Applying Vector Magnetic Field Data to "Real Problems"

**RP #1: Energy Storage:**
Measuring how, where, how much energy is stored and available for a flare CME.

**RP #2: Energy Release:**
Measuring how, where, when energy is released as a flare or CME.
RP #1: Energy Storage

Goal: Quantify the amount of energy available for an eruptive event.
Restate #1: measure the deviation of the magnetic field from the lowest-energy (potential) state.
Restate #2: characterize the solar atmospheric boundary condition.

Have: $B(x,y,t)$, in physically-appropriate form of $B_x, B_y, B_z$.
(NB: $B(z)$ not usually available).
Have also: uncertainties and errors associated with observing and deriving $B(x,y,t)$, both systematic and sporadic.
(NB: sensitivity in the signal is not the same as uncertainty in the answer!)

<table>
<thead>
<tr>
<th>Polarization Signal</th>
<th>$B_{\text{long}}(x,y,t), B_{\text{trans}}(x,y)$</th>
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<tbody>
<tr>
<td>Inversion/Interpretation?</td>
<td>180 degree ambiguity resolution, deprojection</td>
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<td>$B(x,y,t) + \sigma(x,y,t)$</td>
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What can be measured?

Examples:

Horizontal Gradients

Vertical current density

Measures of twist

Current helicity density

Magnetic shear angles

Different parameterizations offer different weighting and sensitivity to non-potential, energy-storage measures.
What do we want to measure?

*Example:* Simple Stress & Release mechanism for energetic events: Magnetic field is stressed away from potential configurations, storing energy which is then tapped to produce a CME or flare.

(a) the "best" force-free $a$, fit over entire active region  
(b) the mean of $a(x,y)$  
(c) the standard deviation of $a(x,y)$  
(d) the kurtosis of $a(x,y)$ plotted as a function of time for three active regions relative to the start of an X and two M-class flares (red, yellow lines).

Thus far, little evidence that *any* single measure derivable from photospheric $B$ implicates a stress/release mechanism in the photosphere.  

*No single silver bullet*  

Handling the effects of atmospheric seeing:

=A significant effect which must be accounted for in all time-series ground-based data.

=For imaging systems, one can model and account for the effects.

=(For spectrograph-based systems, seeing varies spatially and the effects are quite difficult to quantify)
Getting greedy: need many silver bullets:  

A Statistical test of whether event-imminent, event-quiet photospheric magnetic states are distinguishable.  
A Evaluation of a gazillion parameters derivable from photospheric $B$

Example:

A Demonstrate: by considering multiple parameters at the same time, samples from the two populations can be distinguished.  
(Demonstration of method only!)
Restate #2: Characterize the pre-event boundary state

Example: Detailed comparison of observational data and numerical simulations

Comparison of observed photospheric $B$ and "observed" $B$ from an analytical model of twisted flux system into overlying extant field. (Gibson, Leka, Fan, Barnes, work in progress)

Caveats:
- Photosphere is not necessarily force-free:
- Photospheric field may not give accurate measure of energy available for CMEs/flares.
- Measured photospheric field may not represent the state of the atmosphere where energy release occurs.
Real Problem #2: Energy Release

Restate #1: Can photospheric $B$ measurements detect the trigger or release of the stored magnetic energy?

Generally accepted:
A Trigger for energetic events (reconnection) occurs in upper atmospheric layers. Hence, will not be observed directly in photospheric $B$.

Other Notes:
A Magnetic disconnect between photosphere and chromosphere, the "magnetic transition region" between $\beta > 1$, $\beta < 1$ plasmas
A Observationally no well-determined evidence for trigger or magnetic reconnection in photosphere.

So, what can be done with Photospheric $B$ to answer questions about the energy release process?
Restate #2: Can the photospheric B be used as the boundary condition for the coronal magnetic field?

Extrapolations of various ilks (recall T. Metcalf's talk): potential, linear force-free, non-linear force-free...

Varying degrees of success at representing the corona. (General approach: compare extrapolated field lines to bright coronal structures to address issues of helicity, heating, structure, etc.).

Q: What are the coronal bright structures to which the extrapolations are being compared? Field lines? Current Sheets? Separators?
(Fan & Gibson 2003; see poster 1.16, by Fan, Gibson & Barnes)
Quantifying the coronal magnetic complexity: Magnetic Charge Topology
(Barnes, Longcope & Leka, see poster 1.5)

- Model the distribution of field in an active region
- Compute the magnetic flux in each magnetic connection
- Locate magnetic nulls, separators
- Use these topological measures to describe the coronal complexity
What you can get from photospheric $B$: Helicity 
*(the current rage/ debate/hot-topic/ controversy)*

**Given:** measures of $B$, with/without $v$, with/without temporal sampling, can (?) derive:

- Current Helicity density
- Magnetic helicity injection rate
- Relative helicity flux
- Magnetic helicity

Kusano et al, Demoulin & Berger, Longcope & cohorts, Georgoulis, Moon et al.

*Details to be thrashed out here....?*
Consider the chromosphere: physically more appropriate measure of energy storage and release?

A Chromospheric fields are force-free
A Cannot be approximated by photospheric magnetic flux measurements without very, very sophisticated modeling efforts.

Q: Which provides a better boundary condition for extrapolations, photospheric or chromospheric B?

Comparison of SXT images to extrapolated field-lines using the photosphere (left) and chromosphere (right) vector field as boundary conditions. (From Leka & Metcalf 2003)
To Answer David's Question(s): Practicalities and Considerations for measuring $B$ given questions to be addressed:

- Instrument of choice is $f$(what question you are asking).
- Tradeoffs include:
  - Aspatial resolution vs.
  - Afield of view vs.
  - Apolarization sensitivity vs.
  - Atemporal resolution vs.
  - Aspectral resolution vs.
  - Aheight sampled

=(generally get good on two, decent on a third, fail on the rest
=(caveat new technologies/approaches, cf CdF's idea, others?).

Q: Large-scale magnetic changes
T: FOV, P, dt, z
A: SOLIS, SDO (nothing available now)

Q: Active-Region scale magnetic changes
T: FOV, dx, P, t
A: IVM, MSFC, BBSO, Huairou, ASP; future: DLSP, SOLIS, Solar-B, SDO

Q: Physical description of magnetic properties of Blarch (where Blarch is $<1''$ or thereabouts)
T: P, dx, d$\lambda$, z
A: ASP, DLSP (soon), IVM, Solar-B (soon)

Q: Energetic event initiation
T: dt, dx, P, FOV
A: IVM, BBSO, Huairou, SDO (soon)
Summary

Do photospheric B measurements have any useful contribution to understanding Solar Energetic Events?

A yes, qualitatively (it probably has something to do with the solar atmosphere, but there is a disconnect between the photosphere and where energetic events are initiated).

A possibly, quantitatively (new methods are being developed to make use of but not over-use the photospheric measurements)

A no, as has generally been approached ("bumps and wiggles" approaches to variations in photospheric B relative to flares/CMEs is now out-dated; causal relationships and statistical approaches must be used)

Are we looking for our keys where the street light happens to be?

A Photospheric vector magnetic field data are generally available and fairly well-understood.

A However, the degree to which the photosphere is directly informative about energetic events is unclear

A Chromospheric vector magnetic field observations may provide more direct measures applicable to understanding solar flares/CMEs.