Update to the Babcock-Leighton Solar Dynamo and Activity Predictions

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Outline

• UPDATE BABCOCK-LEIGHTON DYNAMO
  1) Shallow Dynamo
  2) Percolation controls small-scale motion
  3) Magnetic forces control large-scale motion

• PERCOLATION COMES IN TWO FLAVORS:
  1) Highly Superadiabatic:
     Convection drives like-sign Ephemeral Regions (EPRs) into sunspots
  2) Normal:
     Normal T structure: field concentrations disperse: spots-> faculae / plage

• MODELING:
  Cellular Automata Modeling – relate to observations & solar dynamo

• PREDICTION:
  Solar Cycle #24 Rz~75; F10 ~125 in ~2012-3
Babcock-Leighton Solar Dynamo

Physical basis for solar and geomagnetic precursor techniques

Solar Dynamo

(a) polarfields

rotation

Solar Min

(b) active regions

Solar Max
Magnetic Carpet & Percolation

Above the Photosphere

In highly superadiabatic environment, like-field drawn together by percolation

Below the Photosphere:
In regions of high superadiabaticity, like fields drawn together

Parker (1984) field sequestered into fibrils by convective flow: field drawn into tight bundles

From Lockheed Group
Percolation Allows Field to Separate from the Flow – Remain Shallow Falling Leaf Instability

Flow can be diverted around field. Flow goes deep, but field can remain shallow!
Superadiabatic Temperature Gradient: Large in Top Layers

Fig. 3.—Amount of ionized hydrogen $\alpha$, its gradient, and the adiabatic exponent $\Gamma_1$ are shown (left panel) throughout the convection zone. The second panel shows the “normal” temperature structure of the convection zone. The shaded area represents the superadiabatic “free energy” available to drive instabilities. Within this central zone, the material is “conditionally unstable,” depending on the amounts of neutral vs. ionized hydrogen present. A general downflow motion (third panel) and upflow motion (right) affect the superadiabatic gradient as shown. The downflow motion enhances the temperature gradient so that more free energy is available (shaded area) for instabilities, and “ion hurricanes” develop. The upflow motion (right panel), however, reduces the free energy available for instabilities, and ion hurricanes are less likely to develop.
Overview – Shallow Dynamo:

A) and B) – Superadiabatic Percolation

C) Normal Percolation
Overview – Shallow Dynamo

Like Babcock-Leighton, but with 1) EPRs and 2) motion from B forces

Development of Fields During an Odd # Cycle:
NH Following Flux => NH pole; NH Preceding Flux => SH pole
Vice Versa for SH Fluxes, and Even # Cycles
Superadiabatic Percolation Model

10% Fill, Random Fields, of Two Signs amidst null field

3 motion steps with Energy reduction

10% Fill, Random Field, of Two Signs in a null Background

25 motion steps with Energy reduction

7 motion steps with Energy reduction

30 motion steps with Energy reduction

The Percolation Process

200 motion steps with Energy reduction

1000 motion steps with Energy reduction

The Percolation Process
Percolation

Superadiabatic

Time Series of Superadiabatic Percolation of Ephemeral Region

Super + Drift → Normal + Drift

Superadiabatic Percolation, Field Drift, and Normal Percolation into Unipolar Magnetic Regions (UMRs)
Modeling and Observations

Percolation of Ephemeral Regions in an External Subsurface Field

Hinode “Trilobite” Movie
Modeling and Observations

A  Carrington Rots. #1880-1884

B

C

D  SUPERSYNOPTIC & SYNOPTIC MAPS OF THE SUN’S MAGNETIC FIELDS: SOLAR CYCLE #22

1

2

3

4

5

6

MODELED BIPOLAR MAGNETIC REGIONS (BMRs): PERCOLATION WITH SUBADIABATIC GRADIENT + DRIFT FROM DIPOLE FIELD + DIFFERENTIAL ROTATION
400 & 100 Year Modeling
Polar Fields vs. Time

North Polar Field Data
South Polar Field Data

Time, Years
Polar Fields, arbitrary units

Different Longitudes, Both Polar Fields

Time, years
Magnetic Field, arbitrary units
How Spot Flux Imbalances Form
(Why spots are not all equal bipoles)

Superadiabatic Percolation of EPRs in a Unipolar Magnetic Region (UMR)

Superadiabatic Percolation of EPRs at a (UMR/Sector) Magnetic Boundary
SODA (Solar Dynamo Amplitude) Index

SODA index vs time, years

- Toroidal proxy (radio flux)
- Polar Field (soda units)
- SODA index
Schatten Prediction: Weak Solar Cycle 24

Use of the idea that the Sun’s polar field is a precursor for the next cycle’s activity level [Schatten et al. (1978)]; Svalgaard et al. (GRL, 32, L01104, 2005); Schatten (GRL, 32, L21106, 2005)

F10.7 Observations and Predicts

![Graph showing F10.7 observations and predictions with data points and a trend line indicating activity levels from 1970 to 2020.]
Geomagnetic Activity - Sunspot Correlation

Activity Index (aa)

Maximum Sunspot # (Rz)

- Expected: 149 ± 24
- Correlation: +0.91 (cycles 9-22)
- Observed: 122

Cycle 23

Activity Index (aa)

- aa (min) = 15.7

Points for cycles 9 to 22:
- Cycle 9: 19
- Cycle 10: 21
- Cycle 11: 18
- Cycle 12: 22
- Cycle 13: 15
- Cycle 14: 16
- Cycle 15: 10
- Cycle 16: 17
- Cycle 17: 20
- Cycle 18: 9
- Cycle 19: 11
Conclusions

• UPDATE BABCOCK-LEIGHTON DYNAMO:
  We update with 3 ideas:
  1) Shallow Dynamo, 2) Percolation in two flavors, and
  3) Magnetic forces help drive faculae/plage towards poles

• PERCOLATION IN TWO FLAVORS:
  1) Highly Superadiabatic:
     Convection drives like-sign Ephemeral Regions (EPRs) into sunspots
  2) Normal:
     Normal T structure: field concentrations disperse: spots-> faculae

• MAGNETIC FORCES: Rather than fields moving towards poles via
diffusion/meridional transport, we suggest magnetic forces, mB, on
subsurface field elements play a prominent role– yield dynamo

• MODELING: Cellular Automata Modeling seems to fit solar dynamo

• PREDICTION: Solar Cycle #24 Rz~75; F10 ~125 in ~2012-3
Backup
LONG-TERM SOLAR OBSERVATIONS

International/Zurich Sunspot Number vs. Year

Time, Years

International Sunspot Number

Moderate Minima

Solar Minimum

Maunder Minimum

Time, Years
Babcock’s shallow dynamo view

Why Field Separates From Flow: Leaf Instability, and Stays Near Photosphere