Secular changes in the solar open and closed magnetic field: the *aa* index revisited

Thierry Dudok de Wit[1], Jürgen Watermann[2]

[1] University of Orléans, France [2] jfwConsult, France

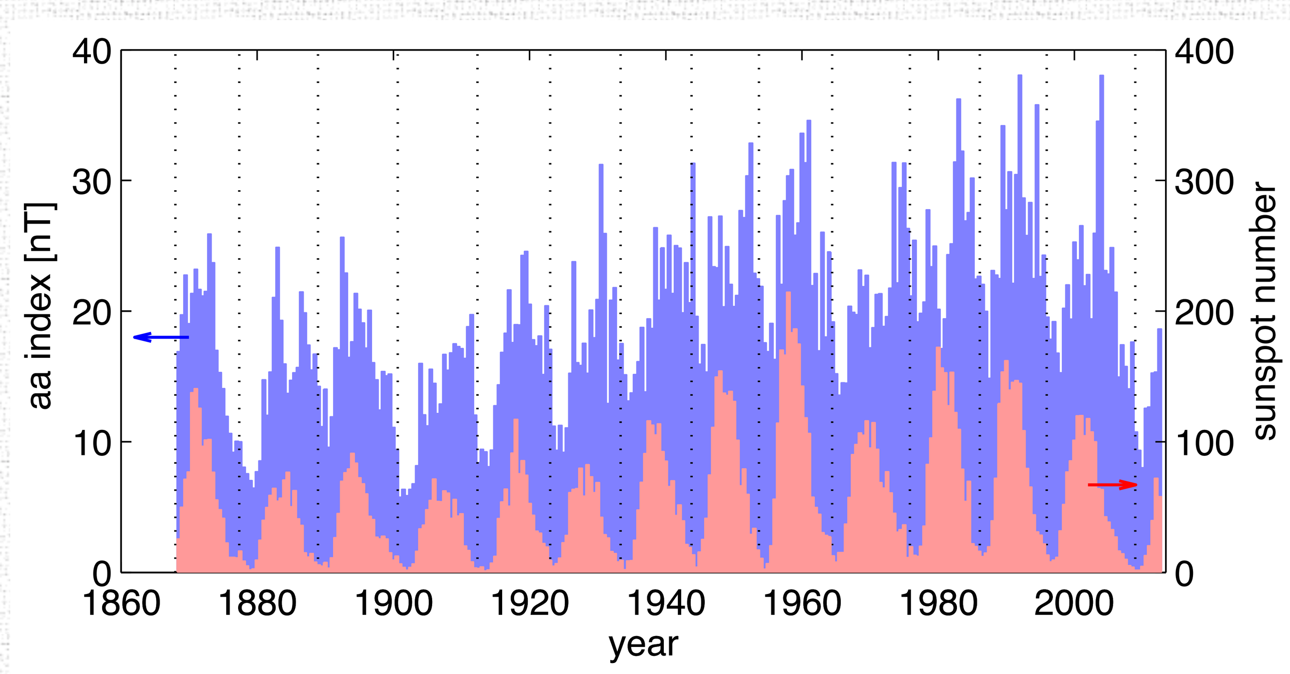
Summary

The *aa* index (3-hourly geomagnetic index) shows a conspicuous upward secular trend, which is indicative of the strength of the solar toroidal and poloidal magnetic flux. The relevance and magnitude of this trend has been hotly debated.

We shed new light on this issue by decomposing the 11-year modulation of the *aa* index into two components, one of which is in phase with the sunspot cycle. Our empirical model reveals sizeably different long-term evolutions in the toroidal & poloidal components. This questions the use of the sunspot index as a proxy for long-term total solar irradiance.

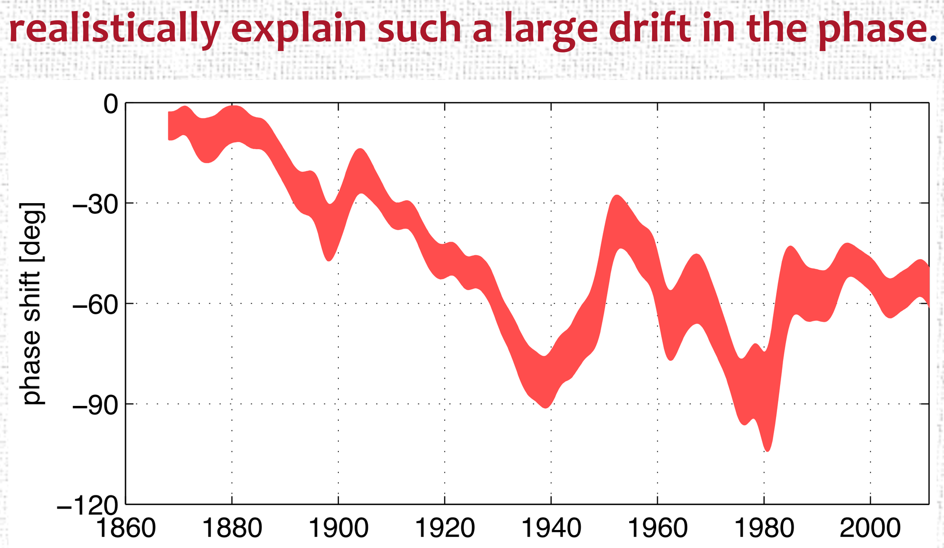
Why the *aa* index for solar activity?

The *aa* index (3-hourly geomagnetic range index measured since 1868) exhibits an upward secular trend, whose origin and significance have engendered much controversy because they can be interpreted as an increase in the solar open magnetic flux [Lockwood et al., Nature, 1999].



Yearly averages of the aa index and of the sunspot number.

The *aa* index exhibits an 11-year modulation. Its transfer function vs the sunspot number reveals a phase lag that drifts in time. **No change in the solar-terrestrial connection can realistically explain such a large drift in the phase.**



Phase difference between sunspot number and aa index, for an 11-year modulation. The same result is obtained when using the f10.7 index as a proxy for solar activity.

Curve thickness represents ± 1 σ

The most plausible explanation is the coexistence of two competing effects [Legrand & Simon, A&A, 1985; Ruzmaikin & Feynman, JGR, 2001; Georgieva & Kirov, JASTP, 2007, ...] with fixed phases:

- a contribution in-phase with the solar 11-year cycle, ascribed to CMEs, and indicative of the strength of the **solar toroidal ("closed") magnetic flux**.
- a contribution out-of-phase with the solar cycle, ascribed to the fast solar wind and CIRs, and indicative of the strength of the **solar poloidal ("open") magnetic flux**.

By measuring the in-phase and out-of-phase components of the *aa* index, we can thus track the long-term evolution of the solar poloidal and toroidal magnetic fields

Modelling the *aa* index

Previous studies have considered the *aa* index as being a linear combination of a toroidal and a poloidal component

$$aa(t) = c_{tor}(t) + c_{pol}(t) \quad \text{with} \quad c_{tor} \propto R_i \quad R_i\text{: sunspot number}$$

This empirical model is not adequate, since the *aa* index is a range index. A more realistic model should be

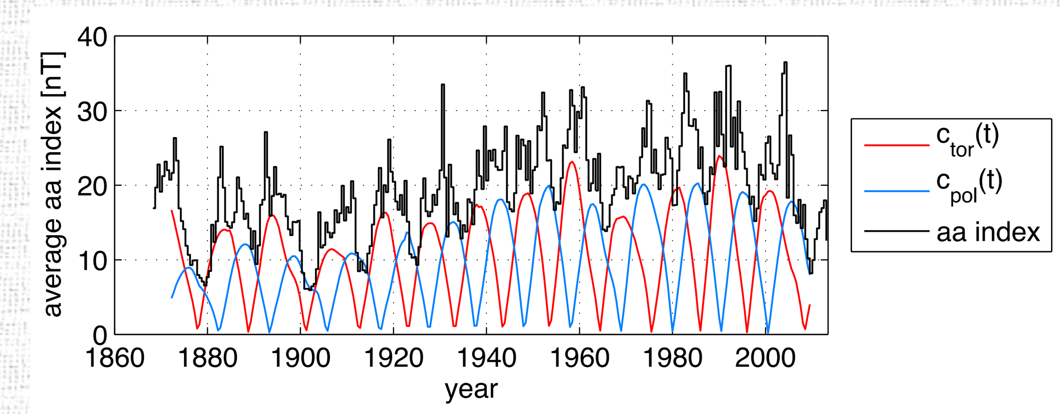
$$aa(t) = \sqrt{c_{tor}^2(t) + c_{pol}^2(t)}$$

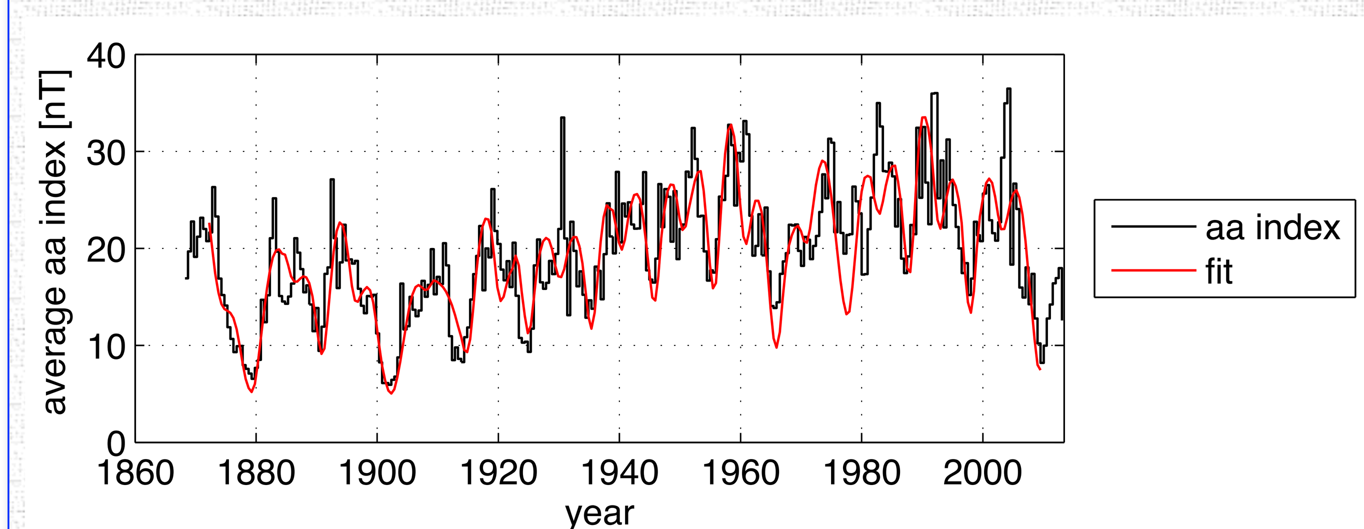
We use this model to fit the *aa* index with a linear combination of two 11-year sine waves. One is in sync with the sunspot number R_i, the other phase is left free. The amplitudes c_{tor} and c_{pol} are estimated using a sliding window of 11 years. We use a Bayesian positive source separation method that enforces the positivity of the two contributions [Moussaoui et al., IEEE Trans. Signal. Proc. 2005].

Results

Our empirical model tracks all variations of the aa index well

Toroidal and poloidal components of the aa index (yearly averages)

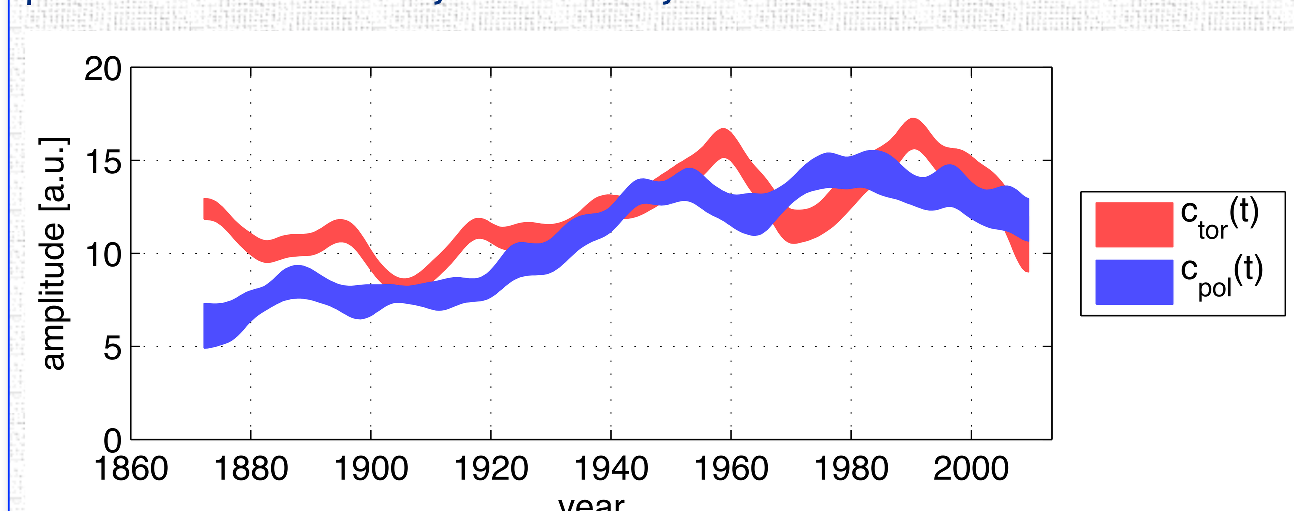




The aa index vs the model fit (yearly averages)

This simple model yields a remarkably good fit of the *aa* index. The poloidal component is systematically found to be 5-7 years ahead of the toroidal one, in agreement with dynamo models.

The "strength" of the solar magnetic flux confirms Ohl's rule: variations in c_{pol} tend to precede those in c_{tor} by one solar cycle

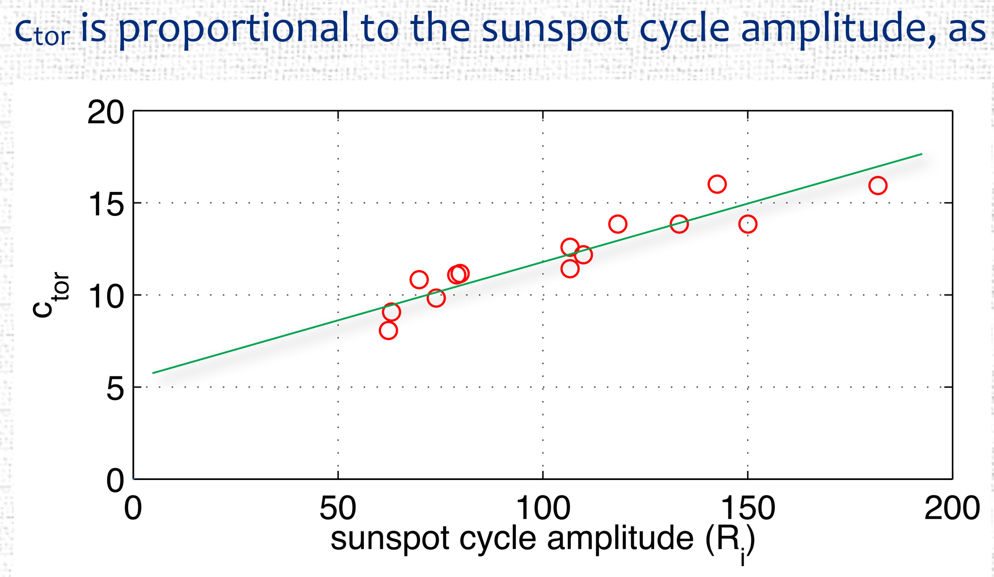


Amplitude of the toroidal (closed) and the poloidal (open) components of the aa index

Curve thickness represents ± 1 σ

The poloidal and toroidal components exhibit differing long-term evolutions: the relative increase between pre-1910 and aft-1970, is 79% for c_{pol} and 34% for c_{tor}

c_{tor} is proportional to the sunspot cycle amplitude, as expected



Intensity of the toroidal (closed) magnetic field vs sunspot cycle amplitude.

Correlation(c_{tor}, R_i) = 0.93
Correlation(c_{pol}, R_i) = 0.66

Conclusions

- A refined model yields a **better fit of the *aa* index**: the intensity of the poloidal (open) and toroidal (closed) contributions of the solar magnetic field can now be properly extracted.
- The long-term evolution of the open and closed magnetic fields **differ**.
- The sunspot number (mostly proportional to toroidal magnetic flux) thus is not an appropriate proxy for the total solar irradiance (mostly proportional to poloidal magnetic flux)

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