Helicity observations as a constrain on solar dynamos

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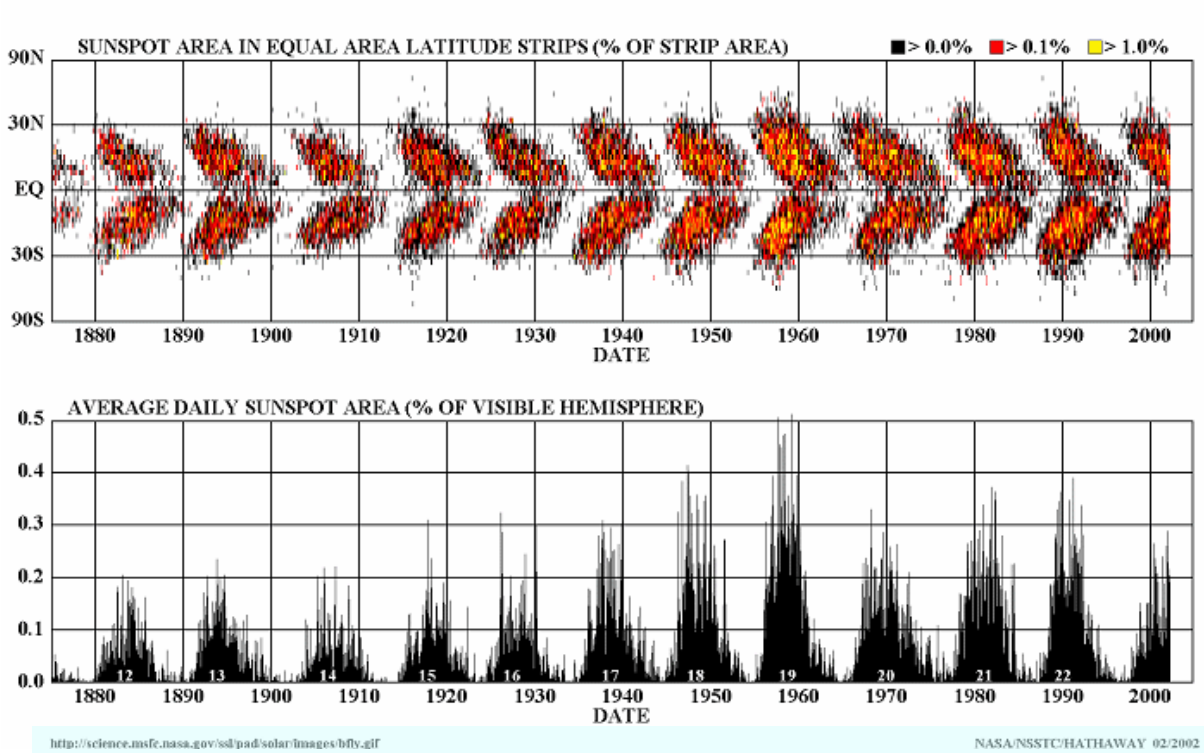
Plan of the Talk

1. Motivation & Mythodology
2. Helicity Observations
   (1) Current helicity in active regions
   (2) Current helicity outside active regions
   (3) Kinetic helicity
3. In Dynamo Models
4. Concluding Remarks

Motivation: Helicity produced by dynamo



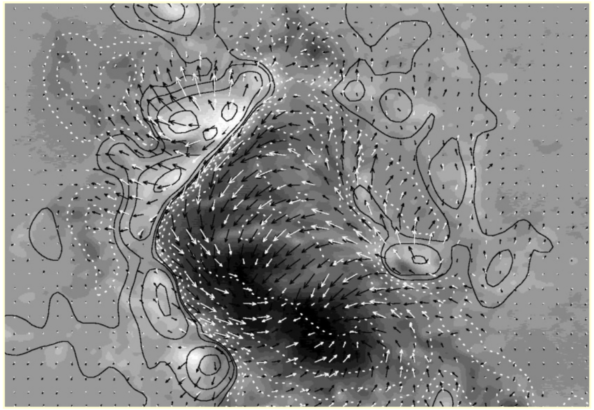
Solar dynamo produces magnetic field in the convection zone. The field emerges to the surface and presents as solar cycle.

Observing helicity patterns produced by solar dynamo would help us understand the dynamo process in the interior, in addition to the traditional butterfly diagram and sunspot numbers.

Obs. Method No.1:

Vector B (on the photosphere)

➔ non-potentiality (helicity)

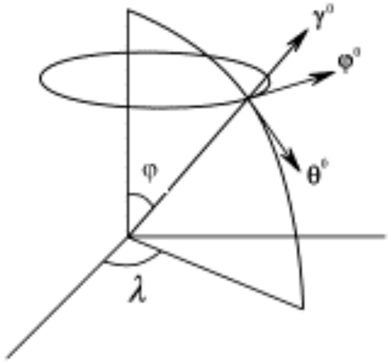


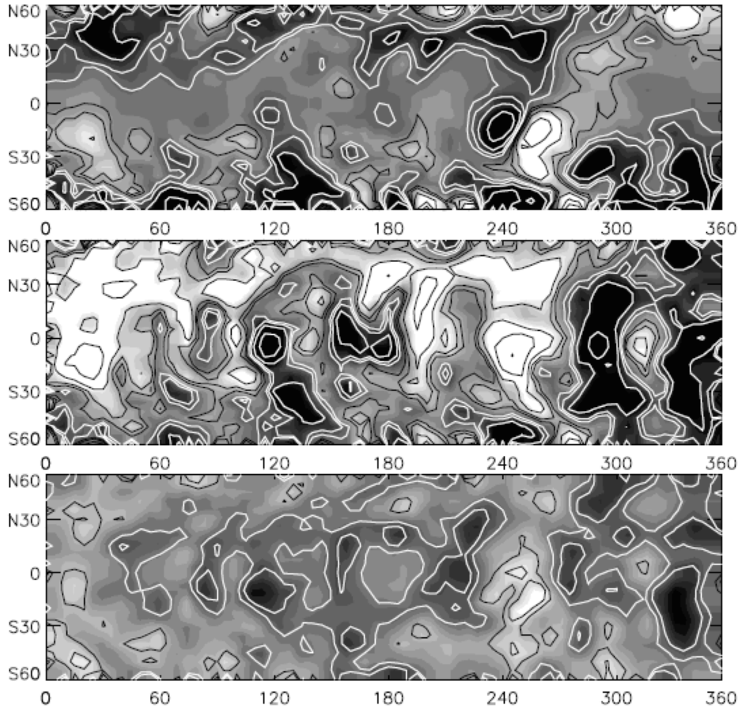
- **Shear angle** $\Delta\phi = \phi_o - \phi_p$ ϕ :azimuths
- **Current (J_z)** $J_z = \frac{1}{\mu_0}\left(\frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y}\right).$
- **Twist (α_z)** $\alpha_z = (\nabla \times B)_z / B_z$
- **Twist (α_{best})** $\nabla \times B = \alpha_{best} B$
- **Current helicity (h_c)** $\boxed{h_c = B_z \cdot (\nabla \times B)_z}$
- **Current helicity imbalance (ρ_h)** $\rho_h = \frac{\sum h_c(i,j)}{\sum |h_c(i,j)|} 100\%,$

Obs. Method No.2: Reconstruction of vector magnetic field in global field

Assuming variation of B_{long} (over days) is a projection effect only.

$$B_{\text{long}}(\varphi, \lambda) = \mathscr{R}(\varphi, \lambda) \cos \lambda \cos B_0 + \mathscr{P}(\varphi, \lambda) \sin B_0 + \mathscr{T}(\varphi, \lambda) \sin \lambda \cos B_0, \quad (1)$$





Reconstructed B_r, B_θ, B_φ (from top to bottom) of one solar rotation (~ CR1914).

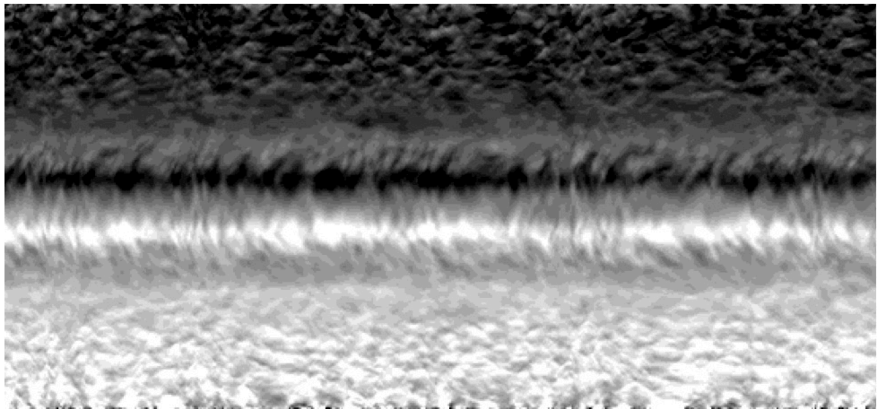
$$h_c(\phi, \theta) = B_r(\nabla \times B)_r$$

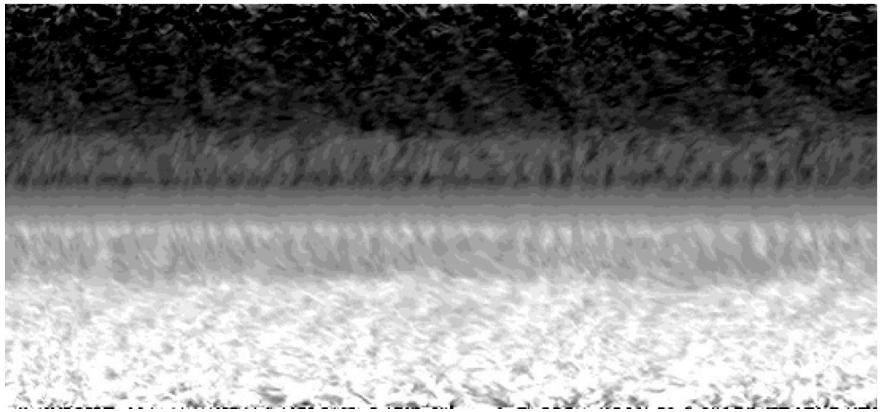
Obs. Method No.3: Kinetic helicity

with horizontal flow obtained by local helioseismology

$$h = \mathrm{div}\boldsymbol{v}\,\mathrm{curl}\boldsymbol{v},$$

(Vertical component of kinetic helicity)





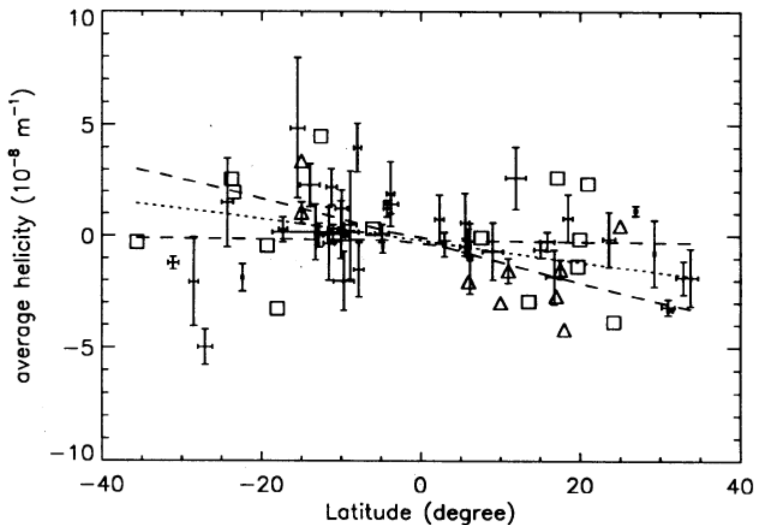
$$H_k = \boldsymbol{\omega}\cdot\boldsymbol{v}$$

$$h = \mathrm{div}\boldsymbol{v}\,\mathrm{curl}\boldsymbol{v},$$

H_k and h are in proportion, data from Miesch & Brown (2012)

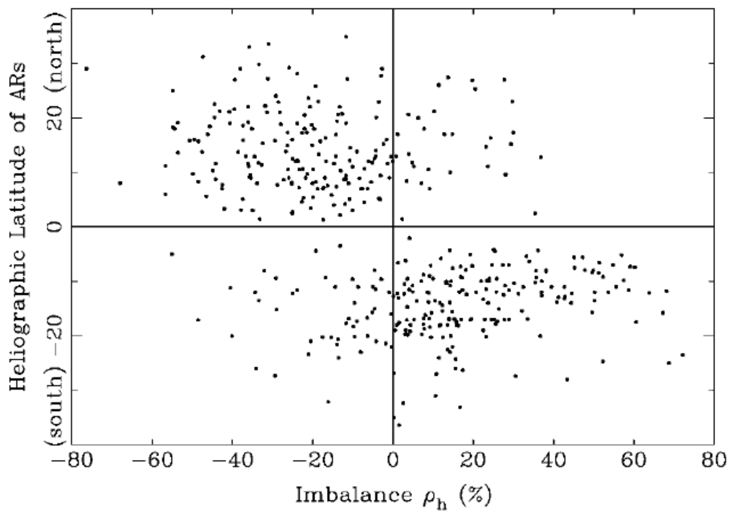
<u>Obs. No.1</u>: Hemispheric helicity sign rule

Twist (α_z)



(Pevtsov et al., 1995, ApJ, 440, L109)

Current helicity imbalance



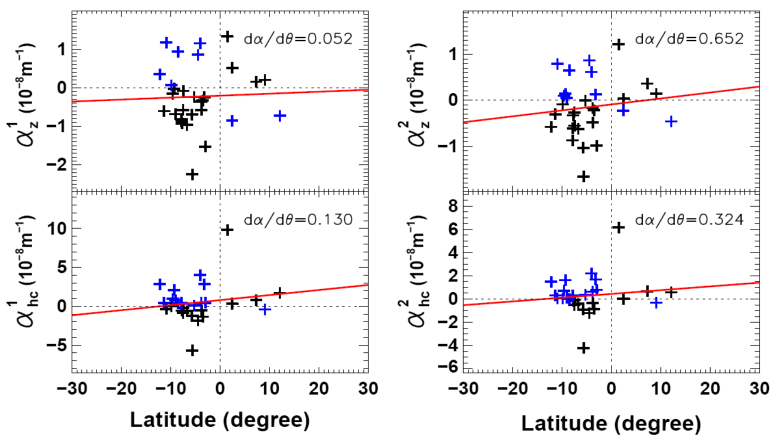
(Bao SD & Zhang H., 1998, ApJ, 496, L43)

Statistically, In the northern hemisphere: α_z, α_{best}, h_c, ρ_h <0

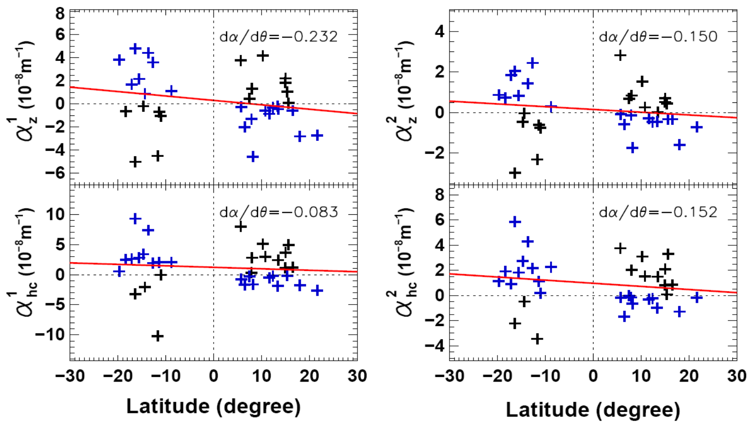
In the southern hemisphere: α_z, α_{best}, h_c, ρ_h >0

Obs. No.2: Solar-cycle variation of hemispheric rule in active regions

Descending phase of Solar Cycle 23



Ascending phase of Solar Cycle 24



Do not follow the usual hemispheric helicity sign rule.

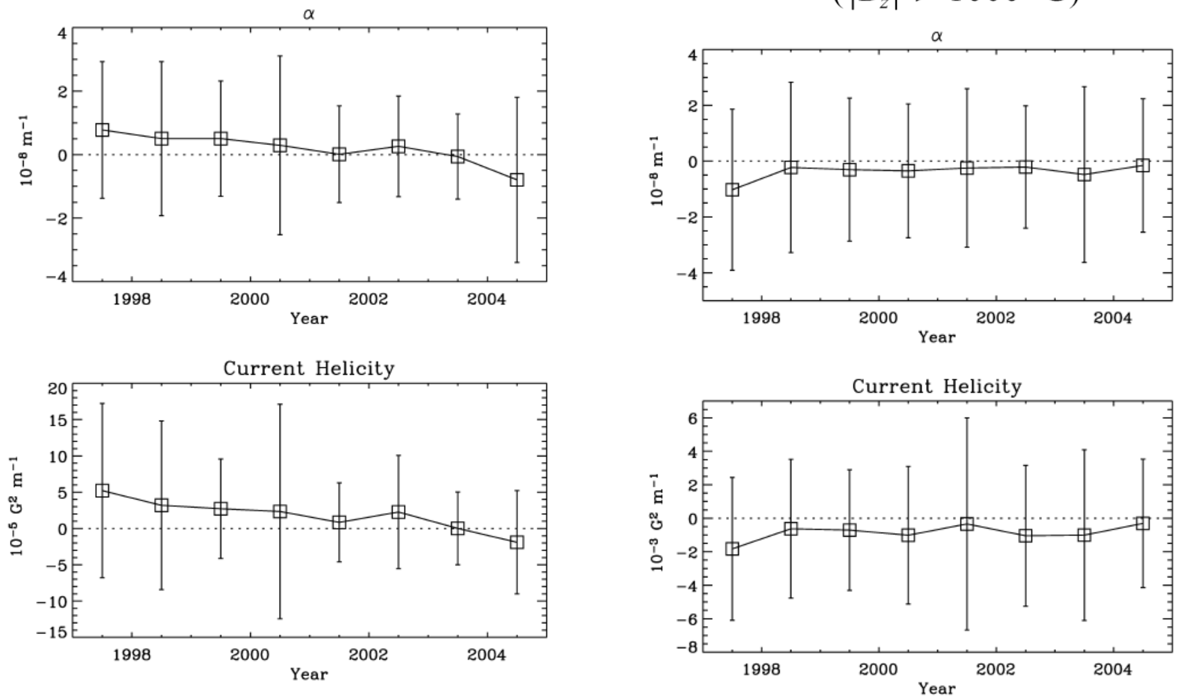
Follow the usual hemispheric helicity sign rule.

(SP/Hinode data)

(Hao J & Zhang M, ApJ, 2011, 733, L27)

Obs. No.3: Weak and Strong fields possess opposite helicity signs

$(100\ \mathrm{G} < |B_z| < 500\ \mathrm{G})$ $(|B_z| > 1000\ \mathrm{G})$



Huairou data
17200 maps
(January 1997 - August 2004)

weighted average, over a whole year

weights:
-1: northern
+1: southern

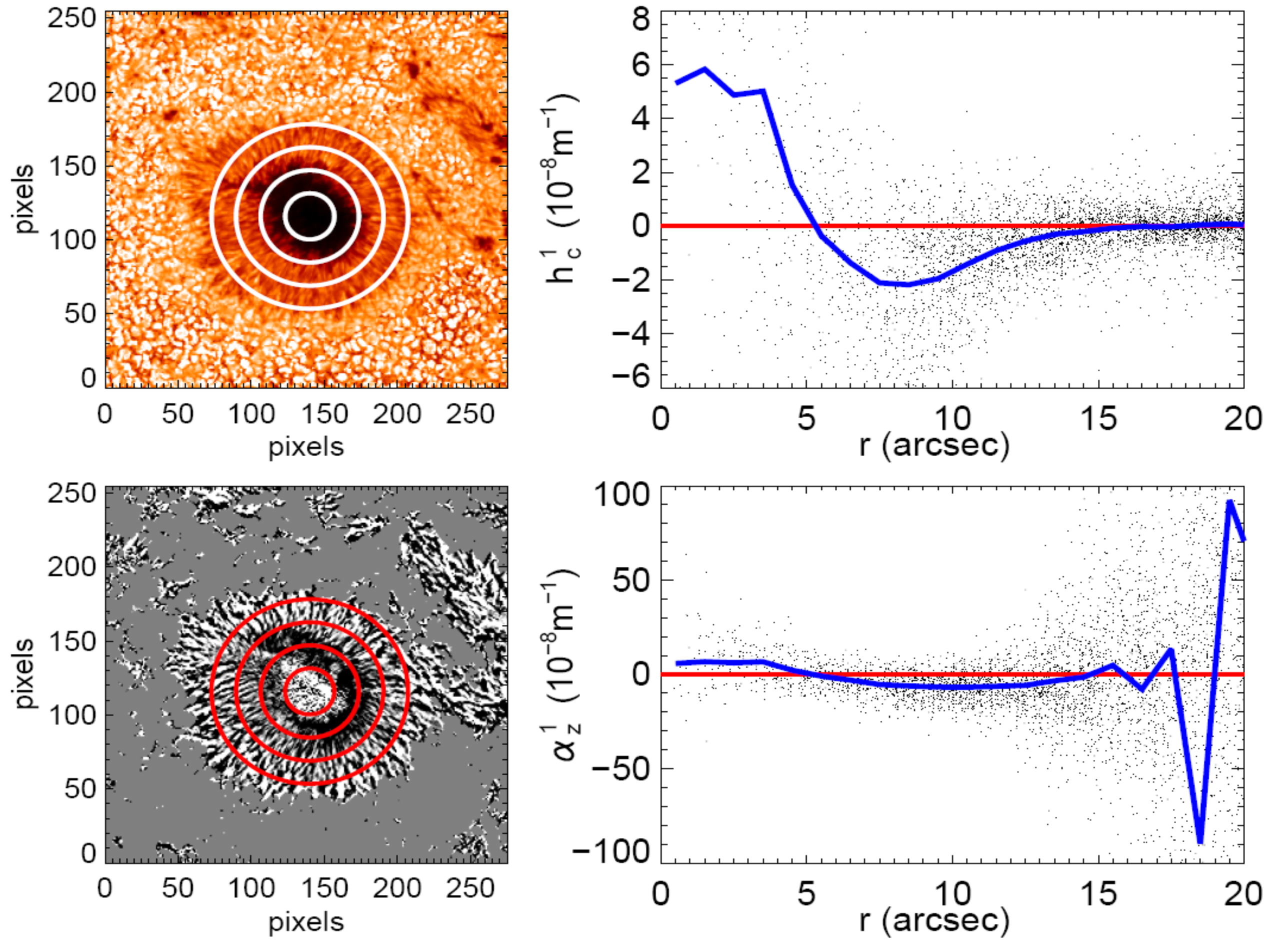
***Weak fields*: Following established hemispheric rule**

***Strong fields*: Helicity sign opposite to that of weak fields**

(Zhang M, ApJ, 2006, 646, L85)

Confirmed by SP/Hinode: Strong (umbra) and weak (penumbra) fields show opposite helicity sign.

NOAA 10940
(Feb 1, 2007)

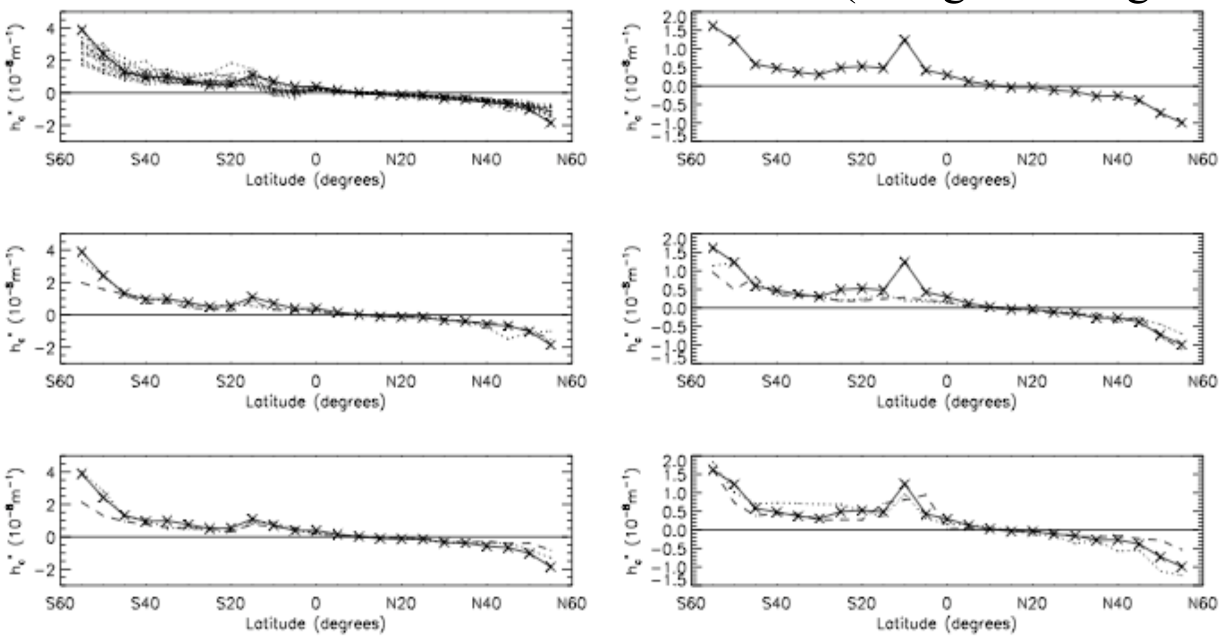


(Hao J & Zhang M, ApJ, 2011, 733, L27)

<u>Obs. No.4</u>: In global magnetic field

The same hemispheric helicity sign rule exists, extending to 60 degrees high in latitudes, and is preserved through the whole solar-cycle.

(Wang & Zhang 2010, ApJ, 720, 632)



Left: MDI; (September 1996) Right: KPVT

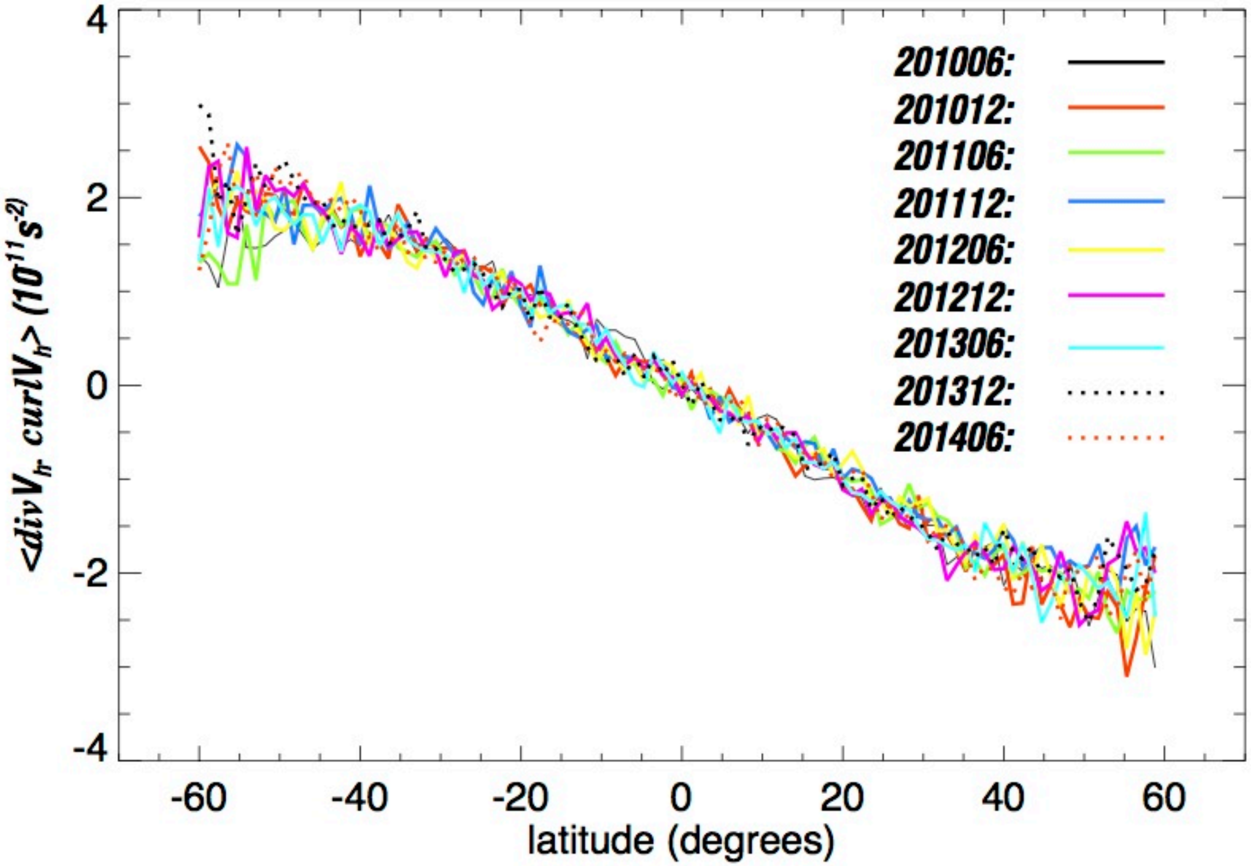
Obs. No.5: No solar-cycle variation on kinetic helicity

Each line:

one-month

averaged

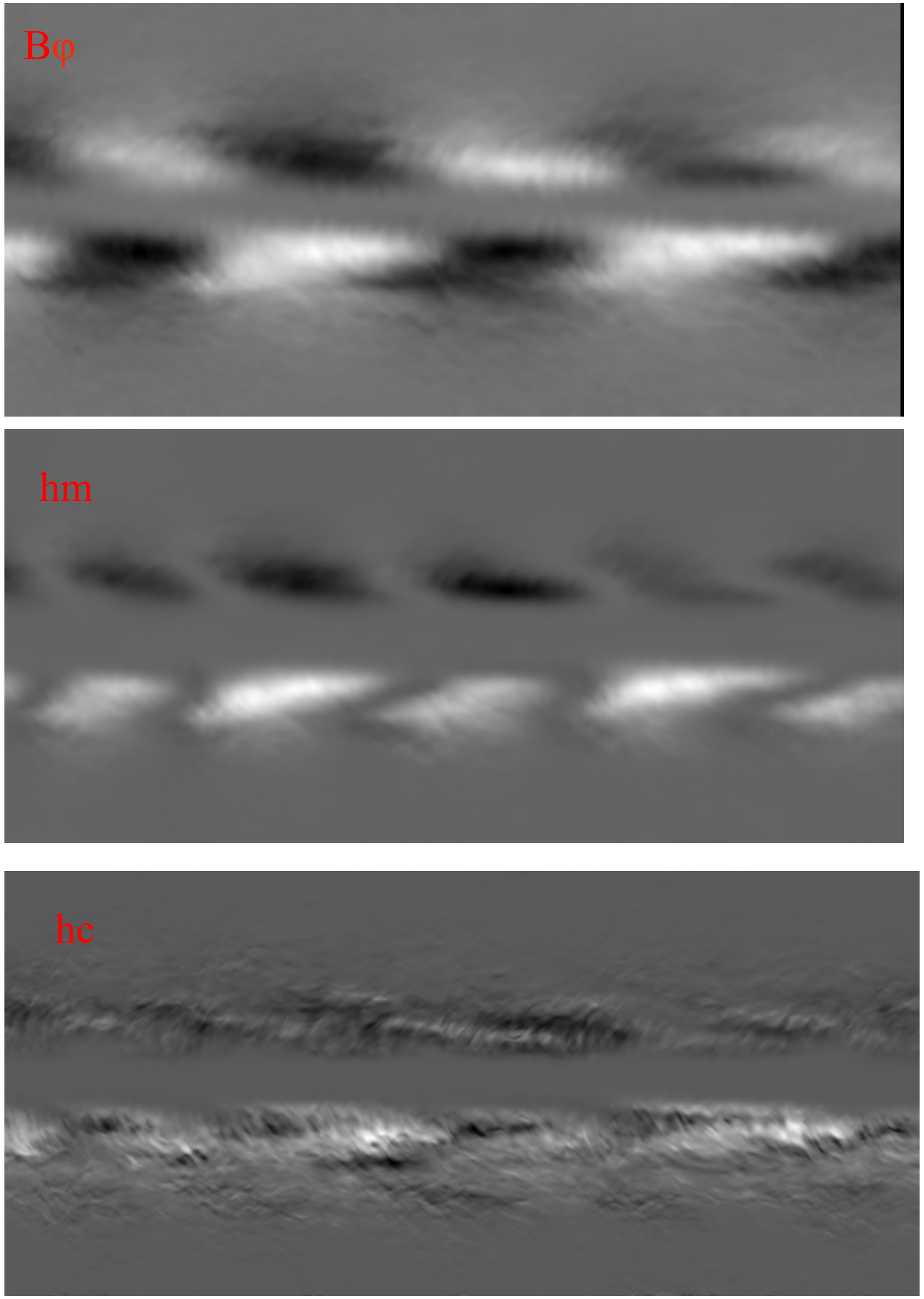
(r= 0 - 1 Mm)



Question: How could a non-solar-cycle-varied kinetic helicity to produce a solar-cycle-varied current helicity in active regions?

These observations put constrains on the mechanism of helicity production as well as on dynamo models.

Will these helicity characters present in dynamo models? Can they be used to distinguish different dynamo models?

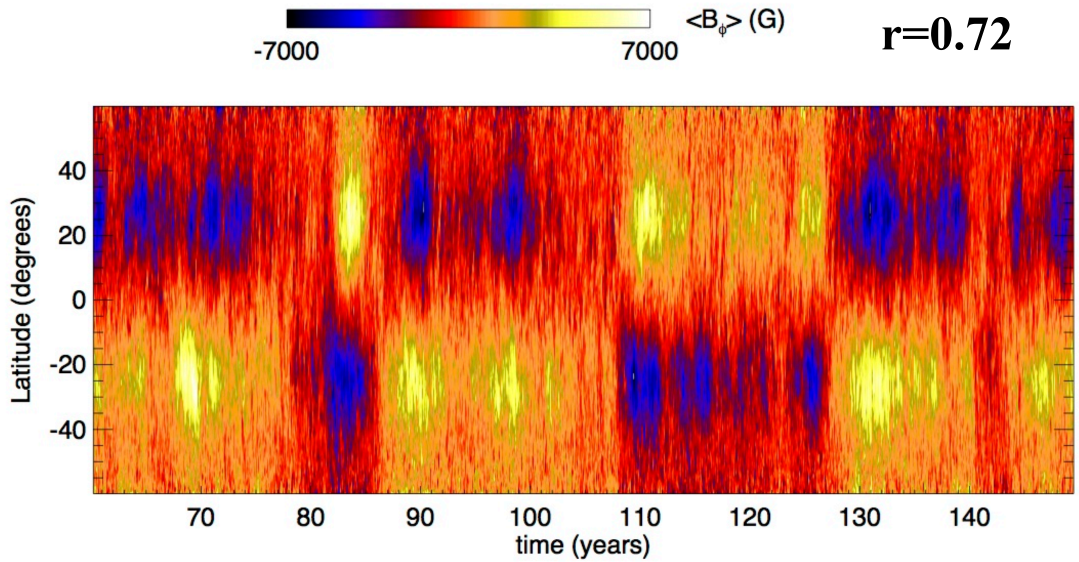


(r=0.96, 28Mm)

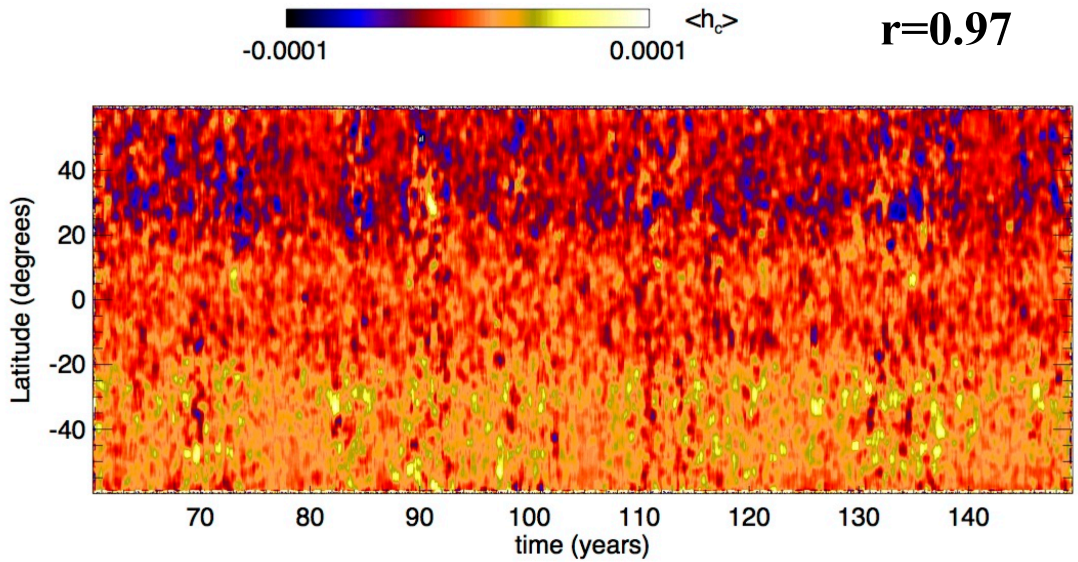
A Convective Babcock -Leighton Dynamo Model (Miesch & Brown 2012)

Hemispheric helicity sign rule shows up clearly in magnetic helicity density map.

Current helicity does show cycle variation, with opposite-sign patches presenting in each hemisphere.



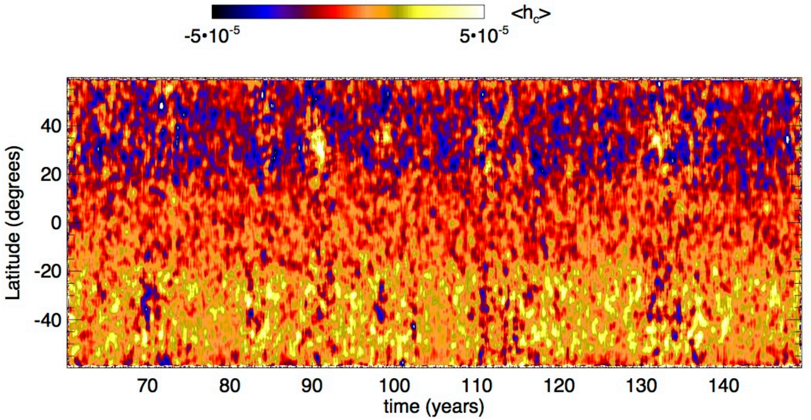
MHD Dynamo Model (Fan & Fang 2014)



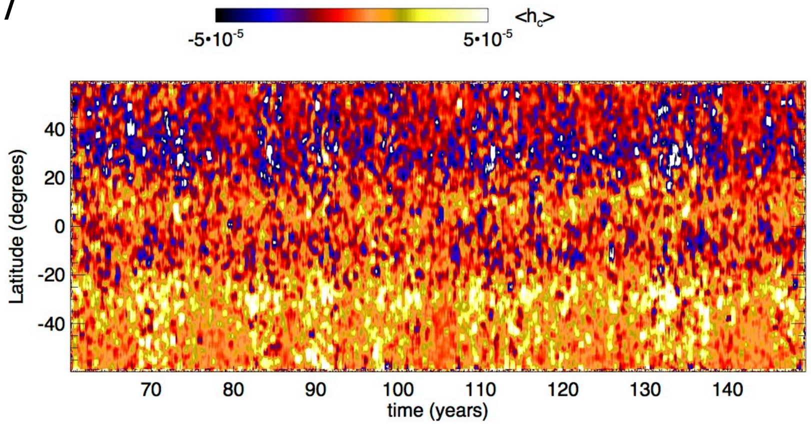
Hemispheric sign rule presents clearly in current helicity, although shows no obvious cycle variation.

If we separate weak and strong fields,

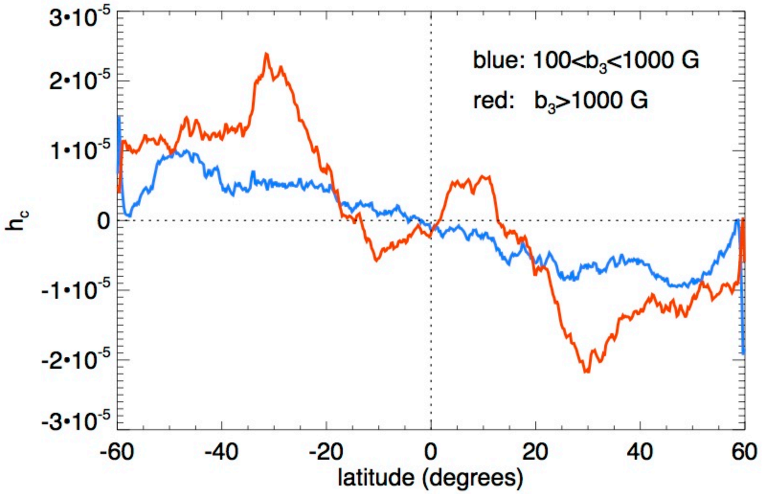
r=0.97



100 G < |b_3| < 1000 G

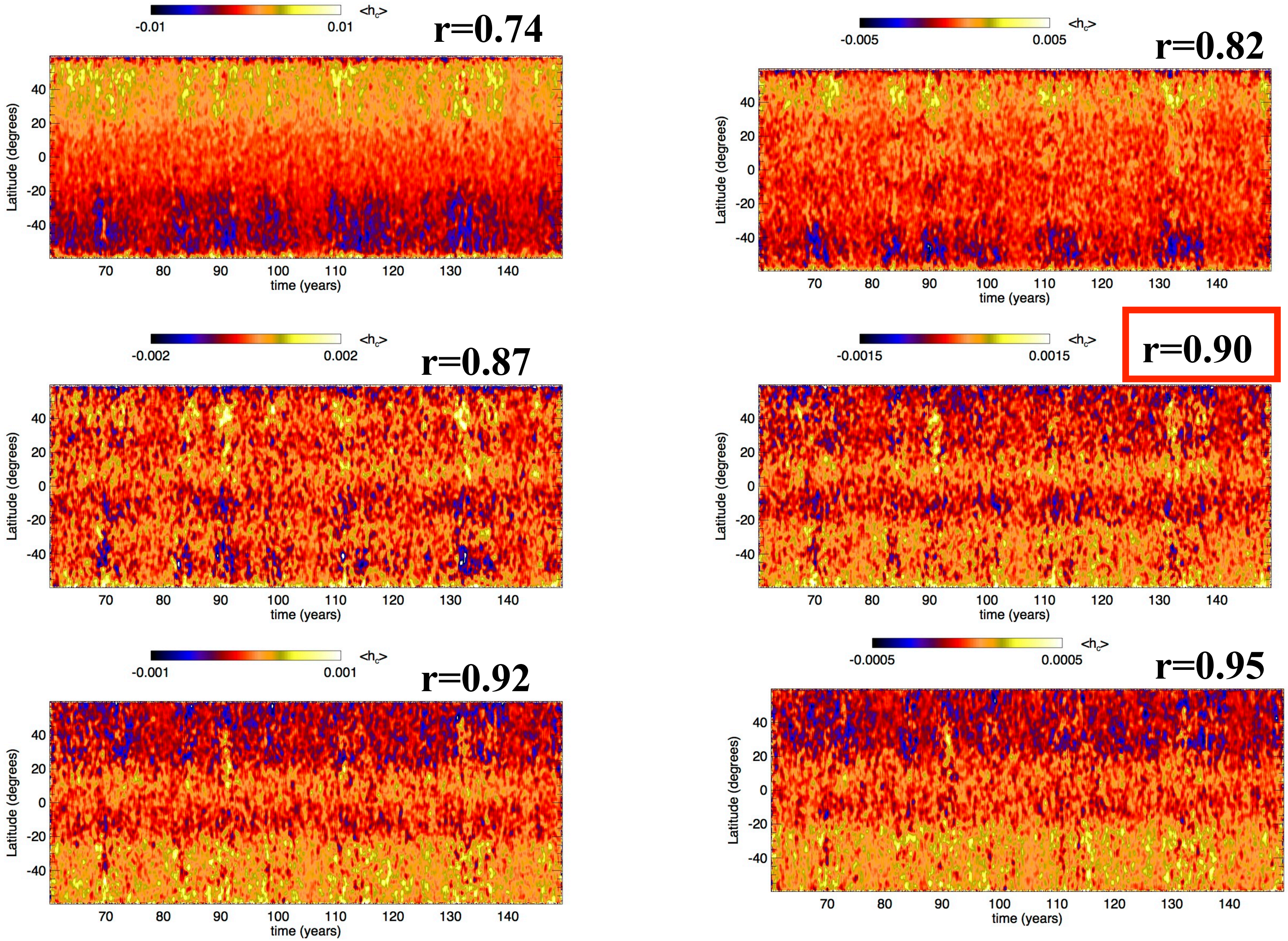


|b_3| > 1000 G



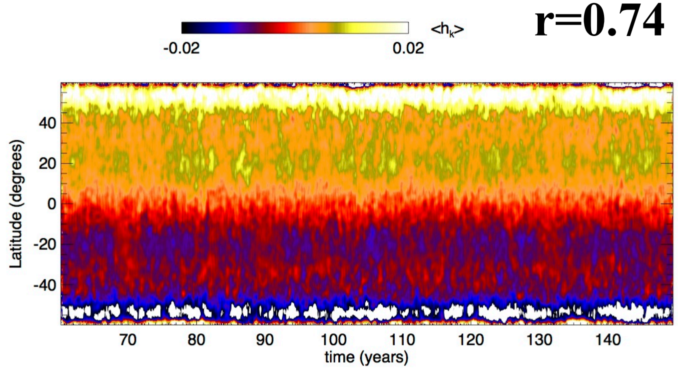
Opposite helicity sign between weak and strong fields presents, in low latitudes (active-region belt).

Opposite hemispheric rule in deep and shallow layers. Strong field comes from deeper?

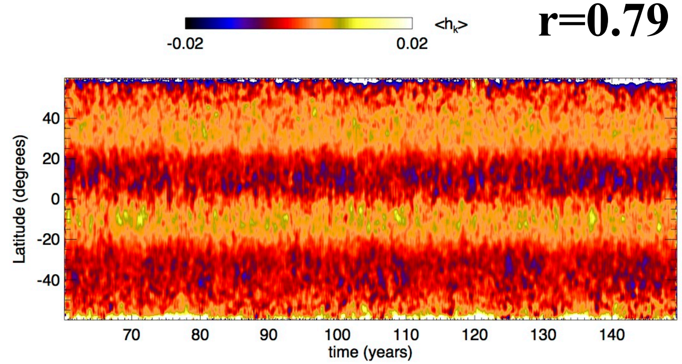


Kinetic helicity becomes 'normal' in relatively deeper layers. Evidence still kinetic helicity produces current helicity?

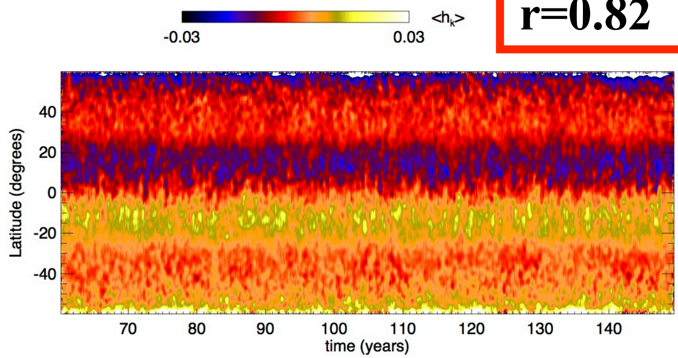
r=0.74



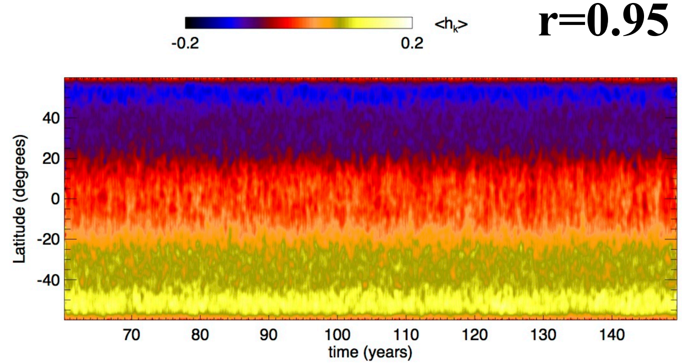
r=0.79



r=0.82



r=0.95

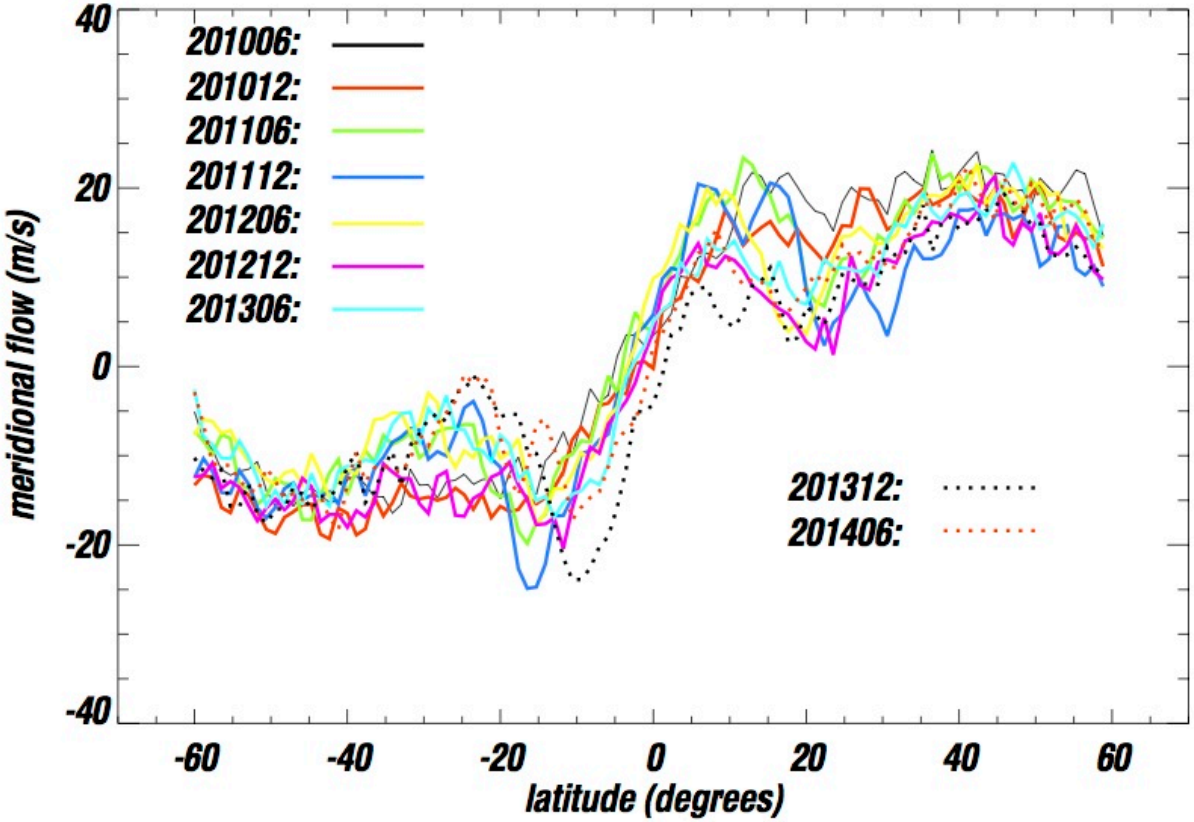


Concluding Remarks

- Observing helicity characters provides us a chance to understand the dynamo process in the interior.
- The hemispheric helicity sign rule is evident on the photosphere, both in active regions and global fields.
- The hemispheric helicity sign rule presents a solar-cycle variation in active regions, where weak and strong field show opposite helicity signs.
- No solar-cycle variation of subsurface kinetic helicity is found.
- Some observed helicity characters also present in dynamo models.


Thank you !

Solar cycle variation of meridional flow?



Yes, as reported before in Zhao & Kosovichev (2004).

Means that our non-detection on H_k is not by large noise.