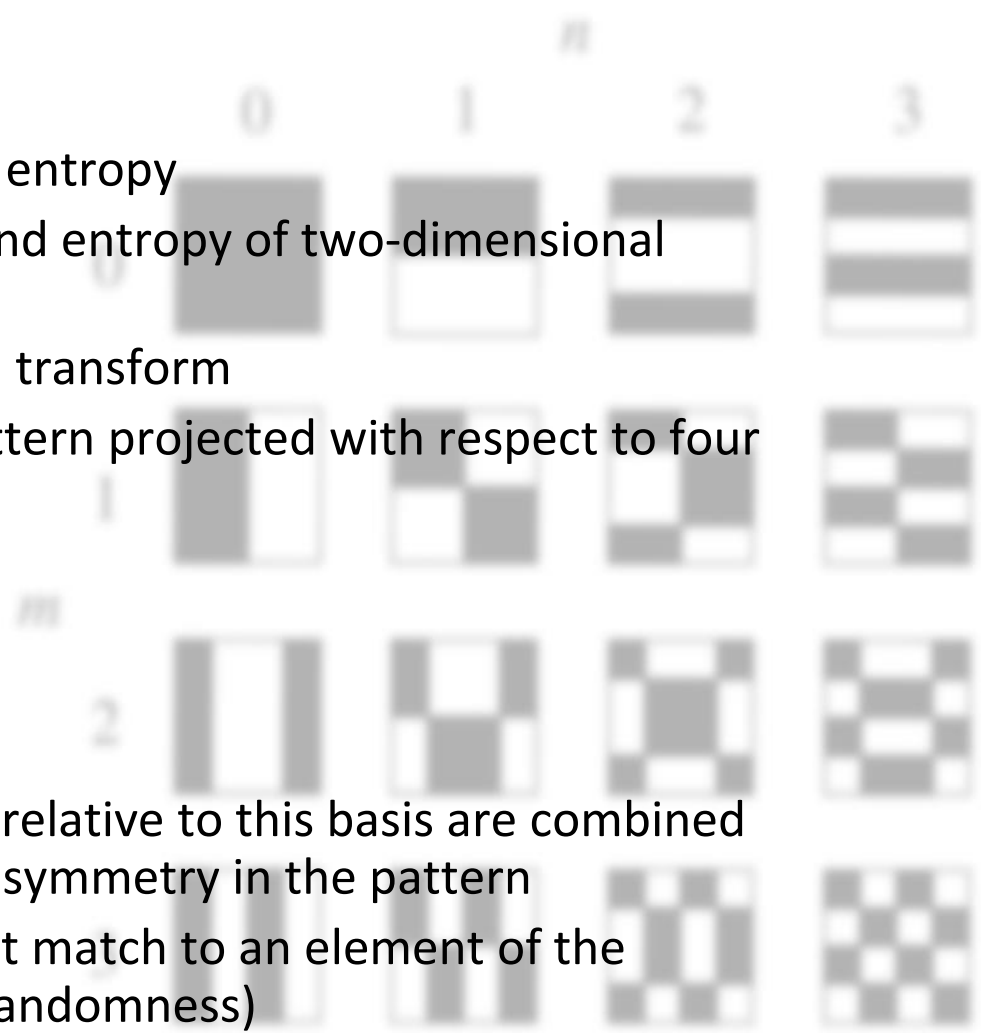
- Monitoring of vessels on approaches to Canada is vital in order to protect Canadian sovereign interests
- Questions of interest:
  - Do all detections correspond to actual vessels, or are some false positives (i.e., apparent detections that do not correspond to actual vessels)?
  - Are any vessels exhibiting anomalous behaviour?
- Proposed approach based on the analysis of fractal (scaling) properties of spatial distribution of detections:
  - Methodology applied previously to analyze the deep nature of the geo-spatial distribution of violent events in Afghanistan
  - Measures explored here:
    - Spatial entropy
    - Symmetry
    - Fractal dimension

# Spatial entropy

- A form of Shannon (information) entropy
- Implementation based on idea of evaluating the spatial distribution of ship detections relative to a regular grid covering an area of interest
- First suggested by Ilachinski [Artificial War] for land combat applications
- Spatial entropy related to fractal dimension computed via 'box counting' method
- Compact, non-dispersed geometric patterns display low spatial entropy; disorganized, spread-out patterns display high spatial entropy
- Theoretical maximum for spatial entropy is  $H_{\max} = \log n$  ( $n$  is total number of points)
  - Here, normalized to  $H_{\max} = 1$

# Symmetry

- A form of Shannon (information) entropy
- Measures combined symmetry and entropy of two-dimensional intensity map
- Utilizes a two-dimensional Walsh transform
- Components of a prospective pattern projected with respect to four principal symmetries:
  - Vertical
  - Horizontal
  - Centro (also known as diagonal)
  - Double (vertical plus horizontal)
- Strengths of pattern symmetries relative to this basis are combined to provide an overall measure of symmetry in the pattern
- Can have values between 0 (exact match to an element of the pattern basis ) and 1 (complete randomness)



# Fractal dimension

- Measures minimum number of variables needed to specify a given pattern
- Dimension of fractal data sets commonly approximated using ‘box-counting’ (or capacity) dimension
  - Relationship between the size of a box,  $\epsilon$ , and the minimum number,  $N(\epsilon)$ , of boxes needed to cover all of the ship detections
- Dependence is a power law expression of the form

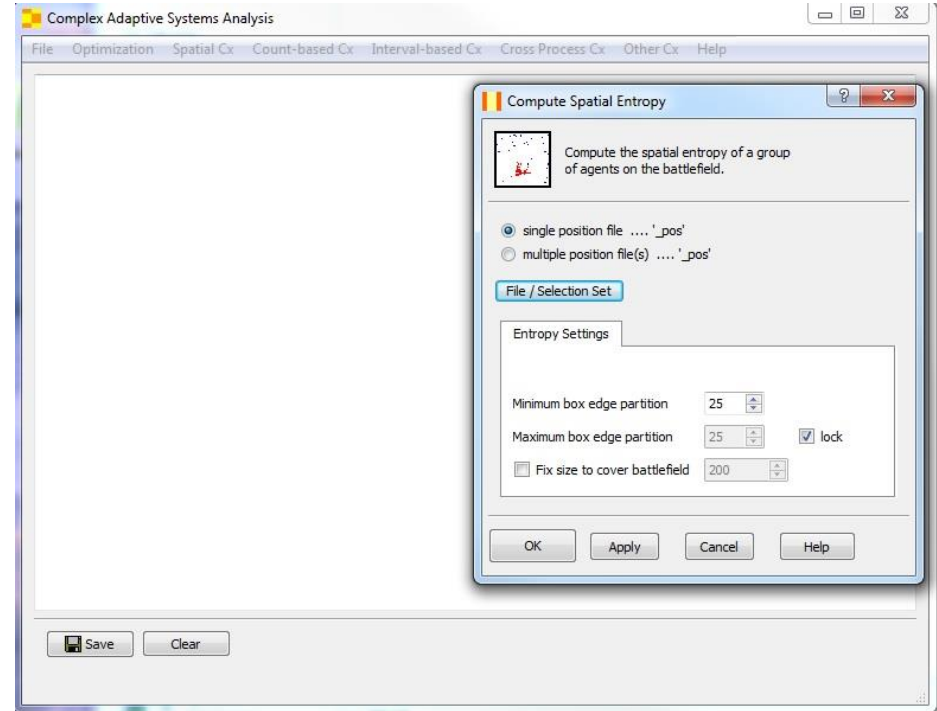
$$N(\epsilon) = (L / \epsilon)^{DF}$$

where DF is the fractal dimension and  $L$  is the size of the area of interest

- Enables characterization of clustering of forces and degree of distribution of ships across area of interest

# Complex Adaptive Systems Analysis (CASA) software

- CASA software represents early attempt by DRDC CORA to characterize both behaviour optimization and complexity awareness factors from output of combat simulations conducted in MANA model
- CASA is a research prototype programmed in C++ and Qt
- Several spatial and vector-based measures are supported



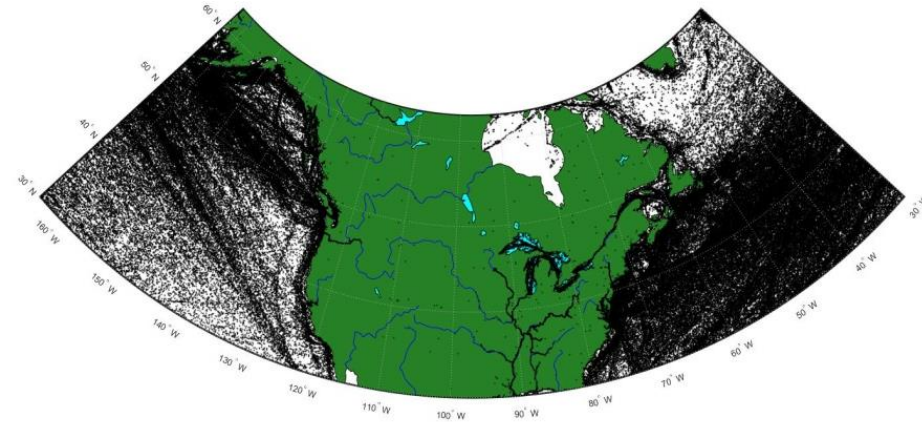
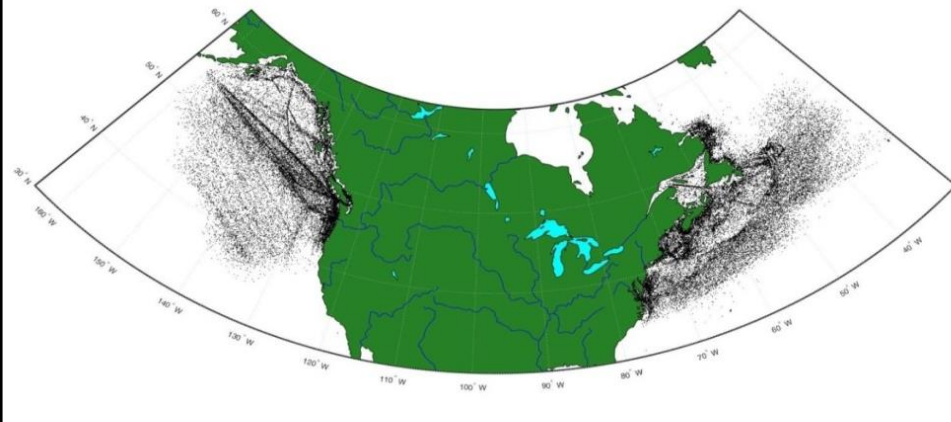
# 2014 RS2 and AIS data

## RADARSAT 2 (RS2)

- SAR satellite owned and operated by MacDonald Dettwiler and Associates
- Two primary imaging modes used for ship detection are DVWF and the OSVN with 450km and 530km swath

## Automated Information System (AIS)

- Radio-based, VHF transponder system which provides position and static identifying information for the purposes of maritime safety
- System designed for ship-to-ship operation; possible to detect from space

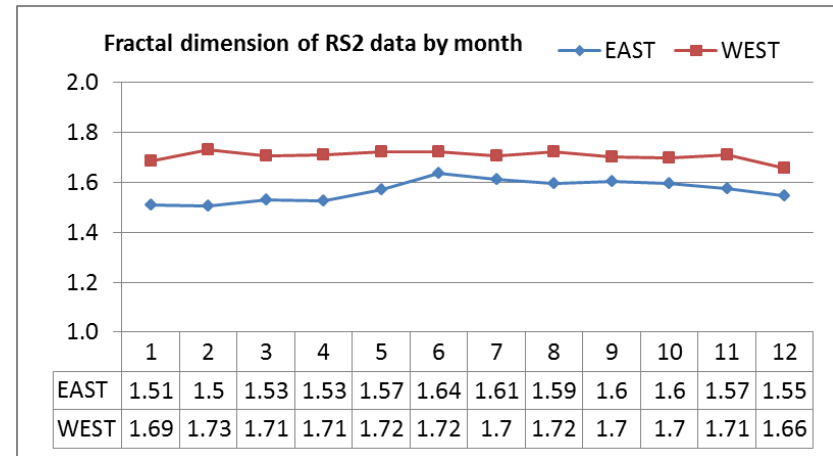
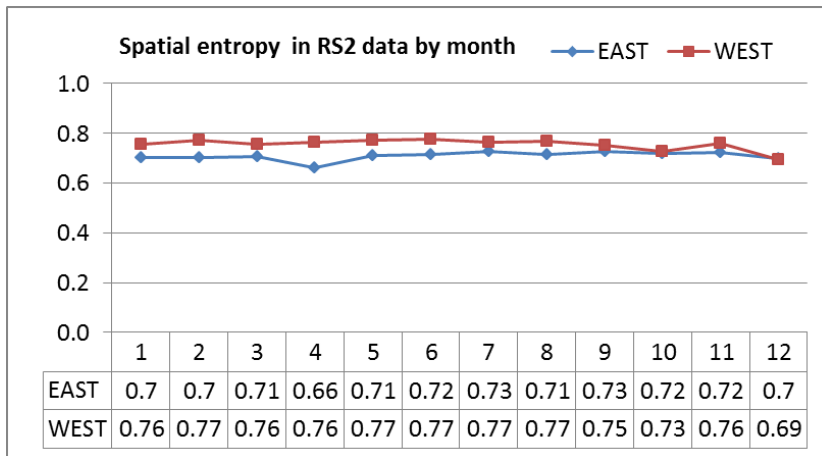
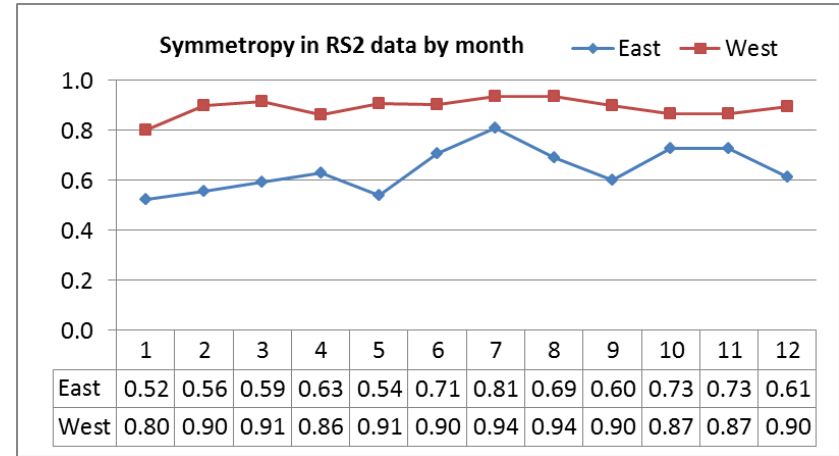




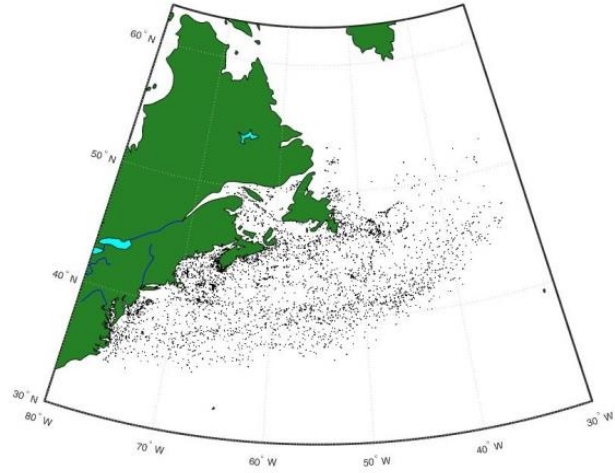
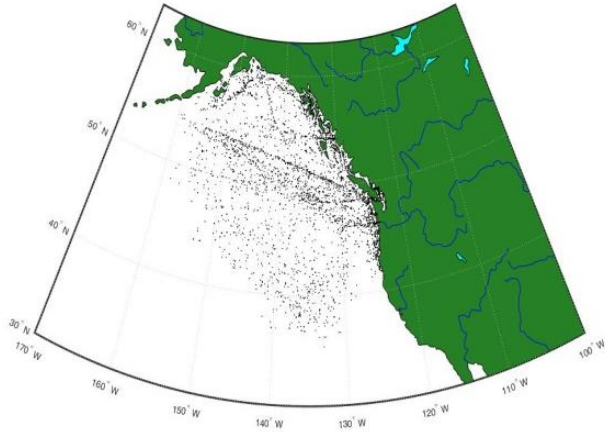
# RS2 results

There is a non-random structure present in RS2 detections:

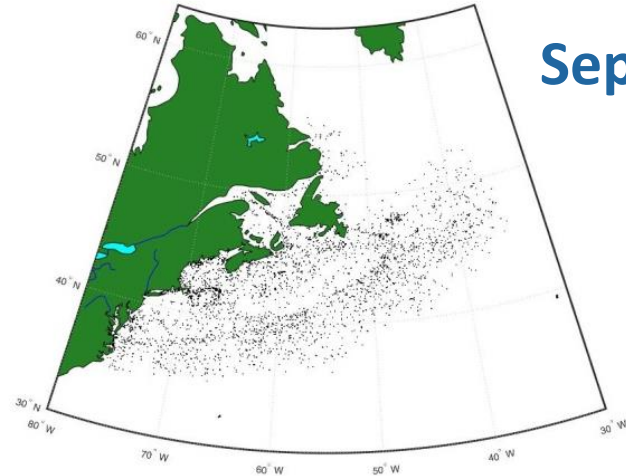
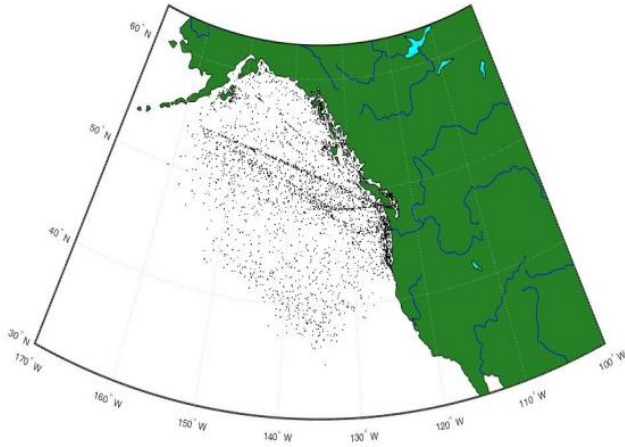
- Slightly greater randomness off the West Coast
- Greater seasonal variability along the East Coast; a transition to more random behaviour in summer



# RS2 detections



May



September

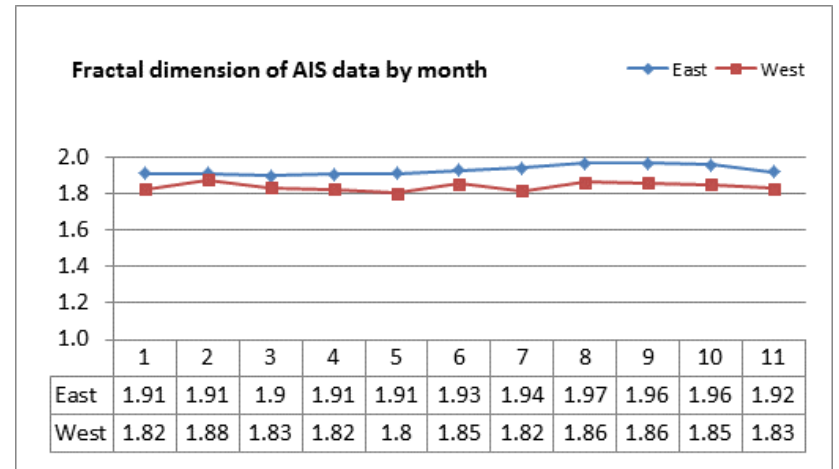
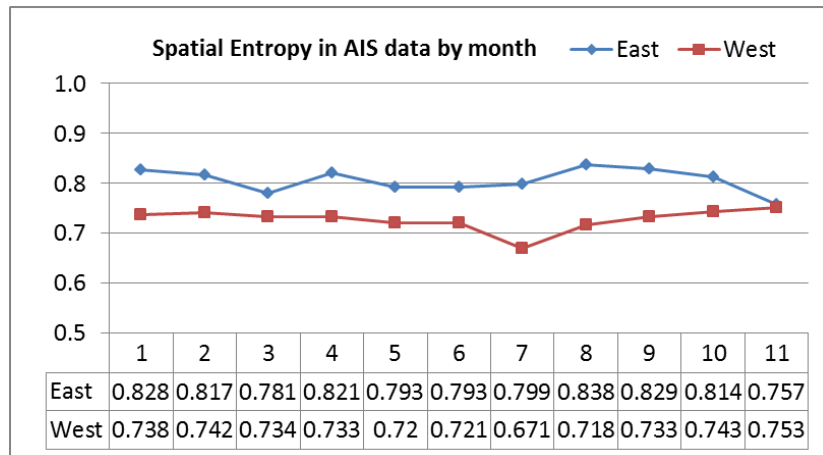
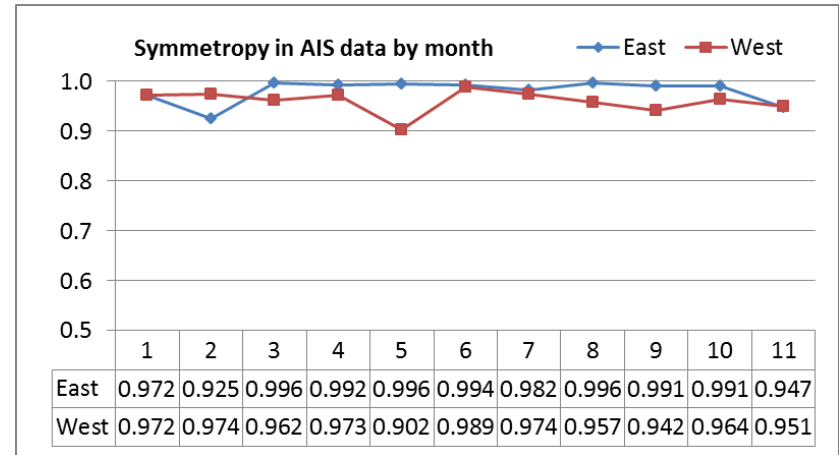
East Coast

West Coast

# AIS results

Result is somewhat reverse of RS2 case:

- Impact of data saturation in CASA may be leading to convergence of fractal dimension and symmetry to max values
- Spatial entropy strongly suggests underlying patterns

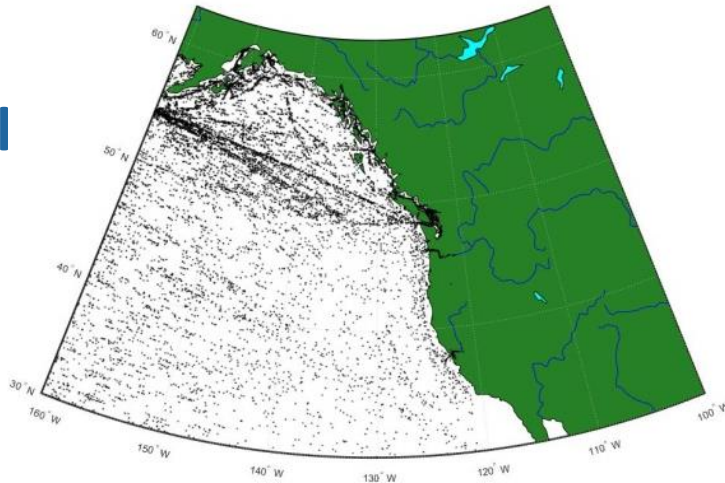


## Comparison of patterns in AIS on the West Coast

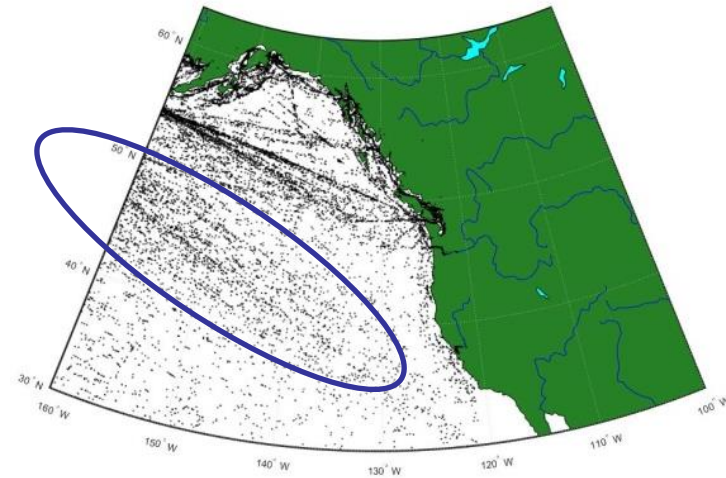
- April presents a fairly random background distribution
- May shows clustering along coasts and in the oval band indicated on the figure
- Coastal clustering possibly due to opening of seasonal fishing

- Band corresponds to the great circle routes that open as the sea state in North Pacific calms down from winter storms
- Likely, once the initial 'spike' in shipping is over in May, pattern returns to normal

April



May



West Coast

# Problems with data saturation

- AIS data appear more random in fractal dimension and symmetry than would be expected from manual review
- Closer inspection suggests that this is due to problems with CASA implementation
  - CASA was initially implemented to work with MANA output files; these contain integer values
  - Actual latitude-longitude data had to be translated to an integer grid (with a finite number of locations)
  - As number of detections increased, so did likelihood of each location being occupied by at least one translated location, leading to a saturation of the symmetry and fractal dimension

# Summary

- Results suggest that maritime detections off coast of Canada exhibit an intrinsic geo-spatial structure reflecting non-random patterns
  - Symmetry identified some month-to-month variability in the detections for both RS2 and AIS; results from RS2 and AIS gave almost opposite trends
  - Could be either due to problems with data saturation in CASA or related to detection methodology (different target set); this limits the value of this measure with respect to the comparison across sensors
- Presence of non-random patterns in detections, in possible combination with other indicators, might potentially provide means for the identification of subsets that do not conform to overall trends
  - Could be either discarded from further analysis (as false positives)
  - Alternatively can be subjected to closer scrutiny (if there are valid detections deviating from these patterns)
  - Before any attempts to employ any of these measures for pattern recognition in subsets can be made further validation of implementation of these measures is required

# Future work

- Validating the observed seasonal effects with known commercial and recreational schedules and major weather trends
- Evaluate the utility of spatial entropy to evaluate the behaviour of ships (as normal or abnormal based on the nature of their motion given the area and season)



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