“An explanation of the scale difference between RGO and USAF/NOAA spot records”

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Thanks for useful discussions to: G. Appleby, T. Baranyi, P. Gilman, D. Hathaway, T. Henry, R. Howard, J. Kennewell, R. McFadden, P. McIntosh, and J. Sutorik.

Evidence for a 1976 Scale Change

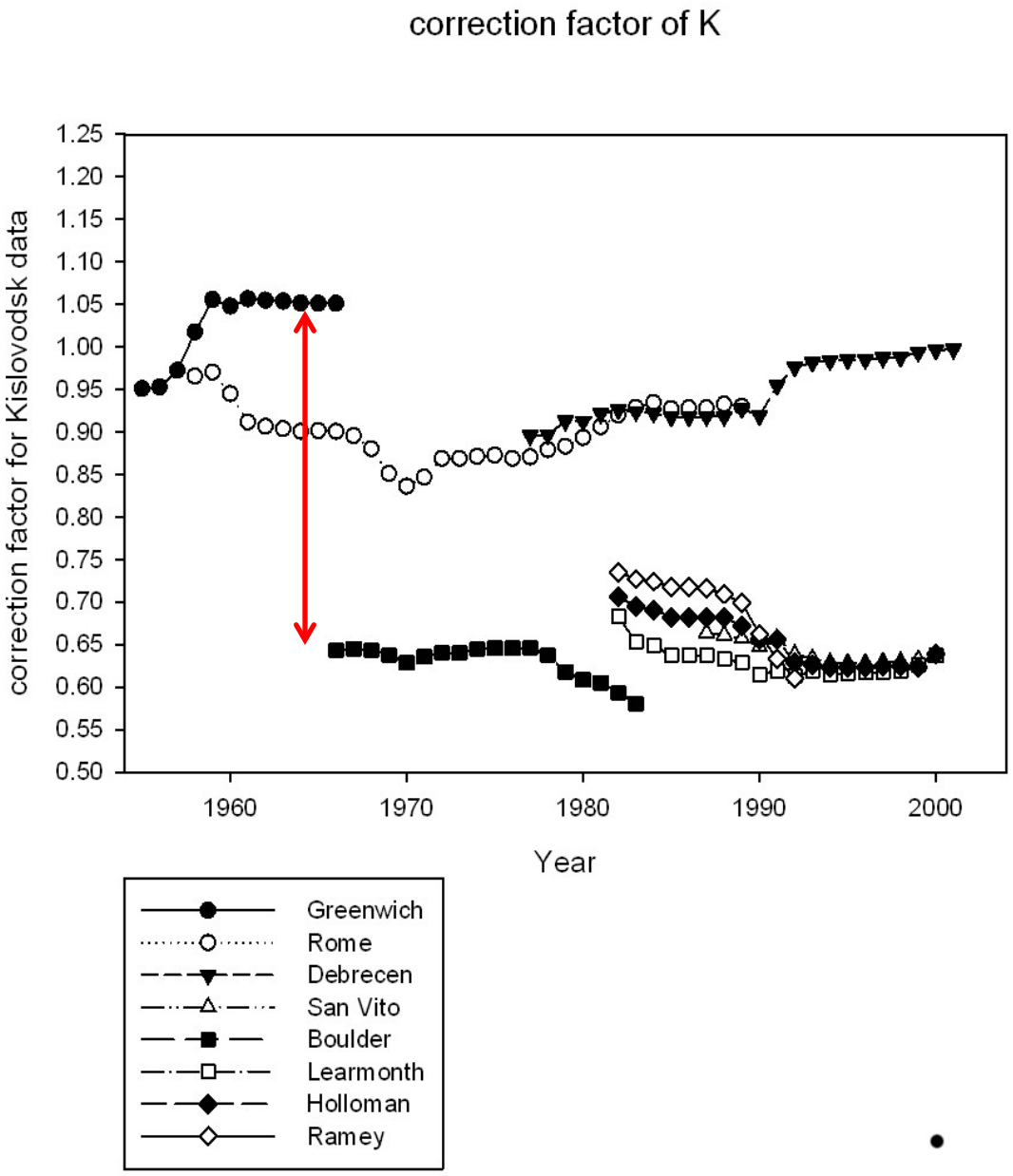
- RGO/Rome ~ 1-1.2 (Fligge and Solanki (1997) over the cycles 19-20.
- RGO/SOON ~ 1.4-1.5 (Hathaway et al.,(2002), Balmaceda et al.(2009); Fröhlich(2011), Baranyi et al.(2001;2013)
- RGO/MWO (umbrae) ~ 1.4 (Hathaway et al., (2002); N.B.: the MWO spot *rotation* data were not intended as a reliable area record; i) small umbrae (< 4μh) are set = 0.5μh; ii) recurrent spots are under- sampled.

What area *accuracy* and *reproducibility* do we *need*?

- We need *accurate* (~ 10% rms) projected areas back to 1978, to compare *amplitudes* of modeled and measured irradiance variations.
- We need *reproducible* (not necessarily accurate) spot areas for the regression – based models that enable us to reconstruct irradiance variation prior to 1978.
- Reproducible spot size distributions that can be compared from cycle- to- cycle, would be helpful for, e.g., studies of the solar dynamo.

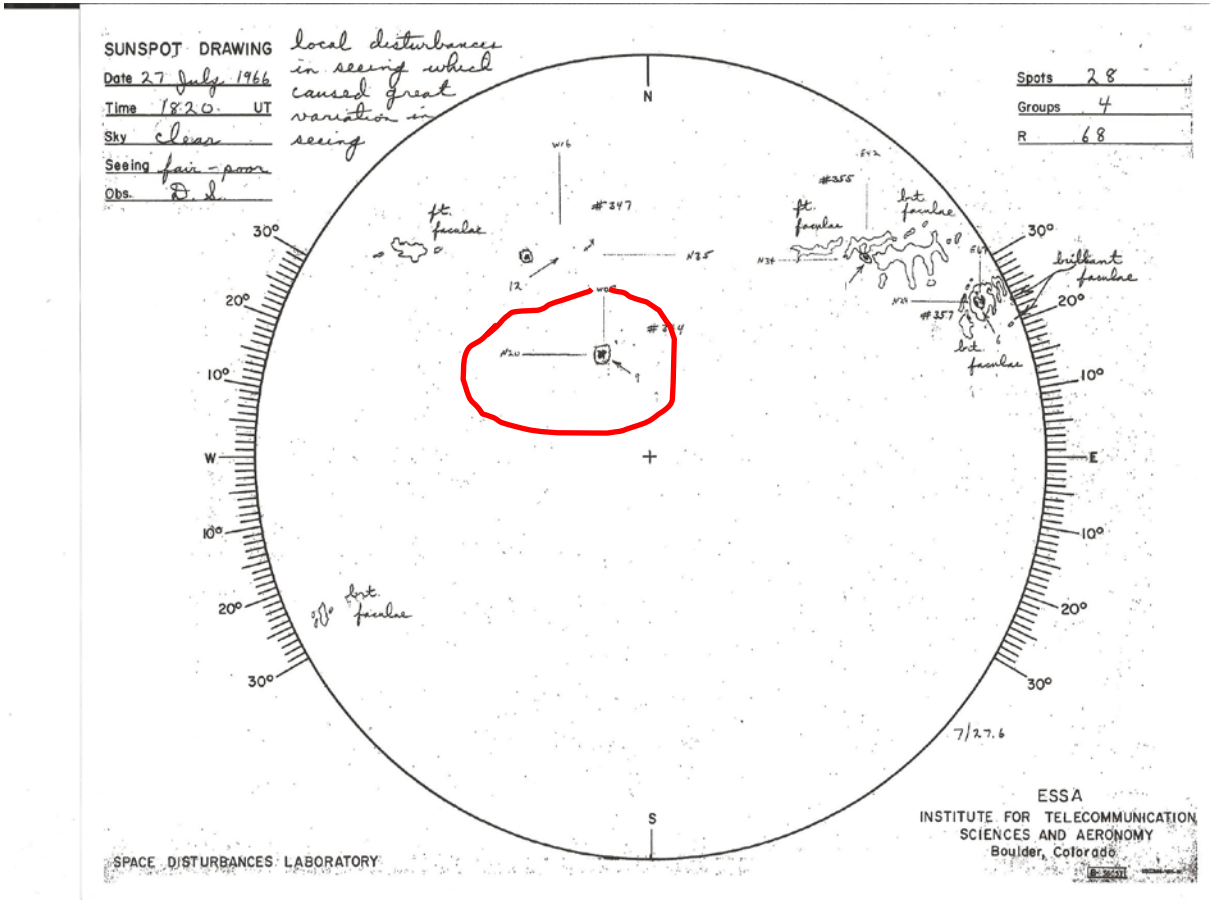
An RGO/USAF scale ratio of ~ 1.5 has existed since Boulder measurements began in 1966 (Baranyi et al., 2013).

- SOON modifications in 1981 affected the scale, but they are *not the source of the difference since 1966.*
- The remarkable persistence of the difference suggests a *dominant* and *durable* cause.



The scale difference exists even at disk center: e.g. 1966 group 344 (RGO/USAF = 408μh/230μh = 1.8)

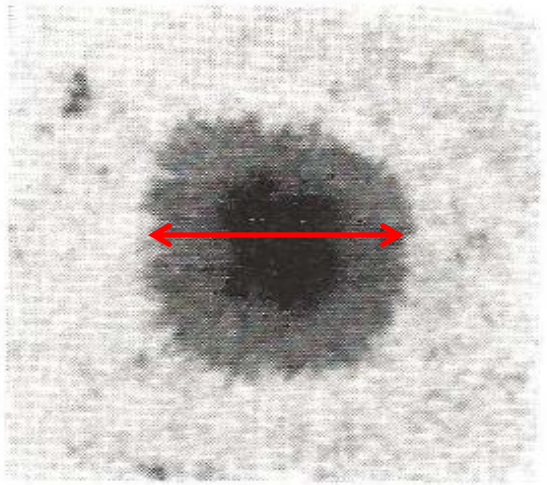
- So it is not caused by near – limb *selection* or *projection* effects.
- Re- measurement of large spots on USAF drawings agrees (< 10%) with USAF areas .
- So USAF *measurement error* (grid scale error or resolution) of *resolvable spots* cannot account for much larger (~1.5 – 2) x RGO group areas.



USAF spot dimensions are *accurate*; they agree with our measurements on photo-heliograms and on *intensity profiles*

(e.g. drawing: 3.2 x 10^4 km; print: 3.2 x10^4 km; scan: 3.1 x 10^4 km)

(SPO photos and scans taken from Wilson and McIntosh, 1968)



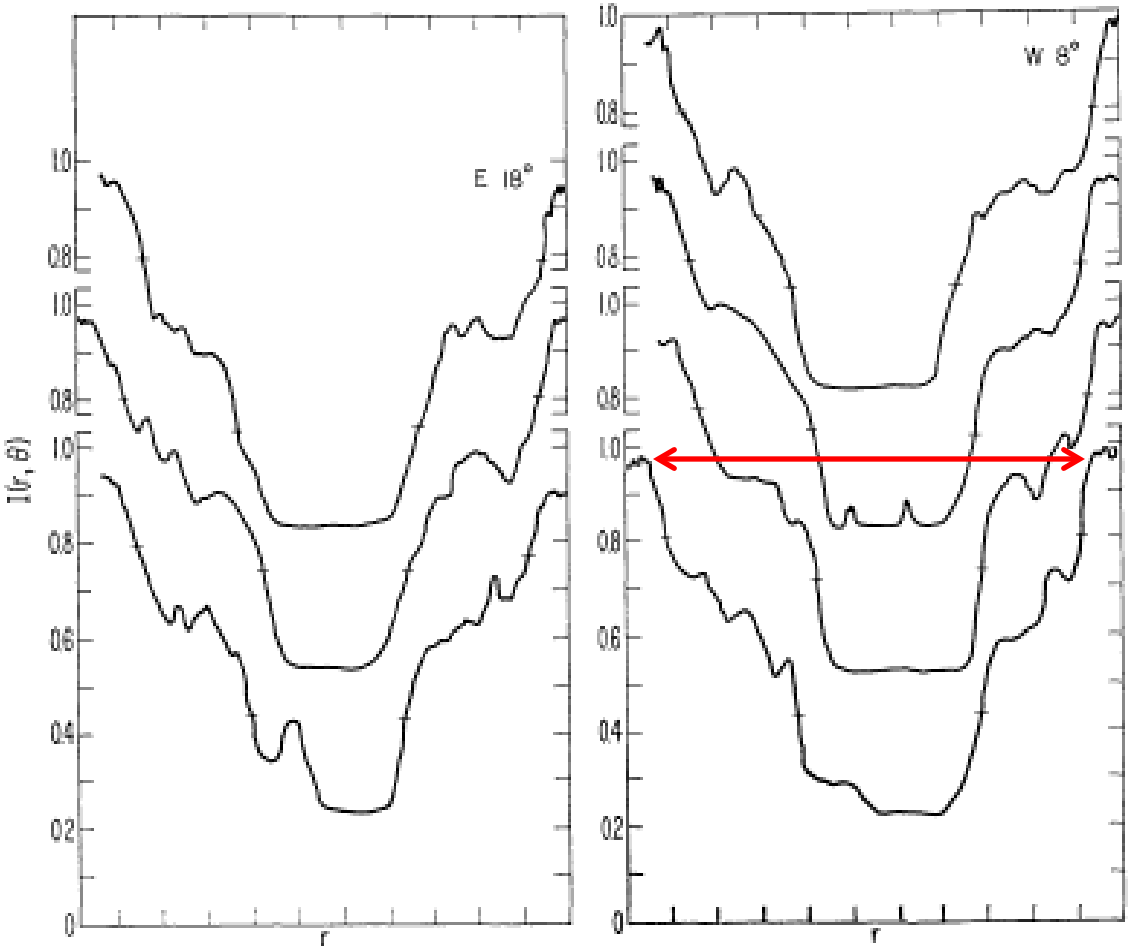
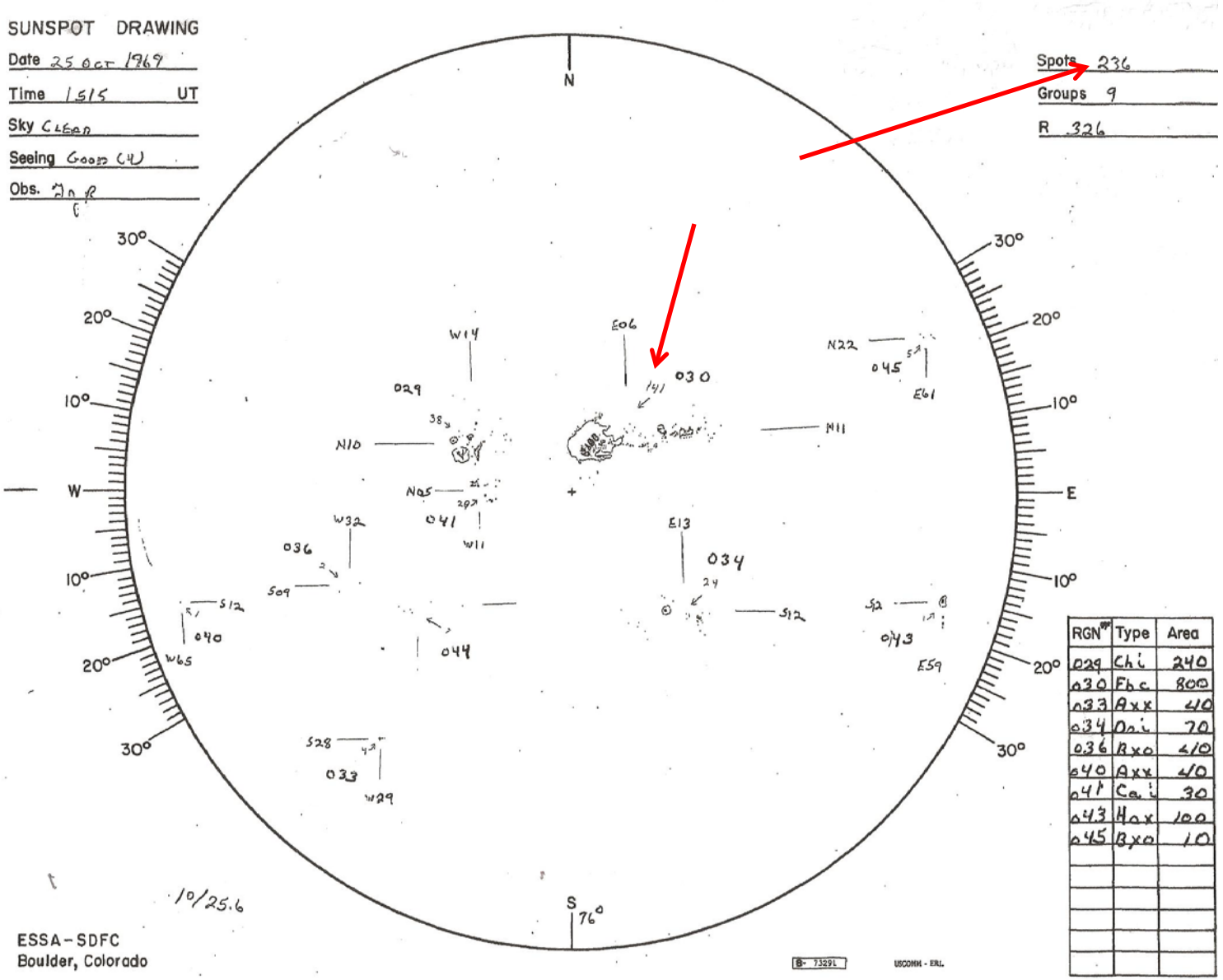


Fig. 4. Intensity profiles for July 25 and 27.

The number of spots, f = (R - 10g). At high R, typically > *100 spots on drawings were too small* for USAF to measure.



Estimated RGO/USAF correction due to these "hidden" spots in a large group:

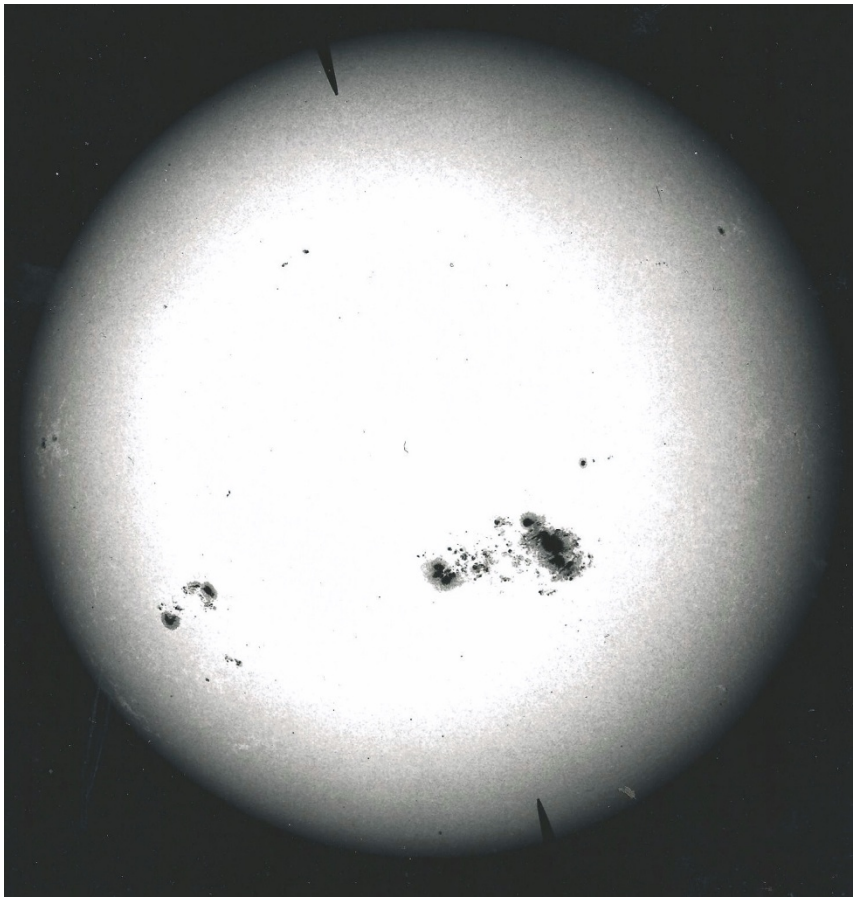
- e.g. USAF area of group #030 = 800 μh;
- Number of unresolved small spots ~ 130;
- USAF set small spots of < 8μh = 2μh, so the area under- estimate/spot ~ (5μh-2μh) ~ 3μh;
- Total underestimate ~ 130 x 3μh ~ 390μh;
- Correction factor = (390+800)/800 = 1.49

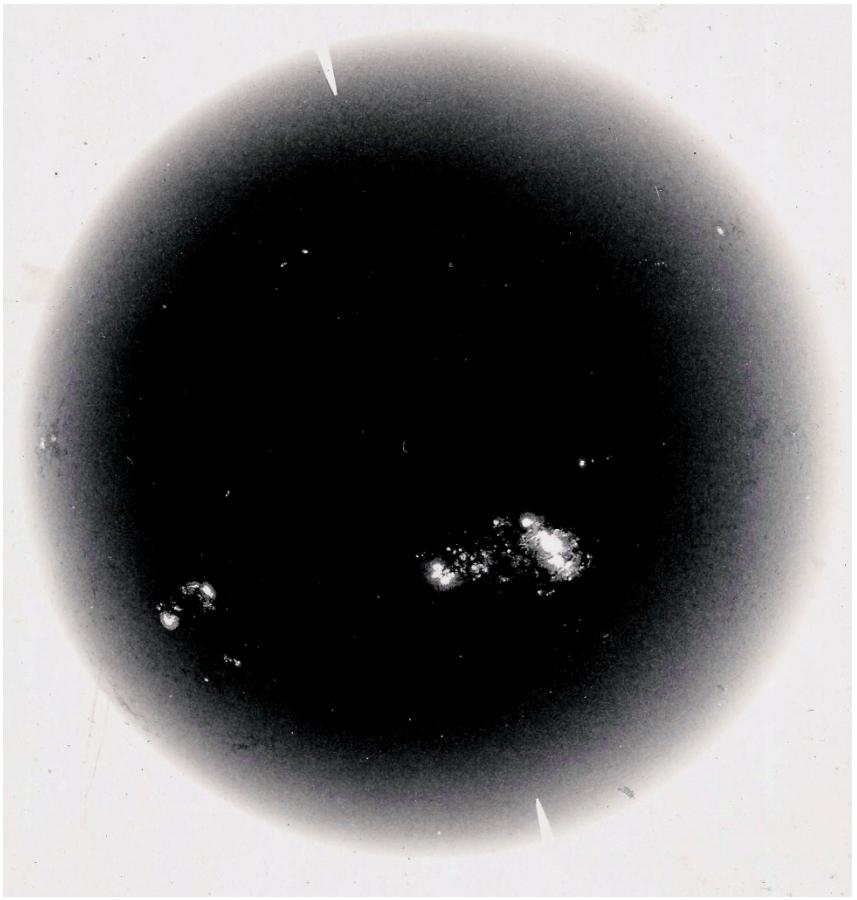
(N.B. Actual RGO area for that group = 1860)

Our explanation of the RGO/USAF scale difference

- The USAF areas for those spots *large enough to draw* are accurate. **But** a large number of spots, many within large groups, are too small (< 10μh) to draw.
- Their area is set = 2μh, so is under- estimated by USAF, but is measurable on the RGO photographic plates at their ~ 25 x higher grid area resolution. The "hidden" contribution of these small spots appears large enough to explain the RGO/USAF correction.
- This also seems consistent with the RGO/**MWO** ~ 1.4 correction, since spots < 5μh are minimized in the MWO data.
- The original RGO ledgers listing every spot they measured, would be required to verify this explanation. If they are unavailable, the Debrecen data might be helpful.

Other suggested RGO/SOON effects may contribute at a lower level: e.g. areas from RGO negatives > from positive images?





Derivation of *irradiance* correction

TSI blocking by spots:

i)**True**; ii) **RGI** (RGO – based); and iii)**USI**(USAF – based).

Where **True** = c(L+βS); **RGI** = c(L+S); **USI** = c(L+αS), and:

- L = area of large spots *resolvable* on USAF drawings,
- S = area of *unresolved* small spots;
- c = photometric contrast of large spots;
- β = fraction (small/large) spot contrast;
- α = fraction of small spot area measured by USAF.

For S/L ~ 6/5; α ~ 2/5; β ~ 1/5, we have:

True/RGI = c(L+βS)/c(L+S) ~ 0.56;

True/USI = c(L+βS)/c(L+αS) ~ 0.84;

RGI/USI ~ 1.5.

Implications for irradiance studies

- The post – 1976 area correction of 1.4 – 1.5 x is probably too high *for irradiance modeling*, because the *photometric contrast* of the small spots is > 5 x lower than for the bigger spots (e.g. Moran et al. 1992).
- Spot irradiance blocking as presently calculated from both the RGO and USAF areas should be decreased. The correction for the RGO – based blocking is (very roughly) a factor of ~ 0.6, reflecting the lowered *contrast* of the small - spot component of the RGO areas. USAF – based blocking should be decreased by roughly ~ 20% to compensate for the under- estimated *area* of small spots, in their measurements.
- More accurate spot blocking models will require better measurements of the parameters α,β, and S/L. Improved estimates of α and S/L should be accessible from the RGO and Debrecen records. Bolometric imaging of spots at higher angular resolution will be required to improve understanding of β

Two points

- The reason that daily areas recorded in *photographic* (e.g. RGO, Rome, Kislovodsk) or ccd (e.g. Debrecen) data sets are larger than those based on drawings (e.g. USAF) is *not* because areas of resolvable spots are larger when recorded photographically or with a ccd. It is because the areas of the hundreds of spots *too small to draw*, are individually measurable on plates. (N.B.: MWO data are also photographic, but they produce *small* daily values, precisely because the small spots (umbrae) were set to ~ 0).
- The sunspot contrast functions (e.g. Steinegger et al.,2006) used in current spot blocking models (e.g. Frohlich, 2011) do *not* address the difference between the large and small spot components discussed here. Such contrast functions are applied to RGO data on spot *groups*. The "hidden" small- spot component discussed here is included within the total area of larger spots given for each group. (Unpublished) RGO data on the *(often hundreds of) individual spots within each of these groups* would be required to make such a contrast correction accurately.

Testing this explanation and correction with radiometry

• For the 10/2003 radiometric dip:

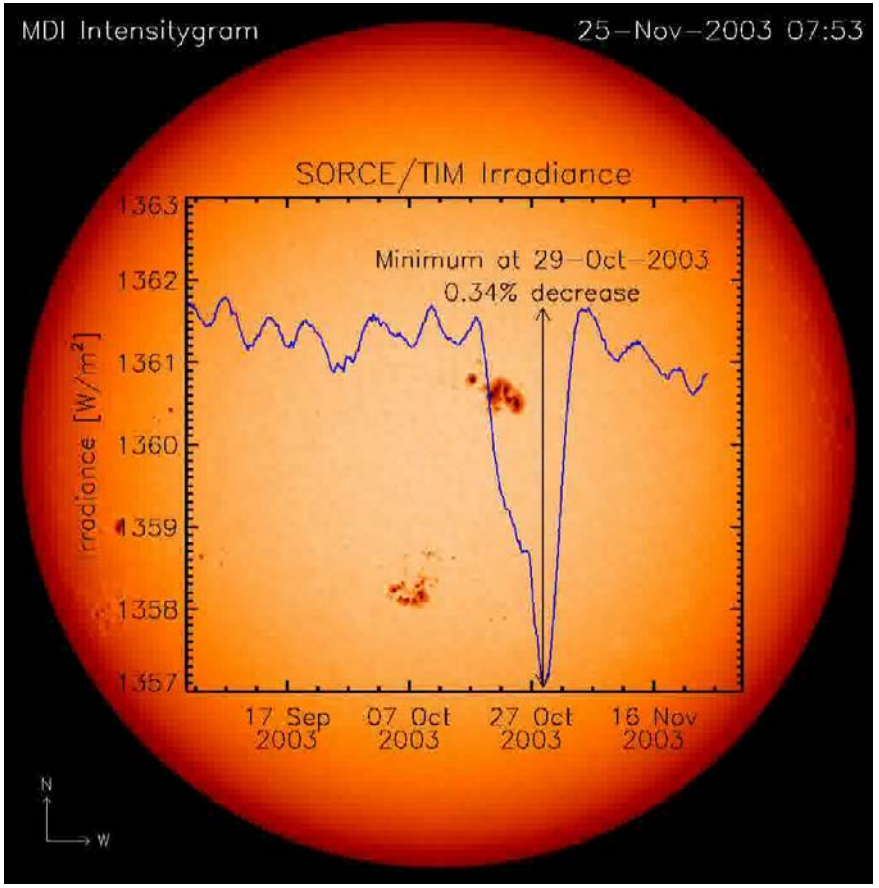
ΔTSI (measured, TIM) = 0.34%,

ΔTSI (from Debrecen areas) = 0. 46%.

• So the calculated TSI dip is ~ 35% too deep.(Facular contribution to this large dip is small).

• The Debrecen and RGO areas agree to < 10% (Gerlei,1987;Baranyi et al., 2013)

• So, this TSI dip excess, calculated including *the smallest spots at standard contrast*, is also consistent with a ratio of RGO/USAF spot blocking lower than 1.4-1.5.



In praise of small observatories…

Daily measurements of spot areas from drawings using similar equipment and procedures to the 1960's USAF/NOAA observers were carried out at EPSO. This proved helpful in realizing the limitations of drawing small spots with the USAF's recommended sharpened 4H pencil!