AFT: Predicting Active Region Evolution Using Far-Side Helioseismology

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Motivation: Space Weather

- Harms satellites, communications, computers, astronauts, etc.
- Active regions are good indicators of where harmful space weather may occur
Science background: Near Side Data

- Helioseismic and Magnetic Imager (HMI) on the Solar Dynamics Observatory (SDO)
- Geosynchronous orbit
- Active regions are determined by areas of higher magnetic field strength
AFT: Advective Flux Transport Model

- Near side magnetic fields input
  - Magnetograms from direct observations
  - Inputs active regions on near side
- Convective flows input
  - Simulates the convective motion, producing the magnetic network on the far side
  - Evolves active regions on far side
- AFT is unable to predict where new active regions will arise on the far side
AFT: Advective Flux Transport Model

- AFT Output: Full-sun map of magnetic field strength
- Near side is in the black outline
  - Data assimilation occurs here
- Active regions evolve on far side
- No new flux is added to the far side

Map of 02/01/2014

Full-sun map of magnetic field strength

Yellow: Positive, Blue: Negative
STEREEO: Full-Sun Data

- Full sun images in various wavelengths
- 2+ years of far-side data (2012-2014)
- Lost contact with stereo B in 2014
- Now satellites are almost back to Earth

NASA, STEREO paths
STEREO data

- For 2012-2014, far-side 304 data is assimilated into the AFT model
- STEREO 304 maps are used to find and map active regions
- Luminosity is used to calculate magnetic flux strength
- Far-side active region locations and flux strength are added into AFT
STEREO data is great, but unfortunately both satellites have returned to the near-side.

Where do we go from here?
Helioseismology

- Sun has inner sound waves
- Active regions disturb those waves
- Determine approximate active region location and size
Helioseismology Acoustic Maps

Near-side dopplergram of surface velocities

Far-side acoustic maps
(a) 31 hour period
(b) Three days of overlapped maps

Hess Webber, et al., 2020
Machine Learning for Dopplergrams

STEREO A+B Magnetic flux

Far-side Magnetic flux

Far-side acoustic imaging using near-side Dopplergrams

Near-side Predicted far-side Magnetic flux

Hess Webber et al., lecture, 2019
Analyzing Helioseismology Data

Full-sun magnetic flux strength map calculated from helioseismology magnetic field strength data

Binary map of active region location and size from smoothed flux strength map

Magnetic flux strength map of only active regions using AFT data

Maps of 02/2014
Active Region data

- Active region Latitude and longitude degree positions recorded
- Active region magnetic flux strength calculated
- Helioseismology data compared with AFT data

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Adding Helioseismology into AFT

Add polarity by Hale’s Law

- Leading polarity in the Northern hemisphere is opposite that of the Southern hemisphere
- Assumes all Northern hemisphere active regions have the same leading polarity, and all Southern hemisphere active regions have the opposite polarity

Add tilt by Joy’s Law

- Active regions’ characteristic tilt
- Tilt is proportional to the latitude

Yellow: Positive, Blue: Negative
Results

AFT without far-side data

- Near side is detailed
- Far side misses new flux

AFT with far-side data

- Both near and far side are detailed
- Far-side flux added in
Results: Adding in new active regions
Next steps

- Graphical comparisons between AFT and Helioseismic data
  - Compare individual active region magnetic flux strength over time
  - Make any necessary improvements

- Incorporate helioseismology into more data
  - Currently only one month has been run, February 2014
  - Next: The full year of 2011 data
  - Long term: Near real time assimilation
Questions?
Resources

Upton, L. 2021. HAO. Lecture.
Upton, L. 2021. WAS. Lecture.
Hess Webber, S. 2020. SWPC. Lecture.

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Additional material
Machine learning for helioseismology

Advantage:
Far-side EUV observations may not be available in the future. But far-side magnetic flux proxies can still be generated from near-side observation alone.

Calibration by training another neural network

Preliminary result

Hess Webber et al., lecture, 2019
AFT and Helioseismology sample comparison

Flux data from AFT

Flux data from helioseismology

Flux data from AFT using helioseismology