Solar Open Flux Migration from Pole to Pole: Magnetic Field Reversal

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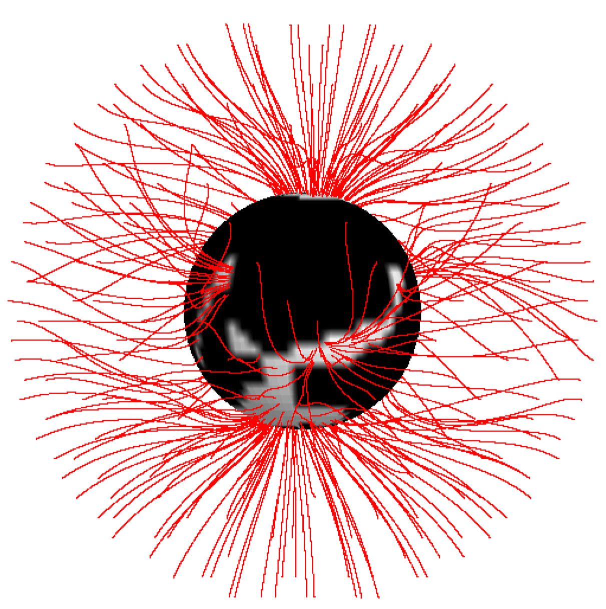
1 / Abstract

Coronal holes are solar regions with magnetic field lines extending far away from the Sun, and thus they are often identified as regions with open magnetic field lines. Coronal holes are concentrated in the polar regions during the sunspot minimum phase, and spread to lower latitude during the rising phase of solar activity. In this work, we identify coronal holes with outward and inward open magnetic fluxes being in the opposite poles during solar quiet period. We find that during the sunspot rising phase, the outward and inward open fluxes perform pole-to-pole trans-equatorial migrations in opposite directions. The migration of the open fluxes consists of three parts: open flux areas migrating across the equator, new open flux areas generated in the low latitude and migrating poleward, and new open flux areas locally generated in the polar region. All three components contribute to the reversal of magnetic polarity. The percentage of contribution from each component is different for different solar cycle. Our results also show that the sunspot number is positively correlated with the lower-latitude open magnetic flux area, but negatively correlated with the total open flux area.

2 / Instruments and Data

We used the radial field synoptic maps from Wilcox Solar Observatory (WSO). The data ranges from CR1642 to CR2158 (about 40 years).



Resolution of the synoptic maps are 72 x 30.

We adopted the Potential Field Source Surface (PFSS) model[2], which can be found on SolarSoft[3].

The soure surface is set at $R_{ss} = 2.5R_{sun}$.

Magnetic field lines are traced from R_{ss} downward to R_{sun}.

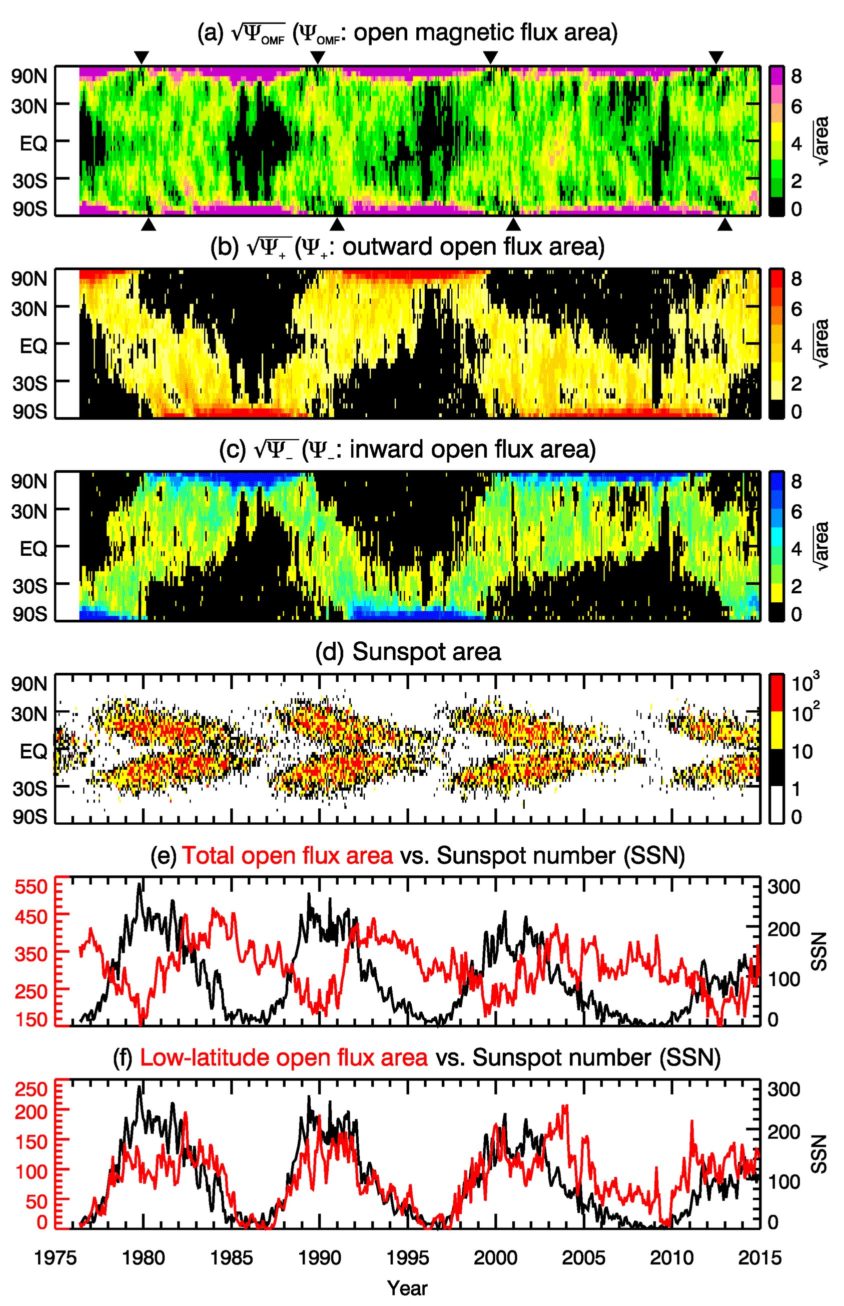
An equal-area open flux map is created with resolution 60 x 30.

Pixels nearest to the footprints of magnetic field lines are identified as open fluxes.

3 / Solar cycle variations of open fluxes

We defined the unsigned (Ψ_{OMF}), outward (Ψ_+), and inward (Ψ_-) open flux area maps, by summing their area along the longitudinal axis.

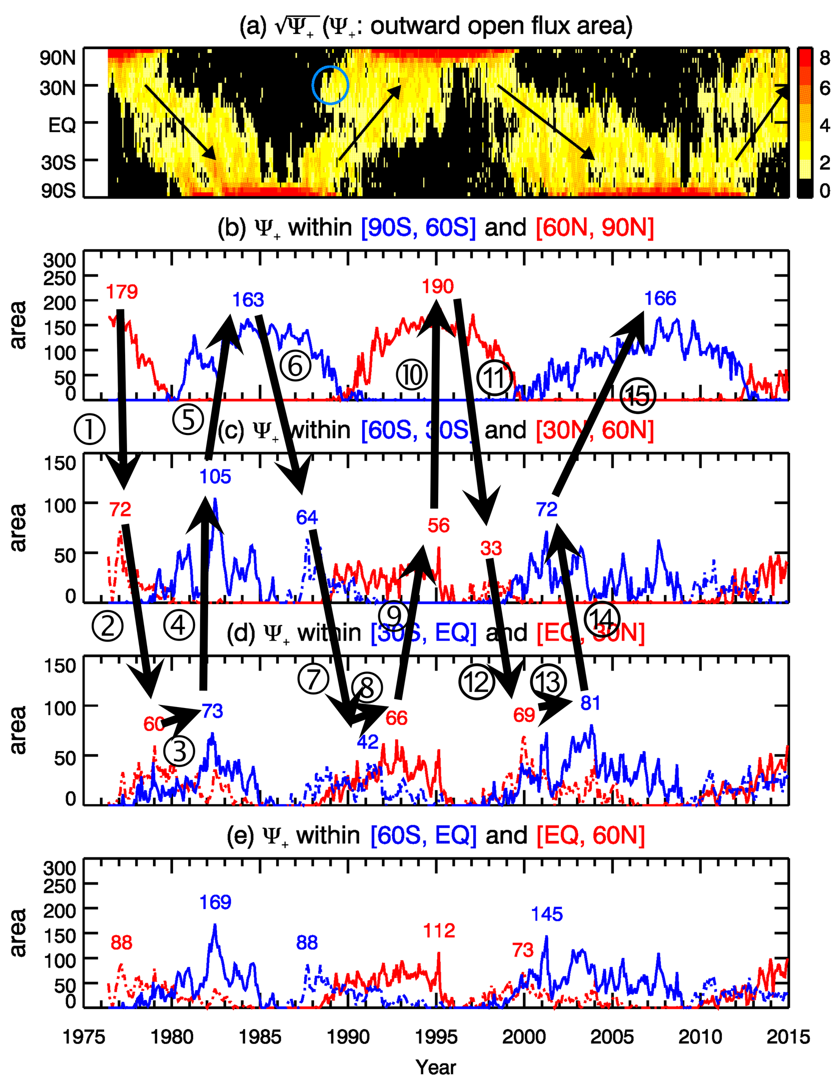
Square-roots are taken for better visibility of patterns. A sunspot area map (butterfly diagram) was constructed using the data from Royal Greenwich Observatory.



- Ψ_{OMF} is generally symmetric at two poles.
- Ψ_+ and Ψ_- reveal a pole-to-pole trans-equatorial pattern.
- In contrast, sunspots migrate toward the equator, but not across it.
- Total open flux area is negatively correlated to sunspot number.
- Low-latitude open flux area is positively correlated to sunspot number, except for the descending phase of Solar cycle 23 (2004—2009).

4 / Generation and Dissipation of open fluxes

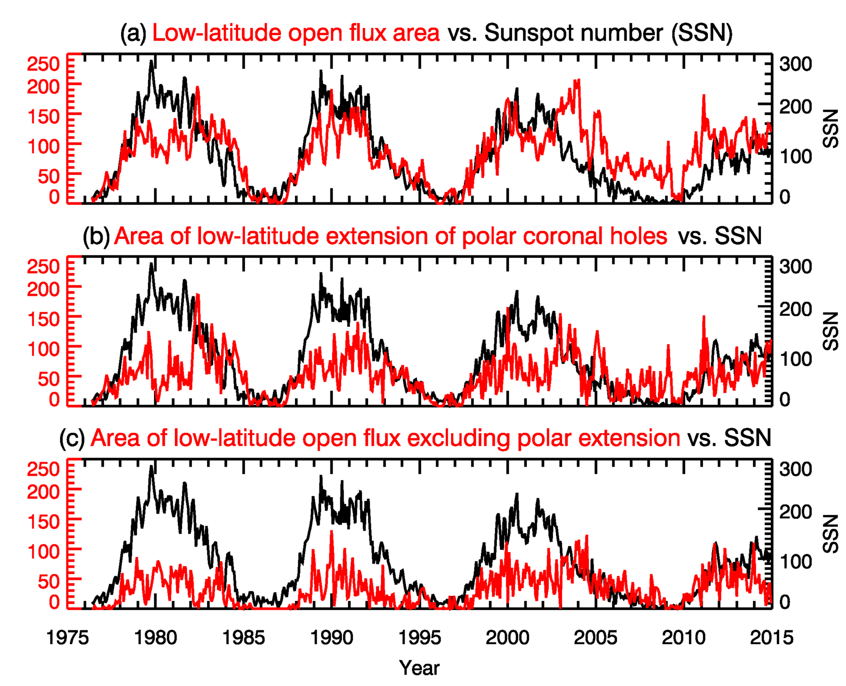
Summing up Ψ_+ over polar, mid-latitude, and low-latitude ranges at two hemispheres:



- From mid-latitude to polar (⑤ ⑩ ⑮), the peak area increases, indicating the generation of open fluxes.
- Similarly, from south low-latitude to south mid-latitude (④), the peak area increases.
- However, in some cases (⑨ ⑭) the peak area decreases, indicating the dissipation of open fluxes.

5 / Polar coronal holes with low-latitude extensions

Some polar coronal holes can extend to low-latitude or the other hemisphere. In such cases, the low-latitude open flux area would be over-estimated.



a) Low-latitude flux area is positively correlated to sunspot number, except for the descending phase of Solar Cycle 23 (2004—2009).

b) Total area of polar coronal holes with equatorial extension.

c) Subtracting (b) from (a), the anomaly of low-latitude open flux area in 2004—2009 is reduced.

6 / Summary

1. The evolution of open fluxes is generally symmetric at two poles.
2. We observed a pole-to-pole trans-equatorial migration pattern of inward and outward open fluxes.
3. Observations showed that open fluxes is locally generated or dissipated while migrating to the other hemisphere.
4. The total open flux area is negatively correlated to sunspot number.
5. The low-latitude open flux area is positively correlated to sunspot number, except for the descending phase of Solar Cycle 23.
6. The anomaly in the Solar Cycle 23 may be caused by the polar coronal hole with low-latitude extensions.
7. Our observations can provide observational constraints to the solar dynamo models.

7 / References

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2. Schatten, K. H., Wilcox, J. M. & Ness, N. F., Solar Physics, 6, 442–455 (1969).
3. Freeland, S. L., and Handy, B. N., Solar Physics, 182, 497 (1998).