On Becoming a Scientist, Studying the Earth and the Sun

Leif Svalgaard
Stanford University

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Today, I am here. Science spans the globe.

In 1972 I was invited to work at Stanford University in California.

As a student I went to Greenland to observe the Earth’s magnetic field in 1967.

The ‘house’ for some of my instruments looked like this [an Igloo: I made it myself; my first try collapsed…]

“The Earth is a Great Magnet”
Gilbert, 1600
Getting to the Station on the Ice

Hercules C-130 with Skis

Low seismic ‘noise’, good for detection of Atomic Bombs

Rocket assisted Take-Off

Not always successful

Inge Lehman Station 77.92°N 39.23°W, 2400 m (7900 ft), 1966-1967
Getting to the Station on the Ice

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But my job was to make magnetic observations…
Classic Method since 1847

Magnetic Recorders

I used the Classic Instruments

Modern Instrument
During a magnetic storm, aurorae become active:

Geomagnetic Storm

1 Day

And seen from Space

I was here

In Ionosphere
Magnetic Fields on Earth and in Space

The solar system is permeated by magnetic fields coming from the Sun with the Solar Wind and connecting with the field of the Earth [and other planets].

The records from Earth’s polar regions show the Sun’s fields. The solar system is permeated by magnetic fields coming from the Sun with the Solar Wind and connecting with the field of the Earth [and other planets].

Magnetic field lines show the direction of the magnetic field.

The records from Earth’s polar regions show the Sun’s fields. The solar system is permeated by magnetic fields coming from the Sun with the Solar Wind and connecting with the field of the Earth [and other planets].

Look how accurately we can see the field in space from Earth.
The Solar Wind

“Blows” all the time and is the expansion of the extremely hot atmosphere into space, visible near the Sun as the ‘Corona’:

Magnetic Field Lines are tied to the expanding atmosphere and therefore ‘rooted’ in the Rotating Sun

The pattern of the magnetic ‘spiral’ rotates with the Sun once in 25 days

Ludwig Biermann
1951

Gene Parker
1958
Expansion is radially outwards

Wilcox & Ness, 1964

1. Interplanetary Magnetic Field
2. Solar Wind Flow 300-800 km/s
3. Bow Shock
4. Geomagnetic Tail
5. In
6. Out
7. Sector Boundary
8. Dust
9. Ions
10. Bow Shock?
11. Comet
12. Comet Tail
13. Sun
14. Earth
15. 30 km/s
16. 400 km/s
Solar Wind Stealing a Comet Tail

Sector Boundary

Reconnection

Fragile: Comet ion tail inside

Comet Encke, 2007/04/20

Comet Morehouse, 1908

In One Day
35 Million km
or 400 km/sec
Where Does the Magnetized Solar Wind Come From?

To find out we build Solar Magnetic Field Observatories!

So, from the ice in Greenland I went to sunny California to study the Sun.

"All the sun, all the time"
Sector Boundaries on the Sun

From the measured magnetic field we can calculate where the boundary between opposite polarities is. It winds its way across the surface looking like the seam of a baseball.

‘Synoptic’ map from 27 daily strips showing the whole Sun
The 11-yr Solar Cycle

An ‘Active Region’ = Lots of Magnetic Fields

First drawn up by Rudolf Wolf

Sunspot Cycles

Max

Min

Cycle

Magnetic Fields

Sunspot Group

Approx. size of Earth
Solar Storms and Consequences

The energy stored in twisted Active Regions can be released explosively causing dangerous radiation and plasma hurled into space. If Earth-directed, this ‘debris’ from the explosions can have damaging and disturbing effects on our technological infrastructure.
Centuries of Sunspot Observing

We have observed sunspots with telescopes for 400 years.

John of Worchester Dec. 8, 1128

Galileo Galilei June 23, 1613

SOHO 1816-1893

Galileo’s Telescope

Rudolf Wolf

Wolf’s Telescope

Still used today

Sunspots observed by Spacecraft

The sunspot number is always determined using small telescopes.
Near the sector boundary the solar wind is denser and slower. As the Sun rotates this builds up spiraling layers of denser plasma wrapping around the Sun many times:

The ‘flapping’ sector boundary in time. Note the changing extent.
Cosmic Rays from the Milky Way Galaxy

At maximum, more Cosmic Rays are deflected out of the solar system and do not reach the Earth:

About 30 [secondary] cosmic rays fly through your body every second

When hitting the atmosphere Cosmic Rays produce radioactive Carbon14 and Beryllium10 isotopes
Drilling for Ice Cores

To measure the 10Be concentration and thus the Cosmic Rays thousands of years back in time

Upernavik, 1130 inh.

First day of school

Machine to count atoms of 10Be one by one

Drill to depth of 3000 m

Cosmic Ray counts are also influenced by the Earth’s magnetic field. We can correct for that.

Annual Layers in the Ice

40,000 Bp
Large Climate Variation over Time

Is the variable Sun the cause of climate variation? Not of the large variations.
But surely, the Shorter Term Variations Must be Controlled Mainly by the Sun?

Much has been made of the period 1645-1715 [called the Maunder Minimum] where it was cold and solar activity was low.

But if we compare the temperature over the past 10,000 years with the $^{10}\text{Be}$ concentration there is very little convincing correlation.

During the Maunder Minimum the modulation of Cosmic Rays was strong and healthy, but almost no sunspots were observed. The reason for this is not known, but there are tantalizing hints that such a situation may arise in the next few decades.
So, what will Solar Activity be in the Future? Can we predict Solar Activity?

Sunspots
Polar Fields
Observations
Theory: Deep circulation?

Many uncertainties remain. Expect SDO to tell us more about the interior of the Sun

Observations and theory suggest that the magnetic field at the poles of the Sun at solar minimum is a good predictor of the next solar cycle.

The low polar fields at the recent minimum predicted a small cycle 24
How is Cycle 24 Evolving? As Predicted!

Active Region Count

Numbered Active Regions per Month

Cycle 24 is beginning to look like Cycle 14

Cycle 24 Sunspot Number Prediction (October 2012)

Predicted by Svalgaard, Cliver, & Kamide, 2004

Lowest in a 100 years
What have we learned?

- Science and Scientists are International
- The Earth itself can be used as an ‘instrument’ to study the Sun and the Solar System
- Such Study crosses many scientific Disciplines
- Science is a Learning Process that lasts your whole Life
- Our technological civilization is becoming more vulnerable to Solar and Space Weather, so we need to study hard and learn more