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

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  - Fractal Dimension
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Motivation

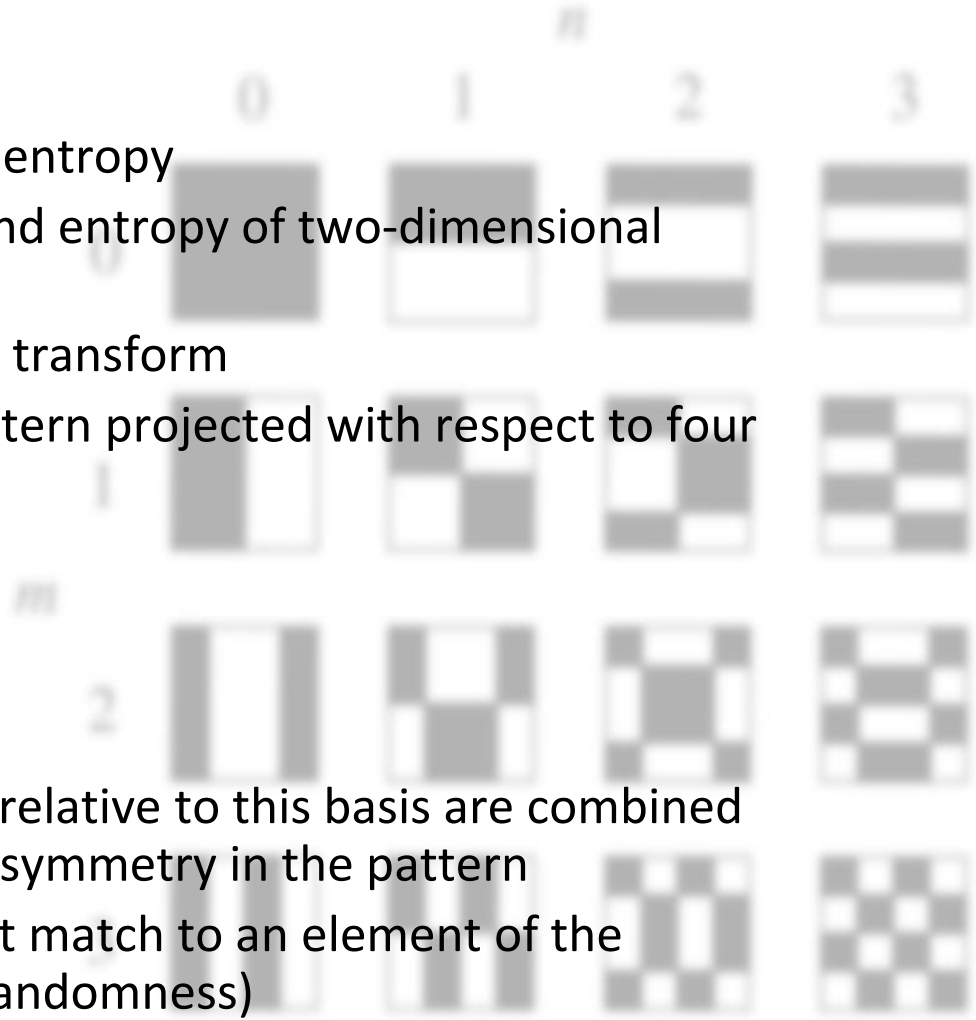
- Monitoring of vessels on approaches to Canada is vital in order to protect Canadian sovereign interests
- Questions of interest:
  - Do all detections correspond to actual vessels, or are some false positives (i.e., apparent detections that do not correspond to actual vessels)?
  - Are any vessels 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
    - Symmetropy
    - 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 $H_{max} = 1$

Symmetropy

- 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

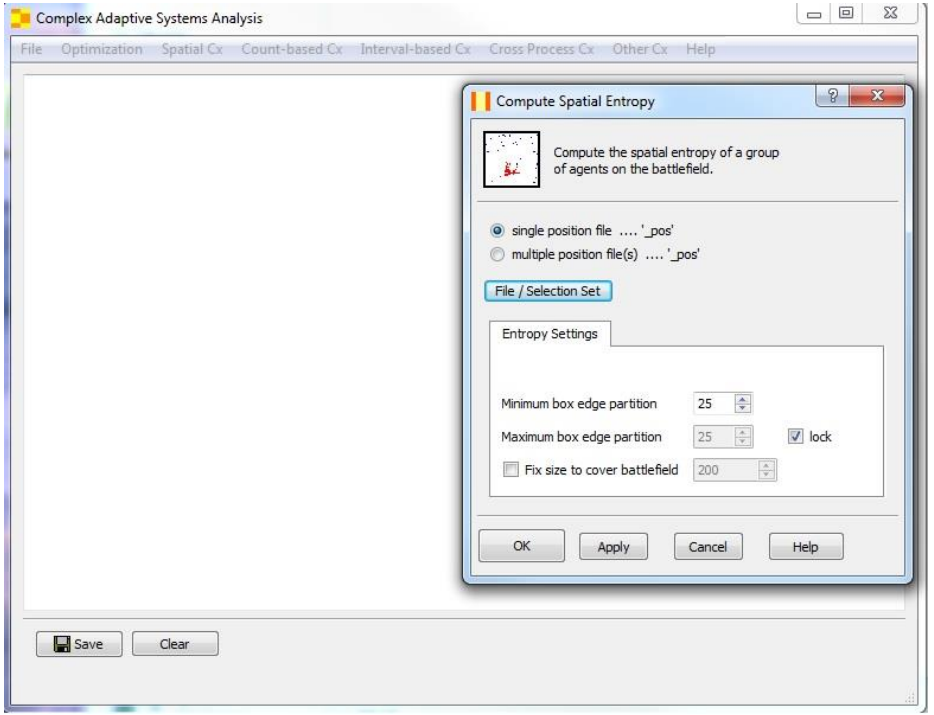
- Measures minimum number of variables needed to specify a given pattern
- Dimension of fractal data sets commonly approximated using ‘box-counting’ (or capacity) dimension
  - Relationship between the size of a box, ε, and the minimum number, $N(\varepsilon)$, of boxes needed to cover all of the ship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

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

  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



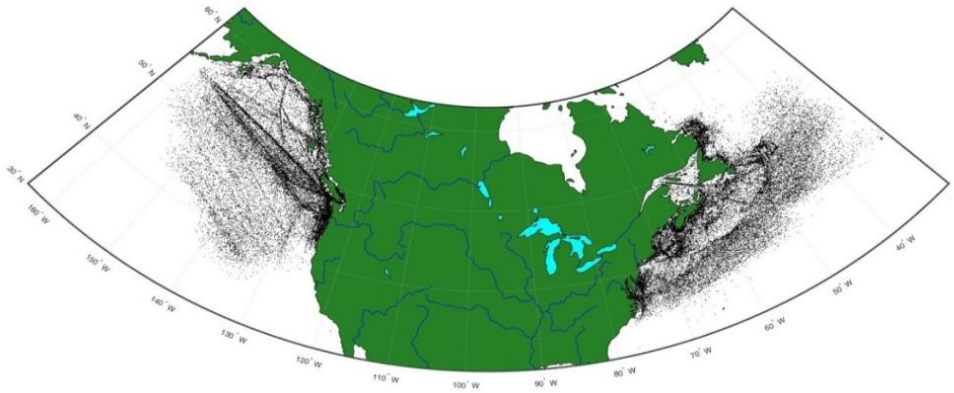
2014 RS2 and AIS data

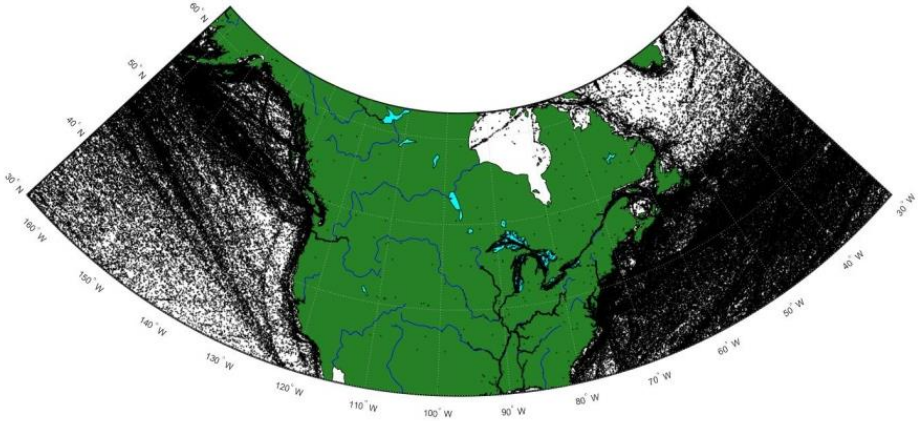
RADARSAT 2 (RS2)

- 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

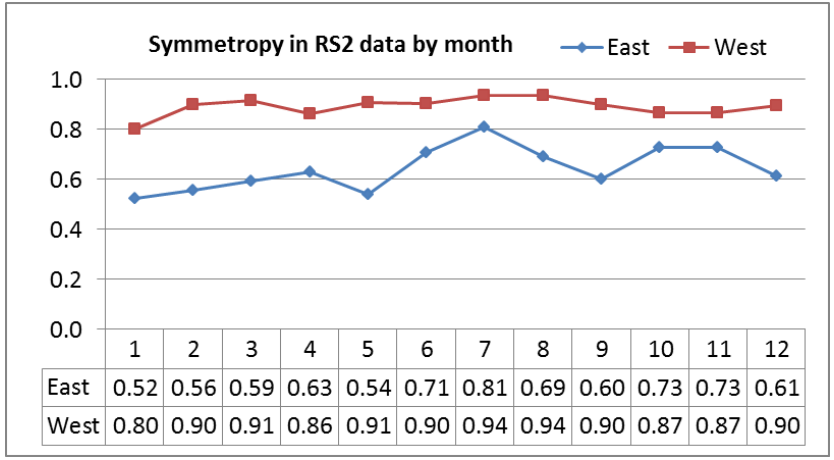




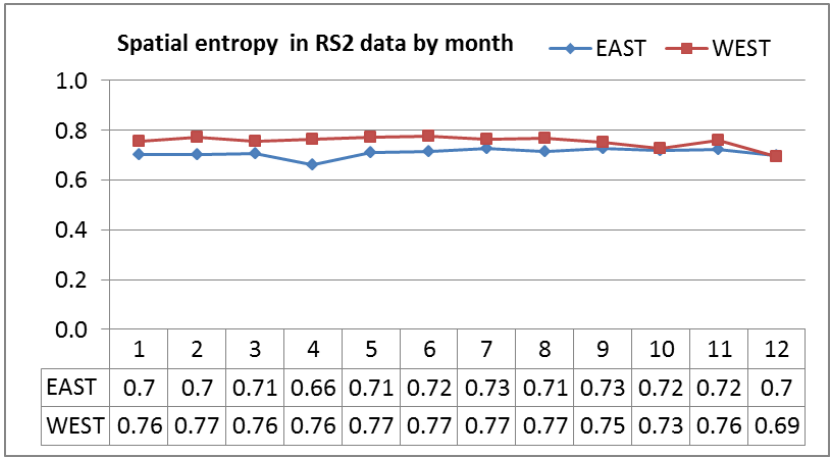
RS2 results

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

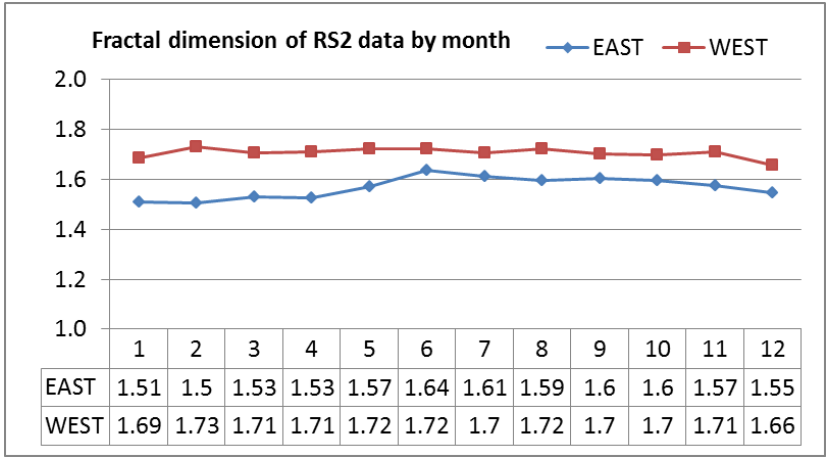
- Slightly greater randomness off the West Coast
- Greater seasonal variability along the East Coast; a transition to more random behaviour in summer



	1	2	3	4	5	6	7	8	9	10	11	12
East	0.52	0.56	0.59	0.63	0.54	0.71	0.81	0.69	0.60	0.73	0.73	0.61
West	0.80	0.90	0.91	0.86	0.91	0.90	0.94	0.94	0.90	0.87	0.87	0.90

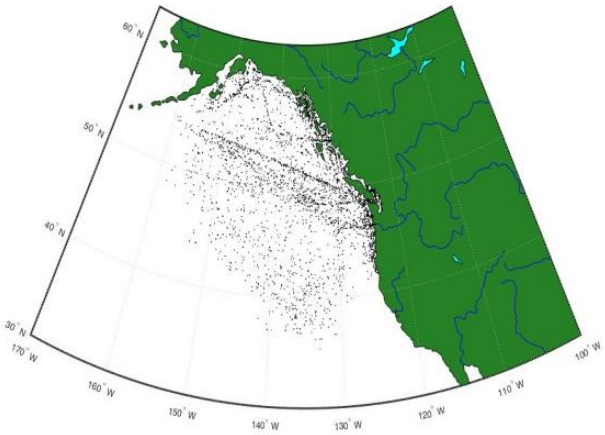


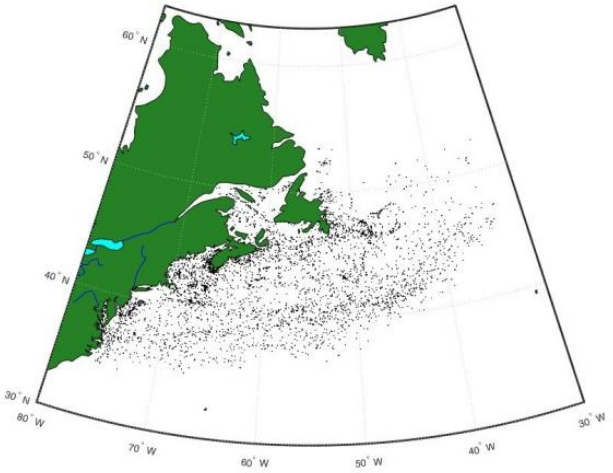
	1	2	3	4	5	6	7	8	9	10	11	12
EAST	0.7	0.7	0.71	0.66	0.71	0.72	0.73	0.71	0.73	0.72	0.72	0.7
WEST	0.76	0.77	0.76	0.76	0.77	0.77	0.77	0.77	0.75	0.73	0.76	0.69



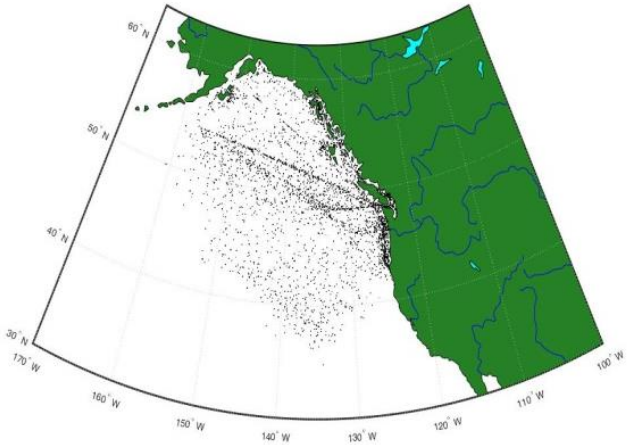
	1	2	3	4	5	6	7	8	9	10	11	12
EAST	1.51	1.5	1.53	1.53	1.57	1.64	1.61	1.59	1.6	1.6	1.57	1.55
WEST	1.69	1.73	1.71	1.71	1.72	1.72	1.7	1.72	1.7	1.7	1.71	1.66

RS2 detections

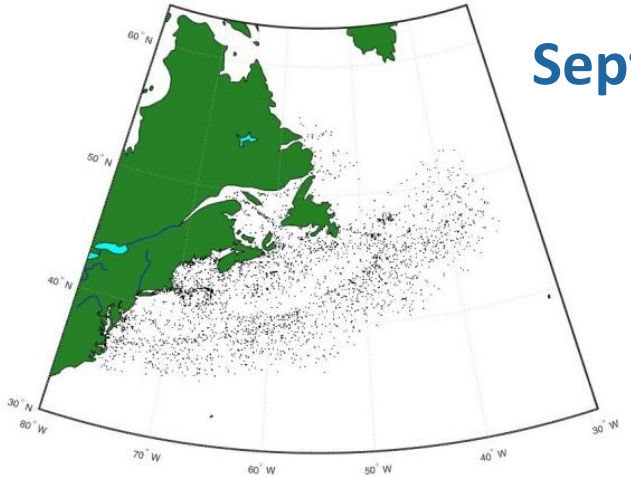




May



East Coast



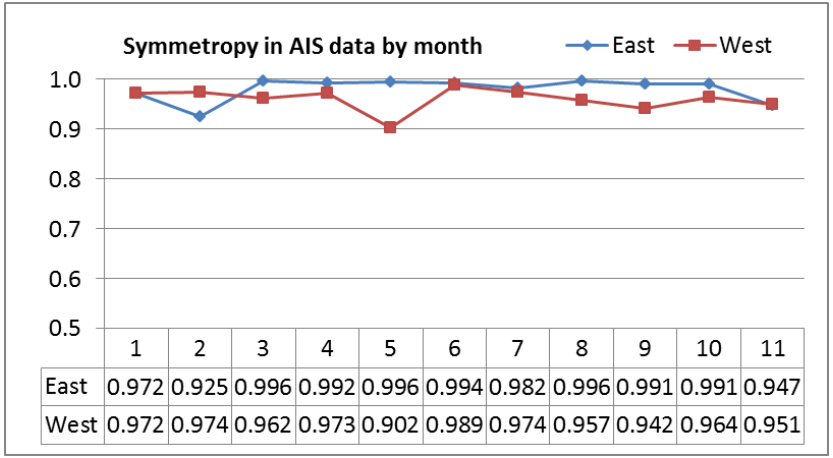
September

West Coast

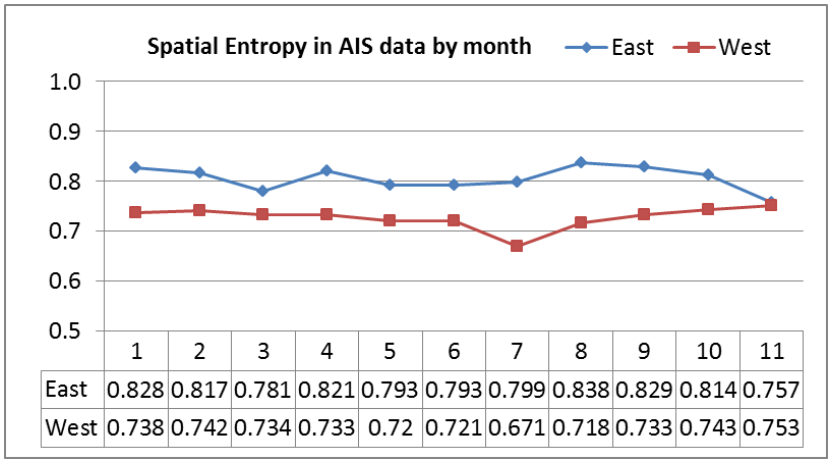
AIS results

Result is somewhat reverse of RS2 case:

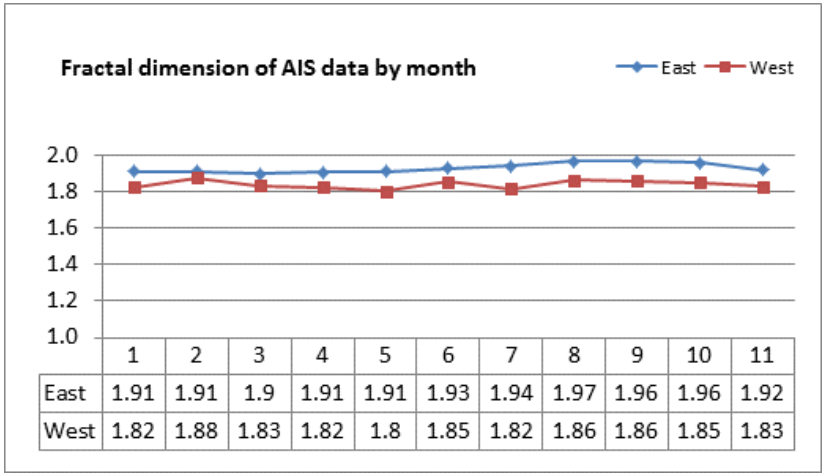
- Impact of data saturation in CASA may be leading to convergence of fractal dimension and symmetropy to max values
- Spatial entropy strongly suggests underlying patterns



	1	2	3	4	5	6	7	8	9	10	11
East	0.972	0.925	0.996	0.992	0.996	0.994	0.982	0.996	0.991	0.991	0.947
West	0.972	0.974	0.962	0.973	0.902	0.989	0.974	0.957	0.942	0.964	0.951



	1	2	3	4	5	6	7	8	9	10	11
East	0.828	0.817	0.781	0.821	0.793	0.793	0.799	0.838	0.829	0.814	0.757
West	0.738	0.742	0.734	0.733	0.72	0.721	0.671	0.718	0.733	0.743	0.753



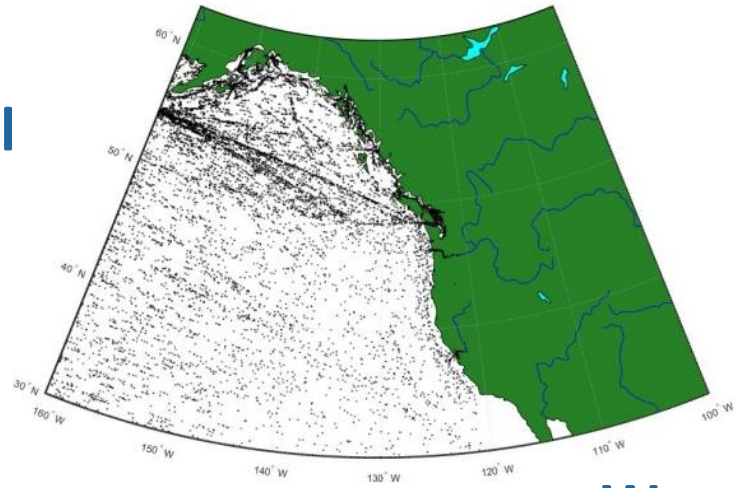
	1	2	3	4	5	6	7	8	9	10	11
East	1.91	1.91	1.9	1.91	1.91	1.93	1.94	1.97	1.96	1.96	1.92
West	1.82	1.88	1.83	1.82	1.8	1.85	1.82	1.86	1.86	1.85	1.83

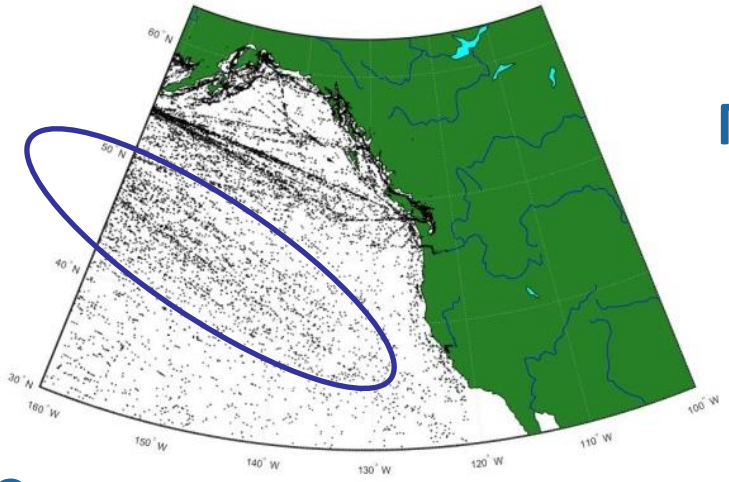
Comparison of patterns in AIS on the West Coast

- 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

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Problems with data saturation

- AIS data appear more random in fractal dimension and symmetropy 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 symmetropy and fractal dimension

Summary

- Results suggest that maritime detections off coast of Canada exhibit an intrinsic geo-spatial structure reflecting non-random patterns
  - Symmetropy 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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