Using NOAA and MWO Sunspot Data to Investigate the Impact of Joy's Law Tilt on Simulations of Solar Cycle 22 with the Advective Flux Transport Model

Blaire Ness, Stony Brook University

Mentors: Lisa Upton (HAO), Andres Munoz-Jaramillo (SwRI), Ricky Egeland (HAO)

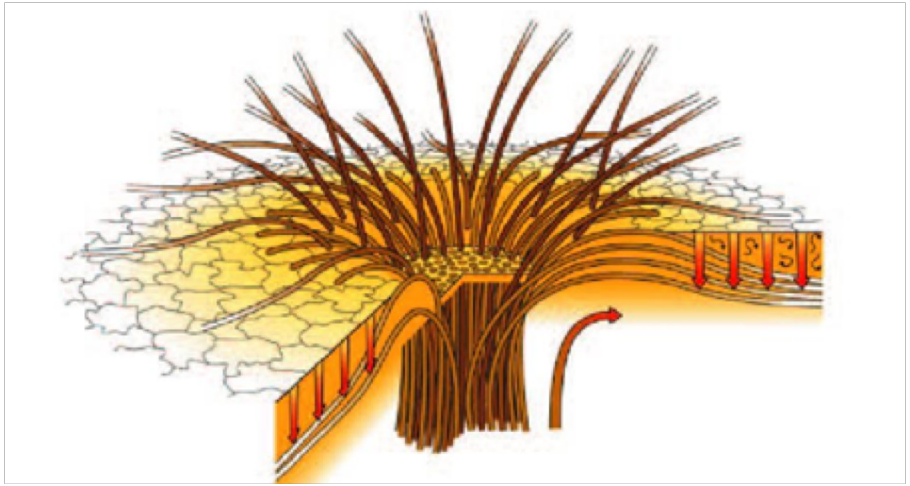
Stony Brook University

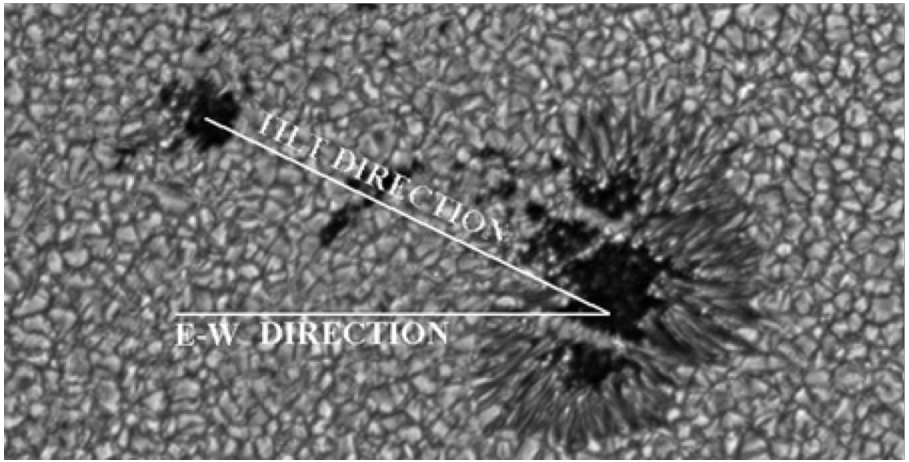
NCAR UCAR HAO

National Science Foundation
WHERE DISCOVERIES BEGIN

Introduction: The Solar Cycle

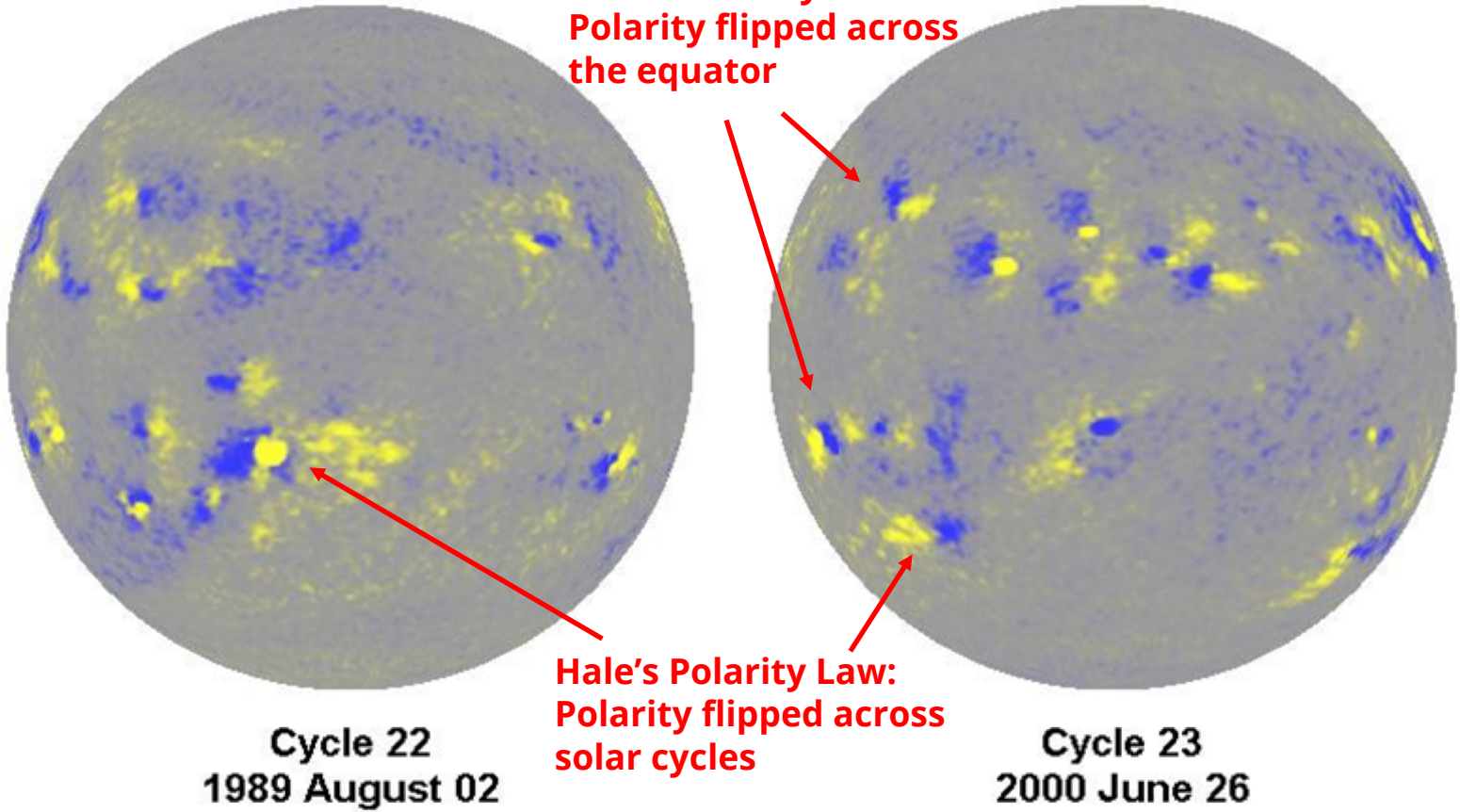
Active Regions

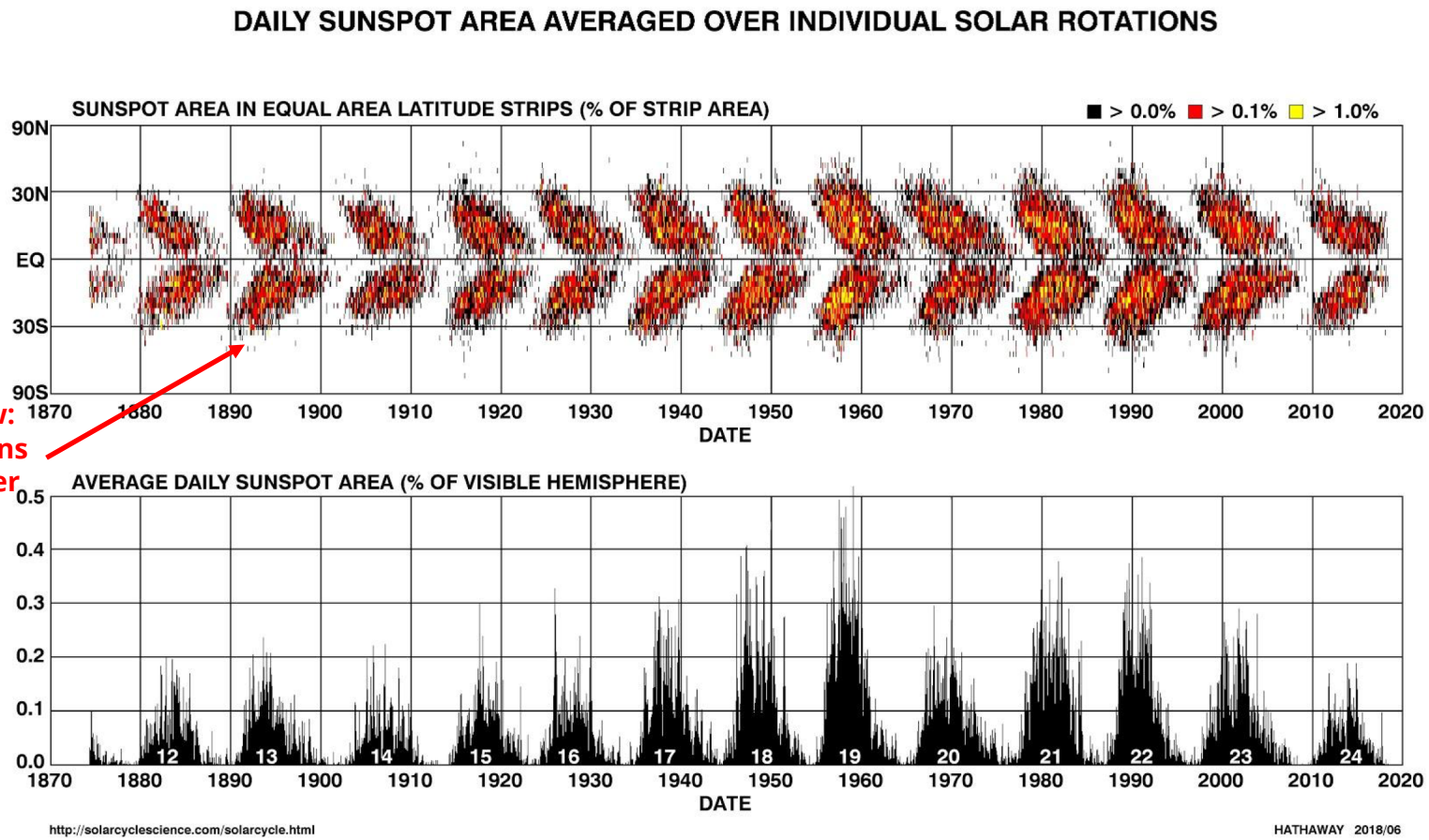




Joy's Law Tilt: Active regions tilted towards the equator, with tilt angle varying with latitude

Active Regions

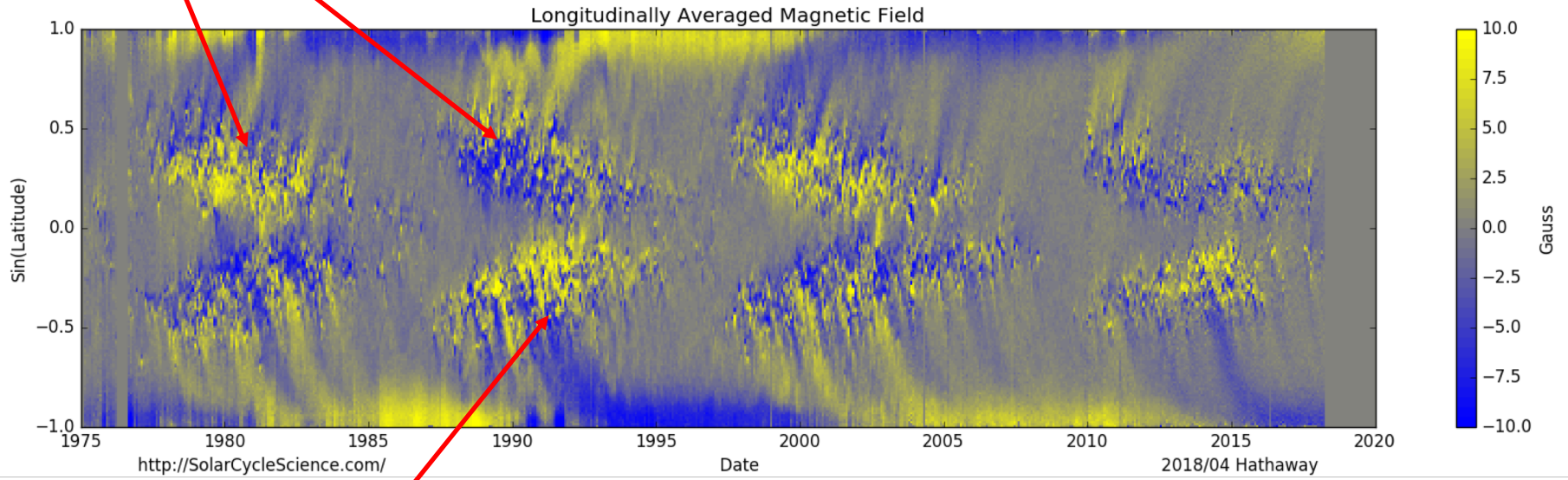




Sporer's Law: Active regions appear closer to the equator as cycle progresses

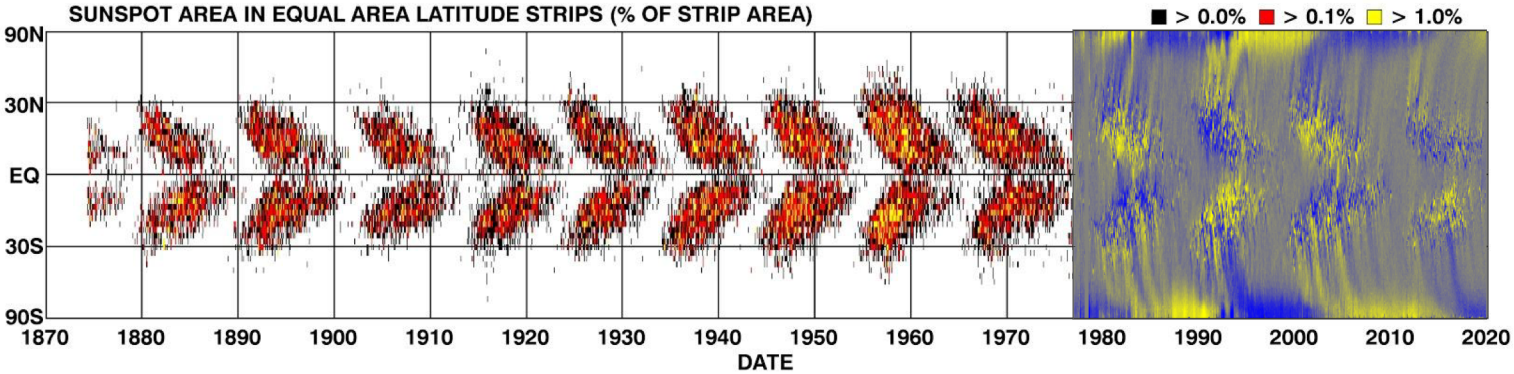
Magnetic Butterfly Diagram

Hale's Polarity Law: Alternating leading/following polarities across cycles



Sporer's Law

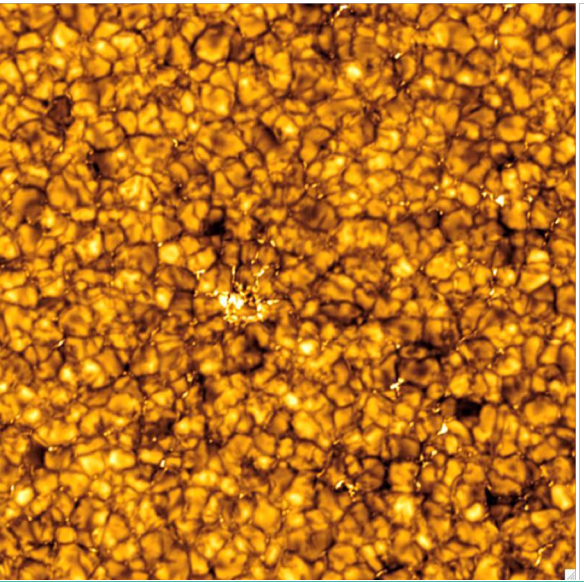
DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS



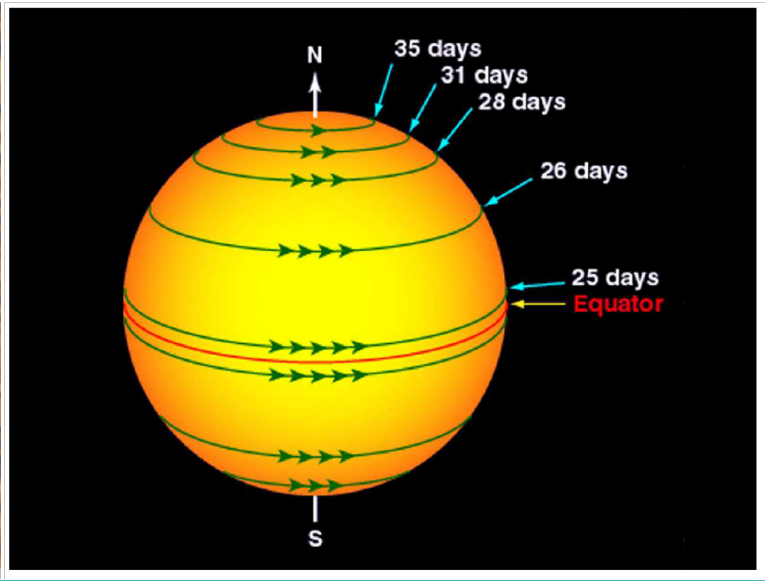
Surface Flows: Drivers of Magnetic Flux

There are three main types of surface flows on the sun:

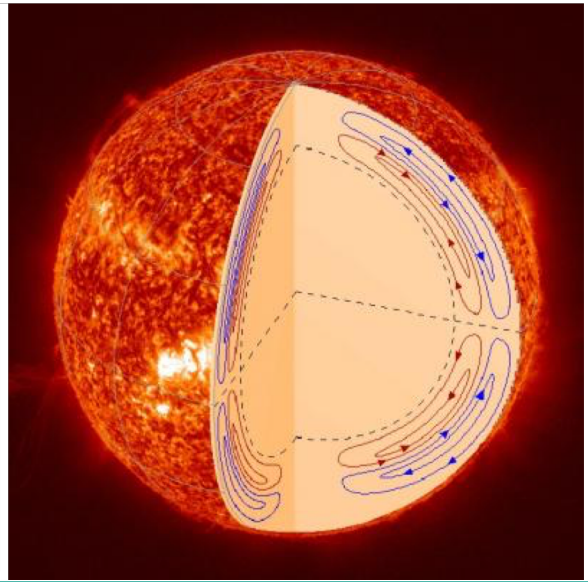
Convection



Differential Rotation



Meridional Flow



Convection

- Shreds active regions

Differential Rotation

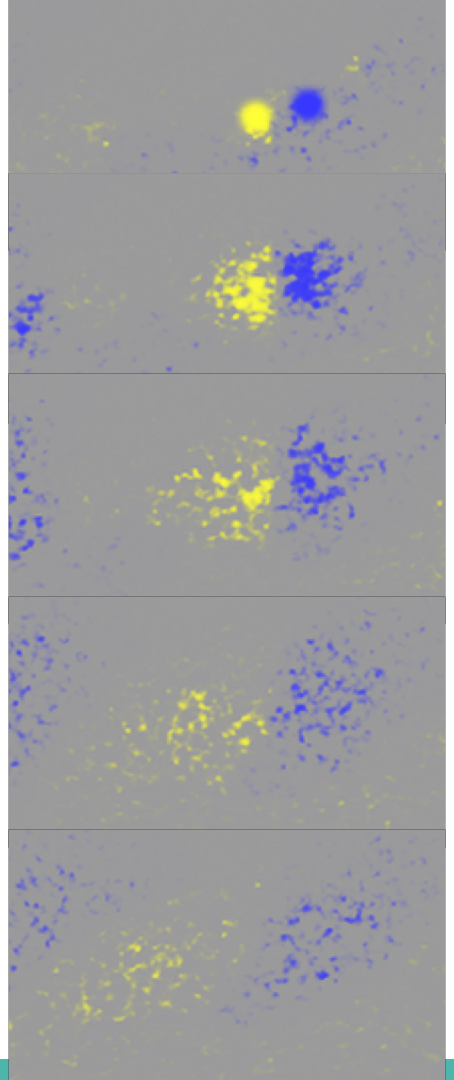
- Shears active regions

Meridional Flow

- Moves flux towards the poles

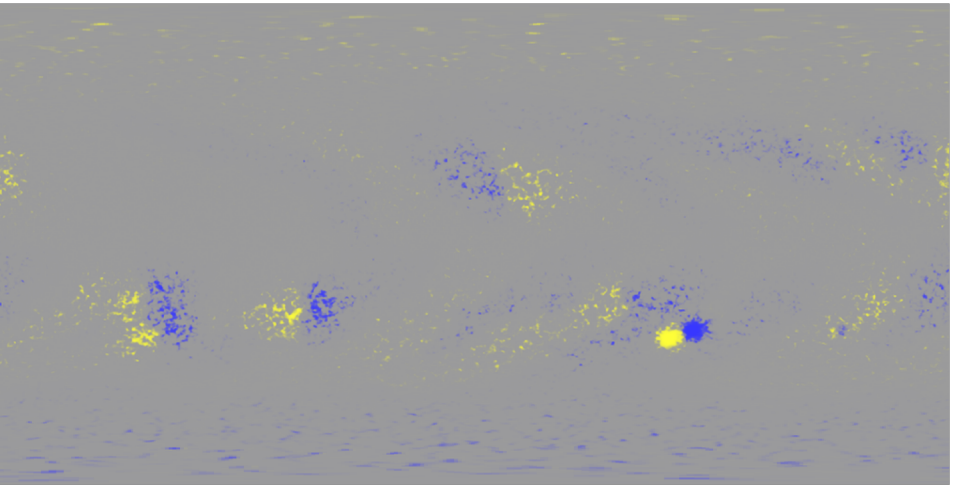
Due to these flows, most of the flux will cancel within an active region

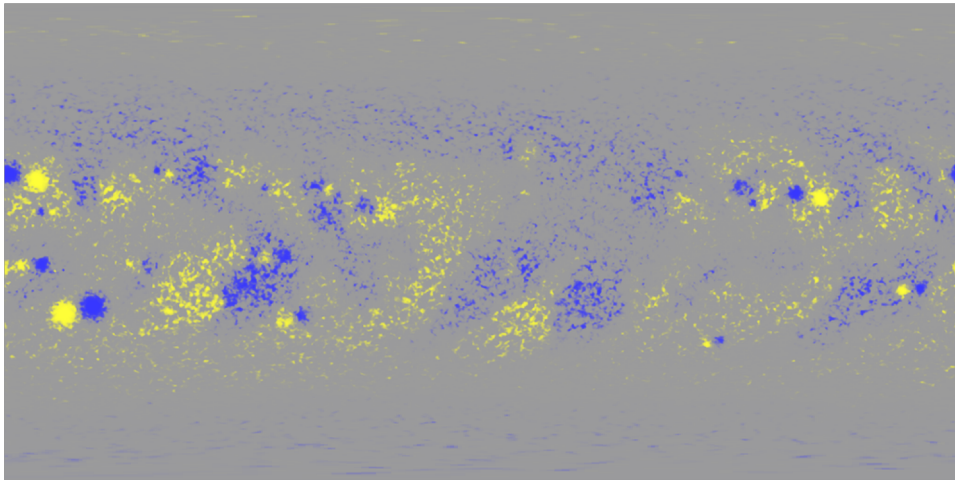
The greater the tilt, the more flux will be left over to be transported to the poles.



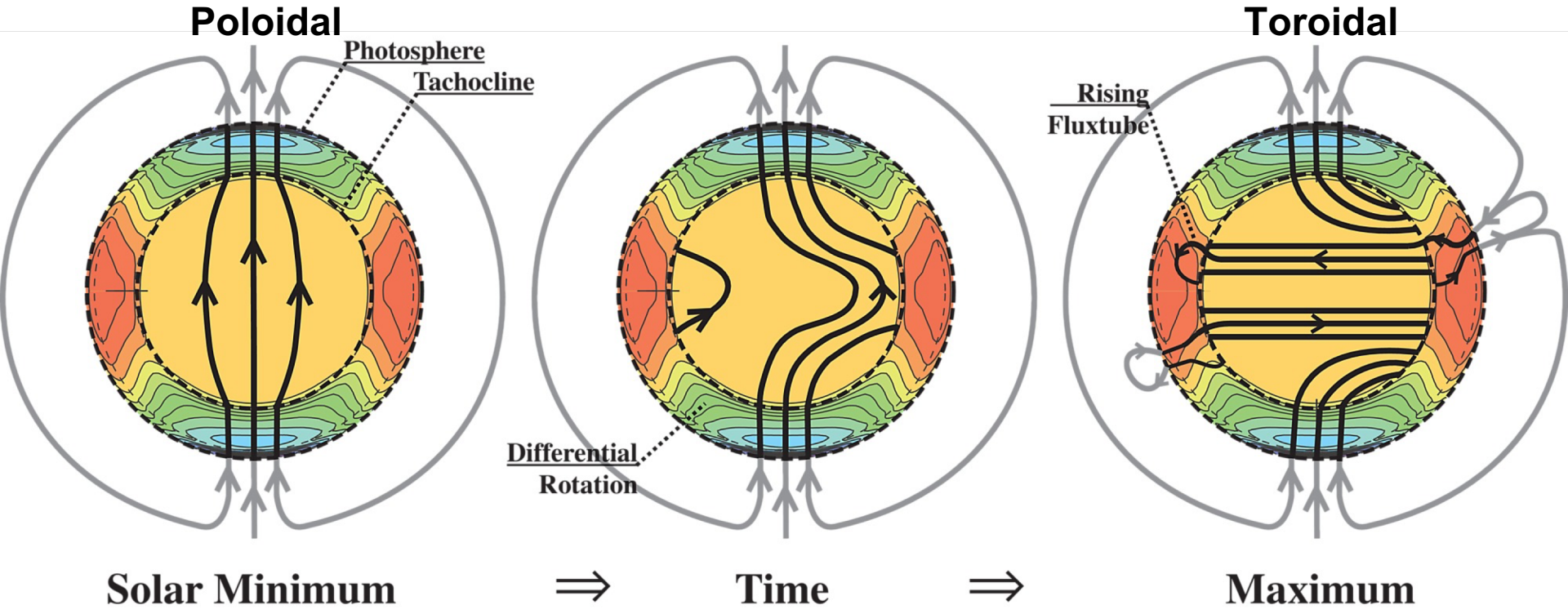
The Advective Flux Transport Model (AFT)

- Takes in active region data
- Simulates surface flows to evolve the active regions over time
- Shows movement of flux towards the poles, where it will build up





The Solar Dynamo



Poloidal

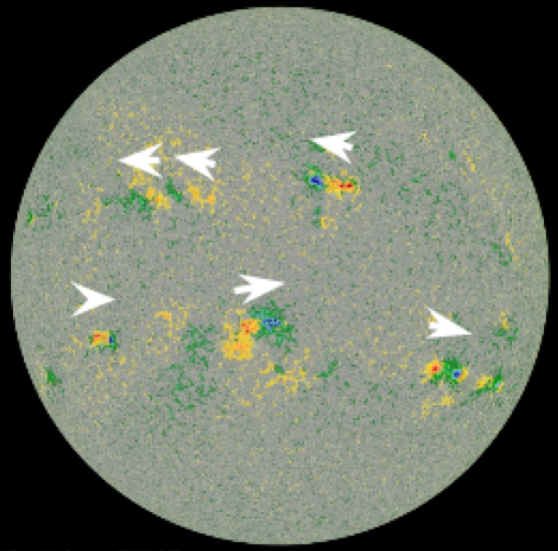
r - θ

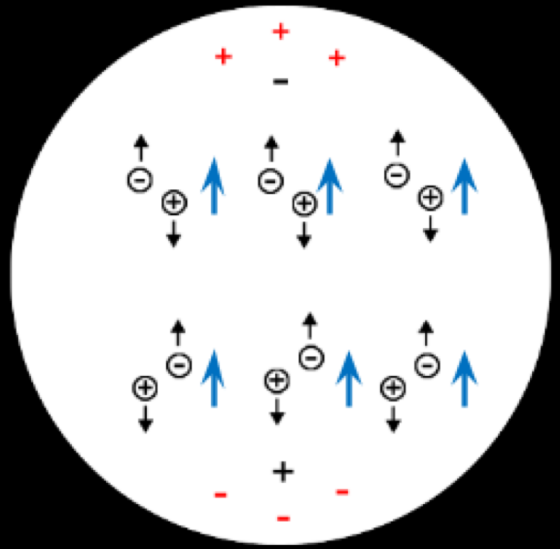
Differential Rotation

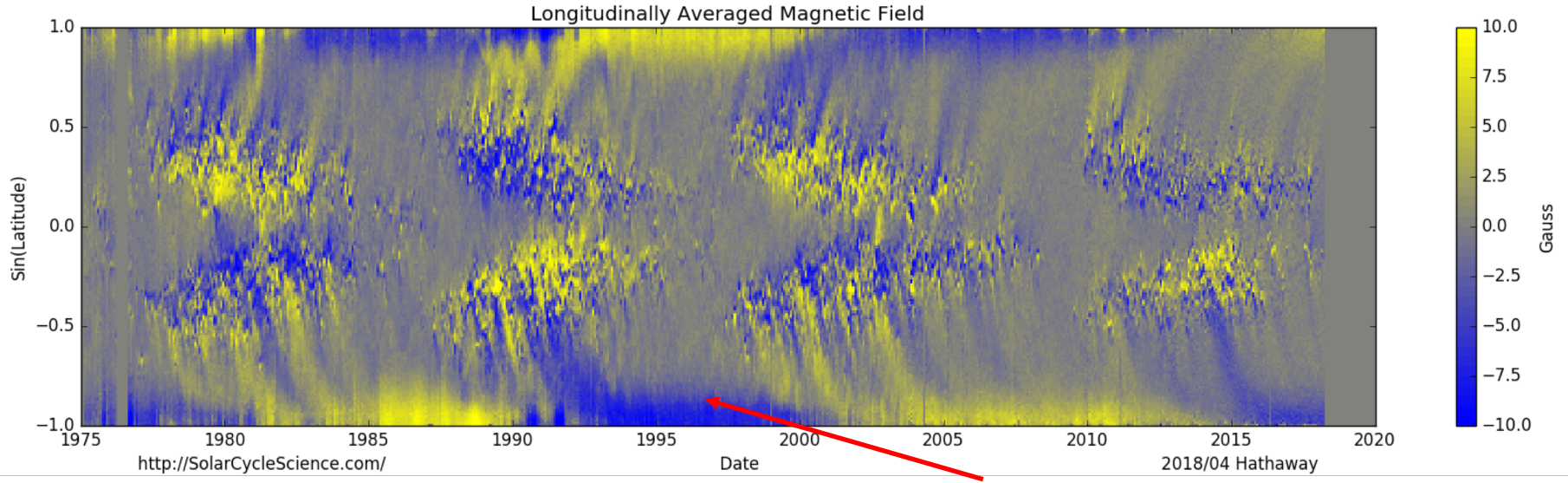
Toroidal

φ

Emergence and Decay of Tilted Active Regions



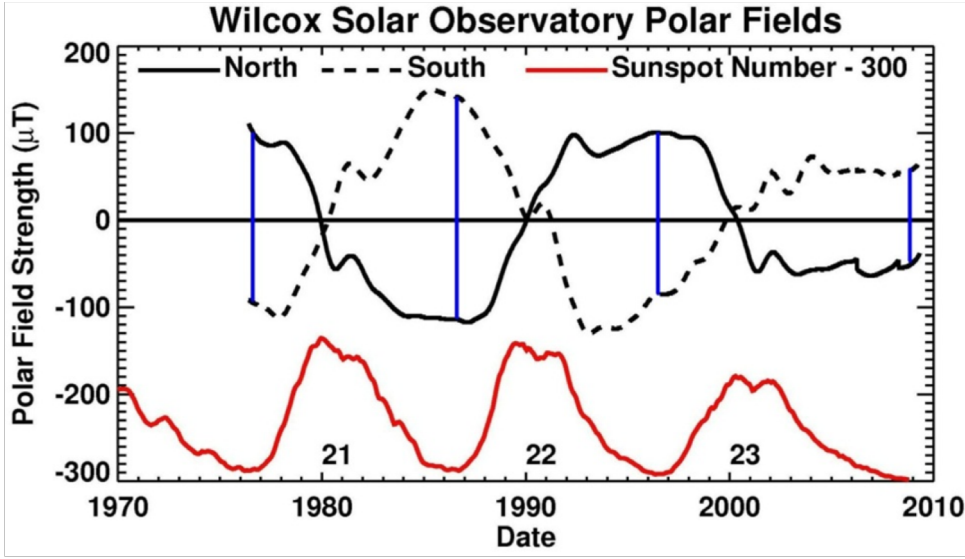




Flux is carried to the poles by Meridional flow, where it builds up

The Polar Fields

- Polar field strength is strongest at solar minimum
- Flux left behind by active region cancellation is transported to the poles by meridional flow
- This cancels with the flux at the poles, leading to buildup of flux of the opposite polarity
- Strength of the polar fields determines the strength of the next solar cycle



Active Region Data

The Datasets

NOAA/USAF/RGO

- List of whole active regions
- Umbral and Penumbral size
- 1874-Present

Mount Wilson Observatory

- List of individual sunspots
- Umbral size
- 1917-Present

The Datasets: Pros and Cons

NOAA

- Tracks active regions over time
- Reliable area measurements
- No missing days after 1979

- No polarity information
- Tilt is calculated using an average Joy's Law relationship

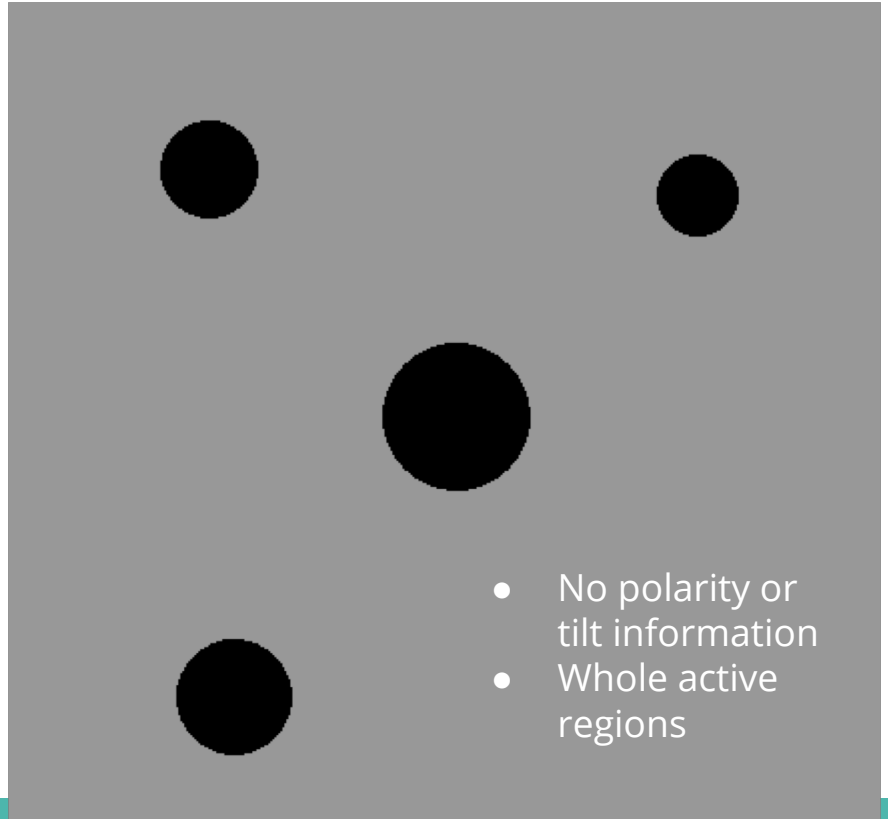
Mount Wilson Observatory

- Does not track sunspots over time
- Less reliable area measurements
- Data is missing from some days

- Includes polarity information
- Tilt can be calculated directly from spot locations

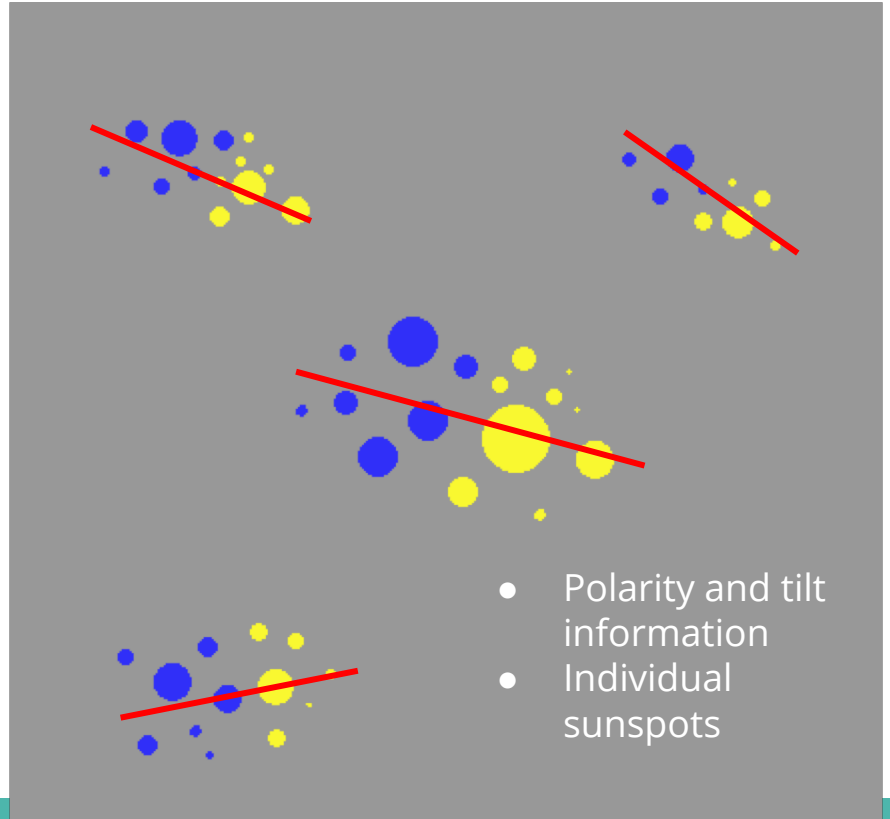
The Datasets

NOAA



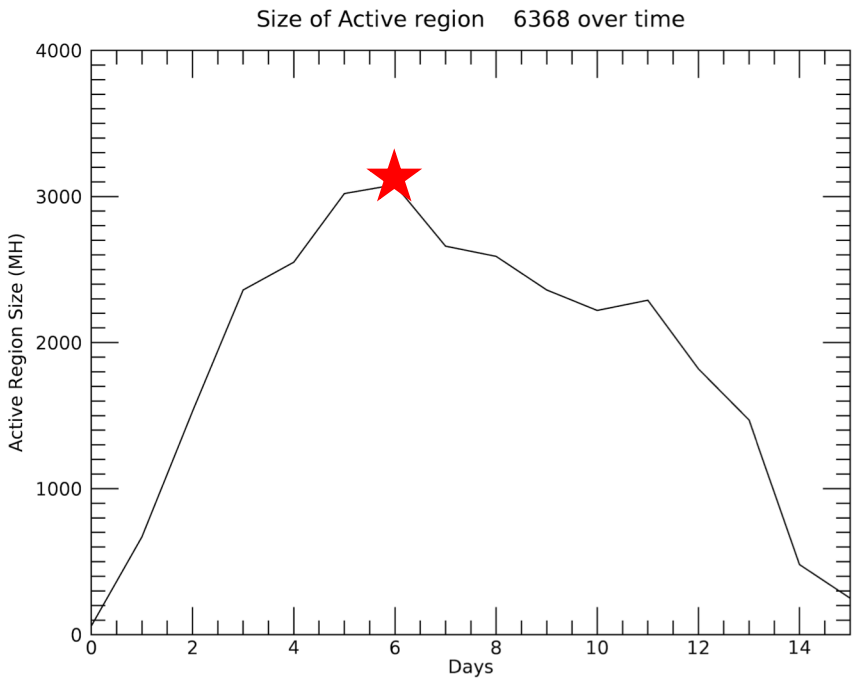
- No polarity or tilt information
- Whole active regions

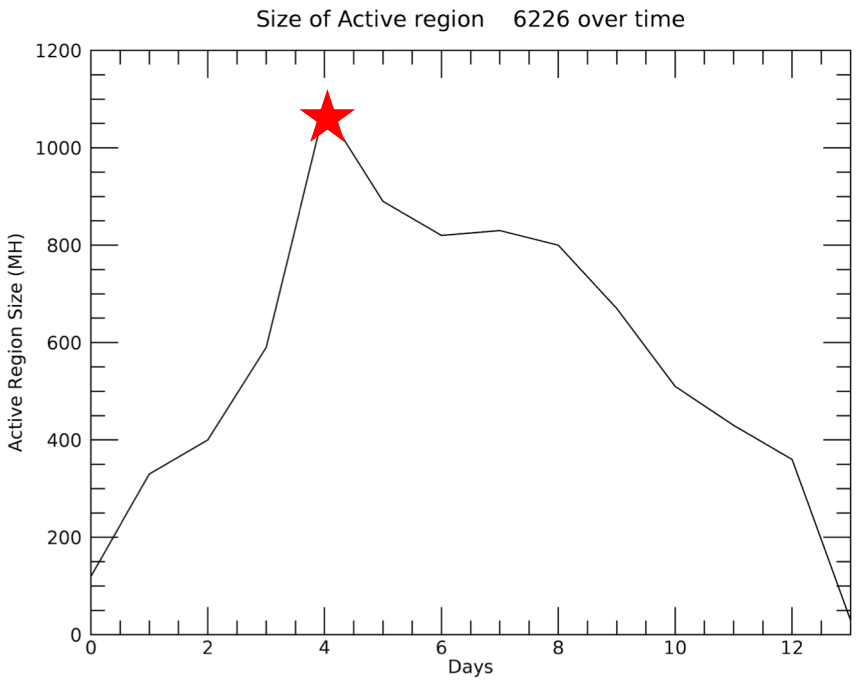
MWO



- Polarity and tilt information
- Individual sunspots

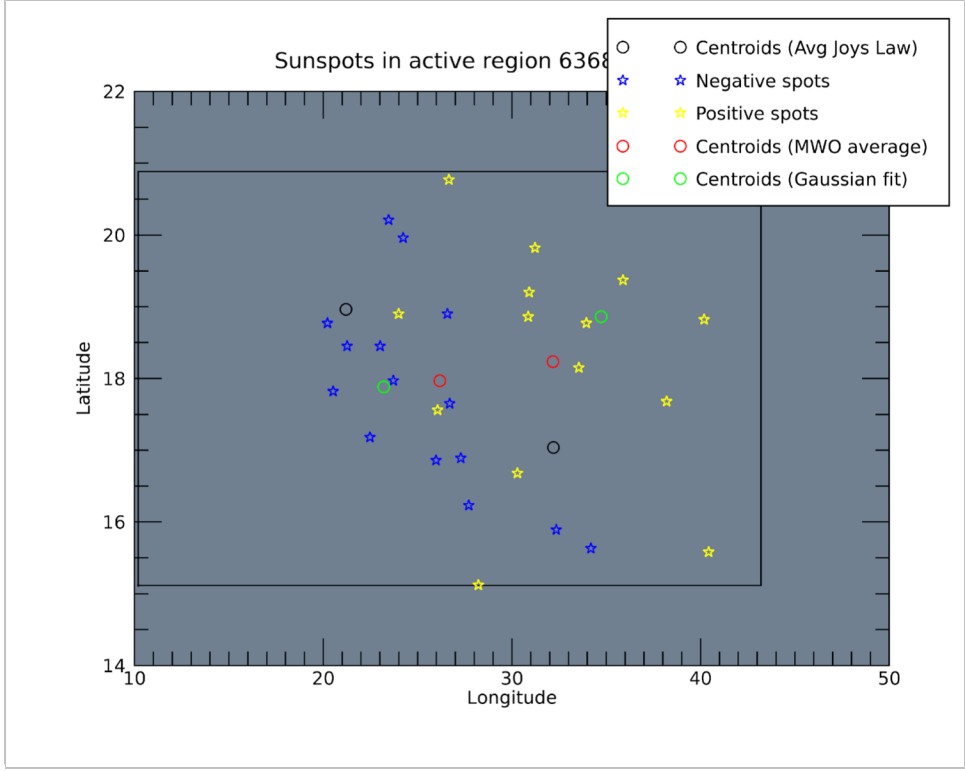
- Active regions change size over time
- Active regions are most coherent at their peak size
- Want to focus on active regions on the dates of their peak area
- Get flux from well-established flux-area relationship

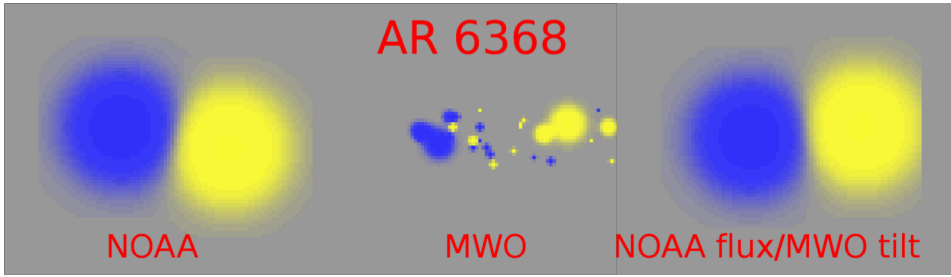


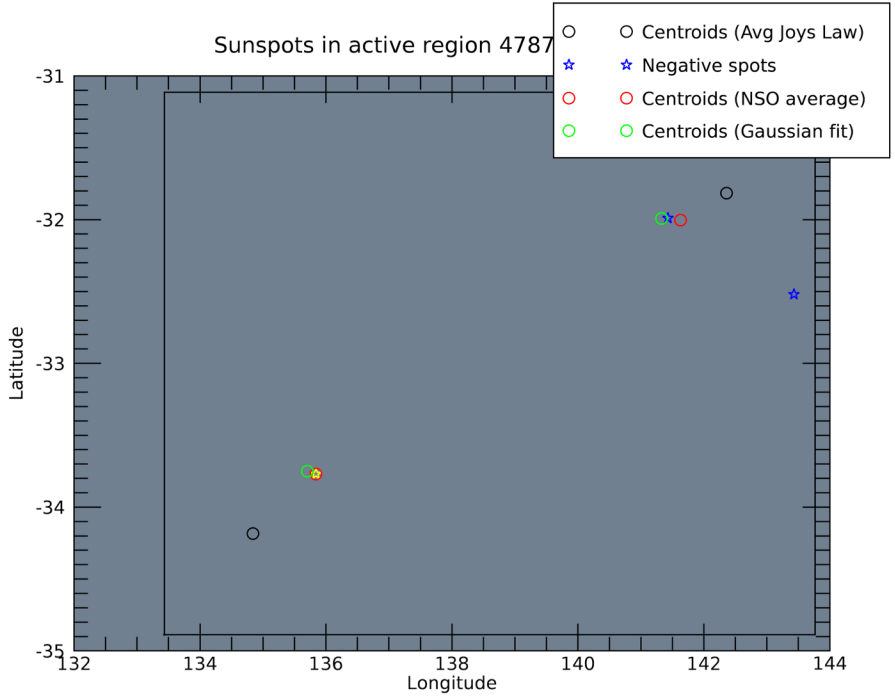


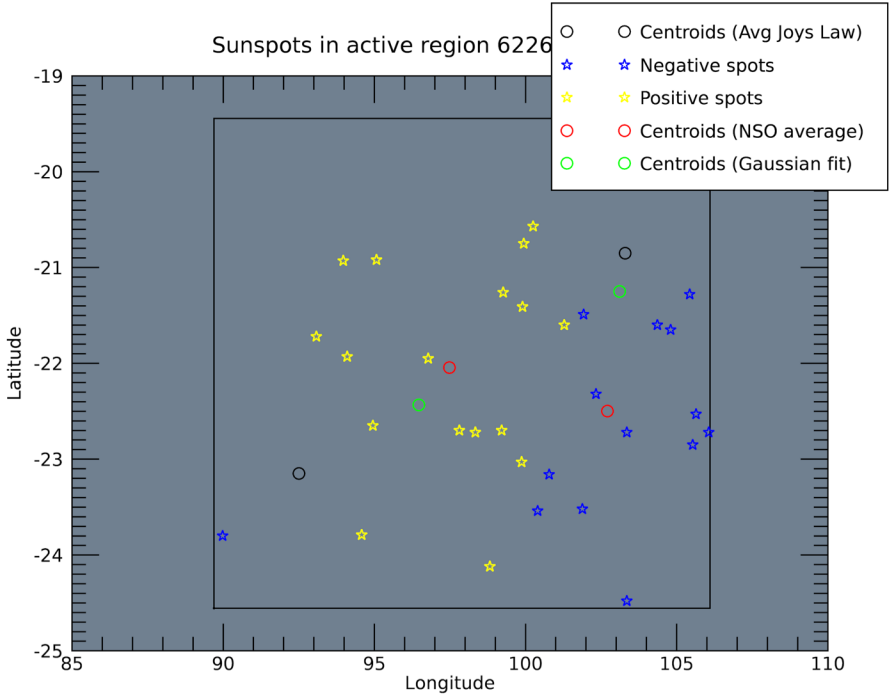
Combining the Datasets

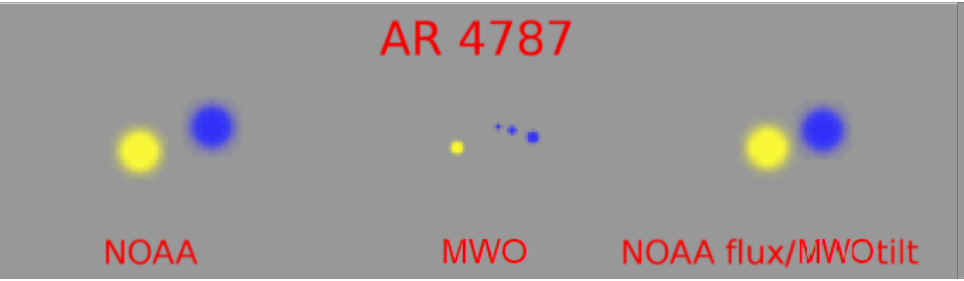
- Define a “bounding box”
- Look for MWO sunspots within box
- Plot sunspots as Gaussian spots
- Find centroids of the bipoles
- Calculate actual tilt from centroids
- Apply actual tilt to NOAA flux

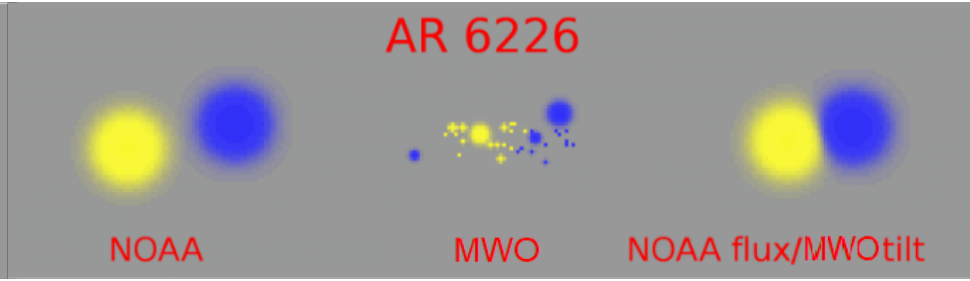




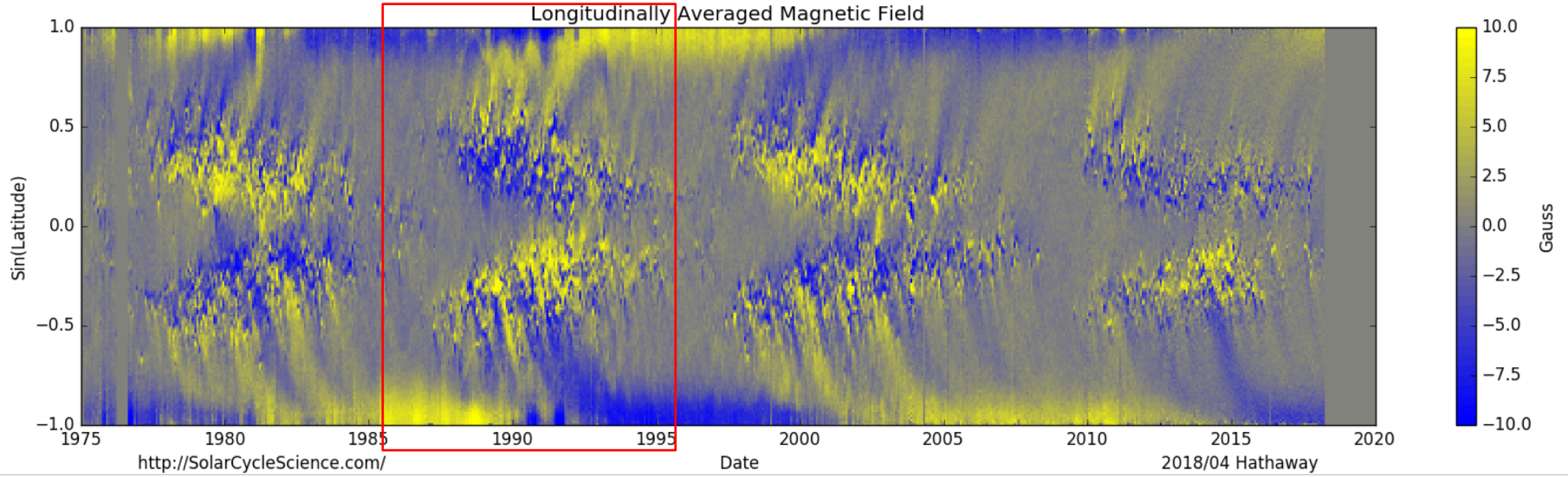

Sunspots in active region 4787
Centroids (Avg Joys Law)
Negative spots
Centroids (NSO average)
Centroids (Gaussian fit)
Latitude
Longitude
-31
-32
-33
-34
-35
132
134
136
138
140
142
144


Sunspots in active region 6226
Centroids (Avg Joys Law)
Negative spots
Positive spots
Centroids (NSO average)
Centroids (Gaussian fit)
Latitude
Longitude
-19
-20
-21
-22
-23
-24
-25
85
90
95
100
105
110


AR 4787
NOAA
MWO
NOAA flux/MWOtilt


AR 6226
NOAA
MWO
NOAA flux/MWOtilt

Simulating the Solar Cycle



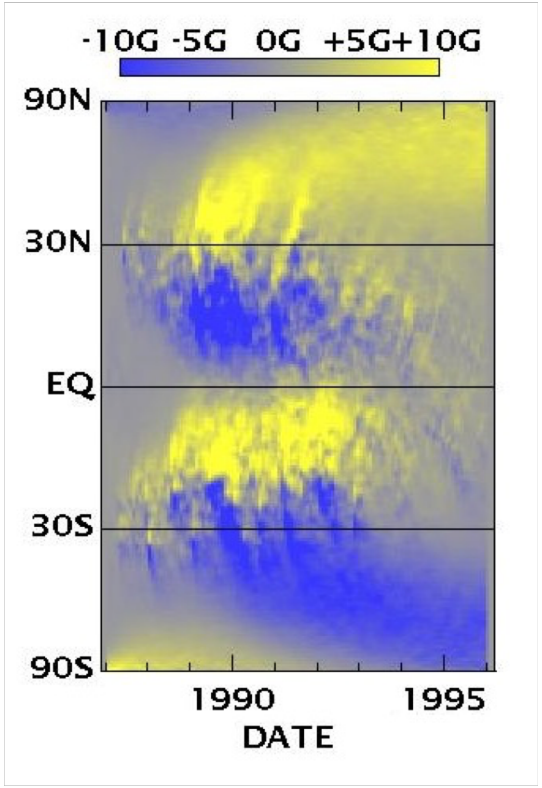
Solar Cycle 22

AFT Simulation Results

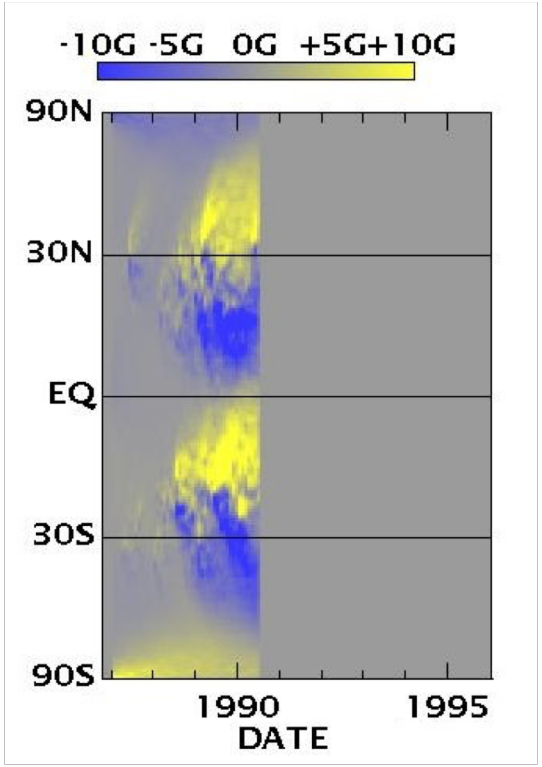
Three different simulations were run:

- One with unaltered NOAA data
- One with NOAA data, filtering out small active regions and unipolar spots
- One with the filtered NOAA flux data and MWO tilt data

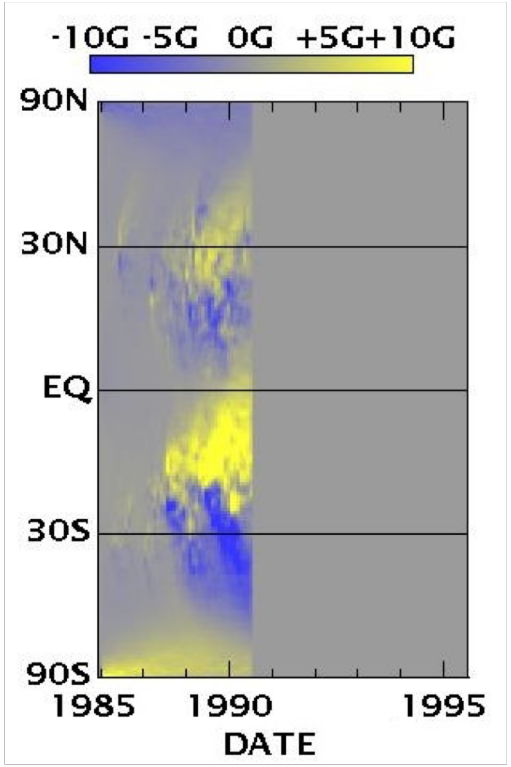
Magnetic Butterfly Diagram Results



Pure NOAA

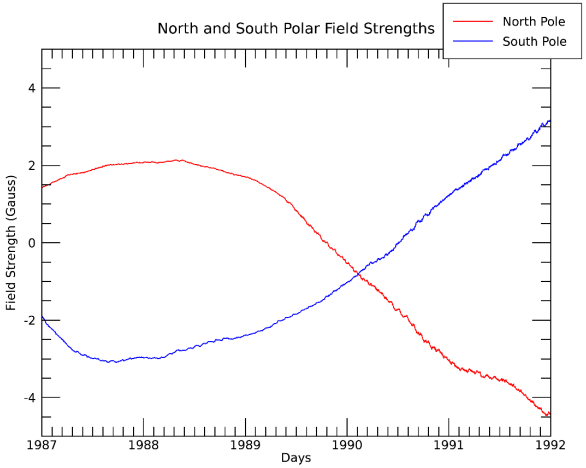


Reduced NOAA

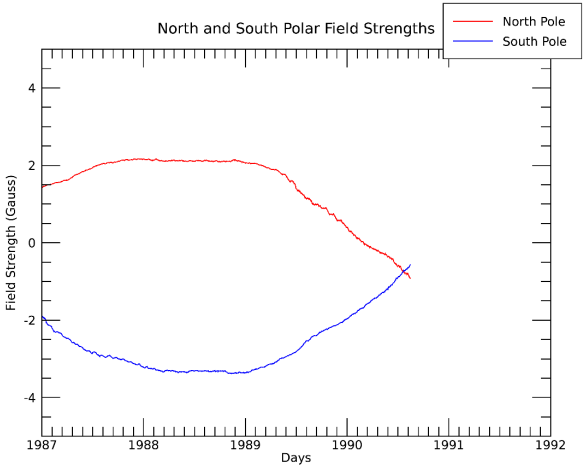


MWO Tilts+NOAA Flux

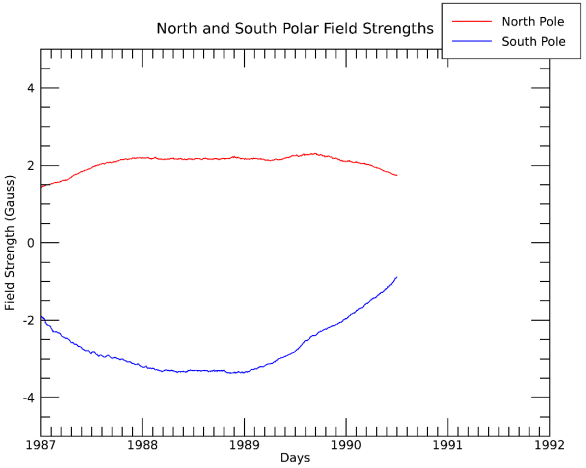
Polar Field Results



Pure NOAA
Reversal: 9/14/1989



Reduced NOAA
Reversal: 1/28/1990



MWO Tilts+NOAA Flux
Reversal: Inconclusive

Conclusions

- Based on their butterfly diagrams, the unaltered NOAA run appears to have the strongest magnetic fields, with the filtered NOAA run having the second weakest, and the NOAA/MWO combination run being the weakest.
- The polar fields of the three runs all have different reversal times:
  - Pure NOAA: 9/14/1989
  - Filtered NOAA: 1/28/1990
  - MWO/NOAA combo: After July 1990
- Interestingly, there is more variation between the northern polar fields of the filtered NOAA run and the MWO/NOAA combo run than their southern polar fields.

Future Work

- Run simulations with corrected starting map and vector velocities
- Run more complete simulations
- Extend data combination beyond Solar Cycle 22

- I will present these future results at the Fall 2018 AGU conference!

Acknowledgements

Thank you to my mentors Lisa Upton,
Andres Munoz-Jaramillo, and Ricky Egeland

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