“On the validation of K index values at Italian geomagnetic observatories” by Mauro Regi et al.

The paper addresses a statistical method of determining the K=9 lower limit (L9) of magnetic observatories. The results agree with the results given by the well-known method endorsed by IAGA and implemented by ISGI. Nevertheless, some major corrections need to be made as well as a complete review of some parts of the bibliography.

Main comments

M1- ➔ Please, in the whole paper, state clearly how the geomagnetic / corrected geomagnetic / altitude adjusted corrected geomagnetic coordinates (latitude here) are determined.

- What is the software used?
- Is there a citation (DOI) of this software (e.g.: aacgm-v2 from Shepherd, S. G. (2014), Altitude-adjusted corrected geomagnetic coordinates: Definition and functional approximations, J. Geophys. Res., 119, 9, doi:10.1002/2014JA020264.])?
- Which underneath main field model is used (e.g; IGRF12? IGRF13?) ?
- What is the date used? (as any geomagnetic coordinates vary with time)

M2- “K=9 lower limit” is traditionally named “L9 value” or abbreviated as “L9”. Indeed, it is the lower limit of classe K=9 at a particular observatory

section Abstract :

A1-*“The method for determining the K values should be the same for all observatories (...)”*

➔ Please, replace by “The method for determining the K values IS the same for all observatories.”

A2- *“INTERMAGNET consortium recommends a software code, KASM (...)”*
This statement is incorrect. INTERMAGNET does not recommend KASM method.

➔ Please, correct according to the following: “INTERMAGNET recommend the use of one of the 4 methods recommended by ISGI (the International Service of Geomagnetic Indices) in close cooperation and agreement with the ad-hoc working group of International Association of Geomagnetism and Aeronomy.”

The original definition of K indices (Bartels et al., 1939) requires hand scaling on analogue magnetograms. The question of the derivation of geomagnetic indices from digital data arose at the end of the seventies! Different algorithms enabling computer derivation of K indices were then developed and carefully assessed in the frame of an international comparison organised by the IAGA Working Group “Geomagnetic indices” (Coles & Menvielle, 1991; Menvielle, 1991; Menvielle et al., 1995).
See references:

- Coles, R., and M. Menvielle (1991) - Some thoughts concerning new digital magnetic indices, Geophys. Trans., 36, 303-312.
- Menvielle, M. (1991) - Evaluation of algorithms for computer production of K indices, Geophys. Trans., 36, 313 -320.

See your paragraph lines 46 to 58 in section 1-Introduction.

section 1- “Introduction “

B1 - line 32 to 35: *“Therefore, K index is the fundamental parameter for Kp estimation that is widely used, for example, in space weather applications, for identify quietest days (Johnston, 1943) used also in the IGRF modeling, for verifying solar wind driven modulation in the atmospheric parameters during disturbed conditions (Regi et al., 2017).”*
This paragraph appears only as a way to allow citation of (Regi et al., 2017).
Kp is a K-derived geomagnetic index at sub-auroral latitudes only. Furthermore, even if Kp purpose was to characterize the intensity of geomagnetic activity on a planetary scale, authors have to be pragmatic. Kp was developed in other times and, because of the historical context at the time of its creation (cold war), the Kp network is heavily weighted towards Europe and Northern America.
The citation of a paper presenting a study « ULF geomagnetic activity effects on tropospheric temperature, specific humidity, and cloud cover in Antarctica, during 2003–2010 » is not a proper example here. Antarctica being far away from sub-auroral and Northern hemisphere.

➔ Please, explain clearly the fact that Kp is an historical index with known drawbacks and erase the citation to Regi et al.

B2 - line 42 to 43*:* *"For example (see Bartels et al., 1939), from higher to lower latitude, at Sitka (AACGM latitude λ=52° N, Alaska), K9=1000 nT, while in Honolulu (λ=21.37° N, Hawaii) K9=300 nT. The GFZ website (https://www.gfz-potsdam.de/en/kp-index/) provides K9 values for the 13 observatories used for Kp evaluation, showing values between 450 nT and 1500 nT; in particular, at Niemegk (λ=47.94° N, Germany) K9=500 nT."*

➔ Please, see M1regarding description of coordinates.

L9 used are different from the L9 determined/calculated.
That fact came from history. In the middle of 20th century, the aim was on one hand, to avoid to constrain the observers of magnetic observatories (to acknowledge their skills and free will), and on the other hand, to let a possible rounding of L9. At that time, when calculations were done by hand and K indices were hand-scaled, differences of some tenths of nT were not a big deal.

Example of Lerwick:
L9 used = 1 000 nT for Kp but
L9 calculated = 921 nT

Indeed, the observers of each observatory were set free to "round" the values :
- towards the "nearest" decade of nT (921 to 920),
- towards the "nearest" fifty of nT (921 to 950 or 900)
- towards the "nearest" hundred of nT (921 to 900 or 1000)

The L9 presented onto the GFZ website are the L9 used for the calculation of Kp.

➔ Please, clearly state here when the L9 are the ones used for historical purposes (derived at the end of the forties by Bartels et al., only with hand-scaling) or the ones calculated and determined by ISGI under the auspices of IAGA, in agreement with the international community in geomagnetism.
The L9 you are showing are mainly the ones used for the Kp data series, to remain consistent along time, Honolulu being not used in Kp calculation but only to show a low latitude example.
➔Please, correct the sentences, for example: "For Kp determination (Bartels et al., 1939), from higher to lower latitude, at Sitka ([coordinates given], Alaska), L9 =1000 nT while Canberra ([coordinates given] , Alaska), L9 =500 nT. The GFZ website (https://www.gfz-potsdam.de/en/kp-index/) provides the 13 L9 values used for the Kp evaluation, showing values between 450 nT and 1500 nT; in particular, at Niemegk ([coordinates given], Germany) L9=500 nT."

B3 - Lines 46 to 58 : *"For many years, K was manually derived by means of a conversion table containing the values of the maximum fluctuation A, expressed in units of nT, for each K value. With the introduction of digitized data and with the increasing access to computers, the manual estimation of K index was progressively substituted with automated algorithms and, nowadays, the reproducibility, one of the cornerstones of science, has become possible. (…) http://isgi.unistra.fr/softwares.php)."*

➔ Please, correct or amend the first sentence: "For many years, K was manually scaled by means of visual determination of the regular daily variation and of the consequent largest range of geomagnetic disturbances in the two horizontal components during a 3-hour UT interval. Then, K indices were determined by means of a conversion table between classes of ranges in nT and K indices."

➔ Please, enclose and introduce the two following missing, but fundamental, references:

- Coles, R., and M. Menvielle (1991) - Some thoughts concerning new digital magnetic indices, Geophys. Trans., 36, 303-312.
- Menvielle, M. (1991) - Evaluation of algorithms for computer production of K indices, Geophys. Trans., 36, 313 -320.

B4 - Lines 59 to 61: *"The International Real-time Magnetic Observatory Network (INTERMAGNET, http://www.intermagnet.org), of which IAGA is associated, endorses and recommends KASM for calculation of geomagnetic activity indices K according to the Adaptive Smoothed method (Nowozyński et al., 1991)."*

➔ Please, see comment A2. This sentence is incorrect, it has to be replaced by: "IAGA, through the ISGI international service, endorsed 4 different methods for calculation of local geomagnetic activity indices K. We used one of them the KASM method that used adaptive smoothed method (Nowozyński et al., 1991)."

B5 - Line 63: "(…) the code derives daily values without fluctuations (mainly daily variation)."

➔ Please correct the wording. "(…) the code estimates the regular daily variation."

B6 - Lines 65 to 70: *"We want to point out that it does not exist an unique K9 at a given geomagnetic latitude since the geomagnetic activity shows a well known magnetic local time (MLT) dependency and, in addition, each site could be affected by different local features such as, for example, crustal anomalies (Chiappini et al., 2000) and/or coast effect (Parkinson, 1962; Regi et al., 2018). For the inclusion of a new geomagnetic observatory into the INTERMAGNET network, K9 should be assigned, for example, by comparing geomagnetic field variations between the new observatory and the historical ones for which K indices are estimated by using well defined K9 levels, obtained from a long time observation."*

➔ **This paragraph is entirely false.** It does exist a unique L9 at a given geomagnetic latitude. The 4 softwares endorsed by IAGA are taking care of the determination of the regular daily variations and are, by construction, considering the day-to-day variability. A simple plot of the regular daily variations extracted from softwares shows it clearly. Although one has to dig into the code and extract the relevant information. Indeed, codes available at ISGI are designed for operational purposes and were designed considering that the user knows their internal functioning.

At a particular magnetic observatory L9 is defined by the distance $\boldsymbol{\delta}$ to "oval auroral" modelled as the +/-69° latitude CGM around 1965.

See:

- Mayaud, P.-N. (1968) - Indices Kn, Ks et Km, 1964-1967, Ed. C.N.R.S., Paris, 156 p.

Especially the Figure A1 page 34.

A more recent paper is using that historical reference and may appear less 'arid' to the authors of the present paper:

- Lockwood, M., A. Chambodut, L. A. Barnard, M. J. Owens, E. Clarke, and V. Mendel. 'A Homogeneous Aa Index: 1. Secular Variation'. Journal of Space Weather and Space Climate 8 (2018): A53, doi: 10.1051/swsc/2018038.

Especially the Figure 3 page 6 and the related section 2.

Bartels defined the L9 of a particular magnetic observatory from hand-scaling of ranges and subsequent statistical study with the intent of producing a geomagnetic disturbance characterisation that does not depend significantly on the location of a sub-auroral, mid- or low- latitude observatory.

However, since beginning of the fifties, and even more since the digital era, the empirical method was put apart and the definition of L9 was chosen with regard to distance $\boldsymbol{\delta}$ to "oval auroral" modelled as the +/-69° latitude CGM. (One has to note that this method remained still unperfect, as the distance to the oval auroral is changing with the main field but this is beyond the scope of your paper here.)

B7 – line 79: *" LMP is the southernmost observatory in Europe"*

➔ Please, correct this statement which is false GUI (Guimar-Tenerife) magnetic observatory is southernmost, not speaking about French austral territories…

B8 – lines 88 to 90: *"Our investigations suggest that NGK is the best reference observatory for Italian geomagnetic observatory of DUR, probably due to the closest magnetic local times: by comparing DUR with NGK we estimated a reliable DUR K9 level of 320 nT. Finally, by comparing also LMP with NGK, a reliable LMP K9 level of 310 nT is estimated."*

A simple computing, considering distance to the oval auroral, leads to:

- for historical determination (without secular variation, Mayaud's method) $L9_{DUR}$ = 356 nT and $L9_{LMP}$ = 315 nT;
- for January 2019 determination (taking the oval auroral given by IGRF) $L9_{DUR}$ = 354 nT and $L9_{LMP}$ = 312 nT.

The results agree with the one provided by the authors. (The agreement is less striking for DUR as its geomagnetic latitude is beyond the range of possible K indices determination.) CGM coordinates of the Italian magnetic observatories remain quite constant along time as the $L9_{NGK}$ does.

➔ Please, correct or explain the part of the sentence saying that "*probably due to the closest magnetic local times*". If the L9 values are wisely chosen, then, local K indices statistical repartition along K values does not depend significantly on the location of the observatory. But in any case, a comparison along time obviously does show a clear Local Time (or Magnetic Local Time) dependence as the magnetic disturbances are impacting differently the day, dawn, dusk or midnight quarter (e.g. : K-derived magnetic indices in 4 Magnetic Local Time sectors ; see Chambodut, A., A. Marchaudon, M. Menvielle, F. El-Lemdani and C. Lathuillere (2013) - The K-derived MLT sector geomagnetic indices, Geophys. Res. Lett., 40, 4808-4812, DOI:10.1002/grl.50947.)

section 2-"Data and methods of analysis"

C1- Please, which time-resolution magnetic observatory data are you using with the KASM method? Please indicate it. A first guess would be "minute data computed from second data using INTERMAGNET 1s to 1min filter".

section 3-"Experimental results"

subsection 3.1 "K9 empirical estimation"

D1- regarding Figure 3 and the related description in the section. The discrepancies observed are for low K indices. Do the authors have an explanation? Can it be a limitation of the K index derivation scheme in really quiet and quiet magnetic conditions?.

D2- regarding Figure 4 and the related description in the section 2. The discrepancies observed between the black and red curves are, for both compared observatories (LMP and DUR), in the same direction. WNG comparison shows an underestimation of L9 values. Would it be possible that the location of WNG observatory nearby the shore (around 10 km to the North sea) leads to a possible bias in daily regular variation estimation in K indices calculation?

D3- lines 146 to 150: *"In addition, the higher correlations are obtained by using NGK, probably due to the lower latitude (i.e. closer to the Italian observatories) and the closer MLT with respect to DUR (table 1). Also at LMP, even if the MLT is closest to that of WNG, the higher correlation is found with NGK: this result suggests that latitudinal effects are dominant with respect to MLT ones. This can be well understood taking into account that the MLT range of all selected observatories is within 11 minutes, well shorter than the 3-hour interval used for K determination."*

➔ Please, consider D1 and D2 questions.

D4-lines 179 to 180: "*We point out how the distributions are close to each other, suggesting that FMI and KASM are consistent algorithms,* (…)"
You obtained the same results as: Coles & Menvielle (1991), Menvielle (1991) and Menvielle et al. (1995).

D5- regarding Figure 5 and the related description in the section 2:

➔Please explain why Figure 5 (left) has to be symmetric for a better L9 value considering that only 2 years of data are used, a tiny part of the solar cycle?

D6- regarding Figure 7 and the related description in section 2: The authors are in fact here doing a comparison of K derivation softwares. The discrepancies observed are similar with the ones observed between Asm method and FMI method in Menvielle et al. (1995).

subsection 3.2-" Comparison with a previous K9 estimation method"

E1- lines 190 and 191: "*According to Mayaud (1980), an approximate value of δ could be given by δ=69°-λ*
but this is really just a rough approximation."

➔ Please, do not be so rude. Mayaud method is still the one in use that proved, and still proves, its robustness. The results of the present paper are similar to the ones obtained with Mayaud's method, see B8.
Furthermore, the correct reference here is Mayaud, P.-N. (1968) - Indices Kn, Ks et Km, 1964-1967, Ed. C.N.R.S., Paris, 156p. (available at http://isgi.unistra.fr/Documents/Books/Mayaud_CNRS_1968_complete.pdf)

E2-lines 193 to 200:

➔ Please correct the approximated equation you are using. Mayaud is using a 4th degree polynomial.

E3 lines 192 to 231:

➔ This part of the present paper is largely incorrect. Please, read Mayaud (1968) (or Lockwood et al. (2018), page 5 to 7, for a more "modern english" explanation) and correct.

section 4-" Discussion and Conclusions"

F1-lines 234 to 236: *"The modern automatic procedures for calculating local K index values, with the setting of some a-priori criteria, have to be carefully verified for their permanent validation in terms of accuracy and stability when delivered to the scientific community."*

➔ Please erase this sentence. The present paper has to be reviewed with major revisions.

F2- line 237: *"(…) This code is distributed by the INTERMAGNET consortium(…)"*

➔ Please see comments A2 and B4.

F3- lines 239 to 241: *"(…) the K9 value, which represents the minimum value of the amplitude extent in the H component of Earth's magnetic field when the local K value reaches the integer 9, the highest level in a scale which ranges from 0 to 9."*

➔ Please correct: "L9 value, the so-called "K=9 lower limit" allows to determine, for each magnetic observatory, the conversion table between classes of ranges and K indices."

F4- lines 263 to 272: *"Moreover, Mayaud (1980) note that the limitation of the method they propose is that it is conceived for sub-auroral and mid latitudes; indeed, they suggest that for lower latitudes a constant K9=300 nT can be chosen. This very approximate value is not very far from the values we estimate (320 nT for DUR and 310 nT for LMP), but would certainly be not accurate as them in the comparison with the values from other reference observatories: indeed our results clearly show that a very precise K9 limit is necessary for obtaining K values well consistent at different sites. As a final remark, from the overall view of this work, we are also definitely convinced that the habit to round the value of K9 in multiples of 50 nT is a simplified approximation, firstly suggested by Bartels et al. (1939), a practice that needs to be abandoned. This approximation is still adopted in some cases, demonstrating that perhaps a critical revision has not been applied yet, differently from the case of Kakioka observatory (Japan) where K9 has a convincing value of 296 nT."*

➔ Please erase that part. Mayaud (1968) clearly stated that the magnetic observatories towards polar areas or towards equatorial regions (58° > |CGM latitude| > 29°) are under magnetic conditions (e.g.: field aligned currents, magnetospheric ring current, etc) that do not allow to produce K indices comparable to mid-latitude ones. The Figure A1 of Mayaud (1968) clearly show a hyperbola with two asymptotes. One may calculate K indices for sub-equatorial or sub-polar geomagnetic observatories but without real physical meaning. The activity of the magnetic field in these observatories cannot be assessed with the proposed softwares. This is also the reason why K-derived Magnetic indices, such as Kp, aa or am, are only fully meaningful for mid-latitude. Dst (equatorial) or PC (polar) are not K-derived indices.

➔ Please, do not patronise and give recommendation. Indeed, the L9 values are presented onto the ISGI website for each magnetic observatory. The rounding of L9 values may easily be overcome by the use of the well-know FKC table developed and used by both Bartels and Mayaud. Magnetic Observatories do not need to update or change their L9 values. Homogeneity of the series is of primary importance.

For each magnetic observatory, the only mandatory point and message that should be given to the whole community is: Please, provide carefully in the metadata the L9 value that was actually used for K indices calculation.