Characteristics of Arctic Sea Ice Meander Coefficients at Daily Frequency

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1 Introduction

The dynamic and irregular movement of Arctic sea ice poses significant challenges for remote sensing analyses. While satellite imagery provides a vital means of observing sea ice velocity, the accuracy of straight-line velocity estimates diminishes over longer time intervals due to the meandering nature of ice trajectories. This necessitates a method to account for the deviations introduced by such nonlinear movement at more granular timescales.

2 Data

This analysis looks at the IABP Level 1 data collected from buoys placed on drifting sea ice as part of the buoy programme. The timestamps on buoy position data range from 2002 through 2023. The data was cleaned using a quality control process described as follows:

1. Fix reversed dates and positions
2. Remove duplicated dates and positions (where both longitude and latitude stayed the same between two observations)
3. Segment the observations into groups that have gaps larger than the threshold. Then, remove segments that are too short.
4. Check for anomalous speeds between consecutive buoy positions

Afterwards, cubic spline interpolation is used to regrid the buoys to hourly time intervals within each segment. The longitude nad latitude coordinates are converted to cartesian stereographic coordinates for analysis.

3 Methodology

For each buoy, we calculate the straightline hourly displacements h_t where t is number of hours after deployment:

$$h_t = \sqrt{(x_{t+1} - x_t)^2 + (y_{t+1} - y_t)^2}$$

We compute daily path distance p_n by summing hourly distances for the nth day. We also compute straightline daily displacement d_n. Days with incomplete data are discarded.

$$p_n = \sum_{t=24n}^{24n+23} h_t$$

$$d_n = \sqrt{(x_{24n+24} - x_{24n})^2 + (y_{24n+24} - y_{24n})^2}$$

To quantify a buoy's deviation from it's straight line path, we define the daily meander coefficient as the ratio of cumulative path length divided to net displacement in position

$$m_n = p_n/d_n$$

producing a time series at daily frequency of meander coefficients for each buoy.

As meander coefficient is relatively far removed from the original GPS data, we conduct sensitivity analysis to determine the uncertainty in meander as a function of GPS uncertainty. We assume that the buoy GPS error be normally and independently distributed with mean 0 and variance σ^2 in both the x and y stereographic coordinates. We derive the uncertainty of daily path length σ_p^2 and daily displacement σ_d^2.

$$\sigma_{h_t}^2 = 2\sigma^2$$

$$\sigma_p^2 = m^2\sigma^2$$

$$\sigma_d^2 = m^2\sigma^2$$

We compiled basic summary statistics of the meander coefficient over time, and plotted a histogram over all regions and times. Observing that the behavior of the distribution was strongly defined by it's tail, we fitted lognormal, power law, and exponential distributions to the histogram, using KS similarity to determine which was best. Further analysis involved plotting the autocorrelation and partial autocorrelation graphs.

4 Results

Based on the distribution, how do we best summarize the resulting data?

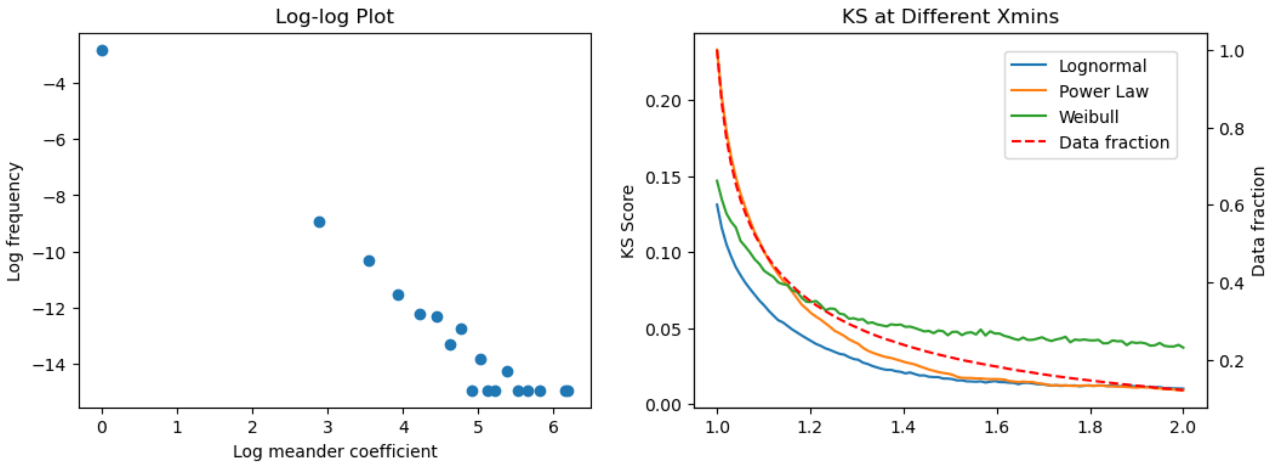

Figure 1: On the left is a log-log plot of meander coefficient frequency. On the right is a plot of KS-score over power law, lognormal, and Weibull distributions at varying xmin cutoffs.

We observe that the distribution of the data fits better and better as we increase the xmin threshold. In particular, the distribution of meander coefficient is better modeled with a lognormal distribution at relatively large meander values.

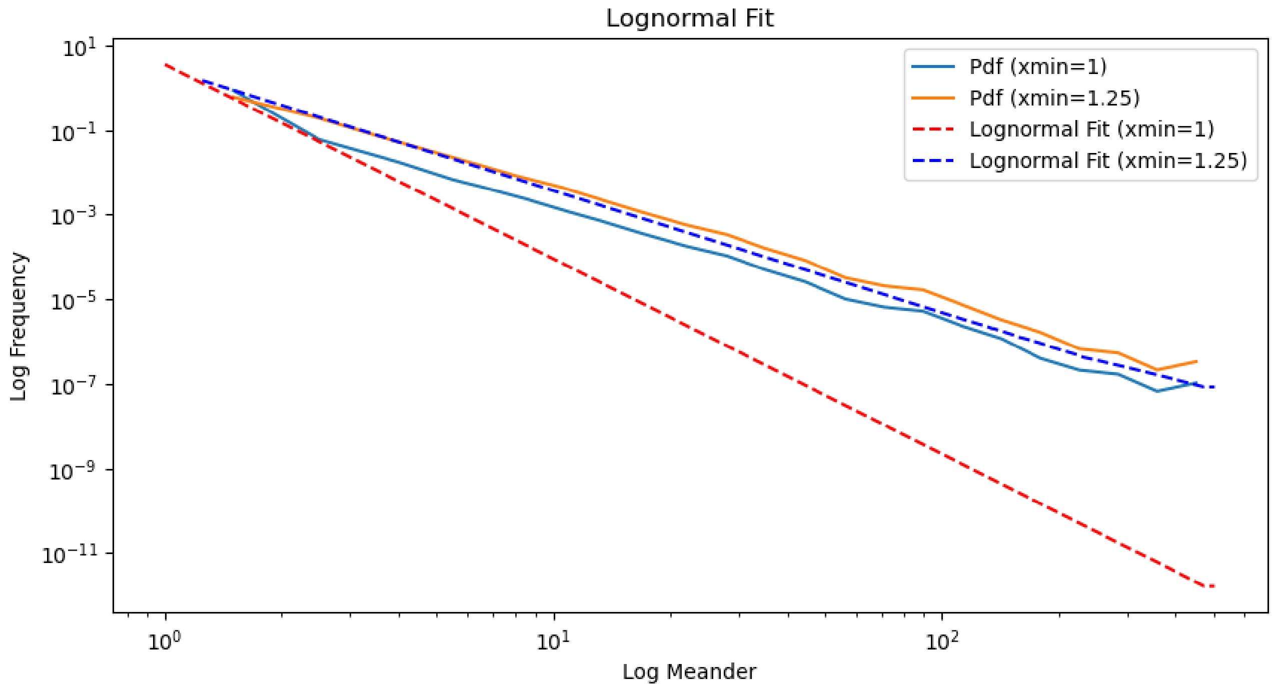

Figure 2: Lognormal fit pdf at xmin=1, containing all of the data and at xmin=1.25, containing the upper 30% of the data.

There isn't a universal distribution or parameterization that works well for all levels of meander, since ice motion integrates velocity variability that itself has a variety of contributors at different time scales. However, the KS-plot suggests that large meanders are close to lognormal.

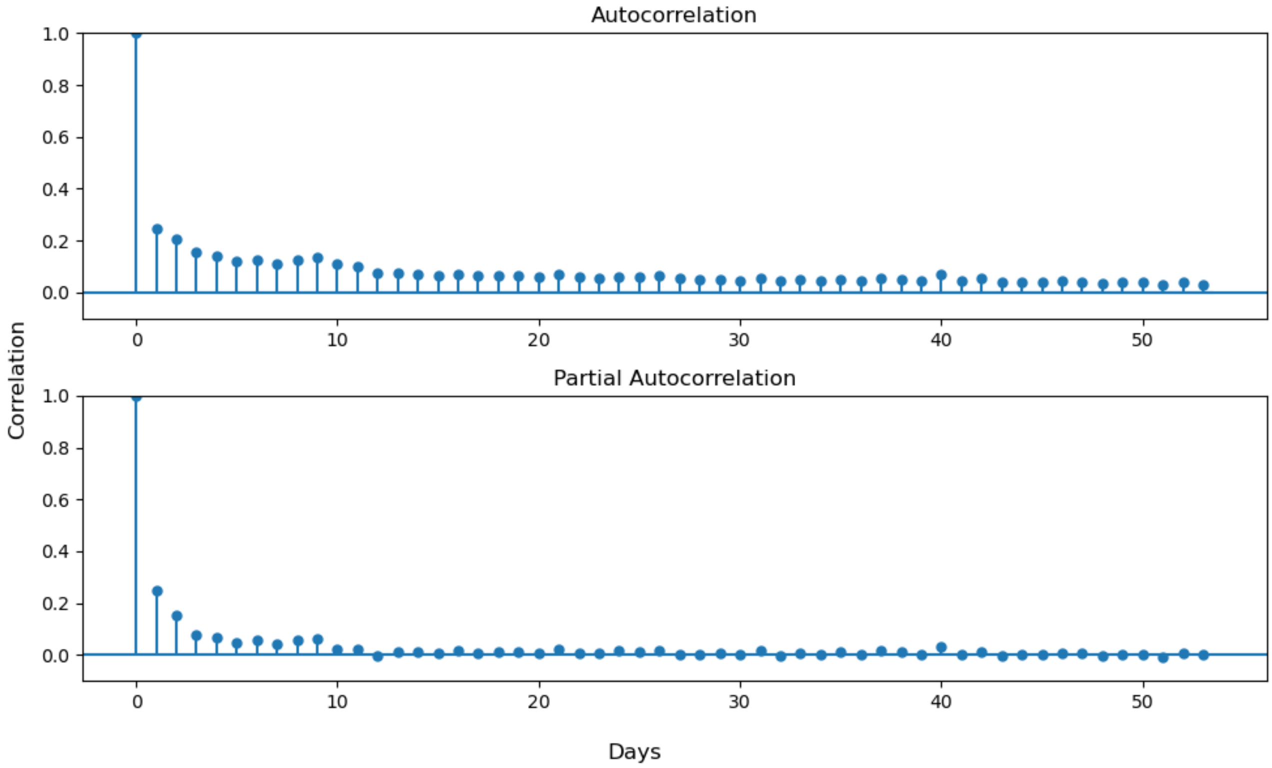

Figure 3: ACF and PACF of meander coefficient. Data from each buoy was concatenated before calculating autocorrelations. Buoys that contain less than 10 days of data were removed to reduce artifacts at longer lags.

The ACF and PACF highlight significant autocorrelation structure in the meander time series.

5 Discussion

Further work will involve

1. Understanding the spatial variation of meander coefficient
2. Modeling meander coefficient as a stochastic process from which discrete observations are taken