Variation with disk position in large-scale flows using GONG data

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Motivation

- East-West trend needs to be removed for evolution of active regions
- $B_0$-angle variation noticed in meridional flow
- Are average large-scale flows affected by these variations with disk position?
Analysis

- GONG data
- Choose epoch of minimum magnetic activity
- 2 years of data; average $B_0$ angle is zero.
- Assumption: large-scale flows do not vary with CMD in the quiet Sun.
Disk-averaged flows

Zonal (left) and meridional flows (right) are averaged over all 27 CRs for each disk position.
Why two years?

Average $B_0$ angle is zero.

5 CRs with $B_0 > 6^\circ$, $B_0 < -6^\circ$, and $|B_0| < 2^\circ$
$B_0$ angle and flow errors

Zonal flow error is small along central meridian.
Positive $B_0$: large error in south high latitude;
Negative $B_0$: large error in north high latitude.
B₀ angle and flow errors

left: B₀=6.7°; middle: B₀=0°; right: B₀=-6.8°

Meridional flow error is small along equator. Error is smaller in direction perpendicular to flow direction: ellipse not a circle.
Zonal flow shows east-west asymmetry at all latitudes for $B_0=0^\circ$. 
Left: zonal flow; right: mean subtracted.
Zonal flow shows east-west asymmetry at all latitudes but especially in the southern hemisphere for $B_0=6.7^\circ$. 

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Meridional flow shows east-west asymmetry at high latitudes for $B_0=0^\circ$. But not near equator. Left: meridional flow; right: mean subtracted.
Meridional flow shows east-west asymmetry at high latitudes especially in the South for $B_0=6.7^\circ$. Again not near equator.
Zonal flow at 0.6 Mm

left: $B_0=6.7^\circ$; middle: $B_0=0^\circ$; right: $B_0=-6.8^\circ$

Zonal flow shows east-west asymmetry. $B_0$ angle produces pattern reversal (counter cell?). Asymmetry might average out in synoptic maps.
Zonal flow at 2.0 Mm

left: $B_0=6.7^\circ$; middle: $B_0=0^\circ$; right: $B_0=-6.8^\circ$

Zonal flow shows east-west asymmetry modulated by $B_0$ angle.
Asymmetry might average out in synoptic maps.
Zonal flow at 7.1 Mm

left: $B_0=6.7^\circ$; middle: $B_0=0^\circ$; right: $B_0=-6.8^\circ$

Zonal flow shows east-west asymmetry modulated by $B_0$ angle.
Asymmetry might average out in synoptic maps.
Zonal flow shows east-west asymmetry modulated by $B_0$ angle.
Asymmetry might average out in synoptic maps.
Zonal flow at 15.8 Mm

left: $B_0=6.7^\circ$; middle: $B_0=0^\circ$; right: $B_0=-6.8^\circ$

Zonal flow shows east-west asymmetry modulated by $B_0$ angle.
Asymmetry might average out in synoptic maps.

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Meridional flow at 0.6 Mm

left: $B_0=6.7^\circ$; middle: $B_0=0^\circ$; right: $B_0=-6.8^\circ$

Meridional flow shows east-west asymmetry modulated by $B_0$ angle. Counter cell at this depth in GONG data.
Meridional flow at 2.0 Mm

left: $B_0=6.7^\circ$; middle: $B_0=0^\circ$; right: $B_0=-6.8^\circ$

Meridional flow shows east-west asymmetry. $B_0$ angle reverses east-west pattern.
Meridional flow at 7.1 Mm

left: $B_0 = 6.7^\circ$; middle: $B_0 = 0^\circ$; right: $B_0 = -6.8^\circ$

Meridional flow shows east-west asymmetry.
$B_0$ angle reverses east-west pattern.
Meridional flow at 11.6 Mm

left: $B_0=6.7^\circ$; middle: $B_0=0^\circ$; right: $B_0=-6.8^\circ$

Meridional flow shows east-west asymmetry. $B_0$ angle reverses east-west pattern.
Meridional flow at 15.8 Mm

left: $B_0=6.7^\circ$; middle: $B_0=0^\circ$; right: $B_0=-6.8^\circ$

Meridional flow shows east-west asymmetry $B_0$ angle reverses east-west pattern.
Summary

- Flow in direction of foreshortening leads to large error. $B_0$-angle effect more noticeable in meridional flow.
- Zonal flow shows E-W asymmetry.
- Meridional flow shows E-W asymmetry mainly at high latitudes.
- $B_0$-angle variation complicates the pattern.
- What will HMI show?