The COFFIES DRIVE Science Center:
A United Quest to Unlock the Mysteries of the Sun's Solar Cycles

SwRI SOUTHWEST RESEARCH INSTITUTE

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Abstract

The solar cycle and its variability are Consequences of Fields and Flows in the Interior and Exterior of the Sun (COFFIES). The COFFIES DRIVE Science Center, funded by NASA's Heliophysics Division, is dedicated to unraveling how the Sun generates periodic magnetic cycles that cause space weather and influences the entire heliosphere. The initiative seeks to understand the drivers behind large-scale plasma motions, their interaction with magnetic fields to create solar activity cycles, the emergence of active regions, and how these solar processes can inform stellar studies. The COFFIES team is comprised of experts from 14 institutions, skilled in helioseismology, dynamo modeling, solar convection, and surface flow observations. Bringing together experts from these diverse fields, we unite to collaboratively tackle three major cross-cutting science themes: the Tachocline, the Near Surface Shea Layer, and Flux Transport and Emergence. By leveraging our varied expertise, COFFIES is primed for rapid advancement in these areas, with the ultimate goal of improving cycle forecasting capability by developing data-driven physical models of solar activity. The center is dedicated to enhancing science knowledge while also inspiring STEM students and sharing the thrill of solar physics with the wider community. COFFIES holds a strong commitment to Diversity, Equity, Inclusion, and Accessibility, creating a supportive atmosphere for collaboration between scientists, students, postdocs, and those at the early stages of their research careers. External collaborations are encouraged, with resources available to facilitate such partnerships. For more information about COFFIES and how to get involved, visit us at coffies.stanford.edu.

COFFIES

The COFFIES Vision

Expand our understanding of the Sun to develop the capability to forecast activity cycles and magnetic field variability by creating a diverse and inclusive center of excellence in Solar Physics To develop data-influenced models of solar activity such that accurate measurements of 3D plasma flows in the Sun can drive a reliable physical model of the solar activity cycle and consequent magnetic field evolution.

COFFIES Top Science Questions

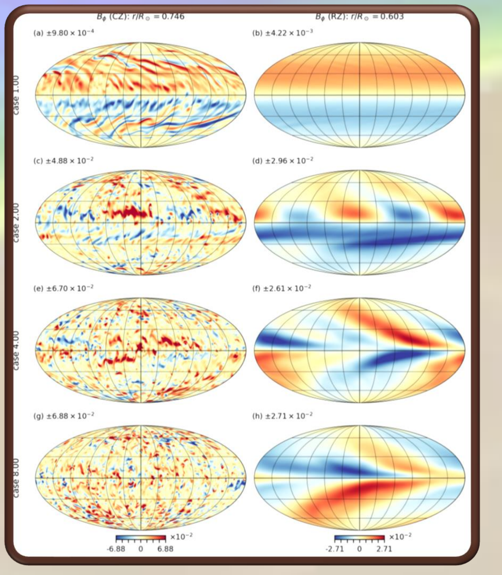
COFFIES brings together science and cross-cutting teams to answer the difficult questions of:

1. What drives varying large-scale plasma motions, such as meridional flow and differential rotation?
2. How do flows interact with magnetic fields to create varying solar activity cycles?
3. What causes active regions to emerge when and where they do during the solar cycle?
4. How is our understanding of solar activity informed by fields and flows on other stars?

COFFIES Science THEMES

COFFIES three Science themes reflect cross-cutting regimes of interest where progress can be made by linking models and observations: Tachocline, Flux Transport & Emergence, Near-Surface Shear Layer

Tachocline



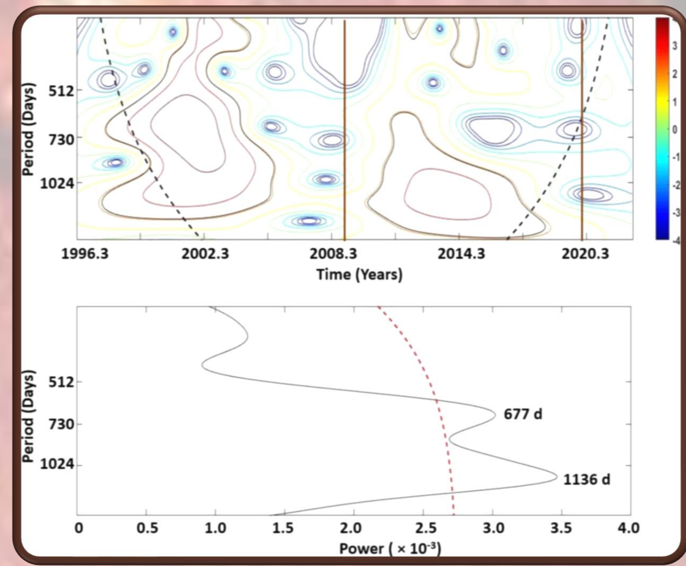
Confinement of the solar tachocline by a non-axisymmetric dynamo

Loren Matilsky, Nic Brummell, Brad Hindman and Juri Toomre report on very exciting results revealing the robustness of a new component of the skin-depth confinement scenario via differentially rotating non-axisymmetric dynamo modes with strong field. This paper is in press now in ApJ. This work reveals that the magnetic field can produce Maxwell stresses that confine a tachocline, but the skin-depth adopted is not restricted to be controlled by the dynamo cycle period. Nonaxisymmetric modes that rotate relative to the deeper radiative zone allow a much wider spectrum of possible diffusive penetrations of the magnetic field. The next big step in this model is to allow this effect to act against radiative spreading rather than purely viscous spreading. **(https://ui.adsabs.harvard.edu/abs/2023arXiv231110202M/abstract)**.

Flux Transport & Emergence

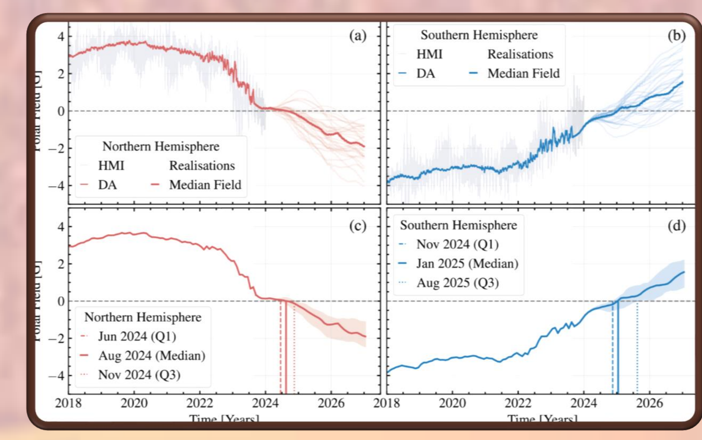
Helioseismic Investigation Of QBO Periods And Their Origin

Kiran Jain, Partha Chowdury, and Sushant Tripathy investigate quasiperiodic variations in the solar cycle, or quasi biennial oscillations (QBOs), with periods ranging from 0.6 to 4 yr. They studied the temporal evolution of QBOs using acoustic mode oscillation frequencies spanning more than 25 yrs from the Global Oscillation Network Group. The analysis reveals that QBO-like signals are present in cycles 23 and 24 but with different periods and double-peak structures in the global wavelet spectra. A detailed analysis suggests that the source region of QBOs is just below the surface, supporting the idea of two dynamo sources separated in space; the first located near the bottom of the convection zone while the second operates in the NSSL. **(https://ui.adsabs.harvard.edu/abs/2023ApJ...959...16J/abstract)**.

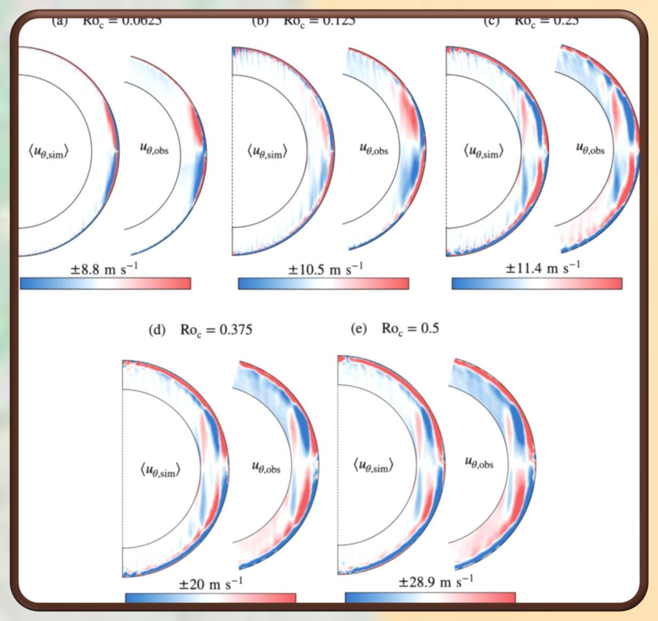


Predicting the Timing of the Solar Cycle 25 Polar Field Reversal

Bibhuti Kumar Jha and Lisa Upton use the AFT model simulate the emergence of active regions and the evolution of the polar field and forecast the timing of the Cycle 25 polar field reversal. Their analysis suggests that the northern hemisphere of the Sun is likely to reverse its polarity around August 2024 (with a 50% probability between June to November 2024), while the southern hemisphere is anticipated to undergo polarity reversal around February 2025 (with a 50% probability between November 2024 to July 2025). Finally, based on our study we can expect Solar Cycle 25 will peak in the 2nd half of 2024. **(https://ui.adsabs.harvard.edu/abs/2024ApJ...962L..15J/abstractt)**.



Near Surface Shear Layer



Assessing the Observability of Deep Meridional Flow Cells in the Solar Interior

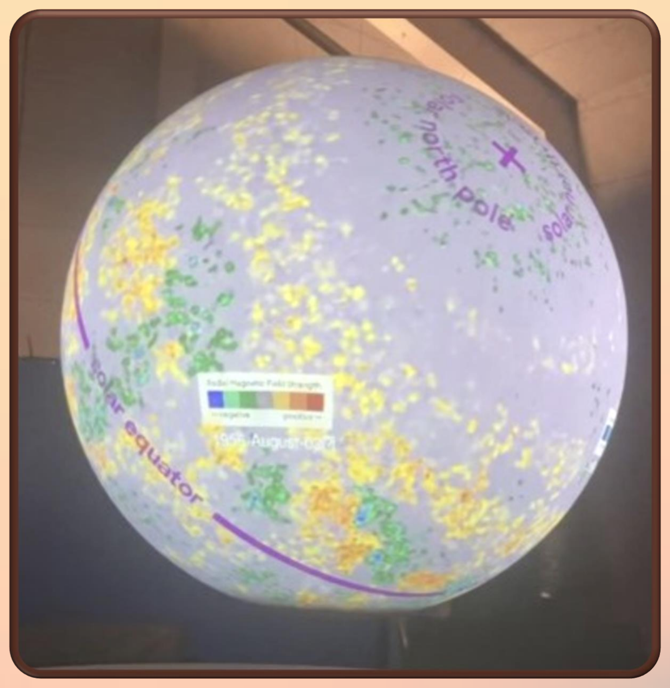
Helioseismic measurements targeting the deep convection zone are unavoidably contaminated by the signal of much stronger, near-surface flows. Recently, J.R. Fuentes, Brad Hindman, Junwei Zhao, Catherine Blume, Maria Camisassa, Nicholas Featherstone, Thomas Hartlep, Lydia Korre, and Loren Matilsky explored the implications of this effect. By convolving time-distance averaging kernels with the meridional flows obtained from a suite of 3-D convection-zone simulations, they were able to simulate the seismic signature of a number of potential meridional flow profiles. The team found that that surface contamination was particularly significant at low and mid latitudes where the deep flows tend to be weaker. In the equatorial region, where deep flows tend to be stronger (> $2ms{-}1$), their results suggest that multiple cells in radius can be reliably recovered. **(https://ui.adsabs.harvard.edu/abs/2024ApJ...961...78F/abstract)**.

CET

CET: Center Effectiveness Team

The CET focuses on finding and exploring novel ways to enable to the science teams achieve breakthrough science. A distributed Science Center faces a number of well documented challenges, and the CET helps COFFIES function effectively as a team. They provide support for communications, collaboration, knowledge integration, and for engagement beyond the COFFIES team.

Broadening Impacts



Education and Outreach

COFFIES organizes an annual REU and participates in a Public Outreach and Informal Science Education (POISE) program to engage the general public.

Mentoring

The COFFIES Beans program serves students and early career researchers by fostering professional identity, establishing mentoring relationships, and organizing additional activities.

Diversity, Equity, Inclusion and Accessibility

COFFIES is committed to modeling diversity and inclusion for the scientific community, and to maintaining an inclusive environment with equitable treatment for all.

***COFFIES: Consequences of Fields and Flows in the Interior and Exterior of the Sun** **join or learn more info at http://coffies.stanford.edu/**