

# THE RAILS INSIDE THE SUN AND THE BUTTERFLIES THAT RIDE THEM

Andrés Muñoz-Jaramillo

[www.solardynamo.org](http://www.solardynamo.org)

Georgia State University  
University of California - Berkeley  
Stanford University

THE FOLLOWING **PREVIEW** HAS BEEN APPROVED FOR  
**APPROPRIATE AUDIENCES**  
BY THE MOTION PICTURE ASSOCIATION OF AMERICA, INC.

THE FILM ADVERTISED HAS BEEN RATED



[www.filmratings.com](http://www.filmratings.com)

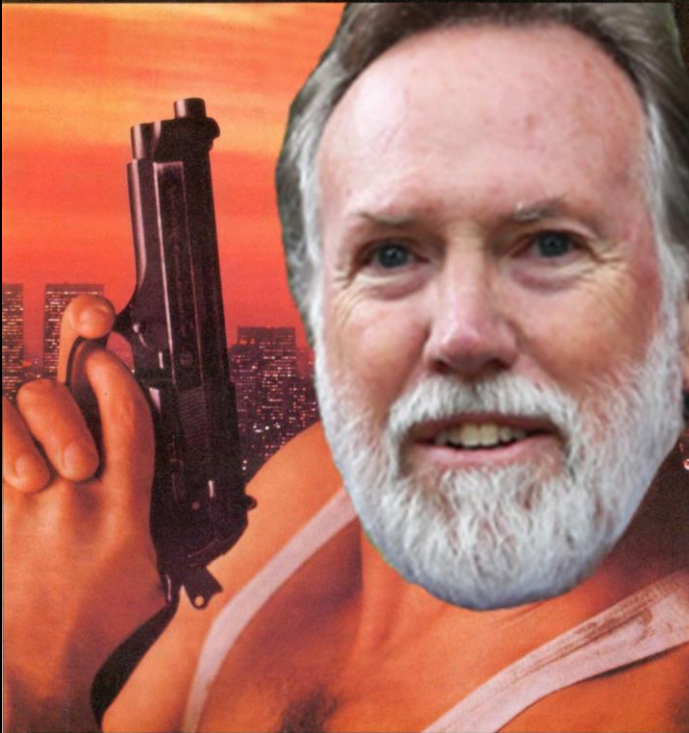
[www.mpa.org](http://www.mpa.org)

# From the creators of

dynamo

observational

Twelve terrorists. One cop.  
The odds are against ~~John McCrane...~~ Dave  
That's just the way he likes it.

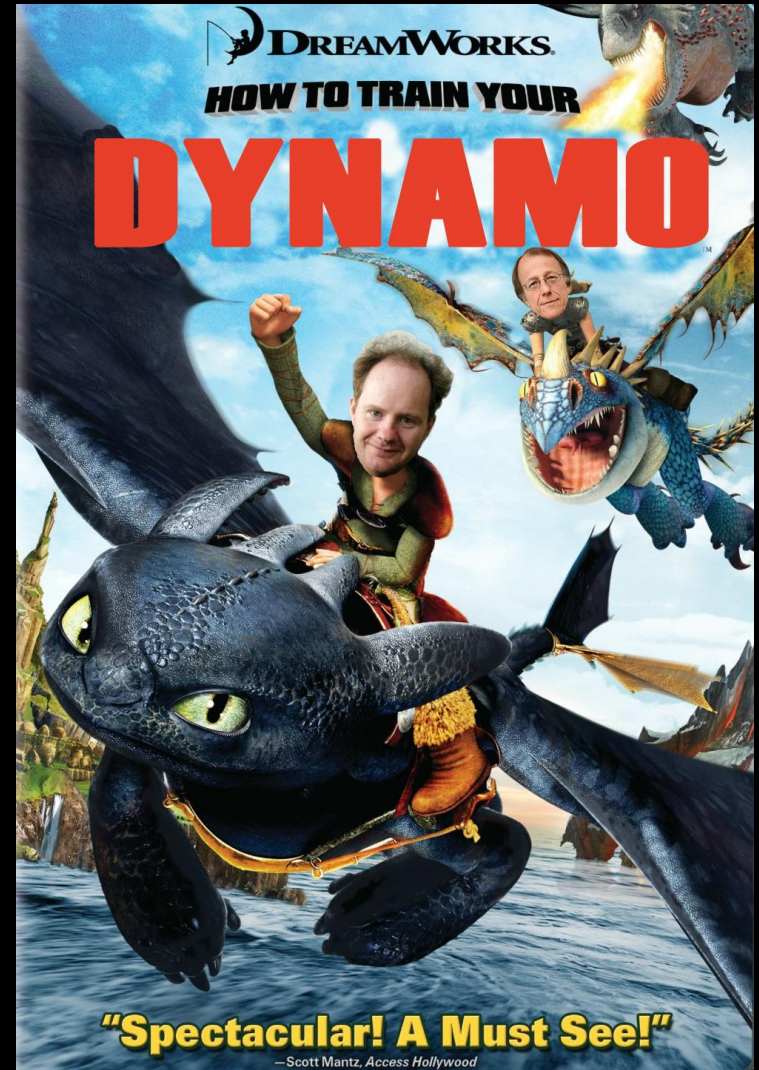


DAVID HATHAWAY  
**DYNAMO HARD**

Twentieth Century Fox presents A Gordon Company/Silver Pictures production A John McTiernan film with Bruce Willis Die Hard  
Alan Rickman Alexander Godunov Bonnie Bedelia Music by Michael Kamen Visual Effects by Richard Edlund Edited by Frank J. Urioste, A.S.C.  
and John F. Link Production Designer Jackson DeGovia Executive Producer Ian De Bont Executive Producer Charles Gordon Screenplay by Jeb Stuart and Steven E. de Souza  
Based on the Roderick Thorp novel Produced by Lawrence Gordon and Joel Silver Directed by John McTiernan Read the latest FoxSearch.com  
Color by National

COMING THIS JULY

(Hathaway 2011)

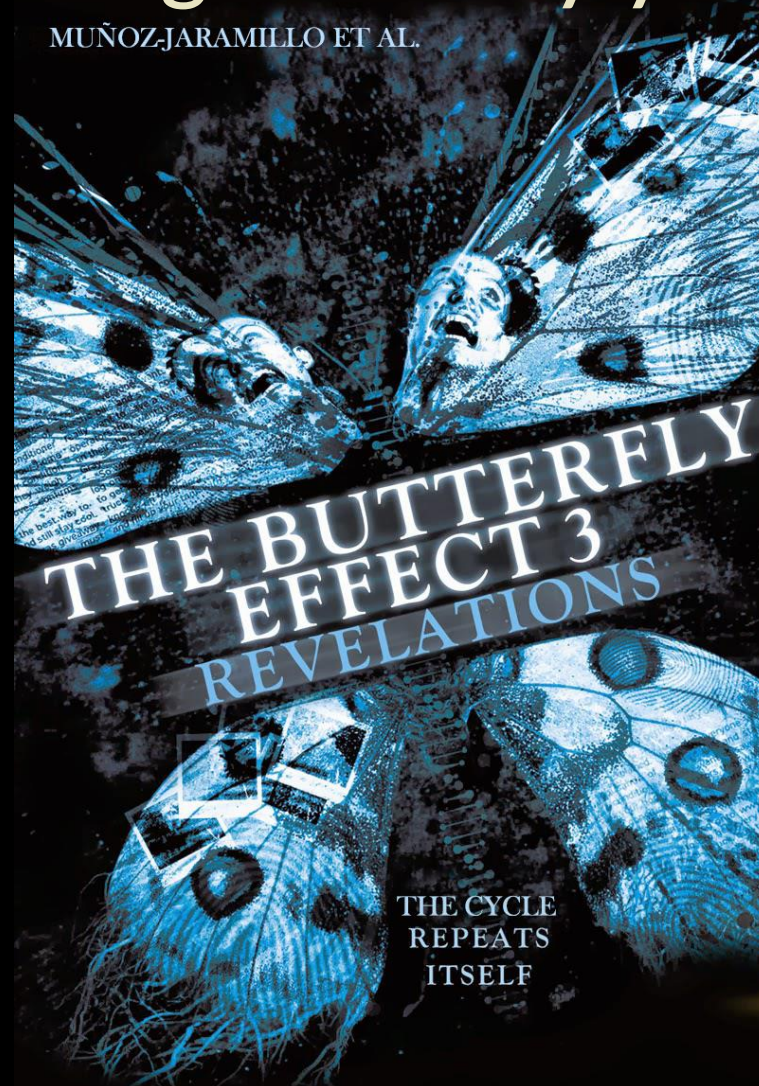


**"Spectacular! A Must See!"**

—Scott Mantz, Access Hollywood

(Cameron & Schüssler 2016)

Comes an action-packed psychological thriller  
that will change the way you see reality



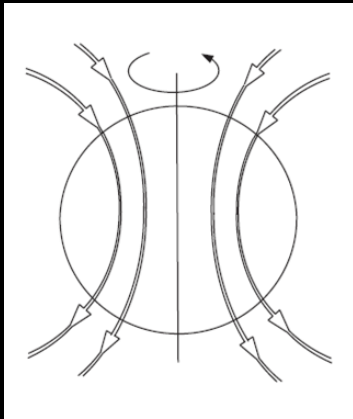
(Muñoz-Jaramillo et al. in preparation)

**A DEEPLY TOUCHING STORY BASED  
ON REAL OBSERVATIONS...**

# ...of magnetic death\* ...

Poloidal

$r - \theta$

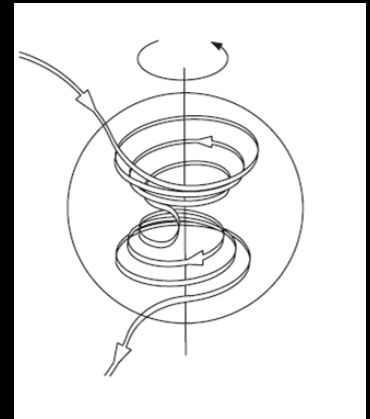


Differential  
Rotation



Toroidal

$\phi$



Credit: J. J. Love

\* Transformation

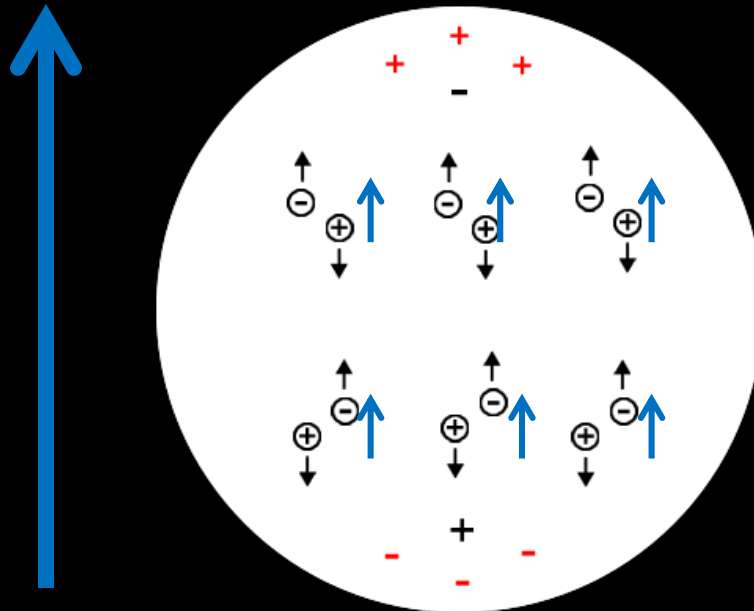
# ... and rebirth

Poloidal  
 $r - \theta$

Differential  
Rotation

Toroidal  
 $\phi$

Emergence and Decay of  
Tilted Active Regions



For decades, our heroes have civilly debated the nature of the solar cycle



It's deep in the interior!



For decades, our heroes have civilly debated the nature of the solar cycle



No! It's near the surface!

# For decades, our heroes have civilly debated the nature of the solar cycle



But new ways of looking at old data may provide the clues that we are missing

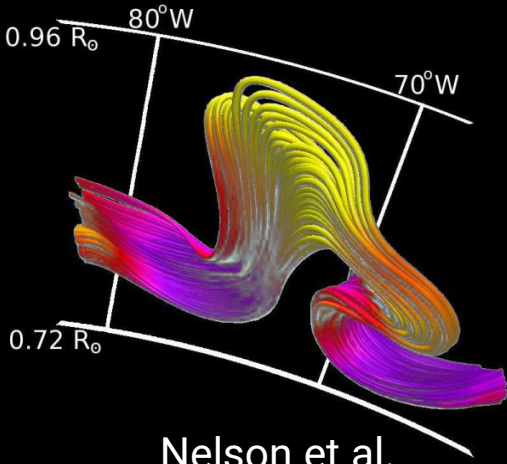
- Referencing sunspot properties to the strength of the cycle at a given time (activity level; Muñoz-Jaramillo et al 2015).
- Using latitude of the toroidal belts instead of time (Hathaway 2011; Ivanov & Miletsky 2014; Cameron & Schüssler 2016; this work).



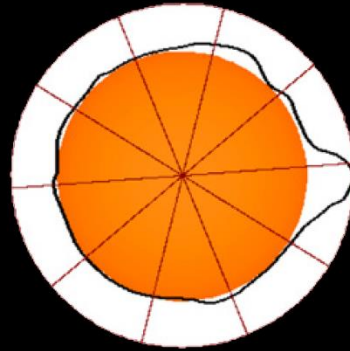
# THE RAILS INSIDE THE SUN

(HATHAWAY 2011; IVANOV & MILETSKY 2014).

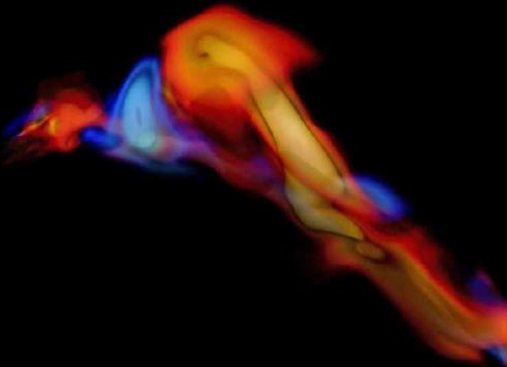
# ACTIVE REGIONS AND THE TOROIDAL FIELD



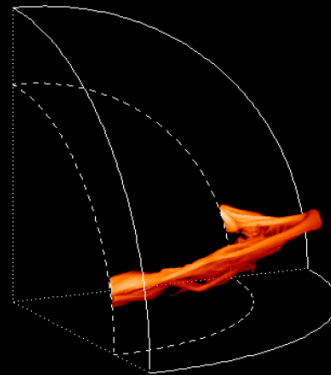
Nelson et al.  
(2014)



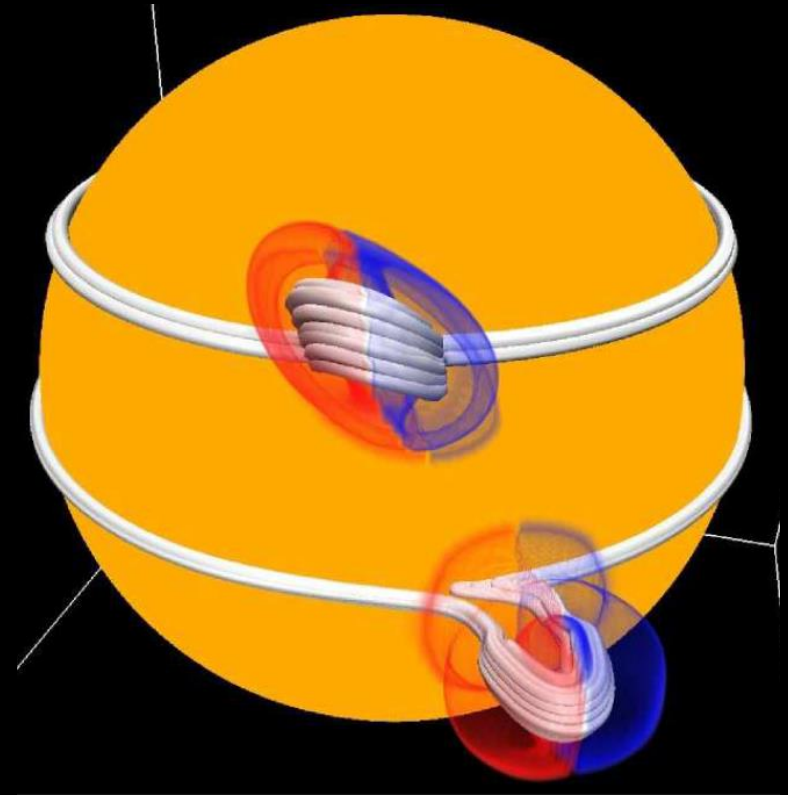
Weber, Fan, & Miesch  
(2011)



Jouve, Brun, & Aulanier  
(2013)

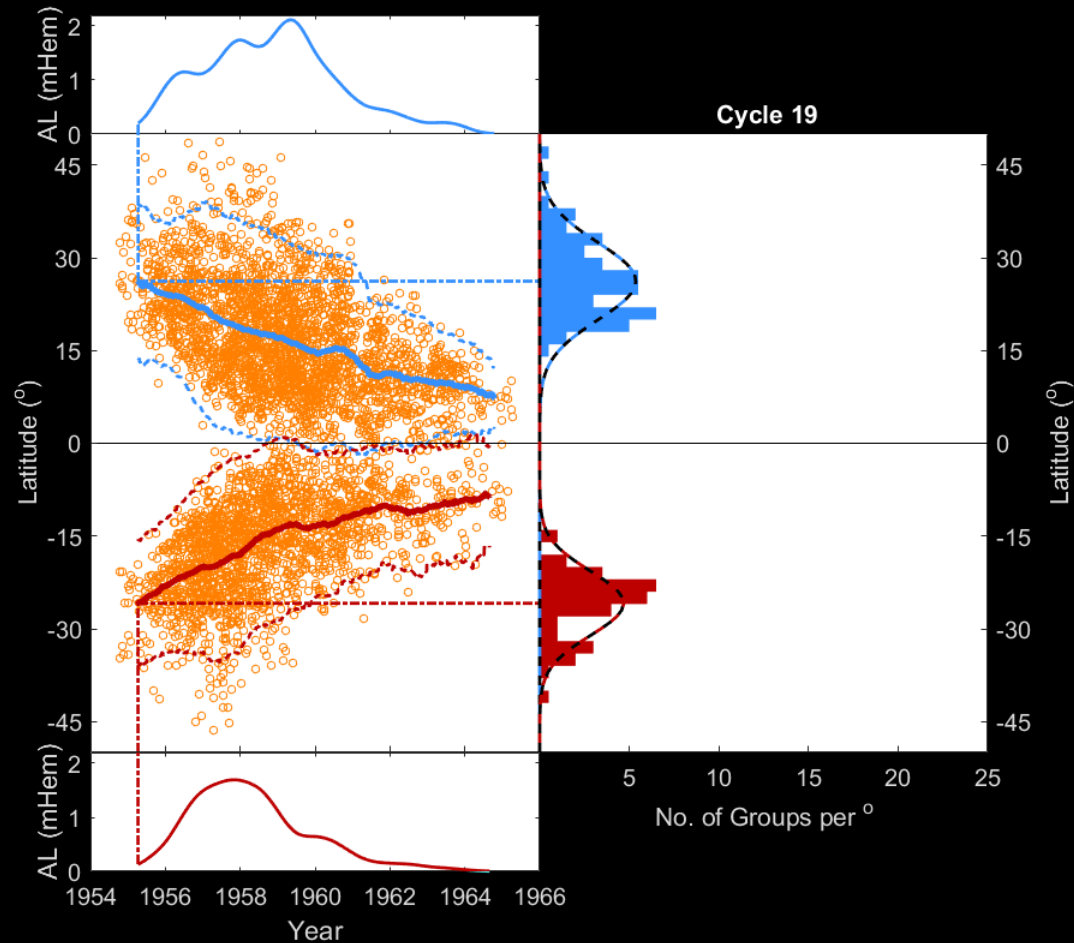


Fan  
(2008)



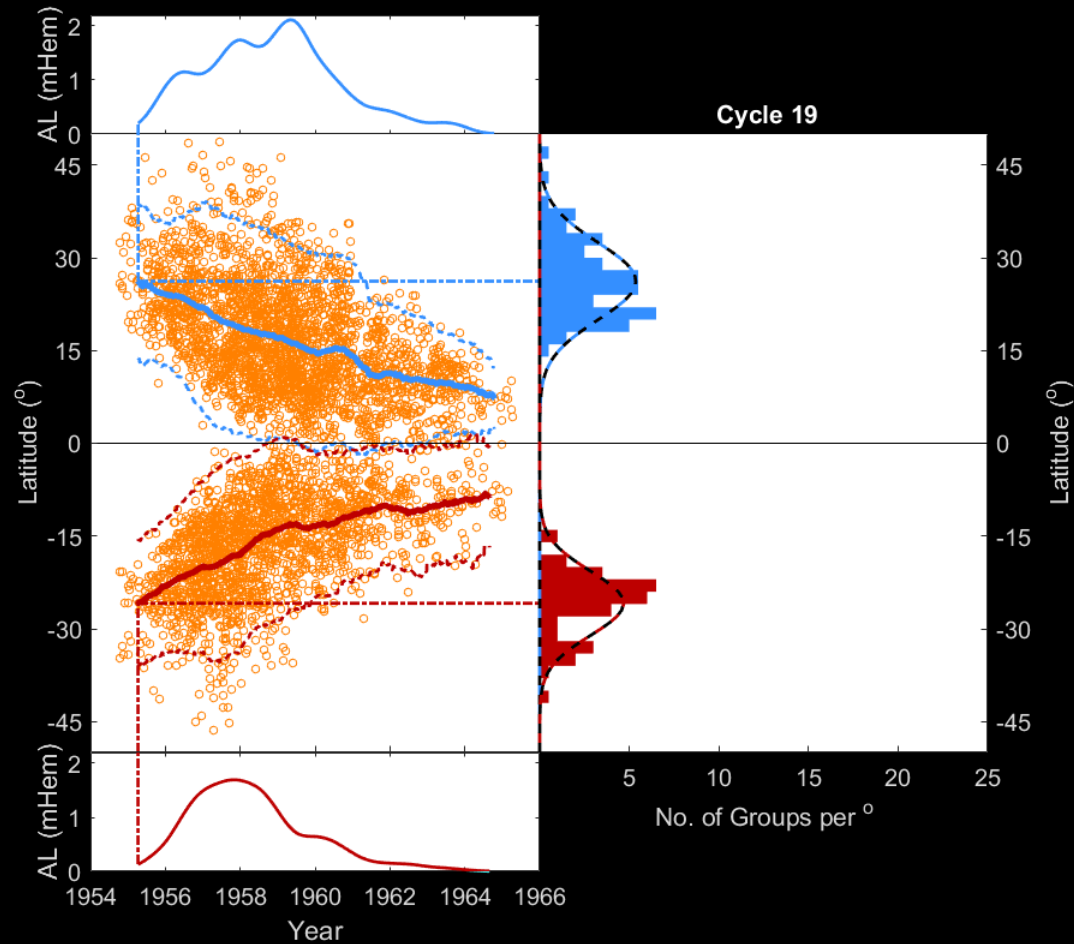
Yeates & Muñoz-Jaramillo  
(2013)

# CHARACTERIZATION OF THE BUTTERFLY WINGS



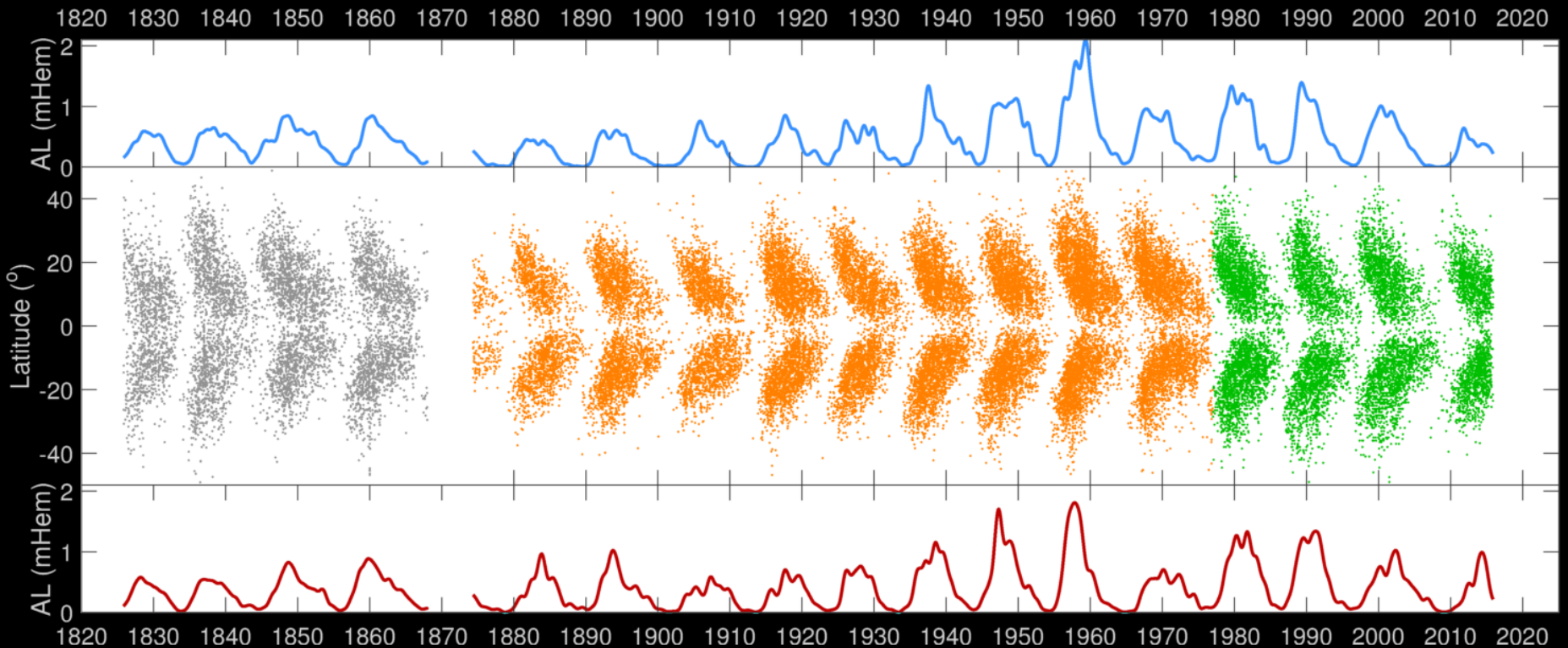
A Gaussian is fitted to the latitudinal distribution of all observed groups within a 24 month window

# CHARACTERIZATION OF THE BUTTERFLY WINGS



A Gaussian is fitted to the latitudinal distribution of all observed groups within a 24 month window

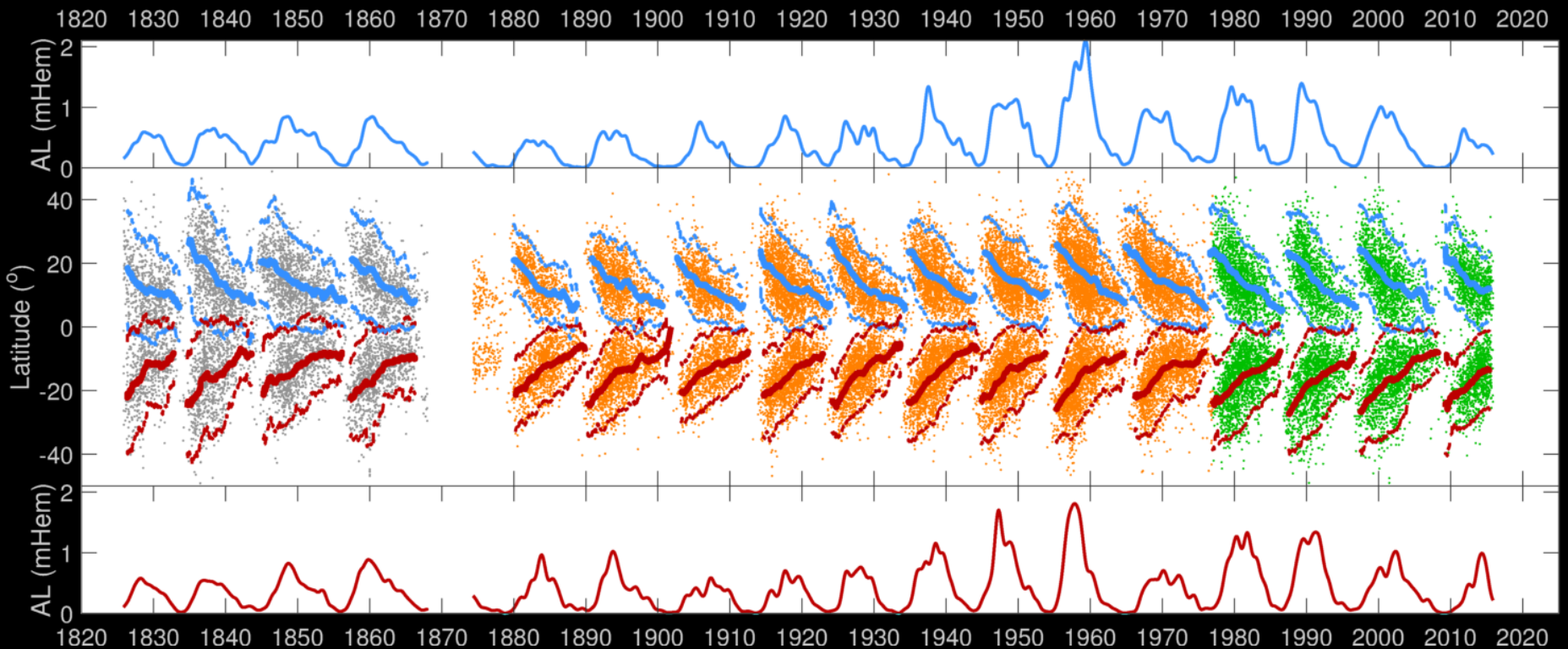
# ALL HEMISPHERIC CYCLES FOLLOW DIFFERENT PARTS OF A UNIVERSAL PATH



We use Schawbe's, RGO and KMAS data

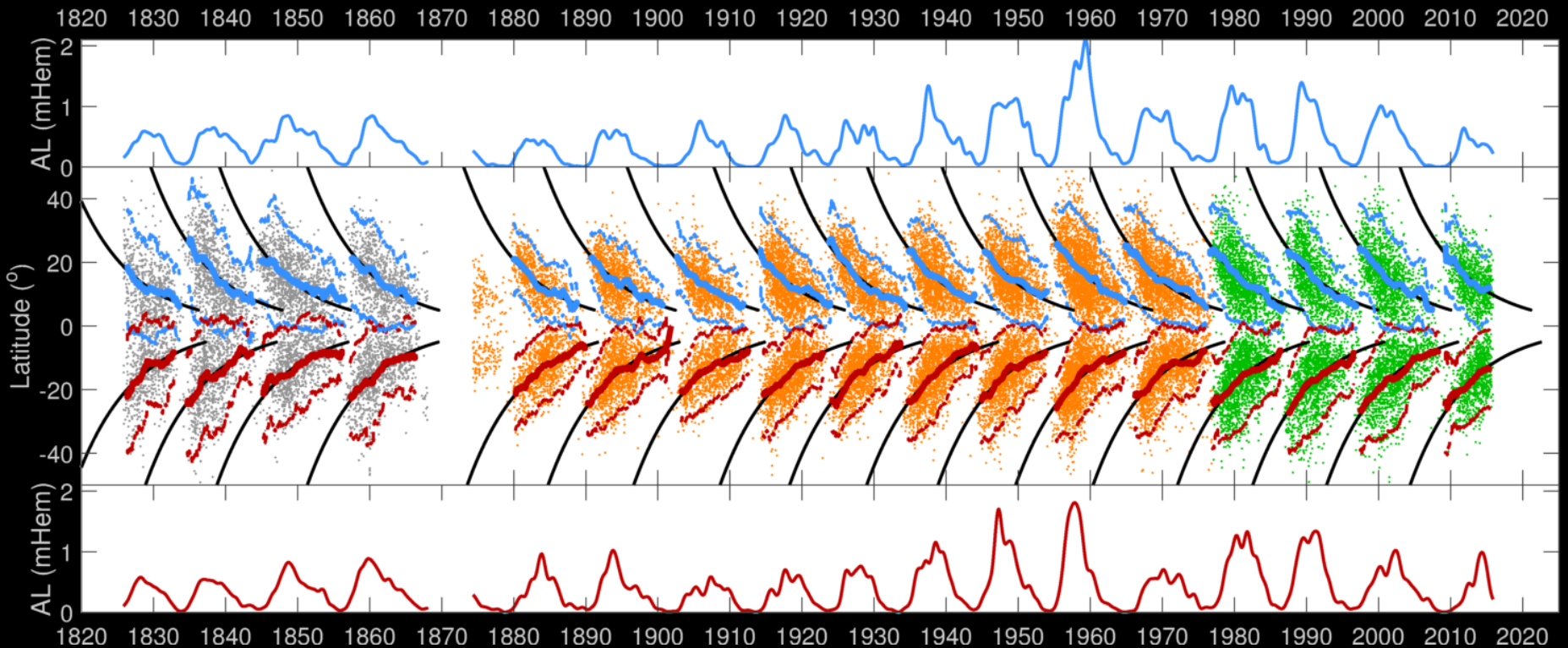


# ALL HEMISPHERIC CYCLES FOLLOW DIFFERENT PARTS OF A UNIVERSAL PATH



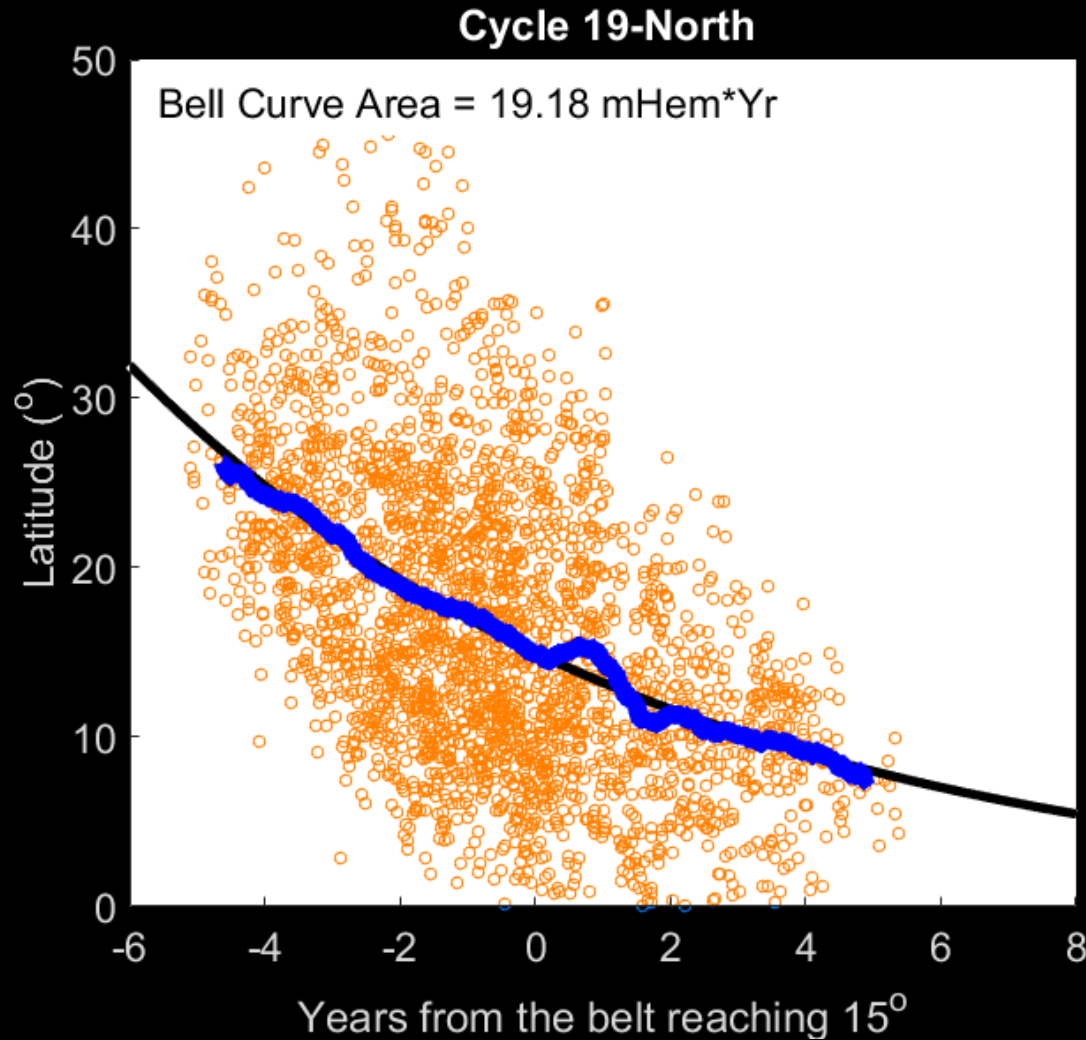
And calculate the path followed by the wing centroids  
and the width of the wings

# ALL HEMISPHERIC CYCLES FOLLOW DIFFERENT PARTS OF A UNIVERSAL PATH

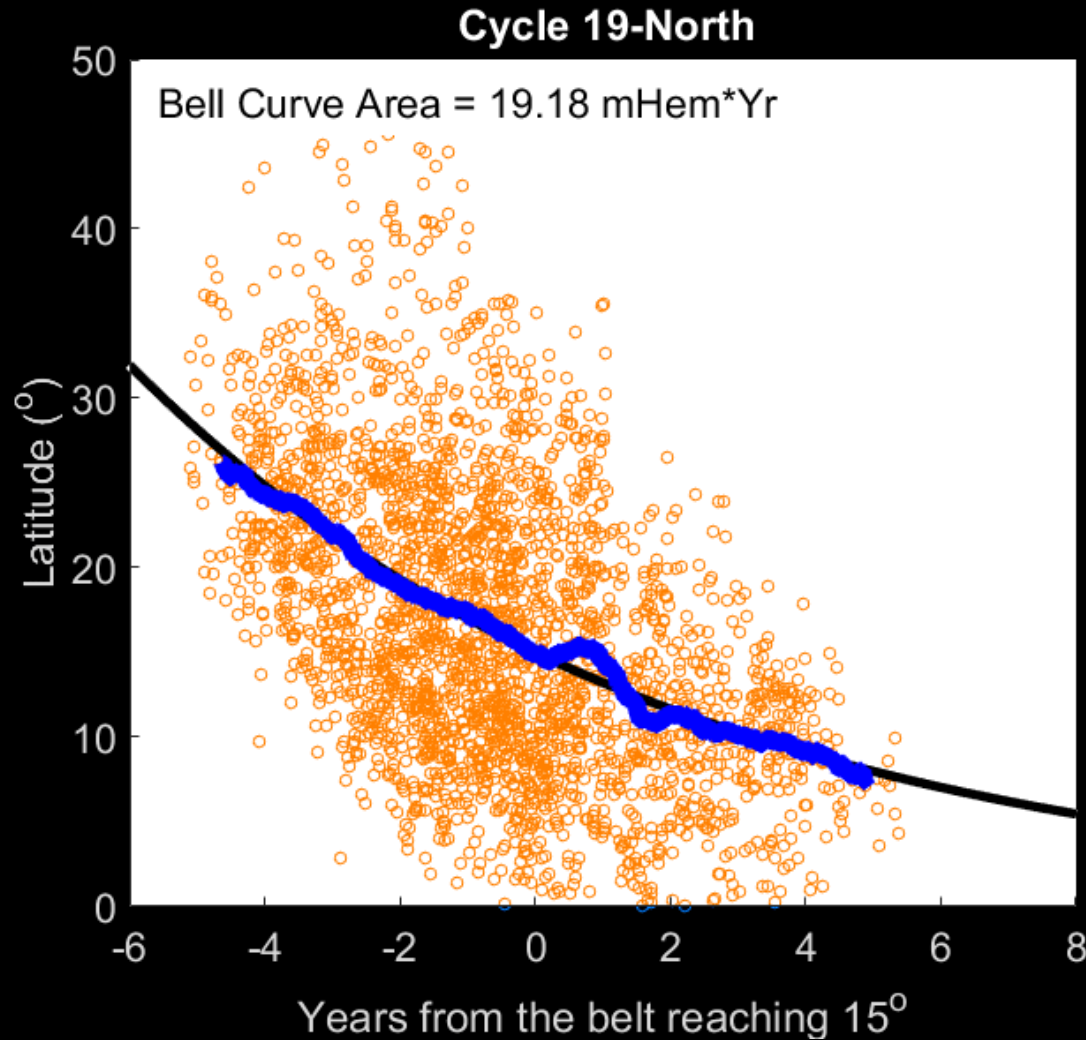


All paths can be fitted by the same function with only a  
difference in time-shift

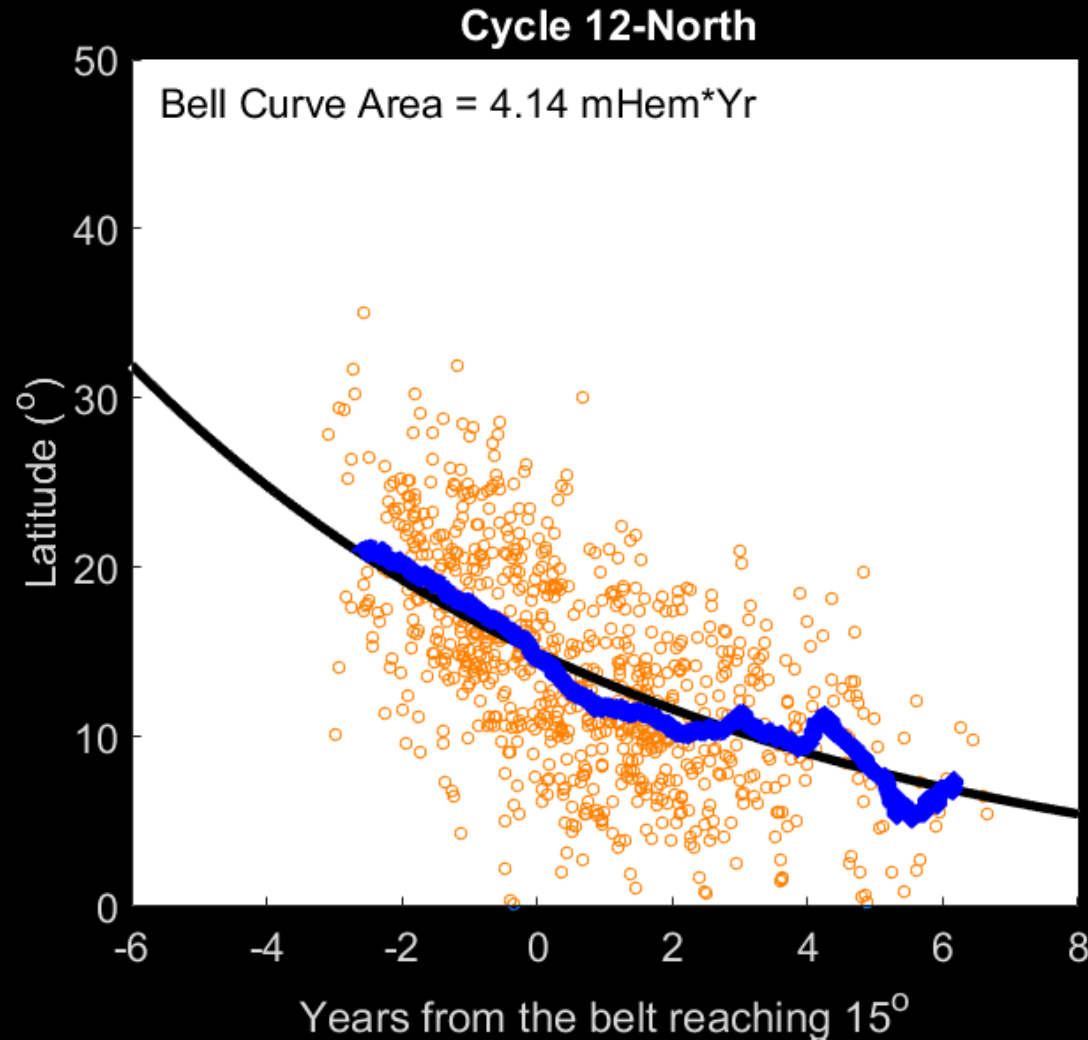
# ALL HEMISPHERIC CYCLES FOLLOW DIFFERENT PARTS OF A UNIVERSAL PATH



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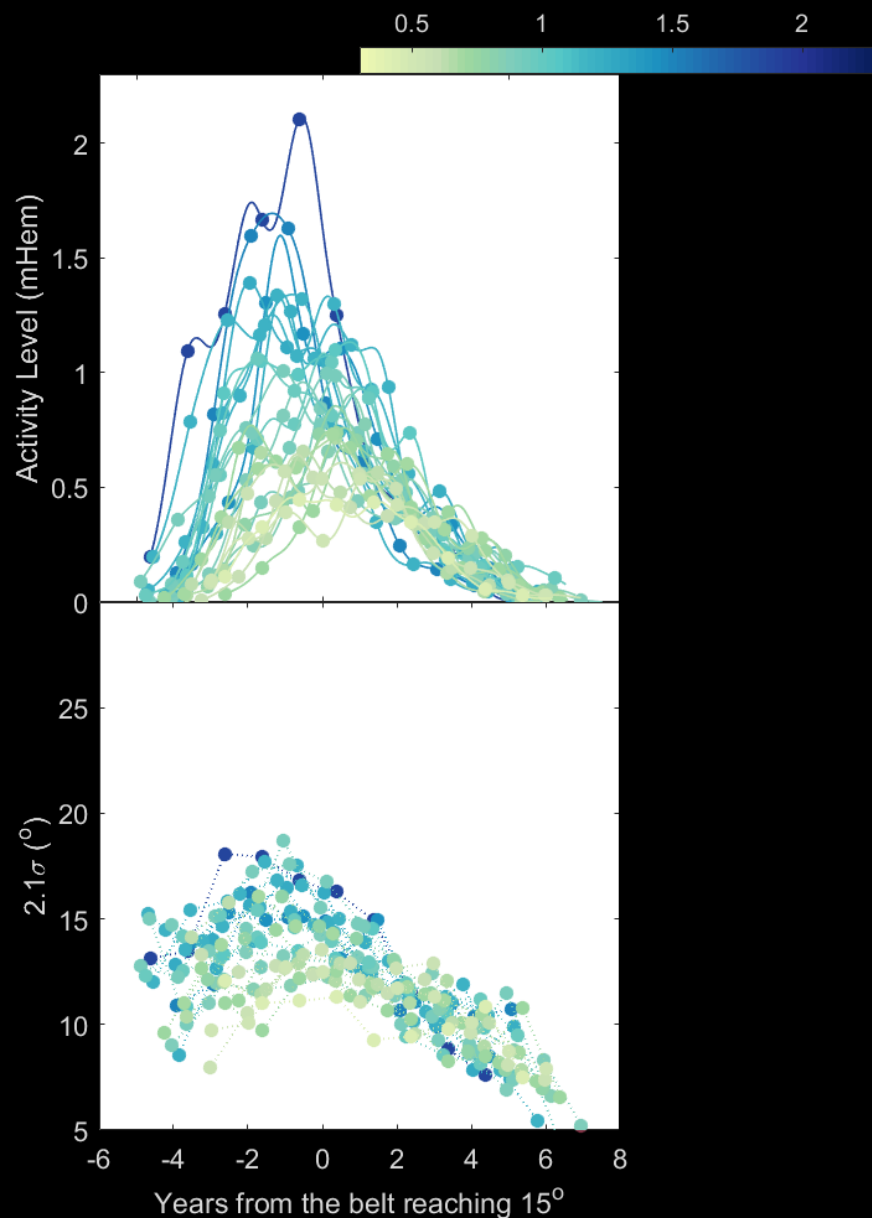
# ALL HEMISPHERIC CYCLES FOLLOW DIFFERENT PARTS OF A UNIVERSAL PATH



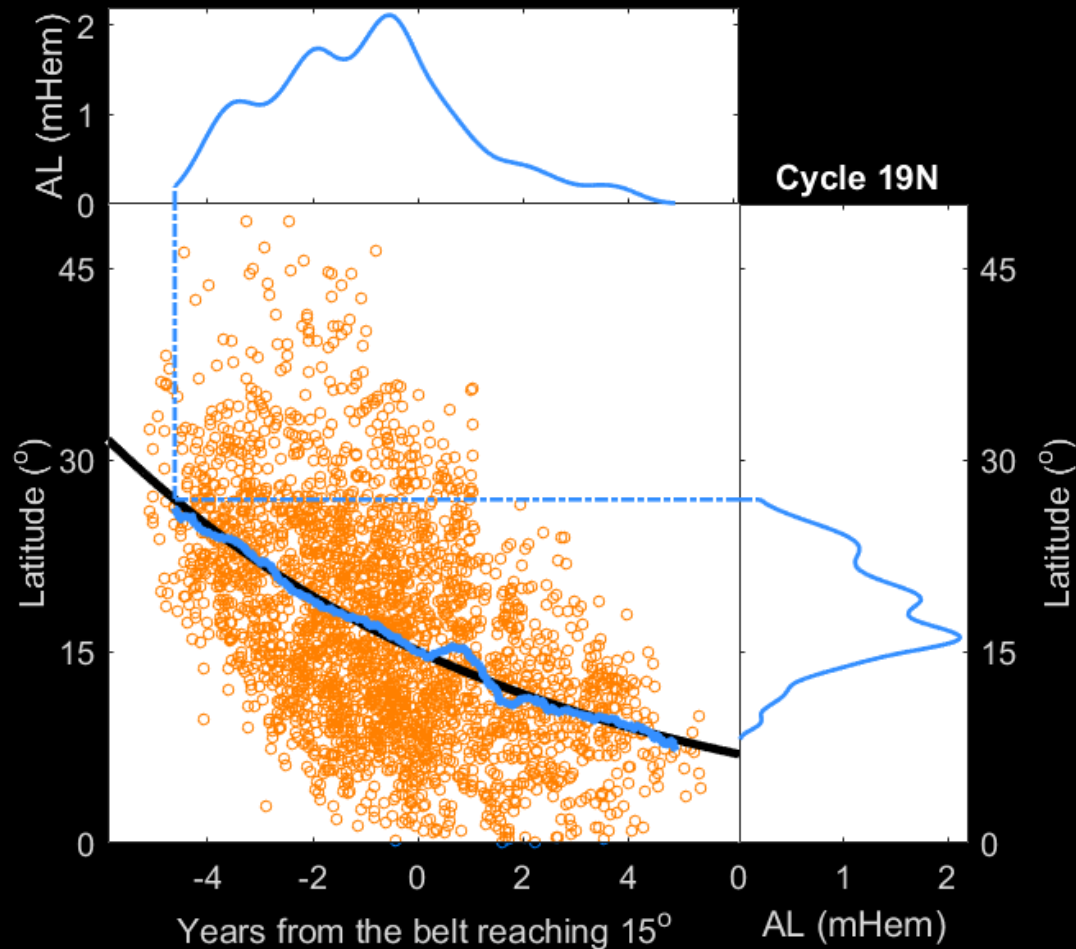


**ALL CYCLES DECAY IN THE SAME WAY  
(CAMERON & SCHÜSSLER 2016).**

# REFERENCED TO THE UNIVERSAL PATH, THE DECAYING PHASE OF ALL CYCLES ALIGNS



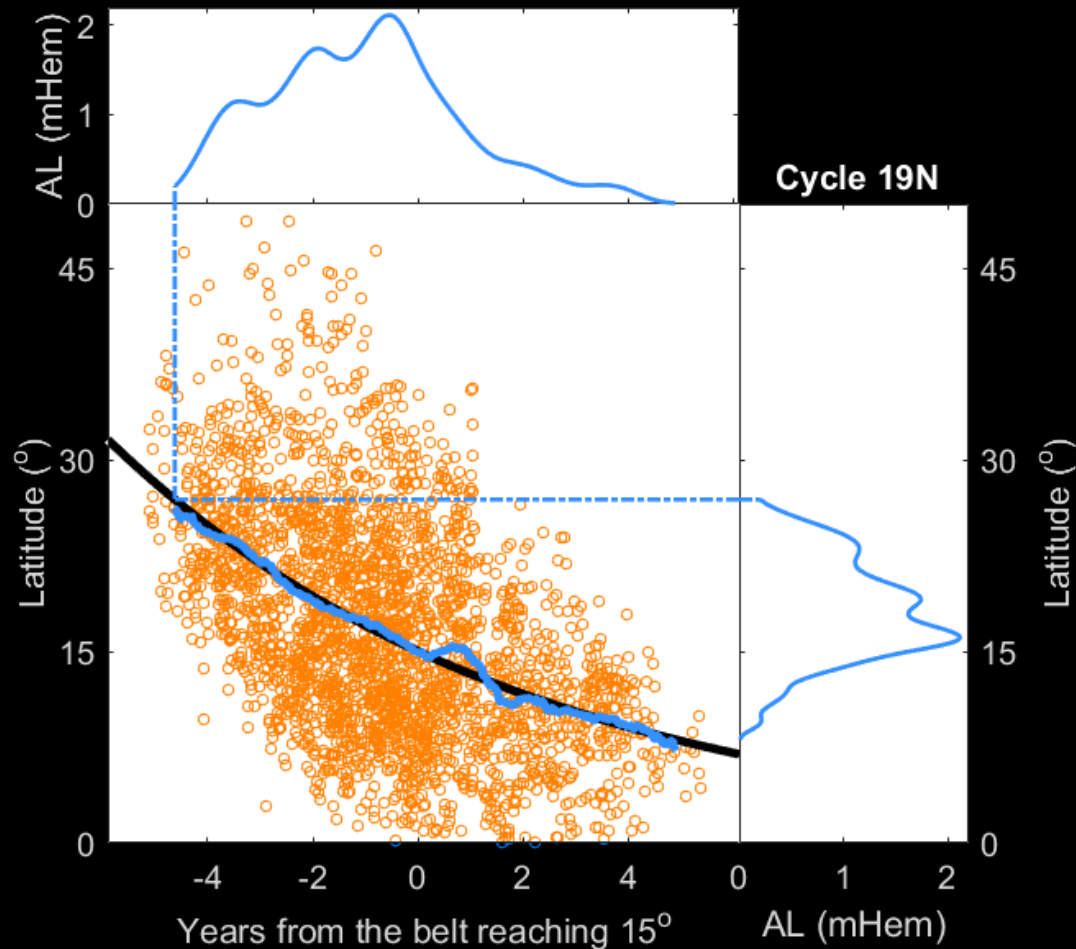
# REMAPMING THE CYCLE TO LATITUDE



Latitude of centroid can be used as the independent variable instead of time

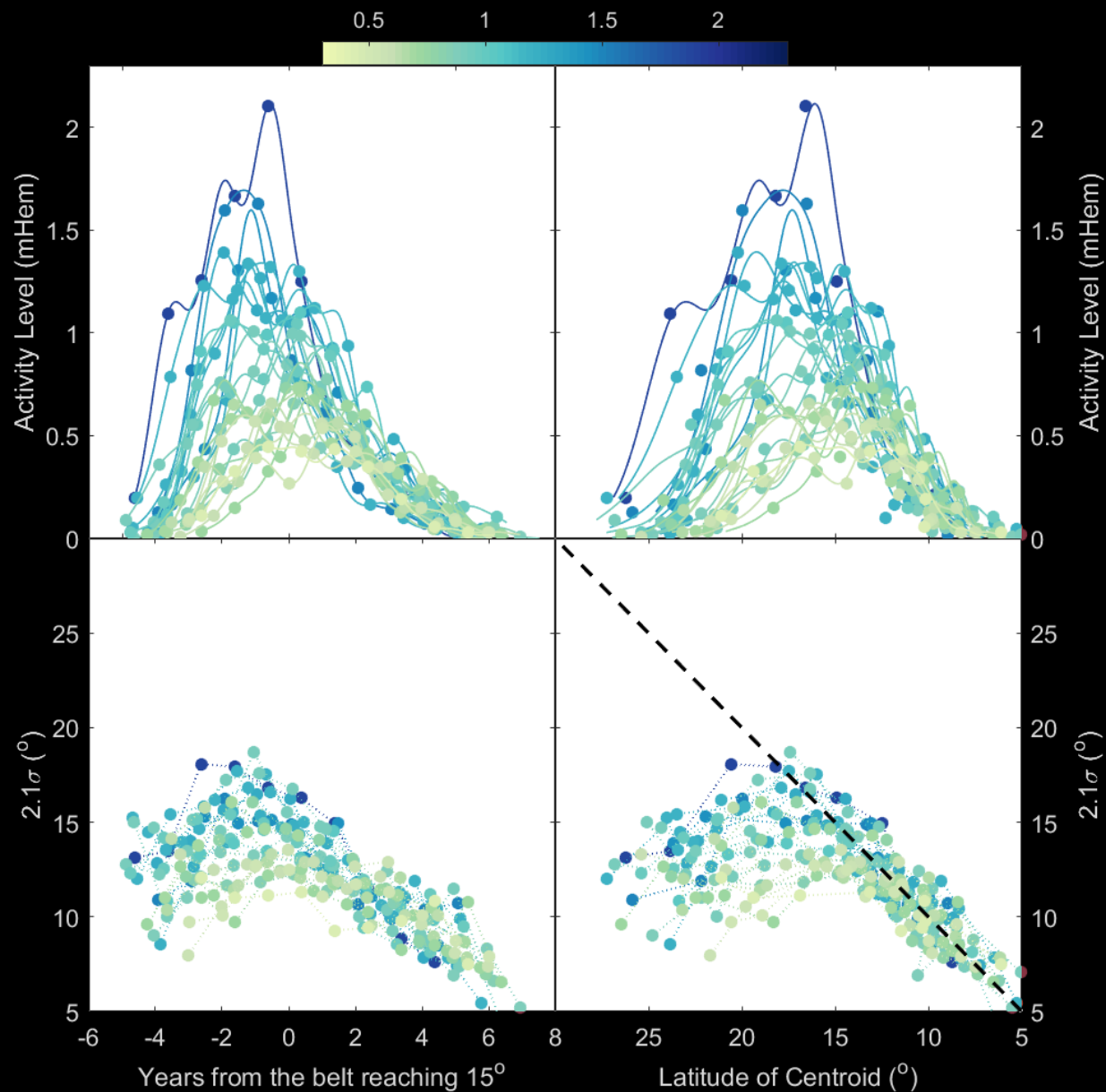


# REMAPMING THE CYCLE TO LATITUDE



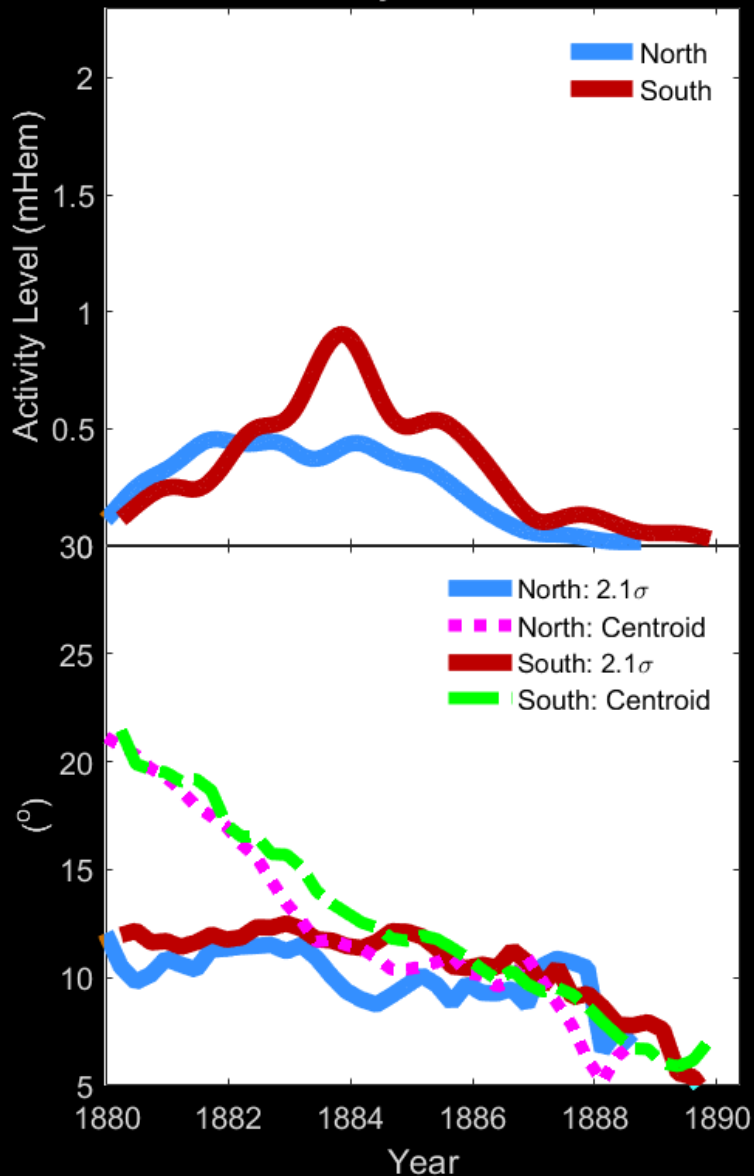
Latitude of centroid can be used as the independent variable instead of time

# REFERENCED TO THE UNIVERSAL PATH, THE DECAYING PHASE OF ALL CYCLES ALIGNS

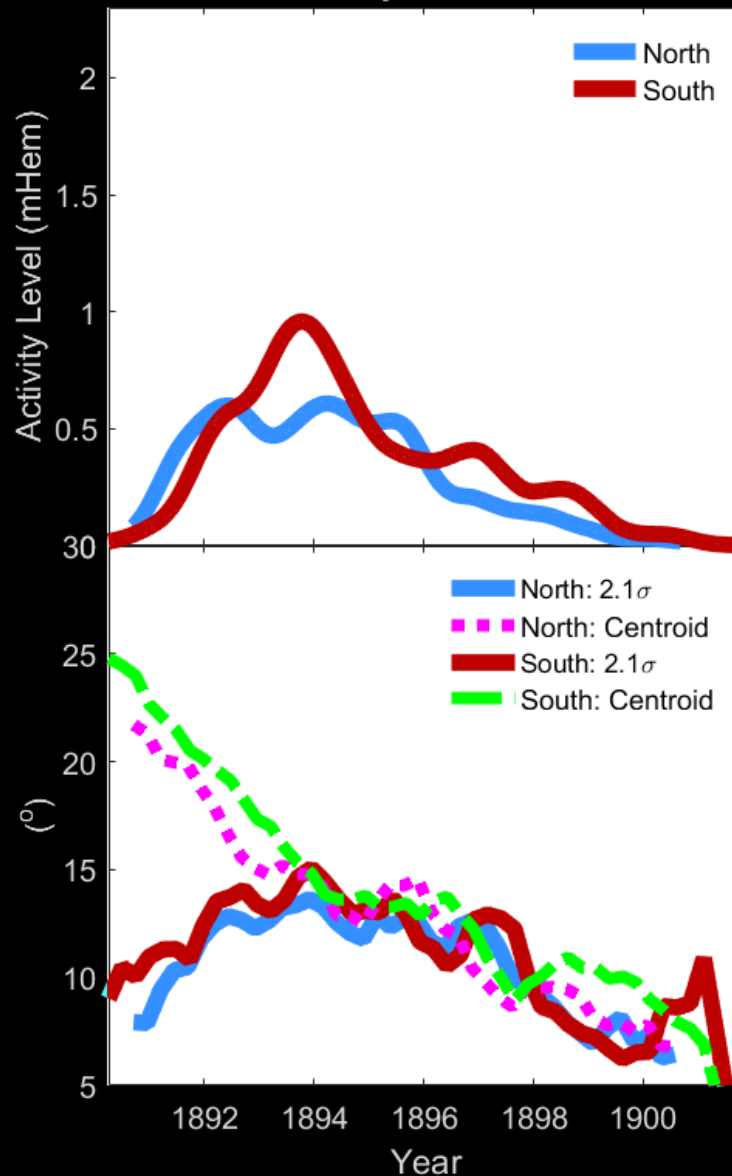


# ALL CYCLES DECAY WHEN THEIR TOROIDAL BELTS TOUCH ACROSS THE EQUATOR

## Cycle 12

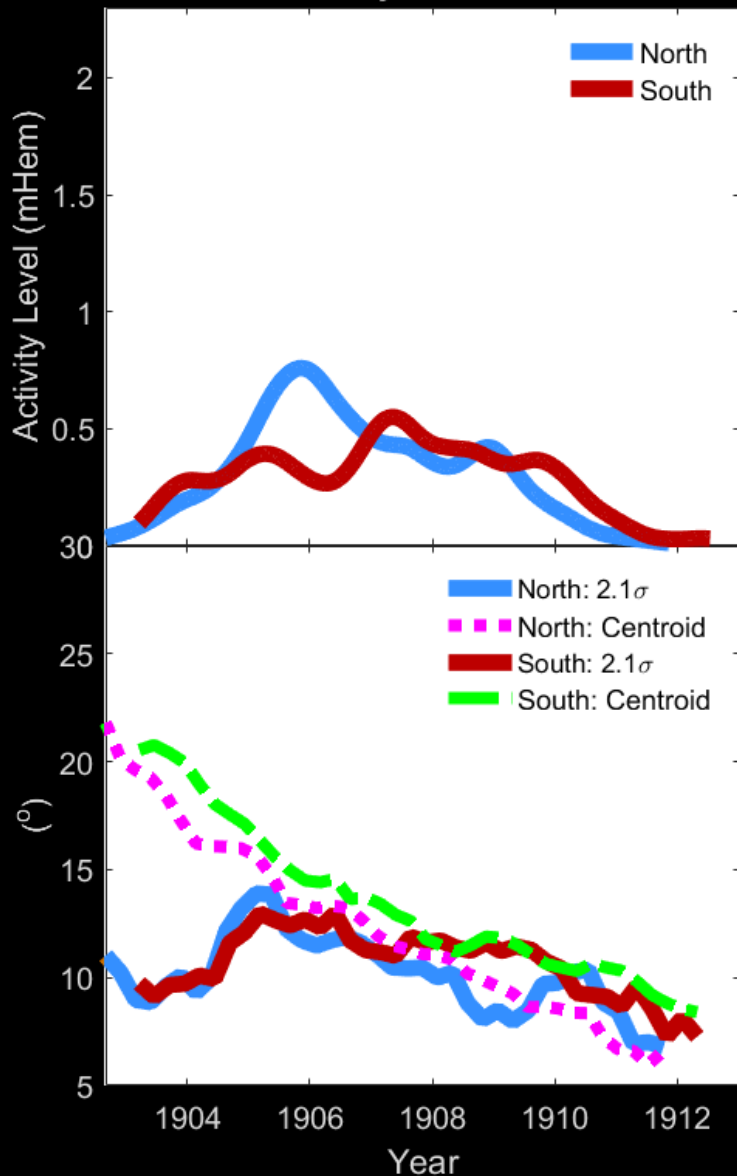


## Cycle 13

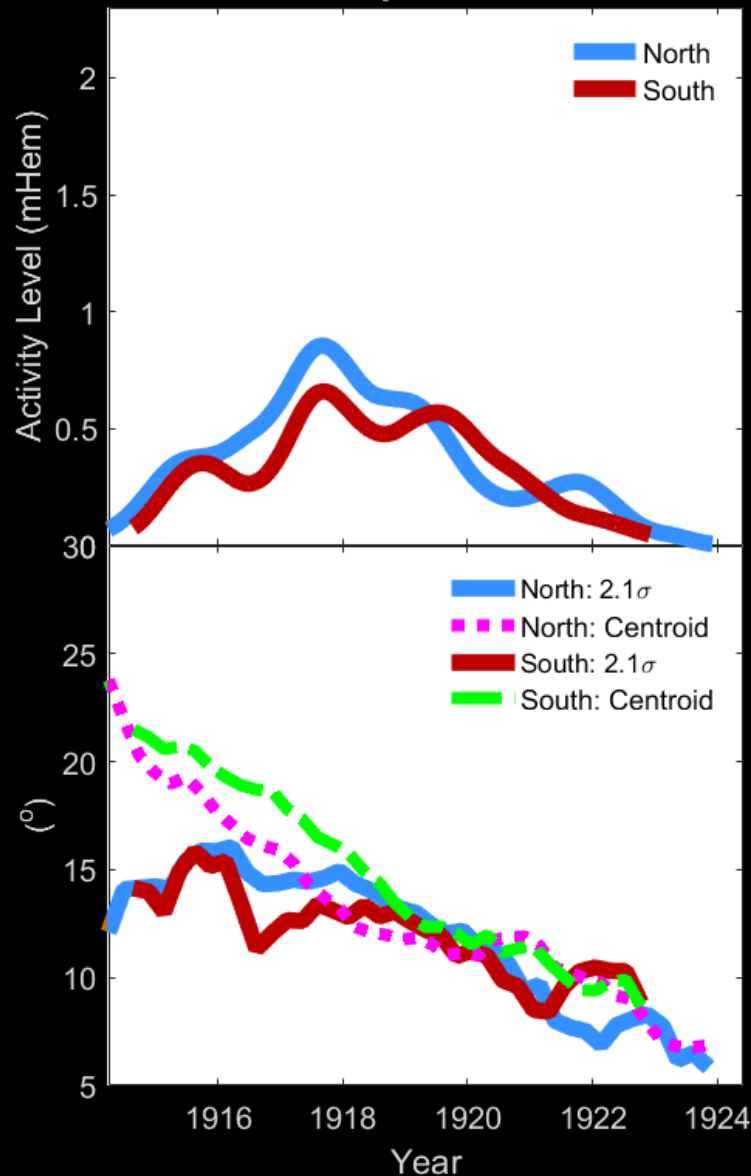


# ALL CYCLES DECAY WHEN THEIR TOROIDAL BELTS TOUCH ACROSS THE EQUATOR

## Cycle 14

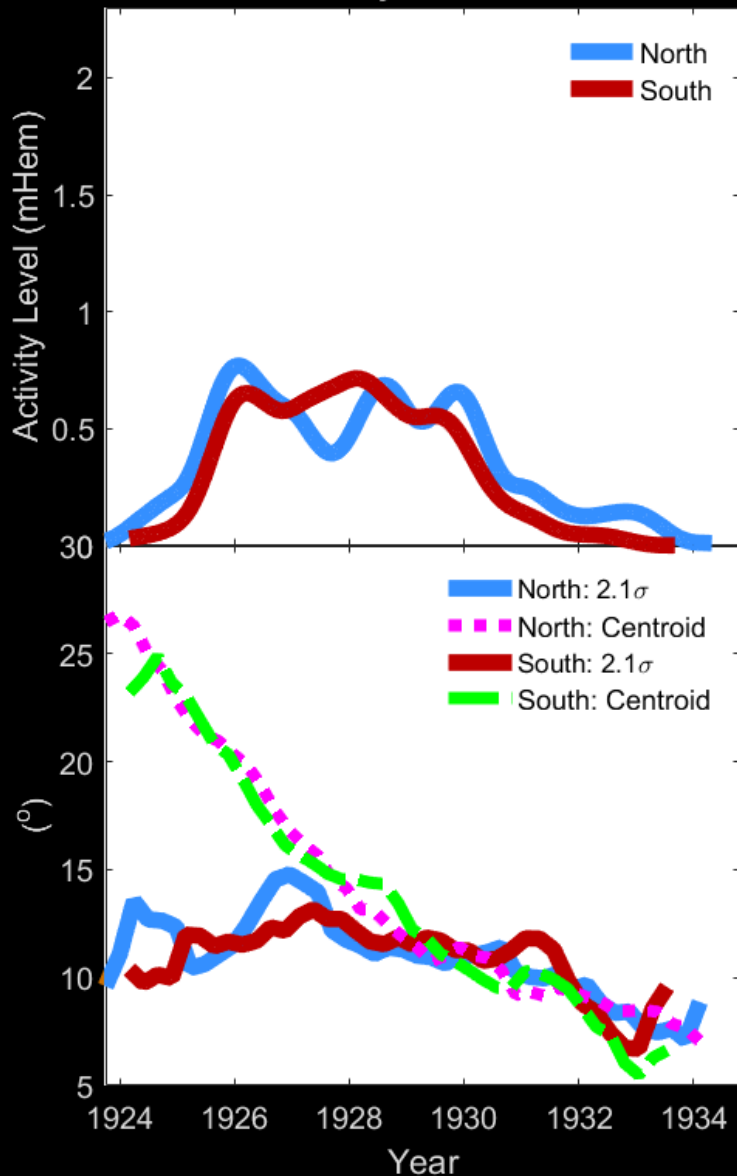


## Cycle 15

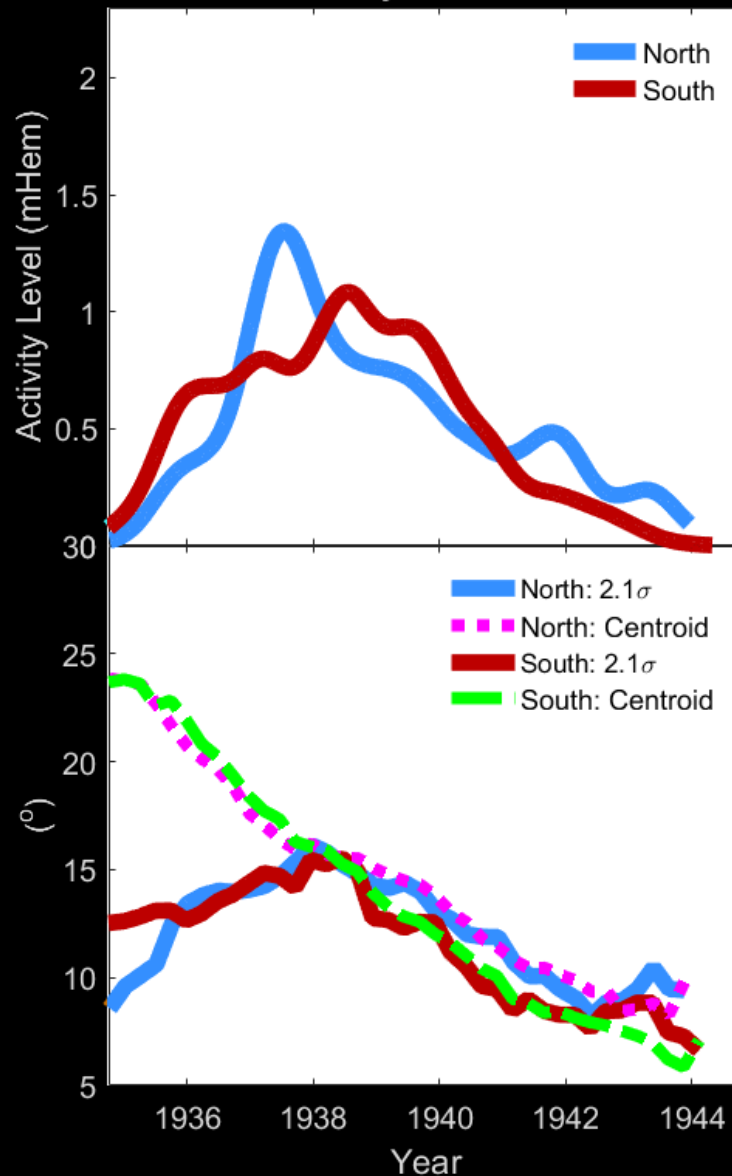


# ALL CYCLES DECAY WHEN THEIR TOROIDAL BELTS TOUCH ACROSS THE EQUATOR

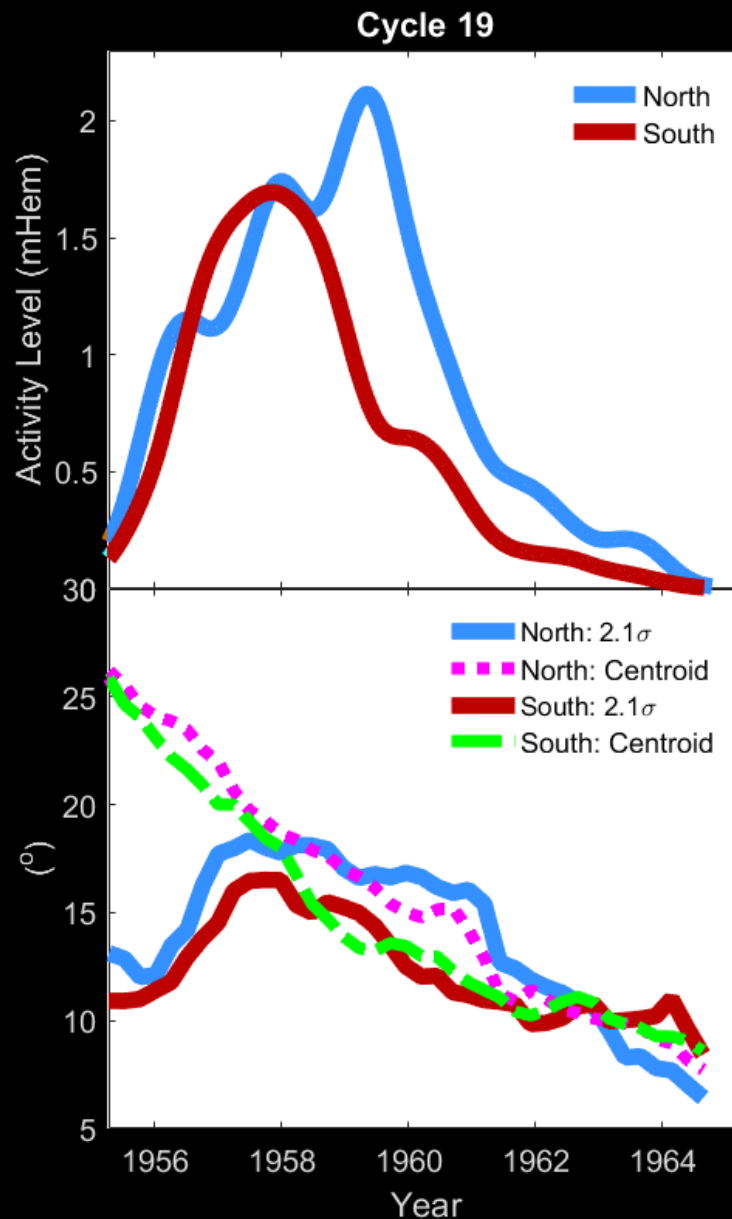
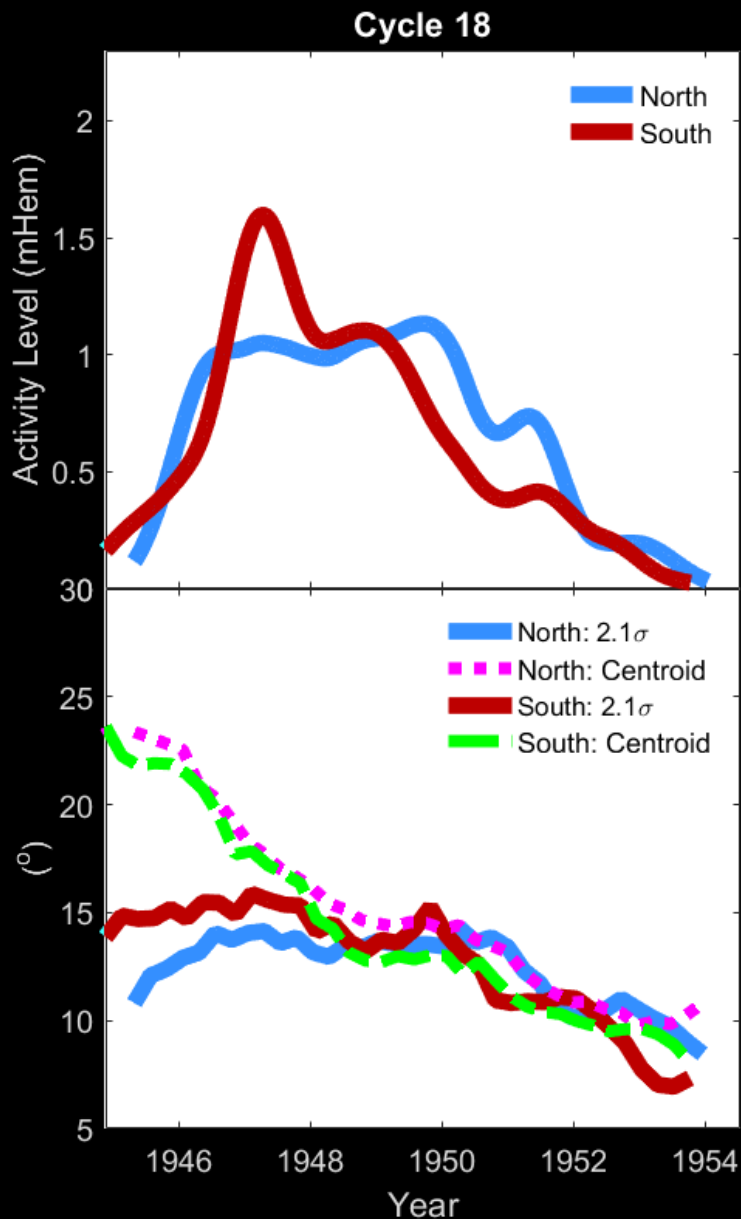
## Cycle 16



## Cycle 17

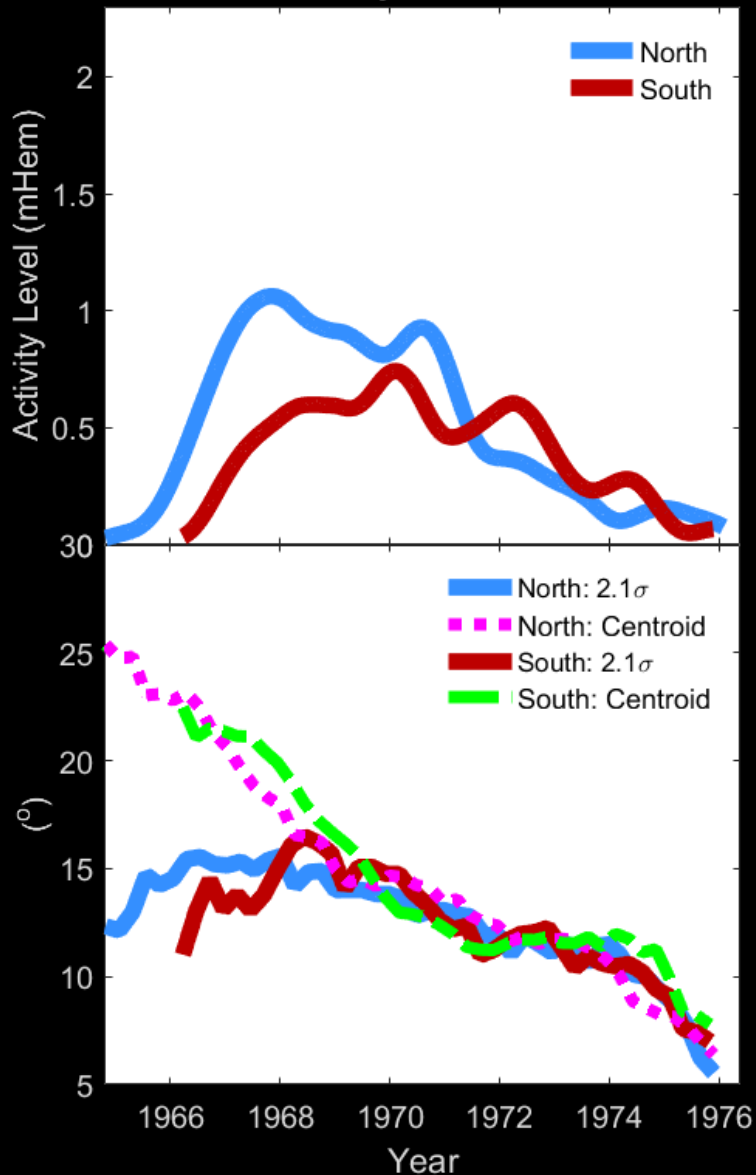


# ALL CYCLES DECAY WHEN THEIR TOROIDAL BELTS TOUCH ACROSS THE EQUATOR

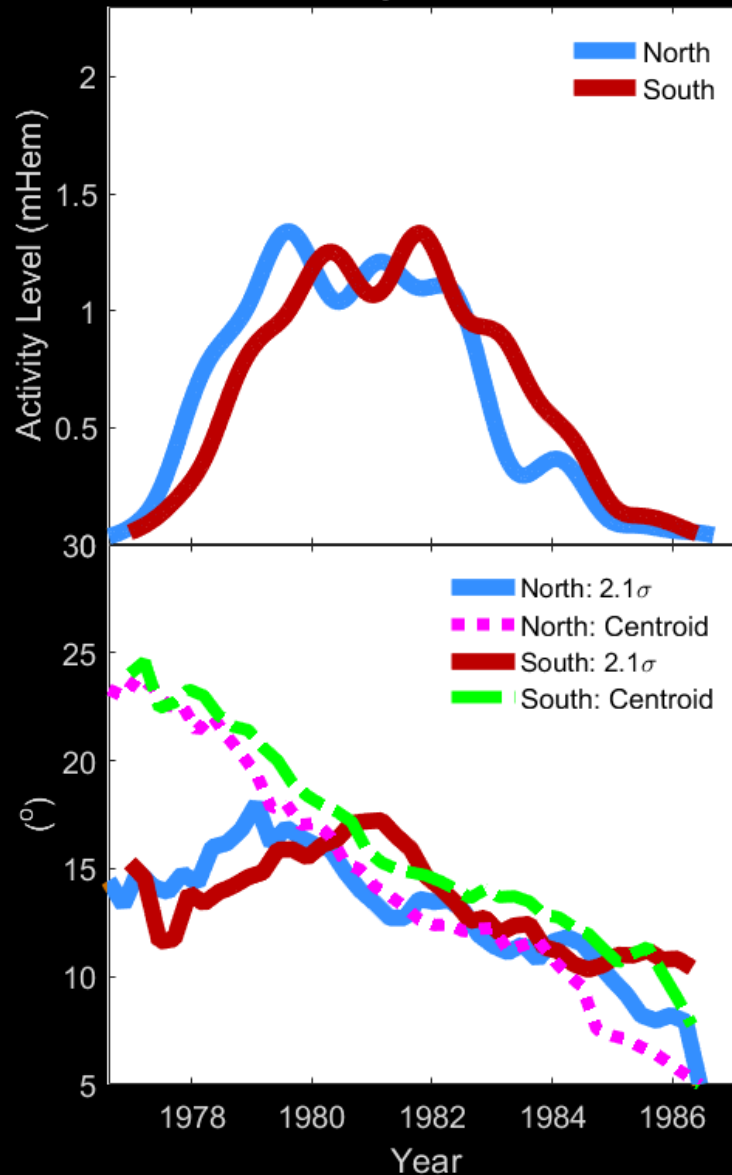


# ALL CYCLES DECAY WHEN THEIR TOROIDAL BELTS TOUCH ACROSS THE EQUATOR

## Cycle 20

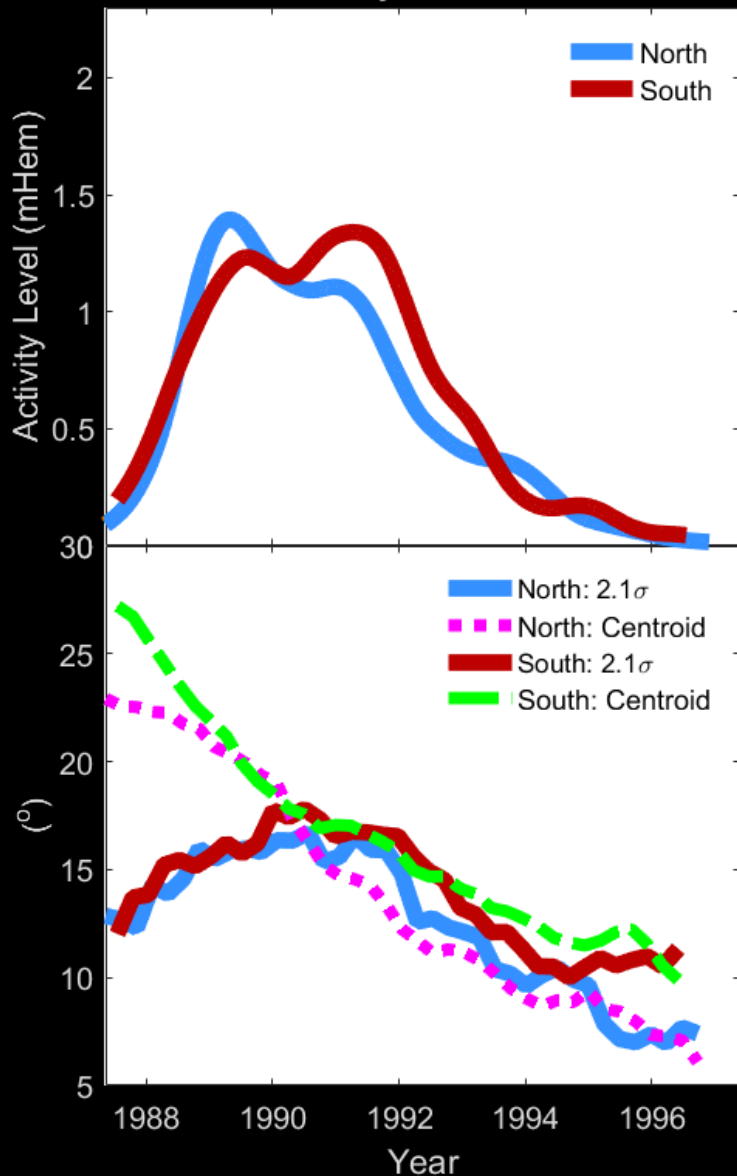


## Cycle 21

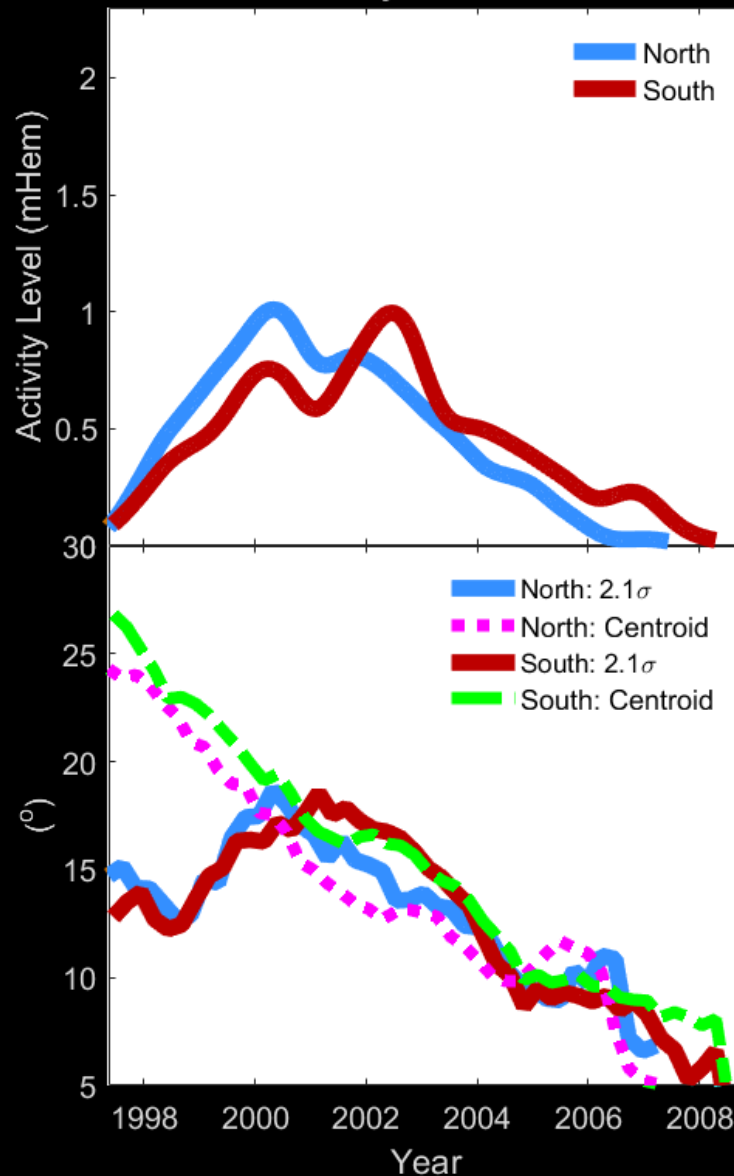


# ALL CYCLES DECAY WHEN THEIR TOROIDAL BELTS TOUCH ACROSS THE EQUATOR

## Cycle 22

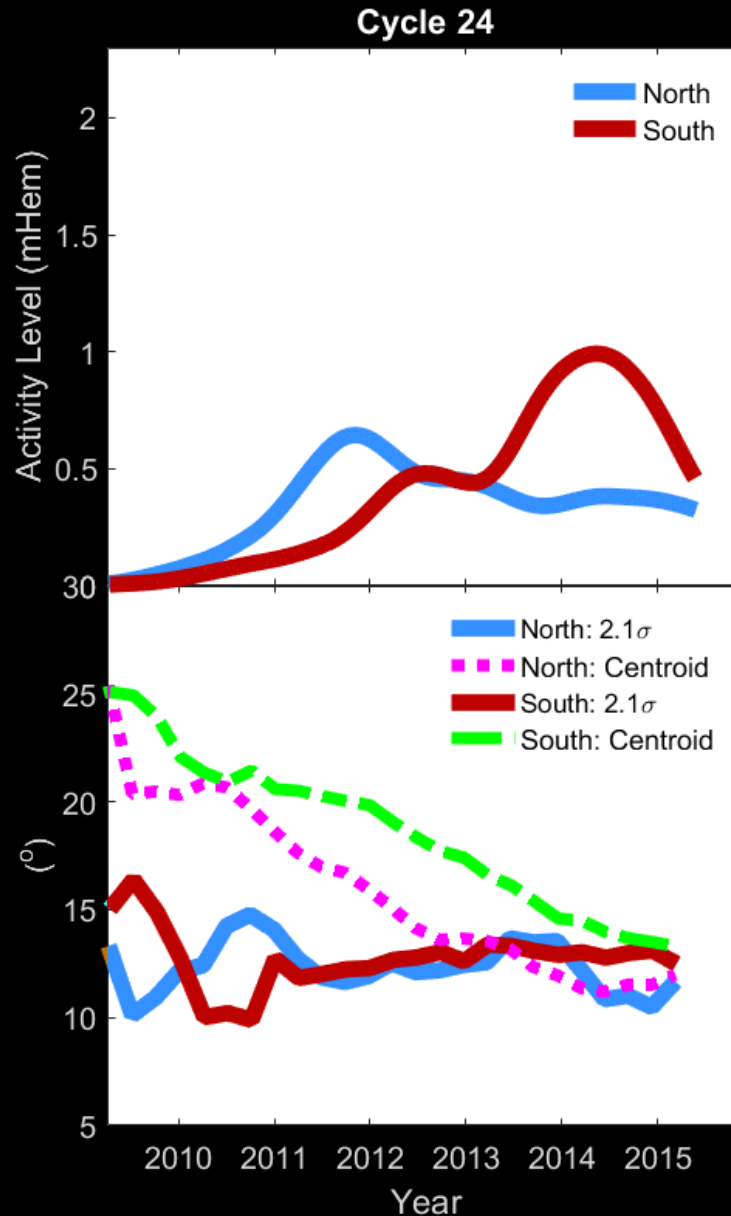


## Cycle 23



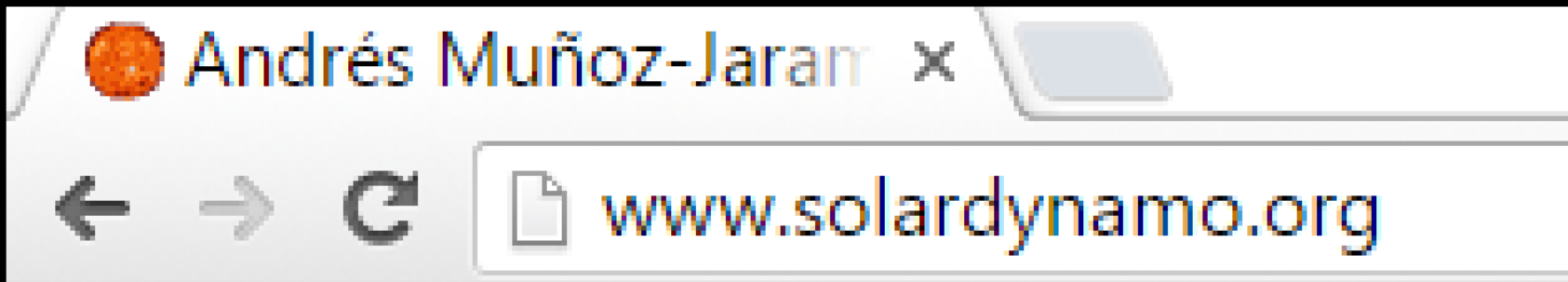


# ALL CYCLES DECAY WHEN THEIR TOROIDAL BELTS TOUCH ACROSS THE EQUATOR



# IMPLICATIONS FOR THE SOLAR DYNAMO

- The solar cycle is operating in a highly diffusive regime (in agreement with mixing-length estimates; Cameron & Schüssler 2016).
- We need to revise the role that the meridional flow as a critical ingredient of the solar dynamo.



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# ANDRÉS MUÑOZ-JARAMILLO

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## RESEARCH SEMINARS

### [The Rails Inside the Sun and the Butterflies that Ride Them.](#)

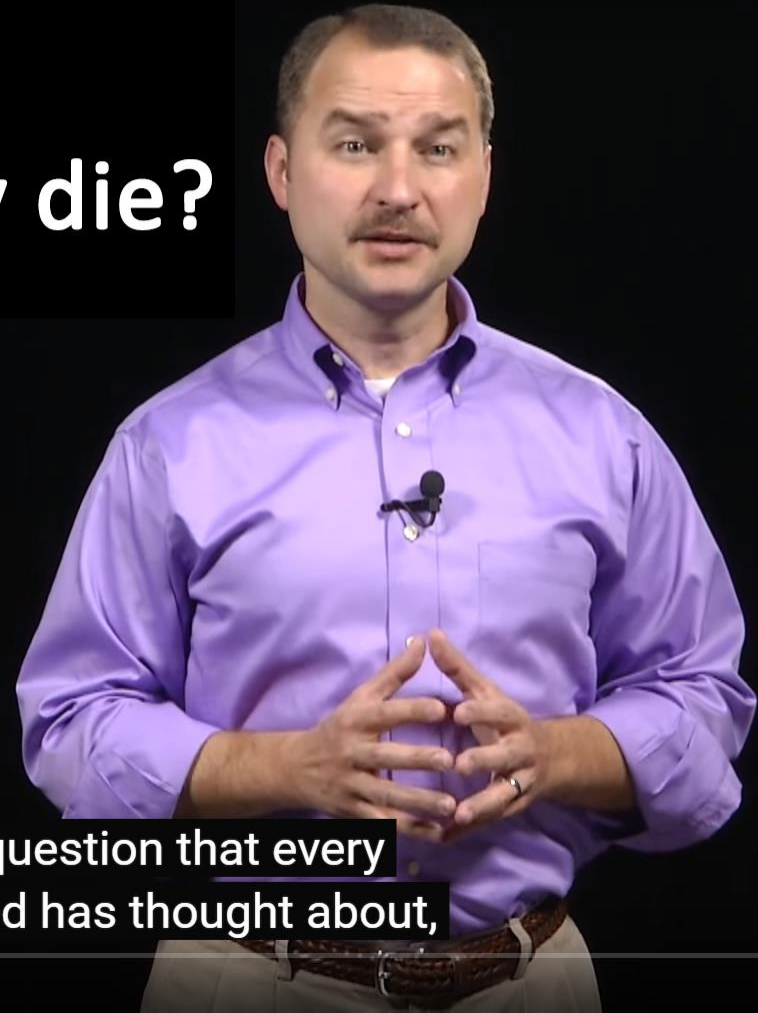
- Seminar at the High Altitude Observatory, Boulder, CO, USA, March 2015. Video Available: [Part 1](#).
- Seminar of the Solar & Astrophysics Laboratory, Lockheed Martin, Palo Alto, CA, USA, January 2015.
- Stanford Solar Group Meeting, Palo Alto, CA, USA, January 2016.



**WHERE DO DATA GO WHEN THEY  
DIE?**

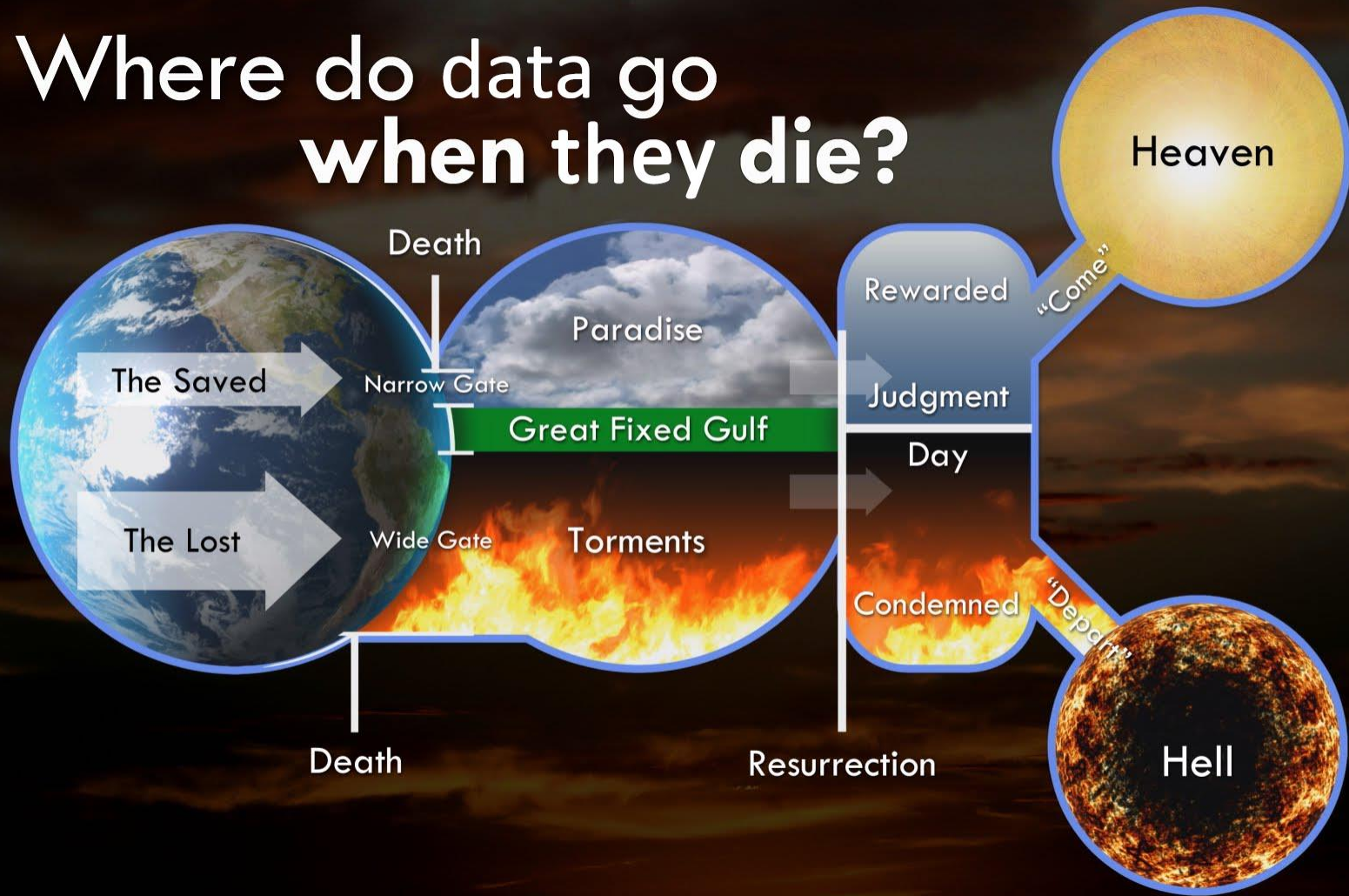


Where do data  
go when they die?



I suppose this is a question that every  
man who has ever lived has thought about,

# Where do data go when they die?



**HOW TO ATTAIN DATA SALVATION?**



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going to happen to me

# 404

## File not found

The Space Weather Prediction Center recently revamped its entire website. The content you're looking for has likely moved to a new location. Please, try searching for it instead. If you still can't find it, let us know. We may have overlooked it.

# REACHING ENLIGHTENMENT THANKS TO THE ApJ/AAS

- The answer is on the 6<sup>th</sup> line of the 6<sup>th</sup> section of the latest AAS LaTeX template (version 6).
- <https://github.com/AASJournals/Tutorials/tree/master/Repositories>
- There are three online repositories that the AAS recommends:
  - <https://zenodo.org/> (CERN)
  - <https://figshare.com/> (Private)
  - <https://dataverse.harvard.edu/> (Harvard)

# REACHING ENLIGHTENMENT THANKS TO THE ApJ/AAS

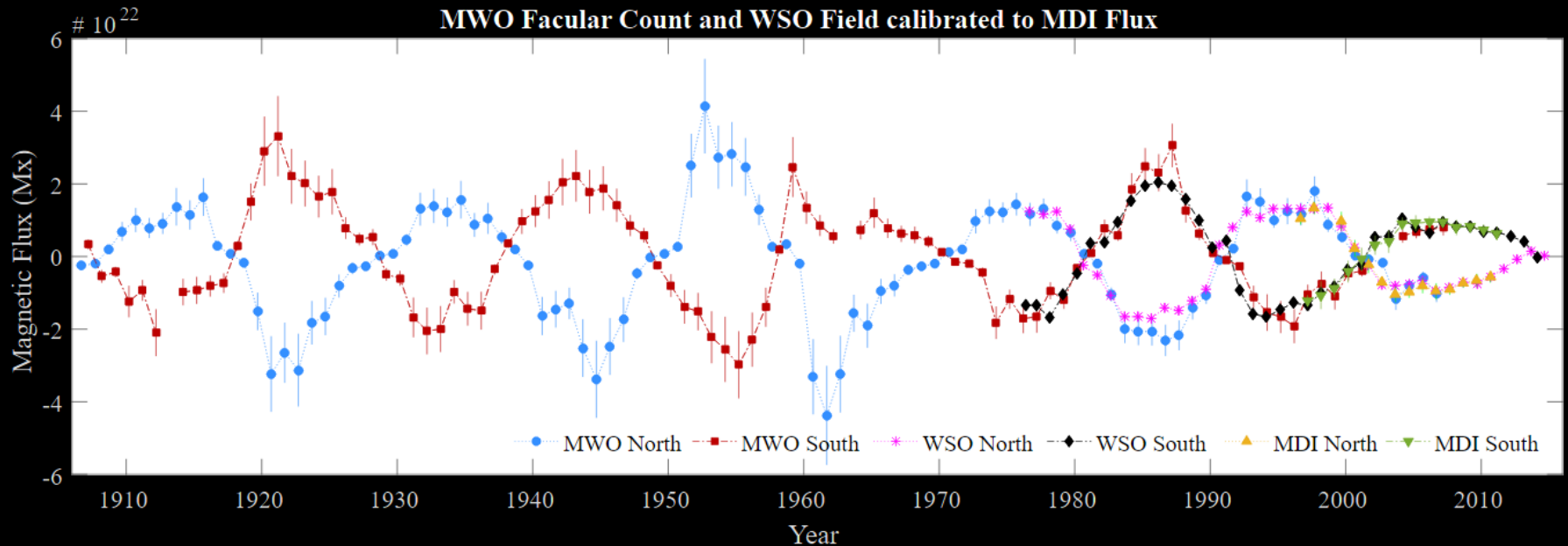
1. They assign each database a unique DOI identifier.
  2. They have contingency plans for migrating databases to another repository should their operation ends.
- There are three online repositories that the AAS recommends:
    - <https://zenodo.org/> (CERN)
    - <https://figshare.com/> (Private)
    - <https://dataverse.harvard.edu/> (Harvard)

# THE SOLAR DYNAMO DATAVERSE

# A century of Calibrated Polar Faculae

Muñoz-Jaramillo et al. (2012)

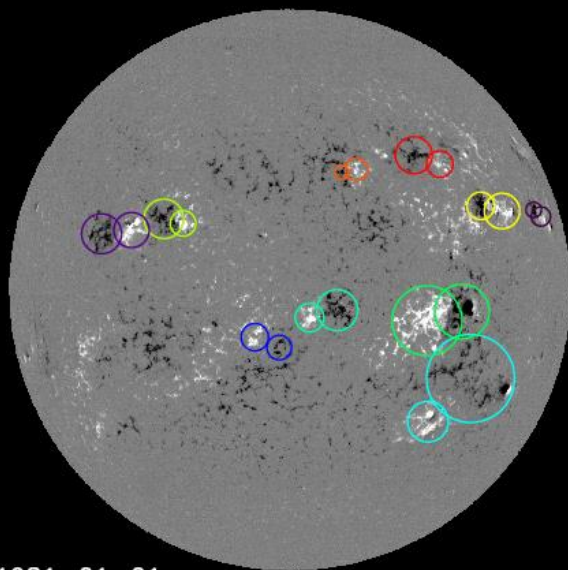
The most direct proxy we have for the evolution of the polar magnetic fields.



# 40 years of homogeneous bipolar active regions

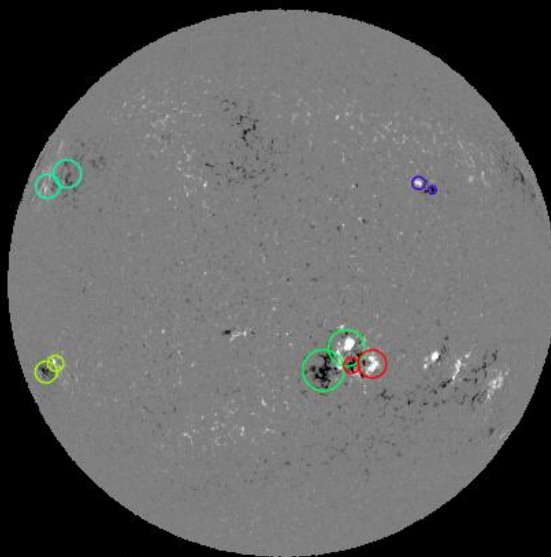
Muñoz-Jaramillo et al. WIP

## Cycle 21



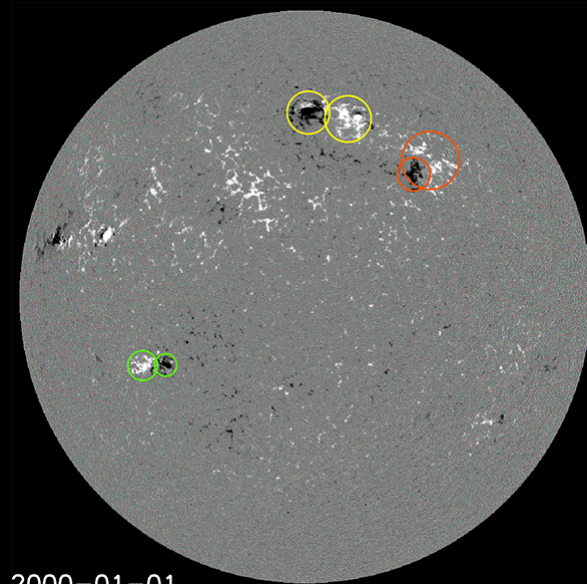
1981-01-01

## Cycle 22



1988-05-01

## Cycle 23



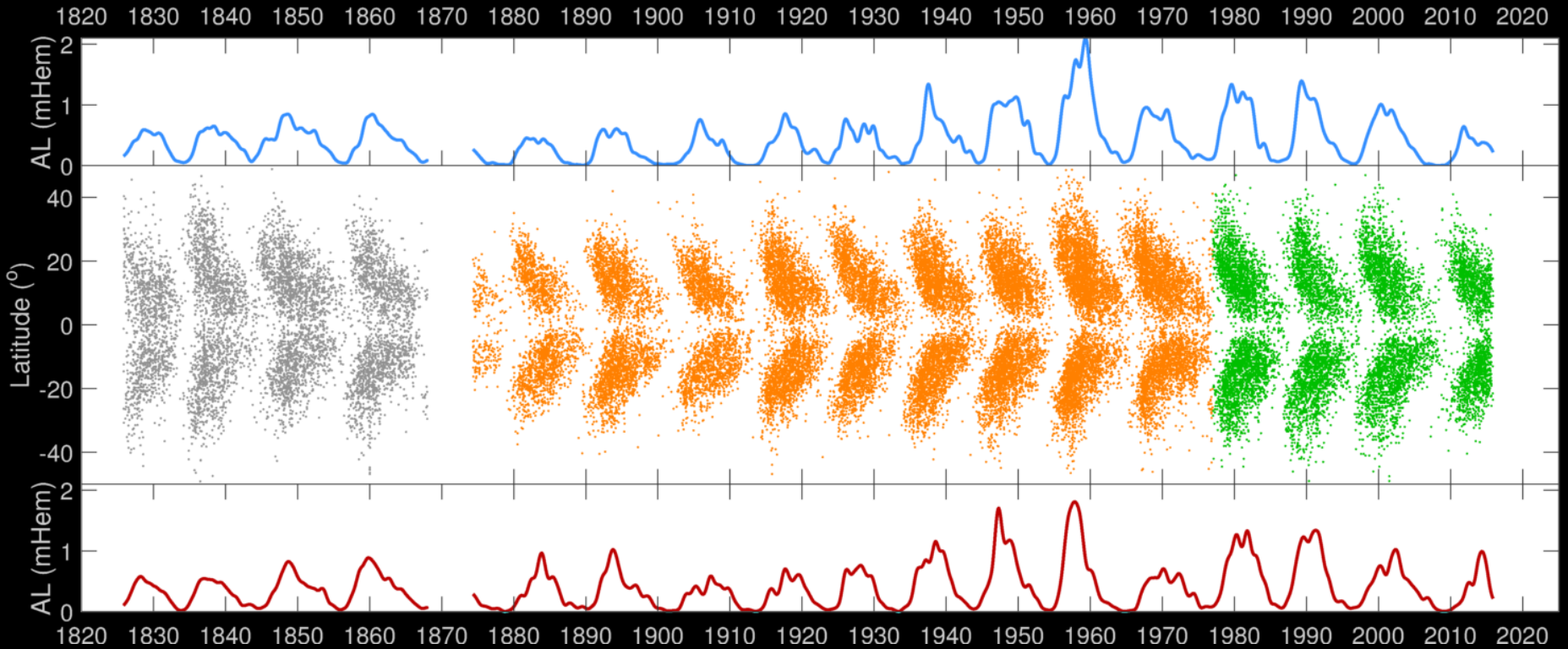
2000-01-01

- MDI and KPVT-512 channel done 6,885 unique objects detected and tracked. HMI is being processed.

**MORE THAN JUST MY DATA**

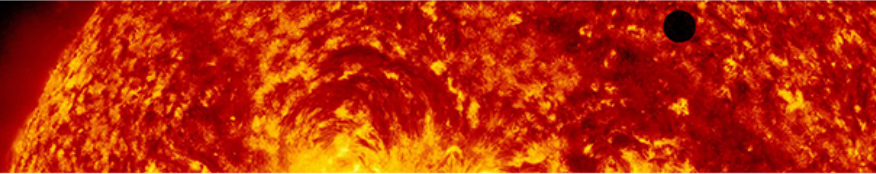


# A homogeneous composite of sunspot group data



Schawbe's, RGO and KMAS data

# SOLAR DYNAMO DATAVERSE



[Solar Dynamo Dataverse](#) (Georgia State University)


A collective of databases and data products tailored to understanding and predicting the solar cycle.

[Harvard Dataverse](#) > **Solar Dynamo Dataverse**



A collective of databases and data products tailored to understanding and predicting the solar cycle. Emphasis is placed on long-term variability and surface magnetic fields.

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[Neil Sheeley, Jr. \(1\)](#)

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 Sort

**Bipolar magnetic regions determined from NSO synoptic carrington maps** 


Mar 30, 2016 - Magnetic Catalogs Dataverse


 Anthony R. Yeates, 2016, "Bipolar magnetic regions determined from NSO synoptic carrington maps", <http://dx.doi.org/10.7910/DVN/Y5CXM8>, Harvard Dataverse, V1

Database of bipolar magnetic regions (BMRs) determined from NSO synoptic carrington maps of the Sun's photospheric line-of-sight magnetic flux between carrington rotations cr1911 and cr2146 inclusive. The attached plots summarize the dataset. In the data file itself, the columns a...


**Magnetic Catalogs Dataverse** (Georgia State University) 

Mar 30, 2016

 Catalogs of solar magnetic features (i.e. bipolar magnetic regions, ephemeral regions, magnetic elements, etc.).

**MWO polar faculae count calibrated to WSO polar fields and SOHO/MDI polar flux** 

Mar 22, 2016 - Solar Polar Fields Dataverse

 Andrés Muñoz-Jaramillo; Neil Sheeley, Jr., 2016, "MWO polar faculae count calibrated to WSO polar fields and SOHO/MDI polar flux", <http://dx.doi.org/10.7910/DVN/KF96B2>, Harvard Dataverse, V2

Faculae counted by hand on the best 5 images during the periods of maximum pole coverage (August 15-September 15 for the North pole and February 15-March 15 for the South pole) and averaged. Standard deviation has been turned into standard error by dividing it by sqrt(5). Years w...

**Solar Polar Fields Dataverse** (Georgia State University) 

Mar 22, 2016



<https://dataverse.harvard.edu>  
Search for “solar dynamo”

<https://www.solardynamo.org>  
go to “Data” section