

What Makes Each Cycle Unique?

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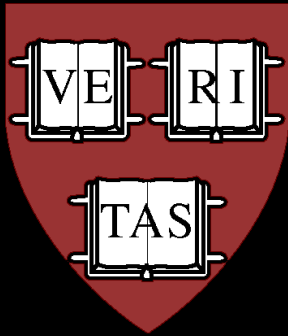
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What Makes Each Cycle Unique?



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(Graduate)**

Our Objective

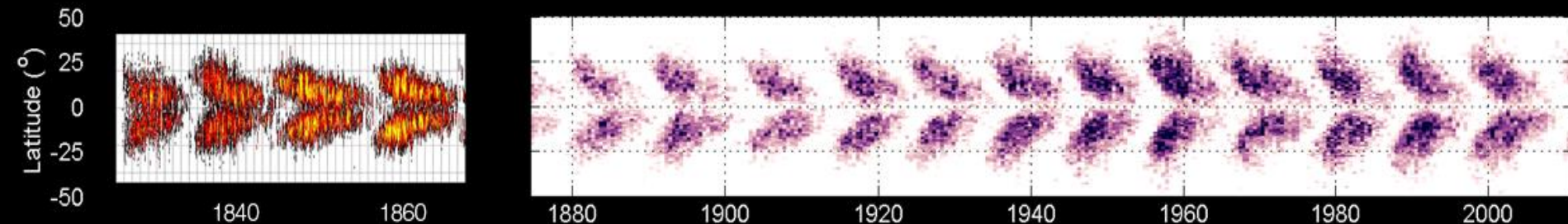
- **Find the minimum amount of information necessary to recreate a fully fleshed solar cycle.**

Why?

- **A window into the past:**
Fleshing out the sunspot number series.
- **A door into the future:**
Seed in a new generation of model based predictions.

Our Data

- **Schwabe's data (1825-1866)**
Compiled by Reiner Arlt et al. (2013)
- **Royal Greenwich Observatory, Pulkovo
Astronomical Observatory, and
USAF/SOON data (1874-2011)**
Compiled by Balmaceda et al. (2009)

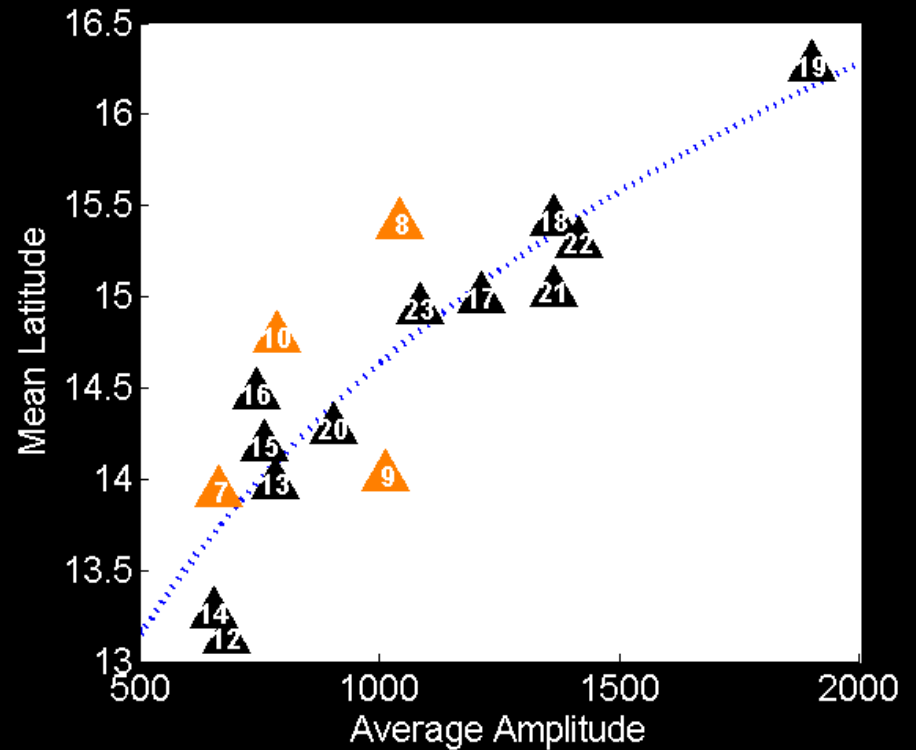
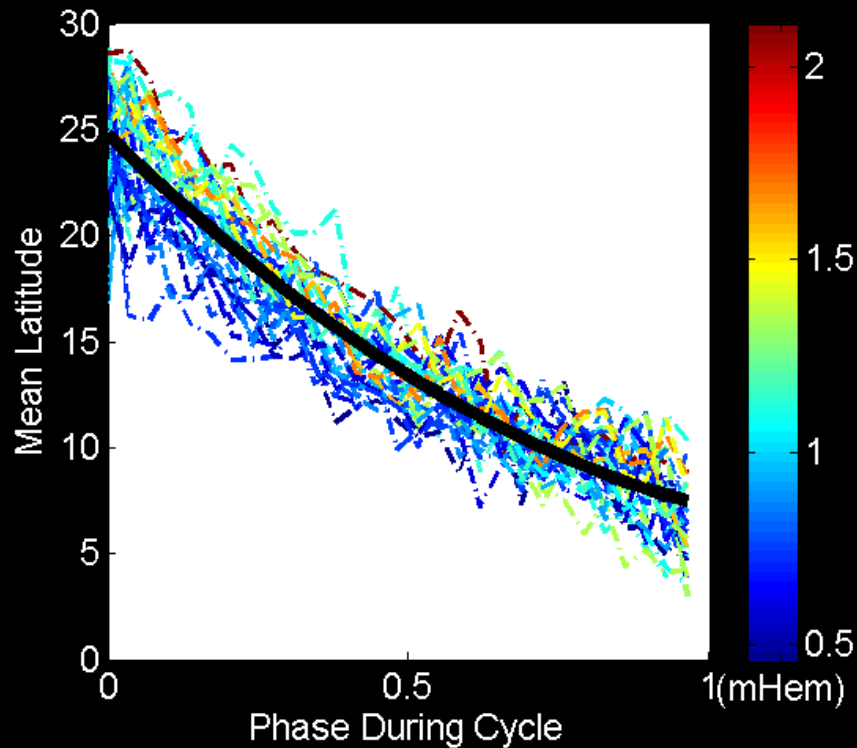


REVISITING PREVIOUS RESULTS

Spatiotemporal distribution of sunspot groups

- Path of active latitude centroid and the width of the active band depend on cycle strength (see review by Hathaway 2010).
- Our approach is inspired by the work of Jiang et al. (2011).

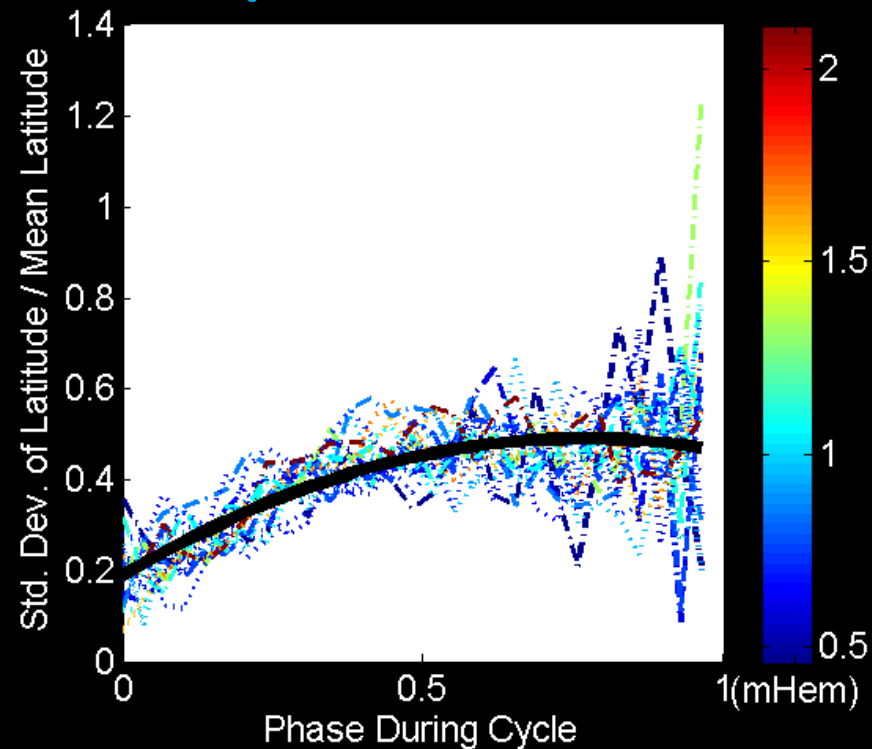
Active Latitude Centroid



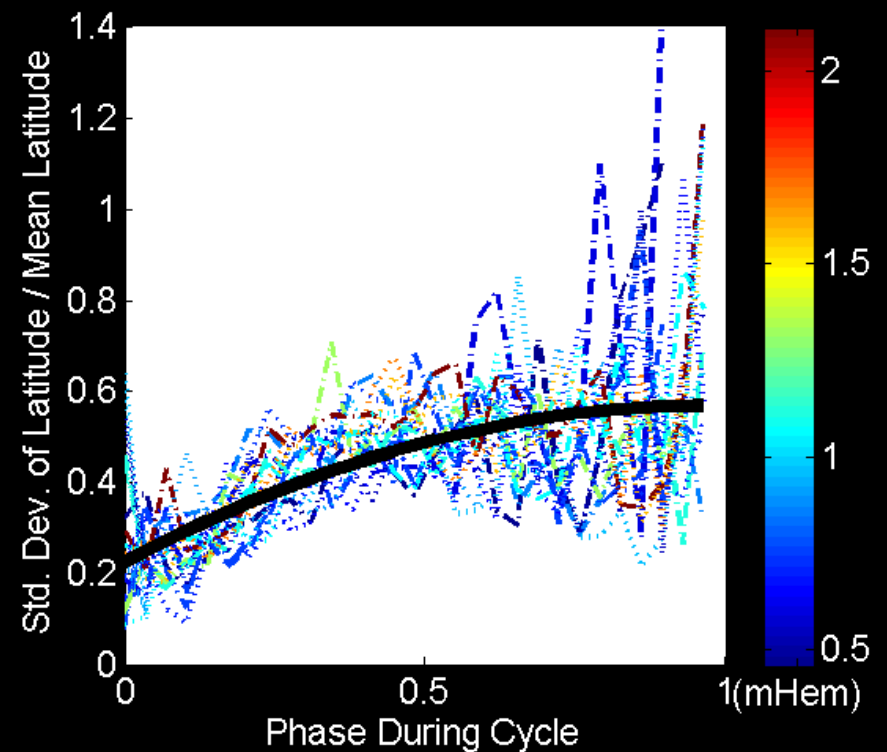
Latitude centroid shifts towards higher latitudes in stronger cycles.

Active Latitude Width

Equatorward side

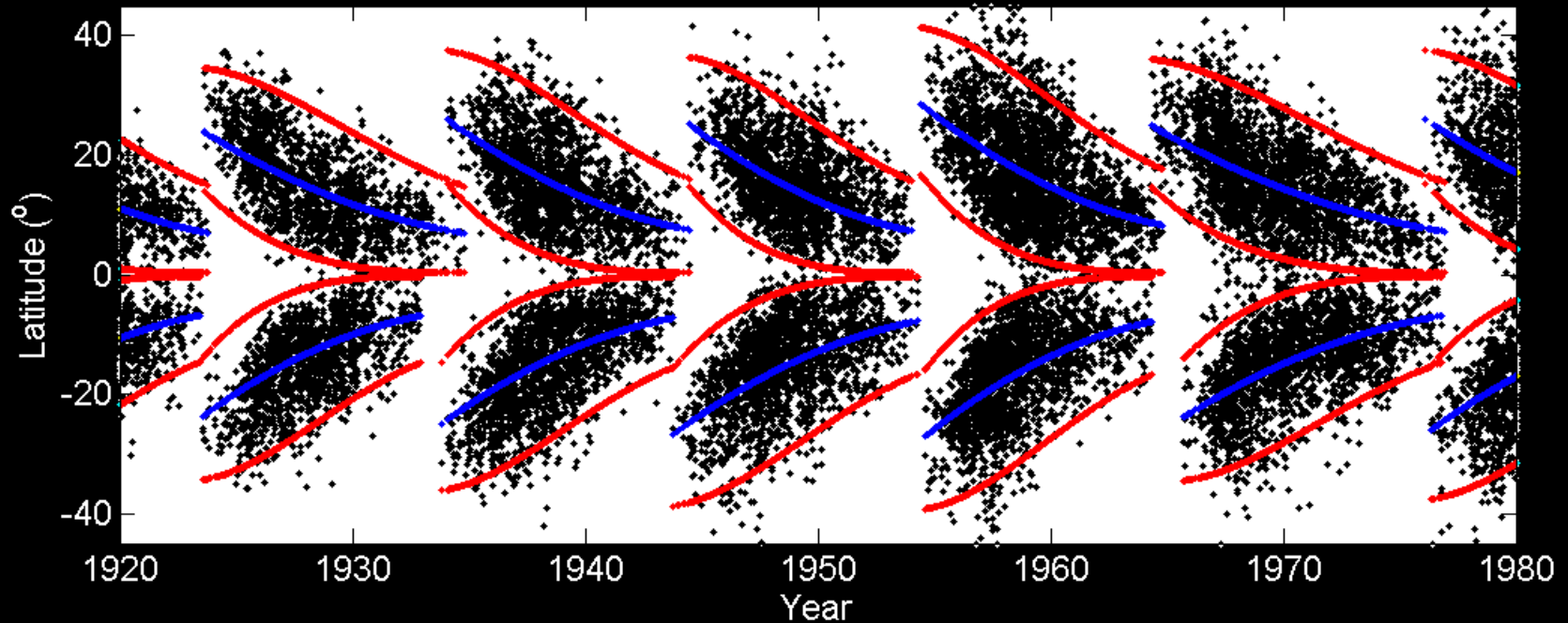


Poleward side



Wing width is slightly larger poleward of the wing centroid

Results



Tying centroid drift and wing span to amplitude and period captures the main characteristics of the butterfly wings

TAKING THE NEXT STEP

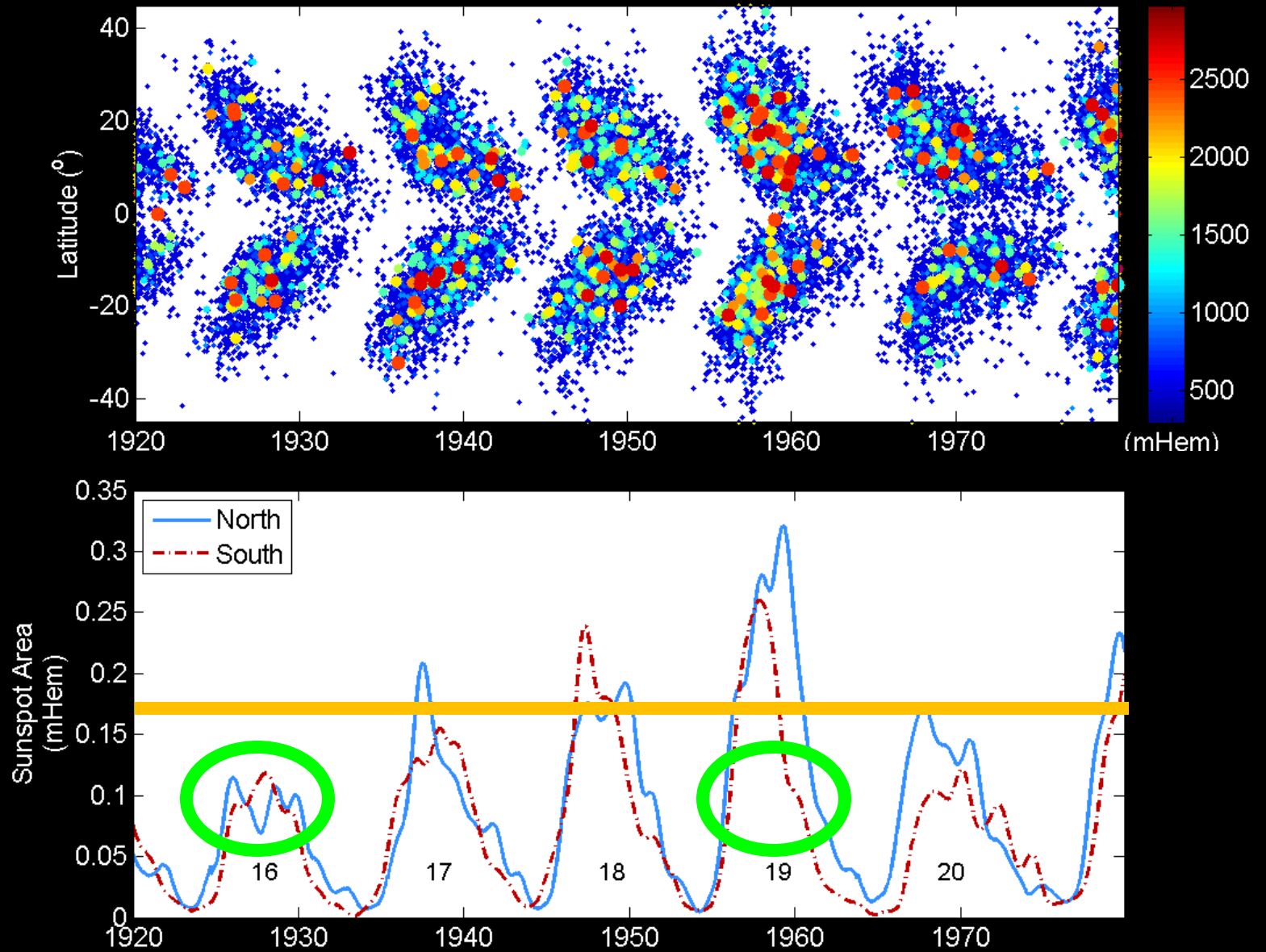
Spatio-temporal distribution of group sizes

- There is a relationship between group size, phase, and latitude, but the exact nature of this relationship was unclear. Jiang et al. (2011).

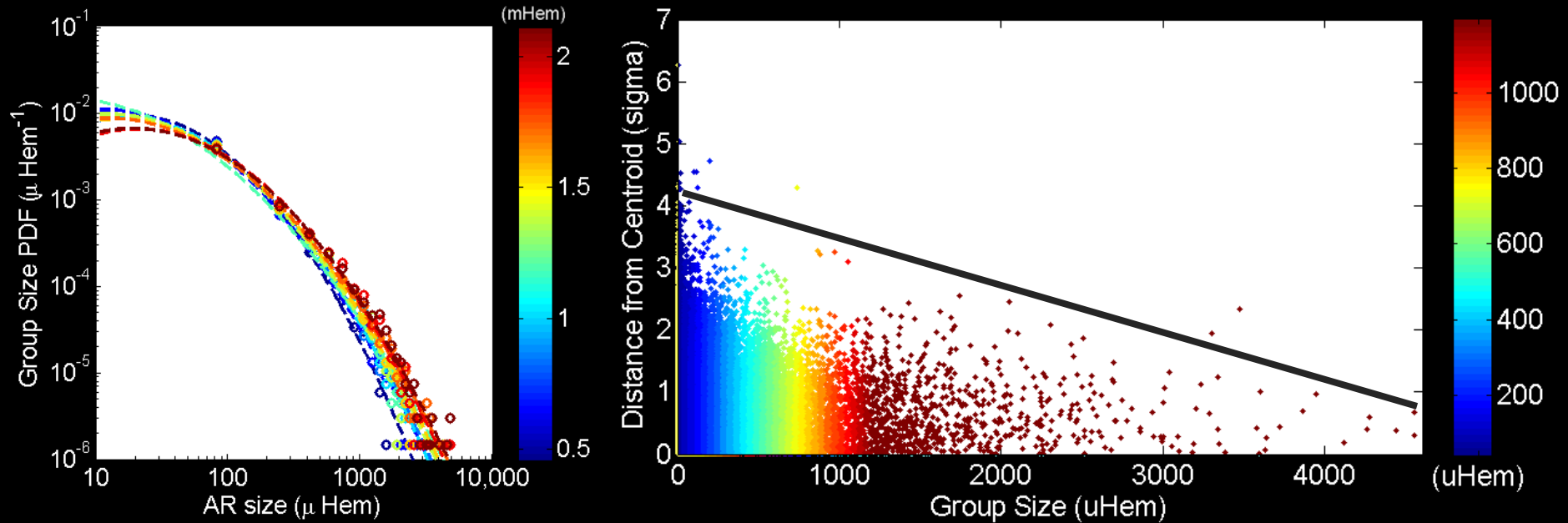
Working Hypotheses

- **Characteristics of active region eruption depend only on the properties of the toroidal belt they come from.**
- **Strength of the toroidal belt is strongly correlated to the amount of active region eruptions.**
- **Stronger toroidal magnetic field produces a larger proportion of stronger active regions.**
- **Toroidal magnetic field is strongest at the centroid and weaker at the edges of the wings.**

Phase Strength



Distribution of Active Region Sizes



- Distribution of sunspot group sizes is well described by a log-normal distribution whose parameters depend on phase strength and distance from the wing centroid.

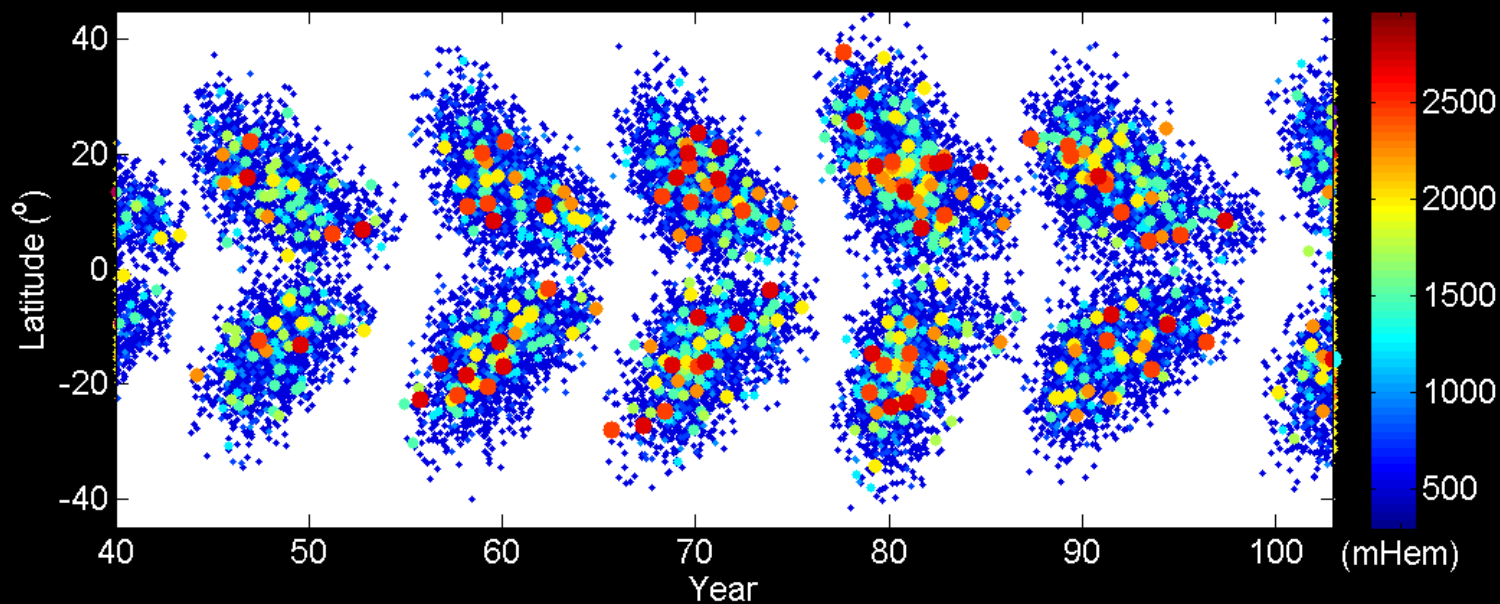
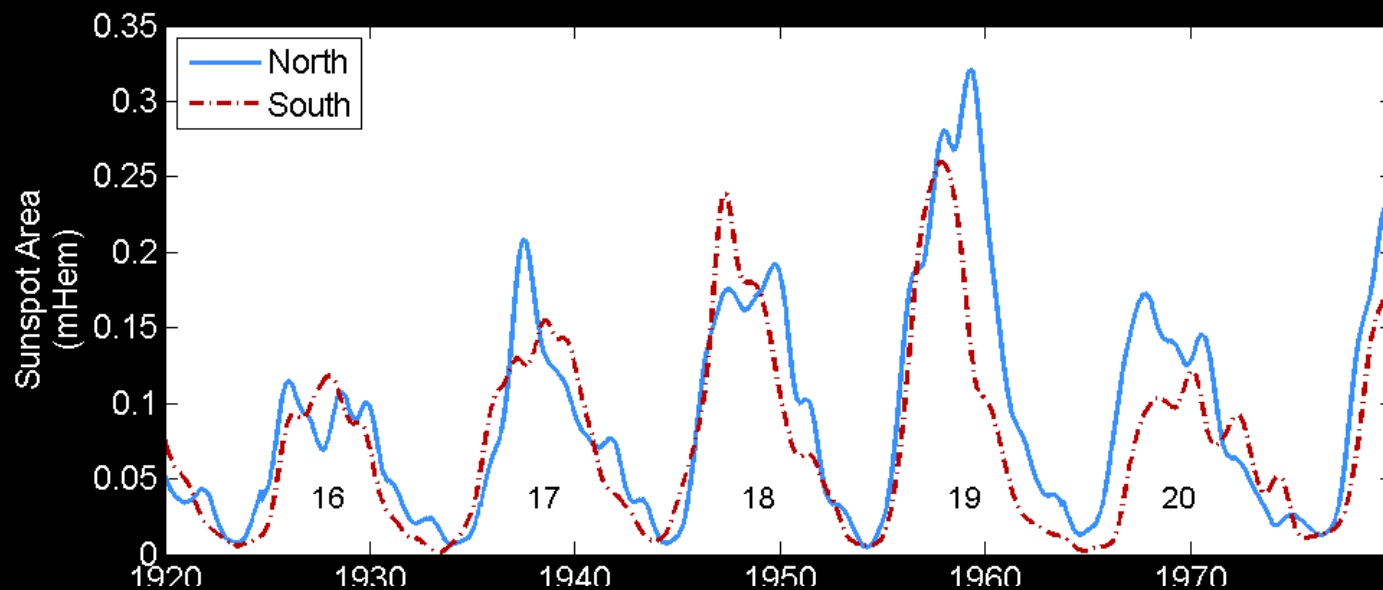
Log-Normal Distribution

$$f(x; \mu, \sigma) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}}$$

- A log-normal distribution fits the data significantly better than other heavy tailed distributions (power law, Pareto, Levy).
- Log-normal distributions arise in nature when growth and fragmentation rates are independent of size (law of proportionate effect).

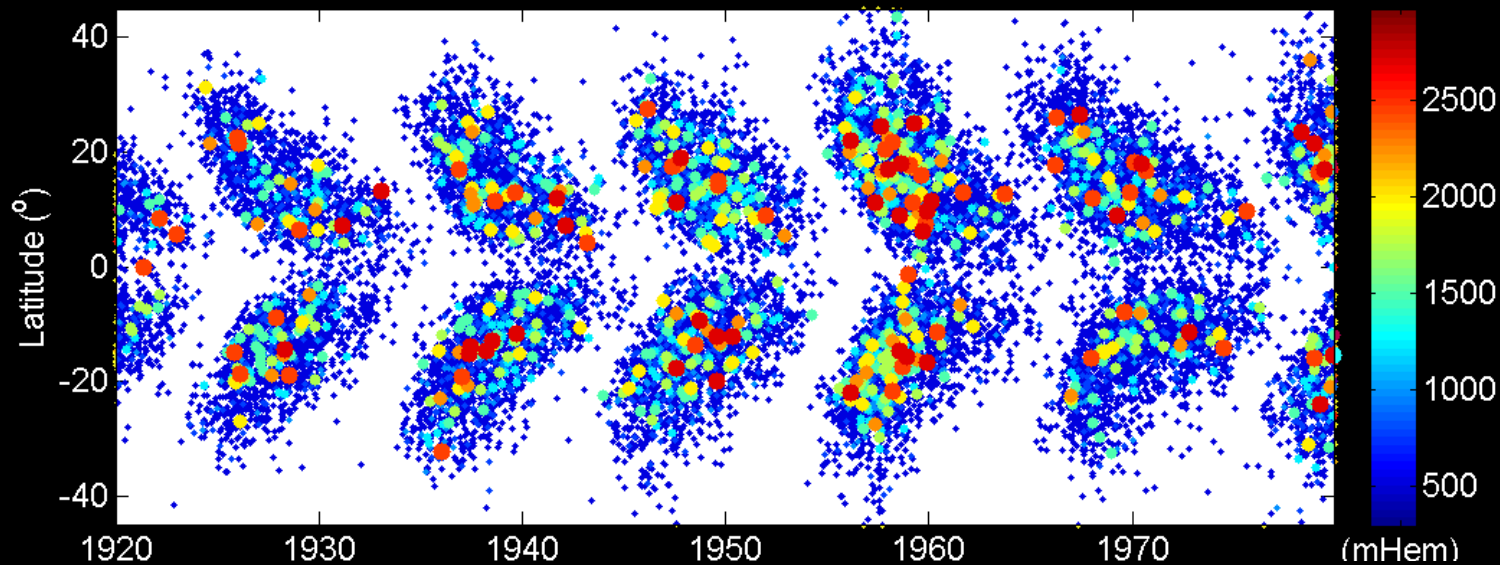
$$x_j = F_j x_{j-1}$$

The inverse problem

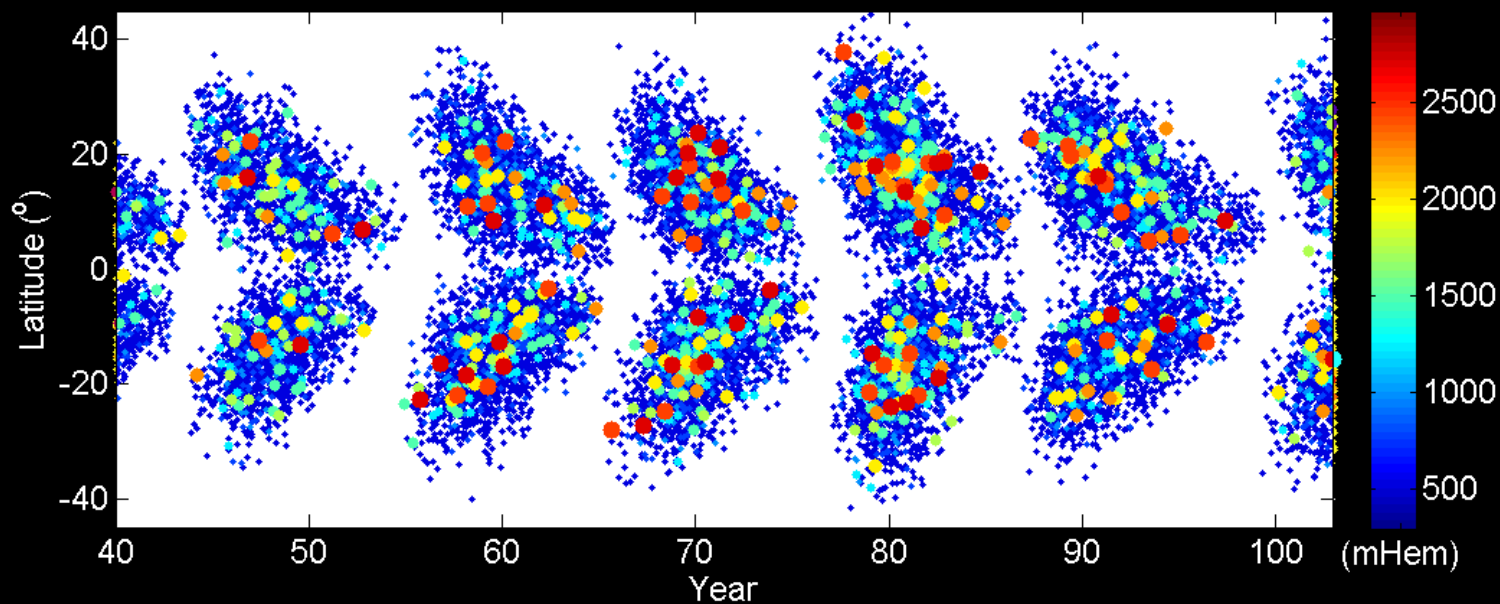


The inverse problem

Observed



Synthetic



Final Remarks

- We have identified a connection between the characteristics of sunspot group populations and global properties of the cycle.
- We have characterized both spatio-temporal distributions of sunspot group size, as well as tilt.
- This set of distributions can be used to create realistic sets of synthetic data.
- This approach is going to change the way we do long-term solar variability studies.

What Makes Each Cycle Unique?

Its amplitude and duration