Predicting IMF $B_z$ at 1 AU
-The past, present, and future

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Research supported by NASA’s LWS TR&T Program
• We can’t predict IMF $B_z$ (well)
• Anyone who tries to convince you otherwise is misinformed, deluded, or lying
• Reproducing 1 AU observations is not the same as forecasting/predicting
• Being able to make useful forecasts of $B_z$ is going to be more difficult than we (or at least I) thought
• If forecasting is the goal, we have to be goal-orientated, not theory-orientated
• If $B_z$ prediction is really a priority, it will require significant investment
Overview

• Why do we care?
• What physical processes produce $B_z$?
• How can we predict non-zero $B_z$?
• Past and current status of $B_z$ predictions
• Basic uncertainties that need to be resolved
• Conclusions
• Future Opportunities
Why do we care about $B_z$?
-Science and Society
Alfvén waves
Pressure Balanced Structures
CIRs
R shock
F shock
Blobs
HCS
Discontinuities
Reconnection Jets
Magnetic Clouds
Sheath
Compressions
Draping
Turbulence
Plumes/jets
Magnetic Holes
Stream Interfaces
How do we Prioritize these Processes?
Techniques for predicting non-zero $B_z$

**Statistical**
- Artificial Neural Networks
- Clustering
- Pattern Recognition
- Dynamic Time Warping
- Probabilistic Forecasts
- "Zero" Model
- Deep Learning

**Empirical**
- Flux rope fitting
- Modular CME Models
- Recurrence
- Persistence
- Turbulence
- The "leaky" Corona
- Jackson et al. (2015)

**Mechanistic**
- Zero-Beta
- Time-dependent MHD
- Magneto-Frictional
Bz ‘prediction’ studies...

- Search based on:
  - (interplanetary | "solar wind") AND (southward | Bz | "z component" | "z-component" | “magnetic vectors” | “magnetic field vectors") AND (prediction | predicting | forecast | forecasting)

- Resulted in ~20 relevant papers
“Historical” attempts to predict $B_z$ ...

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**Real-time identification and prediction of geoeffective solar wind structures**

James Chen, Peter J. Cargill, Peter J. Palmadesso
Plasma Physics Division, Naval Research Laboratory

- Feature-based classification technique
- Extrapolation of coherent signal
- Precursor to flux-rope fitting and/or pattern recognition
- Focuses on sinusoidal variation of $B_z$
  - If $B_z < 1$ during first-half => limited prediction
  - If $B_z > 0$ during first-half => longer prediction
- Danger of false positives
- Only demonstrated for a few case studies
Pattern Recognition
*Riley et al.* (2017)
Pattern Recognition

Ratio of MSE to MSE-Zero

6-hour window
Empirical Modular CME (EMC) Models

- Estimate chirality, orientation, and maximum field strength at Sun
- Estimate kinematic/geometric properties of ejecta near Sun (e.g., cone model => Impact parameter)
- Estimate properties of flux rope in solar wind using dynamically deformed ejecta (e.g., HD pulse model)
- Estimate transit time ($\tau$) of flux rope from Sun to Earth using 1-D MHD solutions or other empirically-based approaches
$B_z$ Prediction: A Comedy of Errors

- Initial helicity (accuracy $\sim 0.75$)
- Photospheric FR axial orientation ($\theta \pm 5^\circ$, $\phi \pm 5^\circ$)
- Flux rope rotation ($\sim \theta \pm 20^\circ$, $\phi \pm 20^\circ$)
- Ejecta speed ($\sim \pm 100$ km/s)
- Ejecta mass ($\sim \pm 1 \times 10^{12}$ kg)
- Ejecta propagation direction ($\theta \pm 15^\circ$, $\phi \pm 15^\circ$).
**$B_z$ Prediction: CME/ICME relationships**

- 46% of ICMEs have no obvious solar event associated with them (*Richardson et al.* (2010))
  - But, many slow, weak events that are convected out with the solar wind.
- 10% of the ICMEs driving “Dst < -100 nT” storms had no clear associated solar event (*Zhang et al.*, 2007)
- Only ~56% of halo CMEs produce MC at 1 AU
Conclusions

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Suggestions for Future Paths for Forecasting $B_z$?

- Invest time/money specifically into forecasting, not coopting research studies
- Work on specific components of the Sun-Earth chain to reduce uncertainties
- Investigate statistical approaches more carefully (c.f. weather forecasting)
- Optimize NASA/ESA/NOAA mission designs to measure critical inputs
- Start with simpler objectives: Predict speed (time of arrival), $B$, $B_r$, and $B_t$
- Identify and focus on “lowest hanging fruit”: CME sheaths, ultra-fast events, etc.