Multi-Regional Analysis of Antarctic Sea Ice Record Lows

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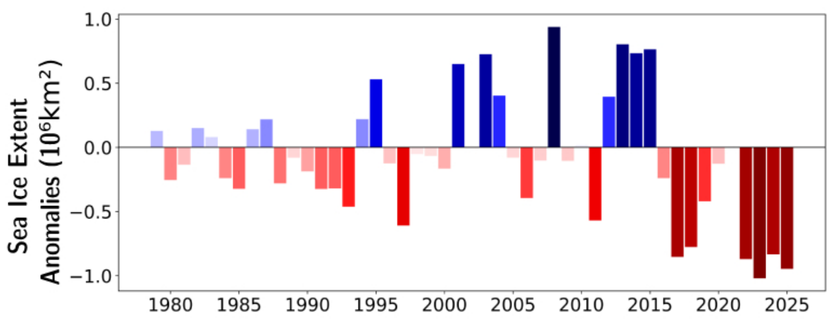
Antarctic Sea Ice Has Reached Historically Low Extents in Recent Years



Sea ice loss threatens both regional ecosystems [1] and global climate stability [2].

Step 1: Pre-Clustering Cells Into Radial Bands

Data: 432x432 spatial grid of daily satellite observations of sea ice concentration from 1979 up to present [6,7].
A cell SIE is defined as 1 if the concentration is above 15%, and 0 otherwise. A region SIE is the sum of all the cells SIE values.

Challenge: many grid cells remain ice-free during summer, limiting the effectiveness of clustering algorithms for defining meaningful regions.

Solution: initialize the clustering by grouping cells into narrow radial bands of 5° to ensure each region includes some ice-covered areas with relatively uniform sea ice behavior.

Step 2: Clustering Bands Into Regions

Group elements based on extremal dependence and spatial closeness using `Scipy` hierarchical clustering algorithm.
Specifically, dissimilarity between elements k and k' is measured as

$$D_{k,k'} = \frac{1}{2}(1 - \chi_{k,k'} + \omega_{k,k'})$$

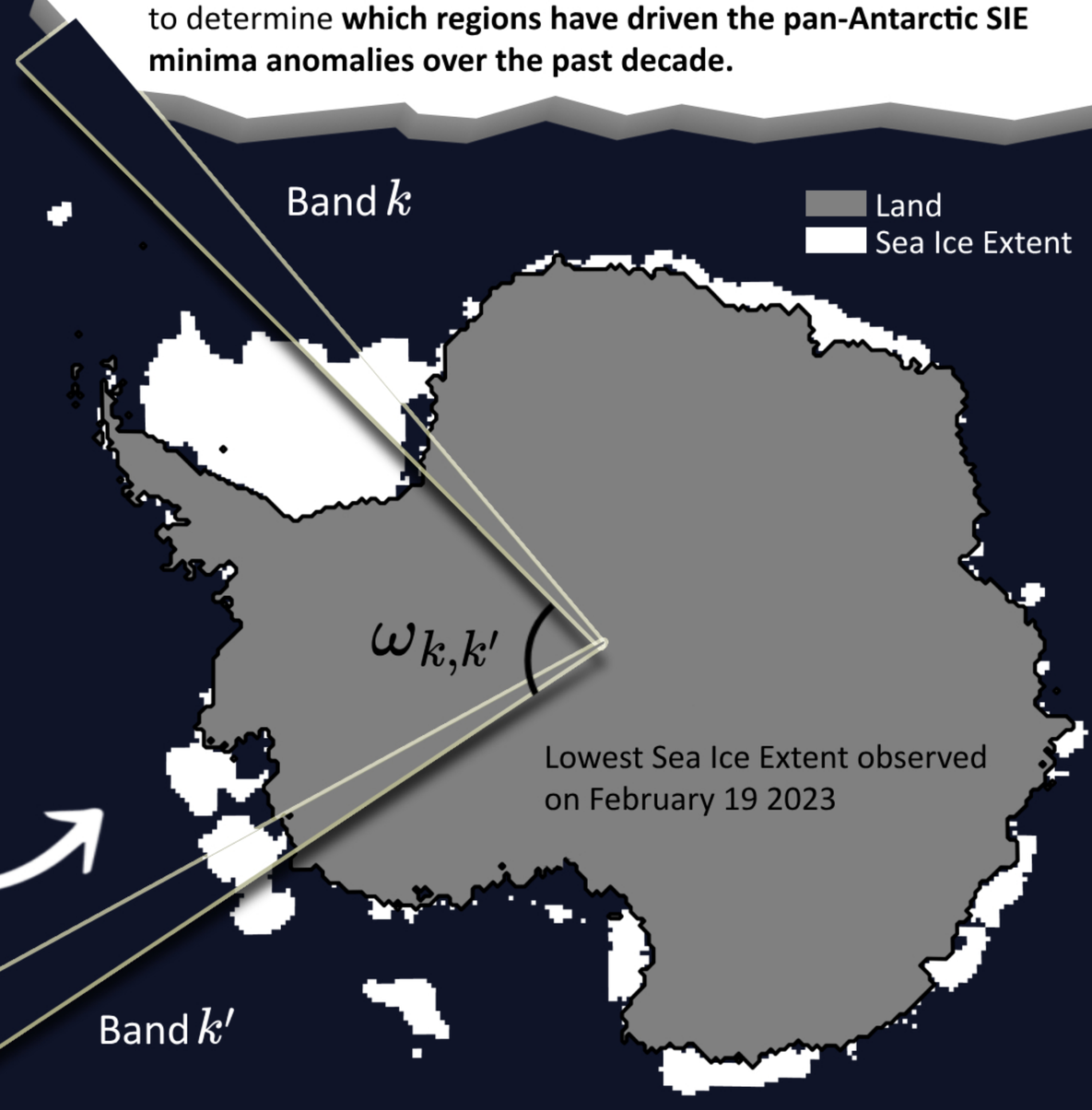
with $\chi_{k,k'}$ the extremal correlation and $\omega_{k,k'}$ the smallest angle (scaled to [0,1]) between the two elements.

and we get...

Going Beyond Averages

Background: Existing statistical analyses of Antarctic summer sea ice anomalies have focused on specific events [3] and mean trends [4]. Although some regional analyses of sea ice extent (SIE) minima exist [5], they rely on regions defined by mean SIE statistics rather than on extremes.

Contribution: We propose a **novel regional division** of Antarctica based on annual SIE minima, and fit **GEV models to the annual minima** time series within each region. With this approach, we aim to determine **which regions have driven the pan-Antarctic SIE minima anomalies over the past decade.**

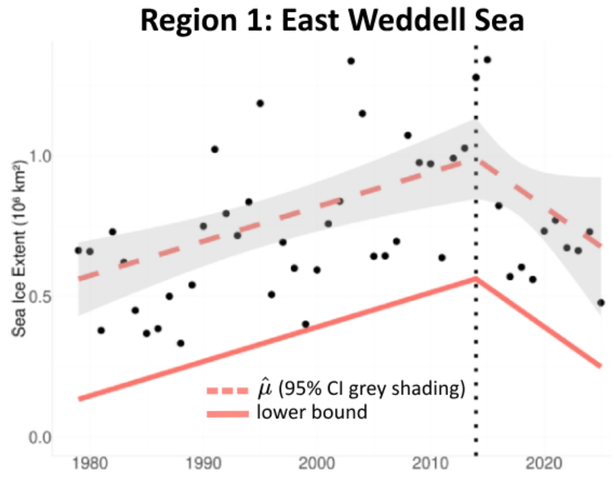


Step 3: Fit Regional GEV Models

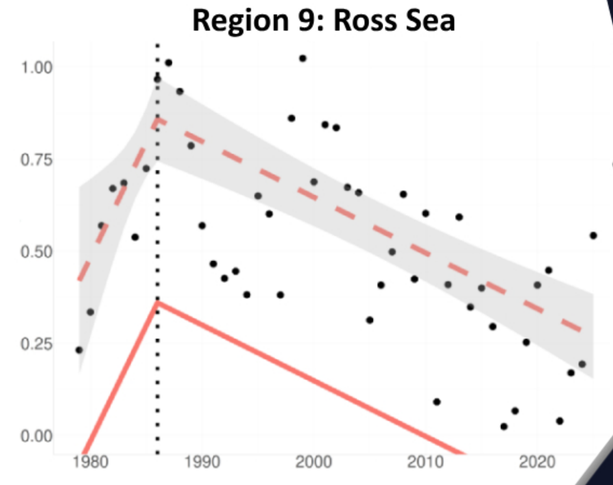
Models: stationary vs non-stationary models (linear and piecewise linear location; linear log-scale). Breakpoint estimated separately via `segmented`; other parameters via `evgam`. Piecewise models are retained only if the breakpoint is significant at the 5% level. Model selection is based on AIC.

Results: Sea ice extent minima have remained stationary in all regions over recent decades, except in Regions 1 and 9, where significant trend reversals have been detected. These two regions contribute substantially to pan-Antarctic anomalies.

Region 1: East Weddell Sea



Region 9: Ross Sea



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