140 Years…..

….of the “Extended” Solar Cycle: predictability, expectations for (sunspot) cycle 25 and what may follow…

Scott W McIntosh
NCAR/HAO

Robert J Leamon
UMD/GSFC

Charles Chree
Bernard Lyot
Walt Roberts
Karen Harvey
Sara Martin
Jean-Claude Viall
Dick Fisher

……..

Ed Cliver, Dick Altrock
NSO
Asking Critical Questions

Part of the scientific method is making critical assessments of the agreement between hypothesis, model and experimental observation.

Do we do this for the “dynamo” problem?

Why does the “polar predictor” appear to be most effective in providing information about the upcoming sunspot cycle?

Why is it that when the Sun shows observational clues that indicate that we’re looking in the wrong place that they’re roundly ignored?
140 Years.....

Contemporary Observations 1

Tracking the evolution of small scale - magnetically rooted - features in the Sun’s corona leads to a picture of evolution that can be used to explain the landmarks and strength of present, current (and possibly future) sunspot cycles in the context of the 22-year solar magnetic activity cycle.

cf. work of Ulrich, LaBonte, Harvey, Wilson, Snodgrass, McIntosh, others in the 1980s

[McIntosh et al. 2014]
140 Years.....

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Where and when does the next cycle high latitude band appear?

Sunspots erupt in a coherent fashion after the low latitude activity branches cancel each other. Hence the “Waldmeier Effect” of an abrupt sunspot onset. No flux to cancel with in that hemisphere.

As the next cycle high-latitude branch appears it begins to impact the activity in the lower latitude band establishing “the declining phase” of sunspot cycle.

“Solar Minimum” - when the high and low latitude bands preclude sunspot emergence in both hemispheres - subsurface cancellation?

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CRITICAL QUESTIONS:

- Do the bands of the 22-year cycle interact/interfere with each other to produce sunspot modulation?
- If so, how?.....looks like 55 degrees plays some role.
140 Years…..

Contemporary Observations 1

Landmarks of [h]SSN Butterfly

Build a schematic depiction of evolution:
• Linear (constant velocities)
• Bands start at 55deg
• Migrate equatorward following hemispheric sunspot maxima.

[McIntosh et al. 2014]
The “prediction” is made possible through the realization that the high latitude behavior of both hemispheres regions is VERY regular - like clockwork - even though they are offset from each other.

Crudely: From superposed epoch analysis every $21.8\pm0.5\text{yrs}$ the Sun (apparently) produces a new flux system at $\sim55^\circ$ which begins to travel towards the equator, taking between 17 and 19 years to get there producing the butterfly pattern of sunspots en route, and a HOST of other phenomena in between that are ALL connected.

**The BIG questions is:**
How does that work?
140 Years......

Contemporary Observations 2

Standing on the shoulders of Dick Altrock

Extract an annulus of emission around the solar corona......

Identify the local maxima in the coronal annular profile....

Repeat...... what pattern do you see?
140 Years…..

Contemporary Observations 2

SoHO [1996 - Present]

Southern Hemisphere – Intensity Maxima +/- 150 Day Window

[McIntosh et al. 2018]

SORCE 2018
140 Years.....

Contemporary Observations 2


Southern Hemisphere - Intensity Maxima +/- 150 Day Window

[McIntosh et al. 2018]
Contemporary Observations 2

SoHO [1996 - Present]  
STEREO “A” [2007 - Present]  
STEREO “B” [2007 - 2014]  
SDO [2010 - Present]

Note the Polar Coronal Hole “LIMITS”
140 Years.....

Contemporary Observations 2


Southern Hemisphere – Intensity Maxima +/- 150 Day Window

Another pretty good match....... .....but it is only 22 years......
From 1880 - 1931 and from 1919 - 1989 the Arcetri and Meudon Observatories respectively cataloged the position, length, and brightness of filaments on the solar disk. Similar efforts continue to the present day.

The Arcetri group published their initial results in 1933.
The red dots mark in lower plot show the maxima of latitudinal filament density on each annual slice - the departures from 55 deg every decade or so became known as the “rush to the poles” - the filament maxima locations map out the progression of magnetic neutral lines over many solar rotations.
The blue dots mark in lower plot show the maxima of latitudinal filament density on each rotational slice - flick back to see correspondence with Arcetri.
Starting with the advent of the coronagraph in the late 1930s, Lyot and his group made routine measurements of the 5404Å “green line” of the corona - before they knew that it was emission from highly ionized iron.

Performed around the globe daily and merged into a continuous record by NGDC.
Because the density of data is getting higher the maxima of annular coronal emission slice can be represented in an image.... looking at a running average over 150 days... flick and forth again.
Same method as before - maximum finding - applied now to 22 years of contemporary data. The same patterns appear. Flick back and forth - number density of points higher still caused by higher resolution.
140 Years....
140 Years
140 Years of the Extended Solar Cycle
140 Years......

**Breathe**

Quick Recap

- EUV Brightpoints
- Global-Scale Coronal Morphology
- Torsional Oscillation
- Progression of Solar Filaments

} ALL Aligned

Pattern STARTS at 55°
Take 17-19 years to reach equator
Polar “repetition” time is about 21.8yrs
Pattern is “same” in both hemispheres for 28 [half-cycles]
Sunspots are a subset of the whole.
Introducing The “SEA” - Superposed Epoch Analysis

1) Use Hemispheric Maxima to delineate the patterns in the two hemispheres.

2) “stack” the extracted timeseries +/-11 years about hemispheric max.
140 Years.....
Introducing The “SEA” - Superposed Epoch Analysis

North

South
140 Years.....

Introducing The “SEA” - Superposed Epoch Analysis

The resulting AVERAGE pattern
Average pattern in both hemispheres essentially identical. Is this then the average repeating unit?
140 Years.....

Statistical Moments of Coronal Green Line SEA Termination Point As the “Key Time” [1939 - 2009]
140 Years.....

Arcetri Filament SEA
Termination Point As the “Key Time”
[1880 - 1931]
Meudon Filament SEA
Termination Point As the "Key Time"
[1919 - 1989]
140 Years.....

Coronal Green Line SEA
Termination Point As the “Key Time”
[1939 - 2009]
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Comparing SEA Analysis

Agreement of 140yrs of data is VERY strong!
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Global-Scale [Magnetic] “Telecommunication”
Robust 22-year Periodicity - Traces out Magnetic Activity Cycle
Bands of that Cycle - Overlap & Interact

Mid-latitude Growth & “Rush to the Poles”
Linked to Termination
Internal Gravity Wave Coupling
Massive Magnetic Fields

Sunspots are a bi-product of global overlap/interaction

55° is a CRITICAL latitude!

Predictable?

Resolved Observations REQUIRED.
“Rosetta Stone”
The closing arguments of McIntosh et al. 2014 indicated that the bands that would produce sunspot cycle 25 may indeed have been visible, and was appearing when/where expected.
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Solar Minimum is close!
Solar Cycle 25 is here!
WILL be < cycle 24!
Terminator in 2020!

Are we heading for an extended 24/25 solar minimum?
Maybe en route to a Grand Minimum?
140 Years.....

.....of observations illustrate that the “extended solar cycle” really is the progression of the 22-year solar magnetic activity cycle.

Continuous high latitude [polar] observations are critical to identify and monitor the growth of sunspot cycle 26[+] in the early 2020s.

The repeated signature of “Terminators” must be mined for critical information about the conditions of the solar interior.

Questions:
• Is this a “wave-like” solution to the dynamo problem?
• Is the dynamo action taking place at high latitudes?
• Is this consistent with B-L and/or flux-transport models of the dynamo?
• What does this mean for the “Alpha” effect?
• Just how strong is the magnetic field?
• Is it almost always in critical balance?
• What are the controlling parameters?
• Why does 55 appear to be so critical?