Open-ended, high cadence, *Kp*-like geomagnetic index Hp

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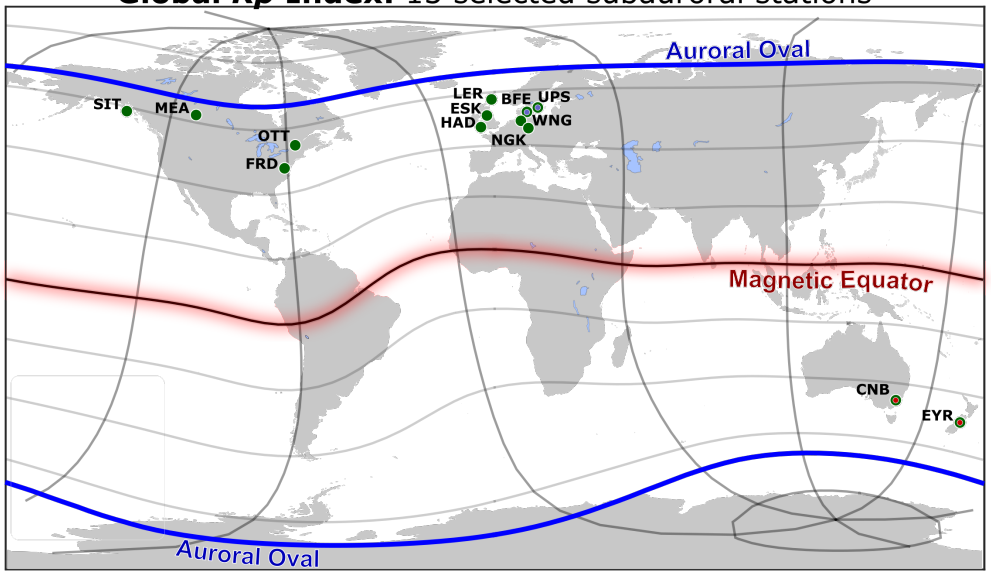
http://swami-h2020.eu/

Some basics on *Kp*

Basics: Geomagnetic disturbances index, *Kp*

Global *Kp* Index: 13 selected subauroral stations



- "*Kp* indicates the intensity of **geomagnetic** activity as expression of solar corpuscular **radiation**, for every three-hour interval of the Greenwich day." (Bartels, 1957)
- Based on *K* values from 13 subauroral geomagnetic observatories
- ***Kp***: "**p**lanetarische **K**ennziffer" (= planetary index)
- 3-hourly index, values from 0 to 9, since 1932
- Endorsed by IAGA, derived and distributed here: http://www.gfz-potsdam.de/en/kp-index/

Basics: Local geomagnetic activity index, *K*

Fig: Siebert (1996)

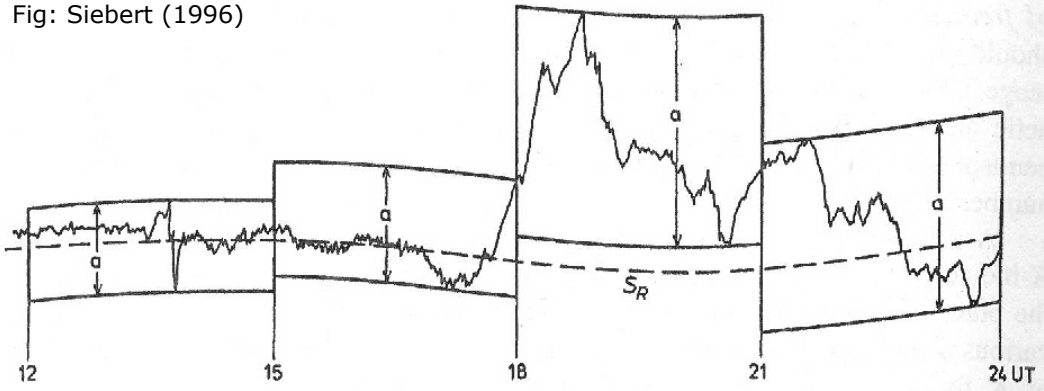


Fig. 1. Record section for 12 h (four 3-h intervals) to illustrate the elimination of the regular daily variation S_R (indicated by the *dashed curve*). The difference between the lower and upper envelopes of the actual trace, parallel to S_R, determines the maximum disturbance range *a* within every 3-h interval

Local *K* index

- magnetic recoding of **X** and **Y** components
- Quiet-day (Sq or S_R) variation removed
- Station-specific ***K*** index**:** variation range within **3-hour** time interval for the most disturbed field component, X or Y, is mapped to *K values* according to the station specific range limits

Standardized *Ks* index

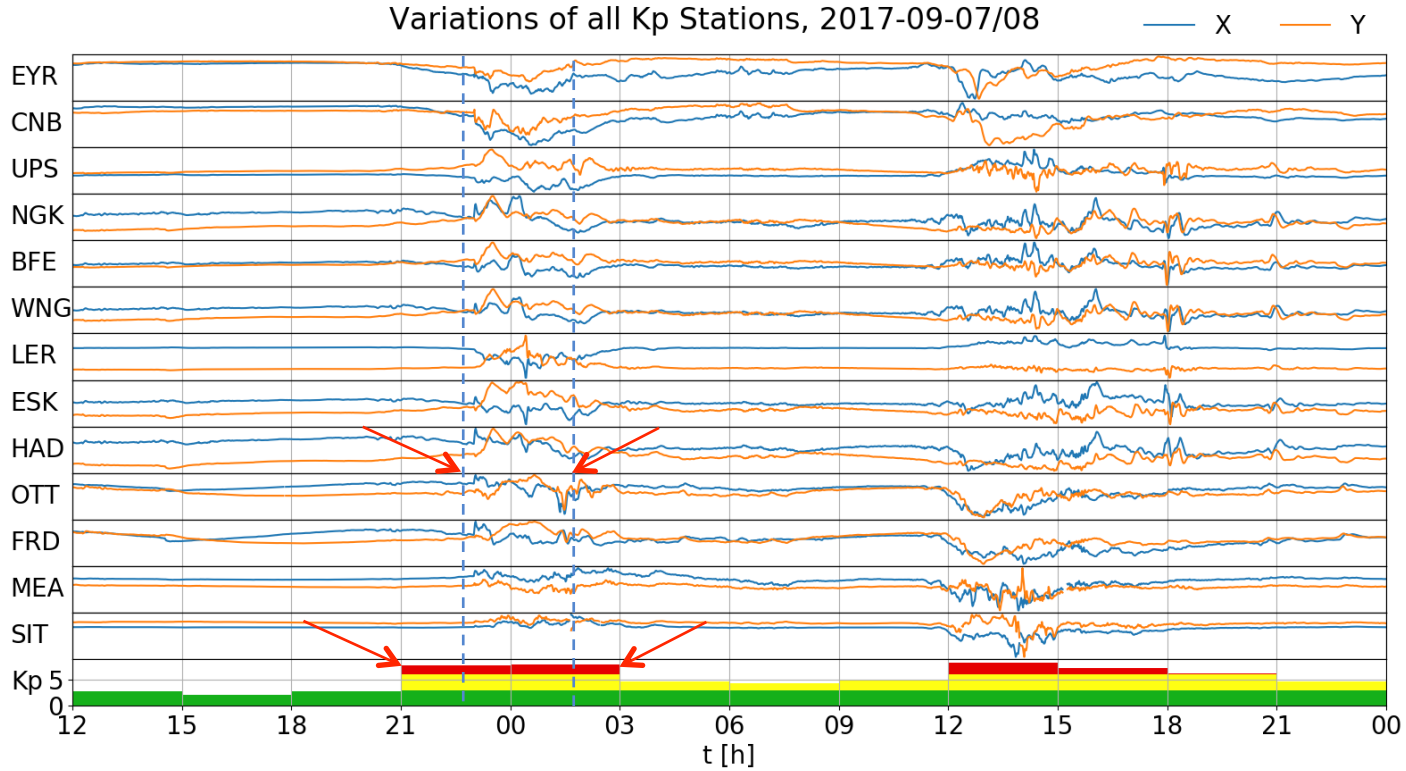
- Normalization of *K* values to avoid (seasonally dependent) LT biases
- ***Ks*** index: conversion tables to eliminate these effects

Global *Kp* index

- mean of ***Ks*** from 13 observatories

Motivation for an open-ended, high cadence *Kp*-like index

Example: geomagnetic variations at 13 *Kp* stations and *Kp* index for Sept. 7 & 8, 2017



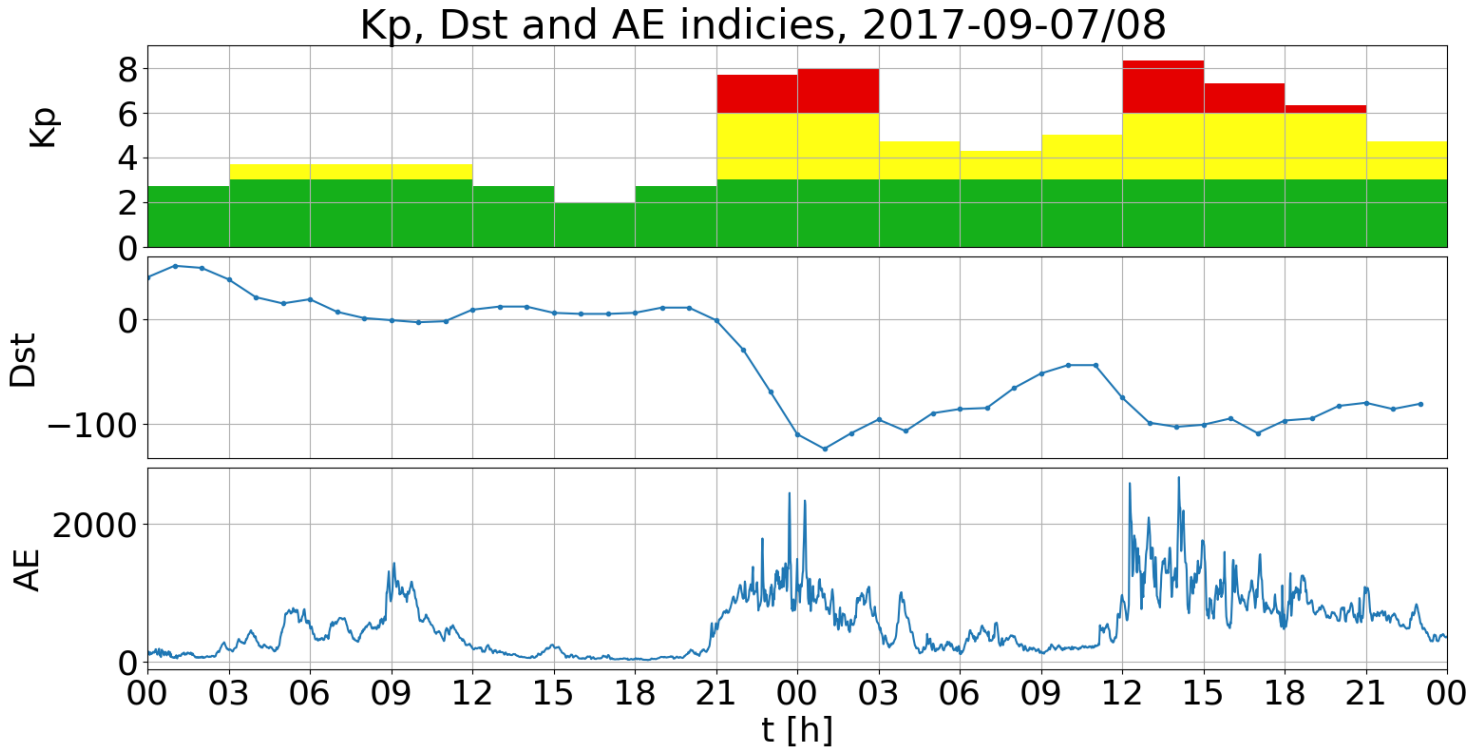
Take away: Strong geomagnetic variations start on Sept. 7 at 22:30 UT and stop about **three hours** later. The *Kp* index by definition (and somewhat misleadingly) shows elevated values for **six hours** (from Sept 7 at 21:00 UT).

Example: geomagnetic indices Kp, Dst, AE for Sept. 7 & 8, 2017

Subauroral and mid-latitudes
Time res.: 3hs
Max. value: 9

Low-latitudes
Ring current
Time res.: 1h
Max. value: n/a

Auroral-latitudes
Time res.: 1min
Max. value: n/a



Take away: Kp has the lowest time resolution of the indices presented here. It is capped, by definition, at 9, irrespective of the actual magnitude of severe geomagnetic events.

Motivation for a *Kp*-like index with higher time resolution

- *Kp* and the derived index ap are widely used indices of geomagnetic activity for space weather monitoring, research, modelling, etc.
- Increased temporal resolution of global geomagnetic activity allows for a better better defined start time and end time of solar wind energy input into the upper atmosphere.
- User survey by the H2020 project SWAMI indicated that *Kp* is a heavily used geomagnetic index and many users would prefer a time resolution of 60 minutes.
- The modelling community sometimes interpolates the 3-hourly *Kp* index in lieu of truly high-resolution data, e.g. thermospheric density (Vallado and Finkleman, 2014), TIE-GCM (Quian et al., 2014).

Motivation for an open-ended *Kp*-like index

- Provide a *Kp*-like index that is more nuanced in describing the highest levels of geomagnetic activity.

- The range of geomagnetic variations caused by a certain event is dependent on geomagnetic latitude. The discussion below is intended for a geomagnetic latitude of 50°.
  - The maximum value of *Kp* = 9 corresponds to geomagnetic variations exceeding a range of 500 nT. In the ap index, these are assigned an equivalent amplitude of 400 (in units of 2 nT), corresponding to geomagnetic variations with a range of 800 nT.
  - Any event with geomagnetic variations just exceeding 500 nT is assigned Kp = 9 and ap = 400, i.e. a range of 800 nT, which is too large to describe this event properly.
  - Any event with geomagnetic variations significantly exceeding 800 nT is also assigned Kp = 9 and ap = 400, i.e. a range of 800 n,T, which is too small to describe strong events properly.

Developing the high-cadence, *Kp*-like index Hp (open-ended comes later)

Note:
Since we a priori don't know to what extent the increased time resolution could degrade the capability of the index to represent geomagnetic disturbance in the same way as the *Kp*-index, we develop and evaluate three versions with different time resolution (90, 60 and 30 minutes). At the same time, we assume that the indices with 60 minutes (user survey) and 30 minutes (highest time resolution) would be the most useful versions.

Developing the high cadence, local geomagnetic activity indices H, and the high cadence planetary Hp

- Based on data from 1995 – 2017 (digital 1min values available for all 13 stations since 1995)
- Developed indices Hp90, Hp60, Hp30 (90, 60, 30min cadence)
- Station specific **H90, H60, H30** indices correspond to **90, 60, 30-minutes** time resolution. We slightly changed the definition of range (to also take into account deviations from the quiet curve, details will be presented elsewhere) and changed the range limits until the H value distribution corresponds to that of *K* (principle of assimilation of frequency distribution, Bartels)
- Calculate global high cadence **Hp90, Hp60, Hp30** from corresponding H indices, such that the frequency distribution is assimilated to that of *Kp*.

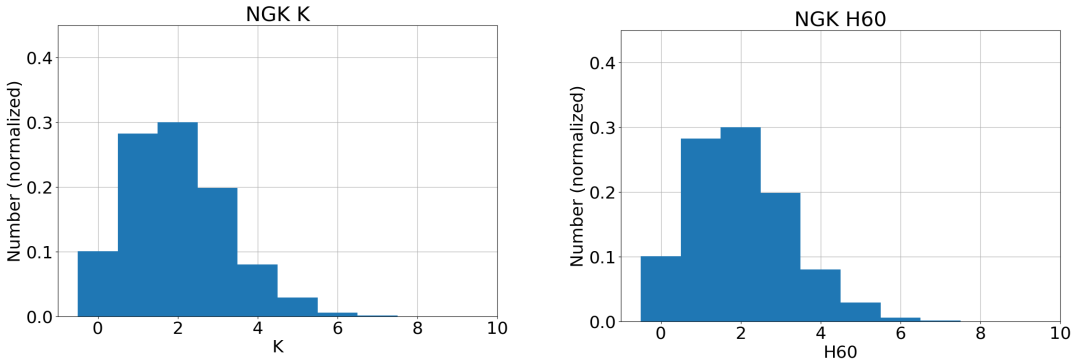
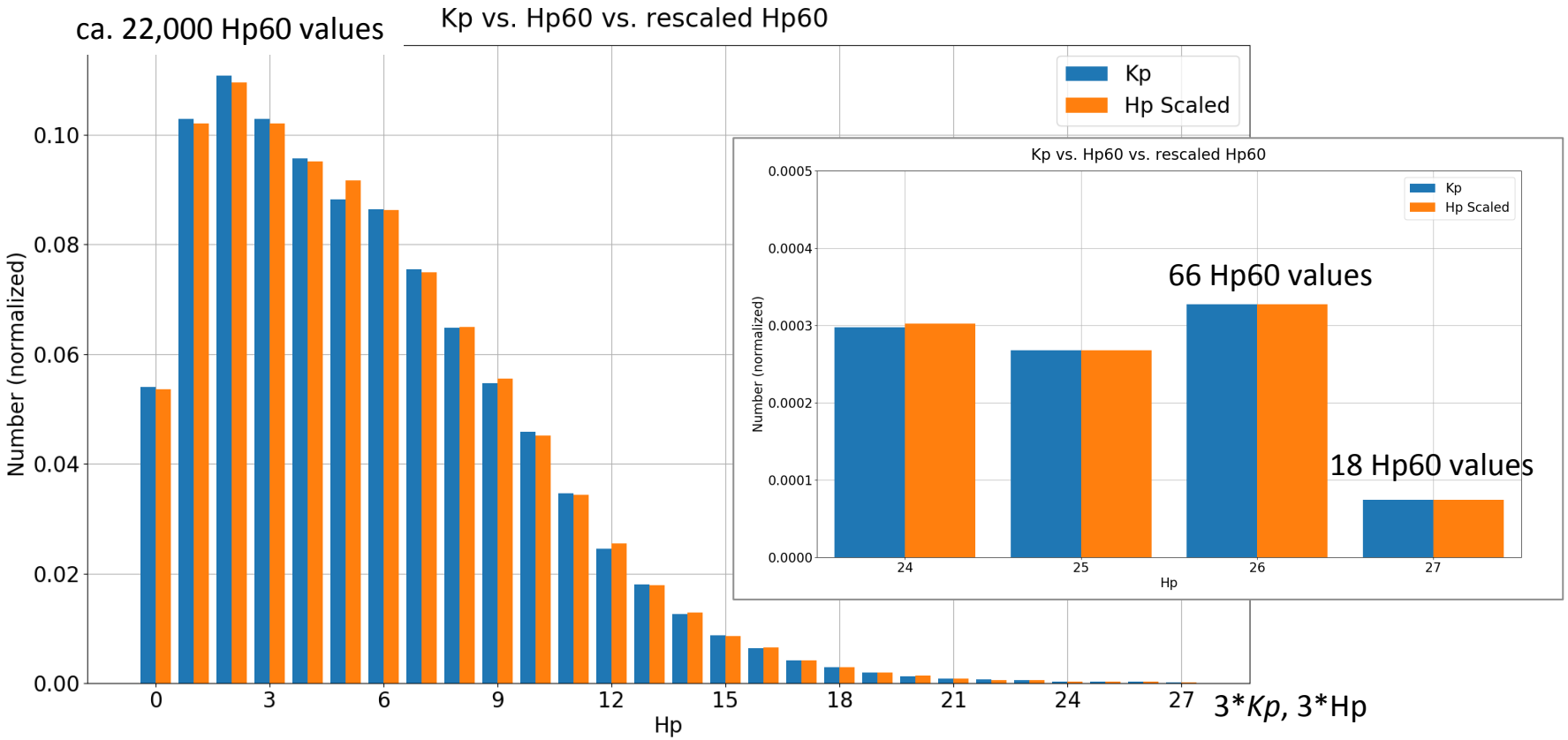


Figure: Distribution of *K* and H is identical, example NGK, H60

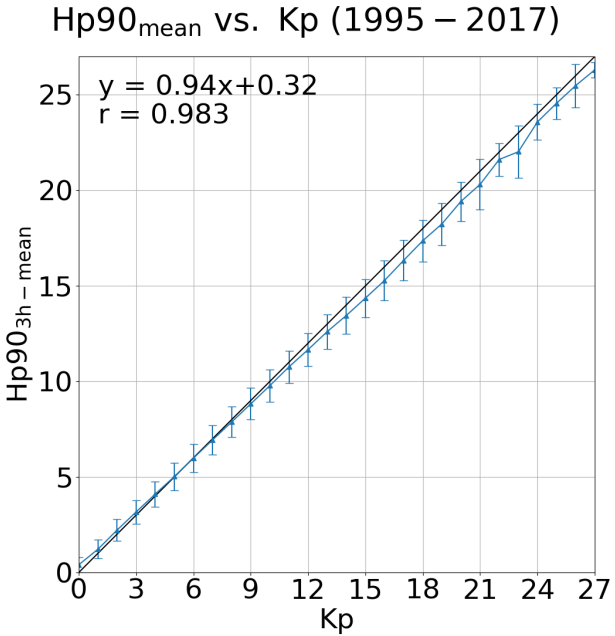
Take away: As *Kp* is an average based on K from 13 station, Hp is based on H from the same stations. To make the H and Hp index as comparable to *K* and *Kp* as possible, we assimilated their frequency distributions.

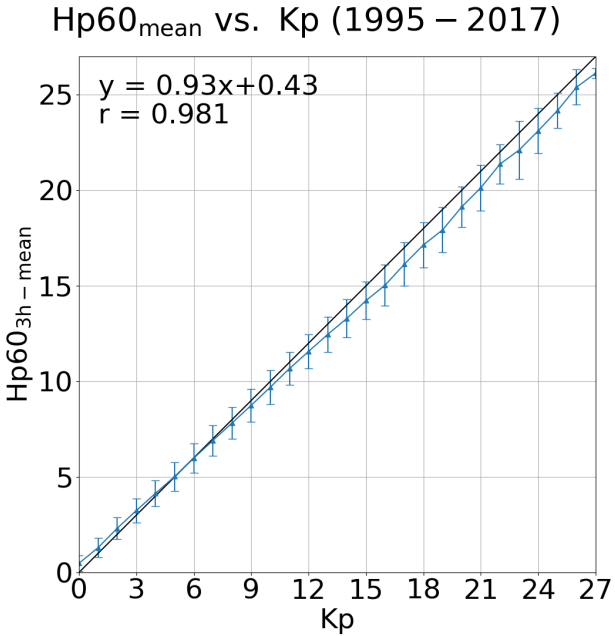
Comparing high cadence Hp and *Kp* (open-ended comes later)

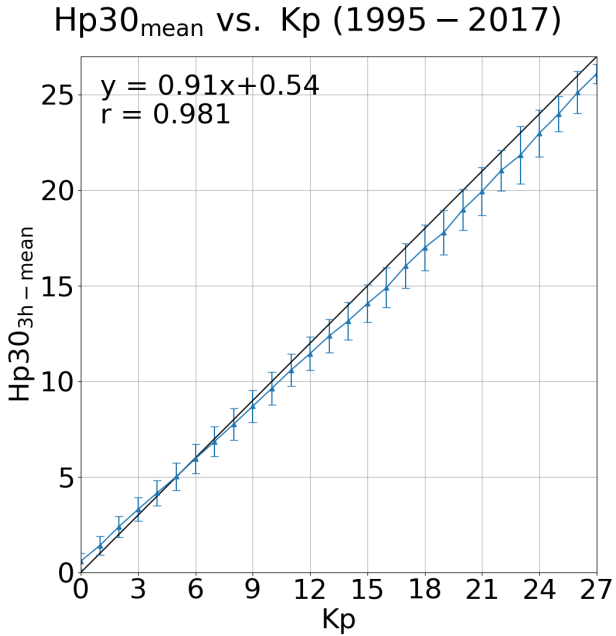
Frequency distribution of *Kp* and Hp is almost identical



Correlation Hp indices vs. *Kp*: 1995 – 2017

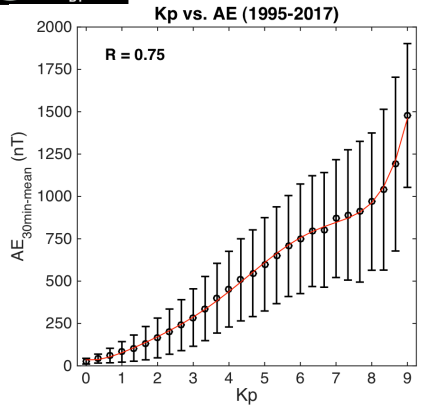


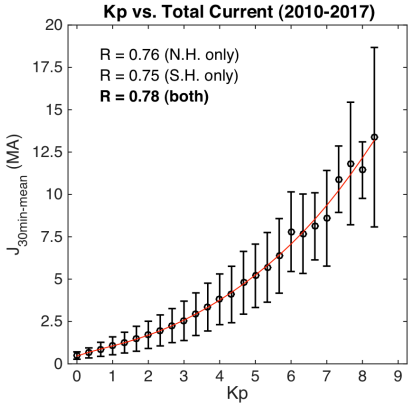


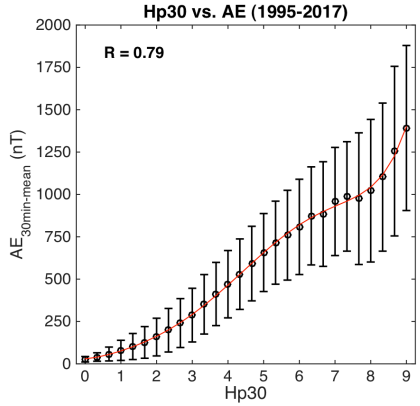


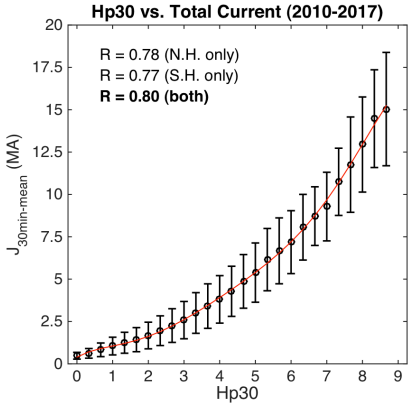
Take away: Frequency distribution (HP60 shown on previous slide) and good correlation of *Kp* and Hp show that *Kp* and Hp have similar properties. Hp90 correlates slightly better with *Kp* than Hp60 and Hp30 do.

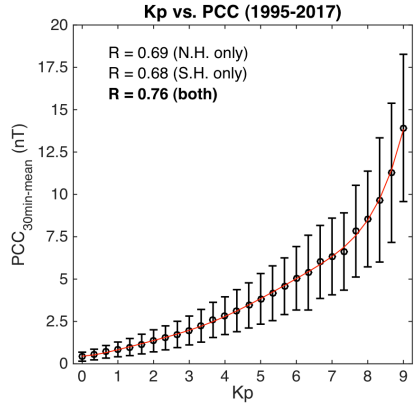
Kp (left) and Hp30 (right) vs. AE index, AMPERE Total Current, PC index, Newell coupling function: 1995 – 2017

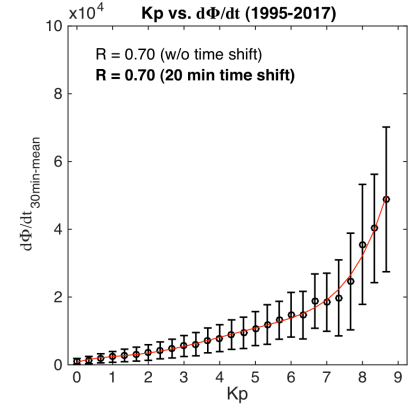


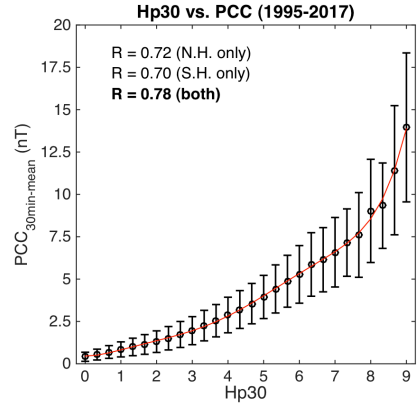


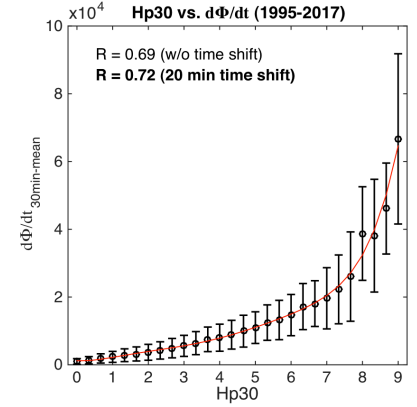






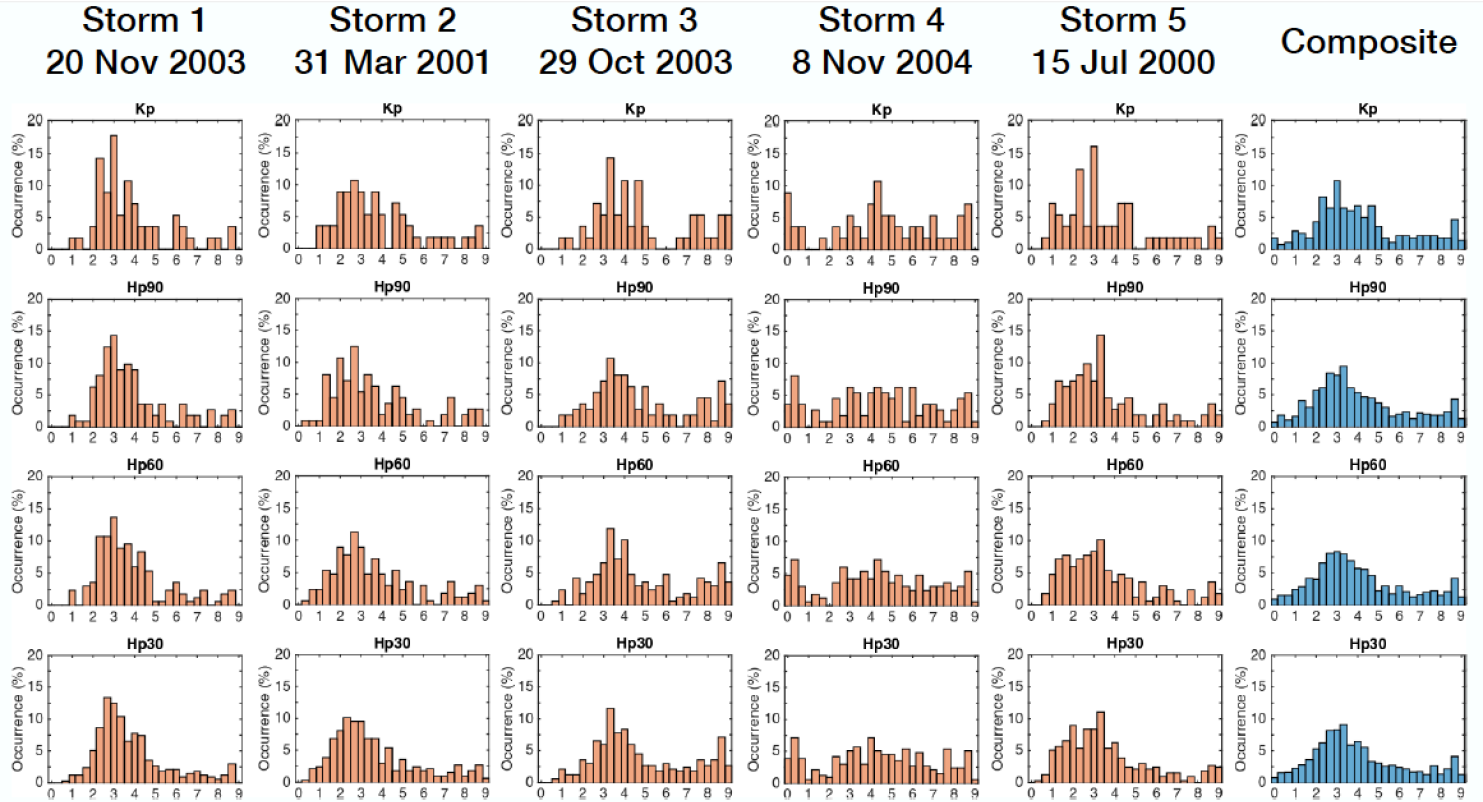






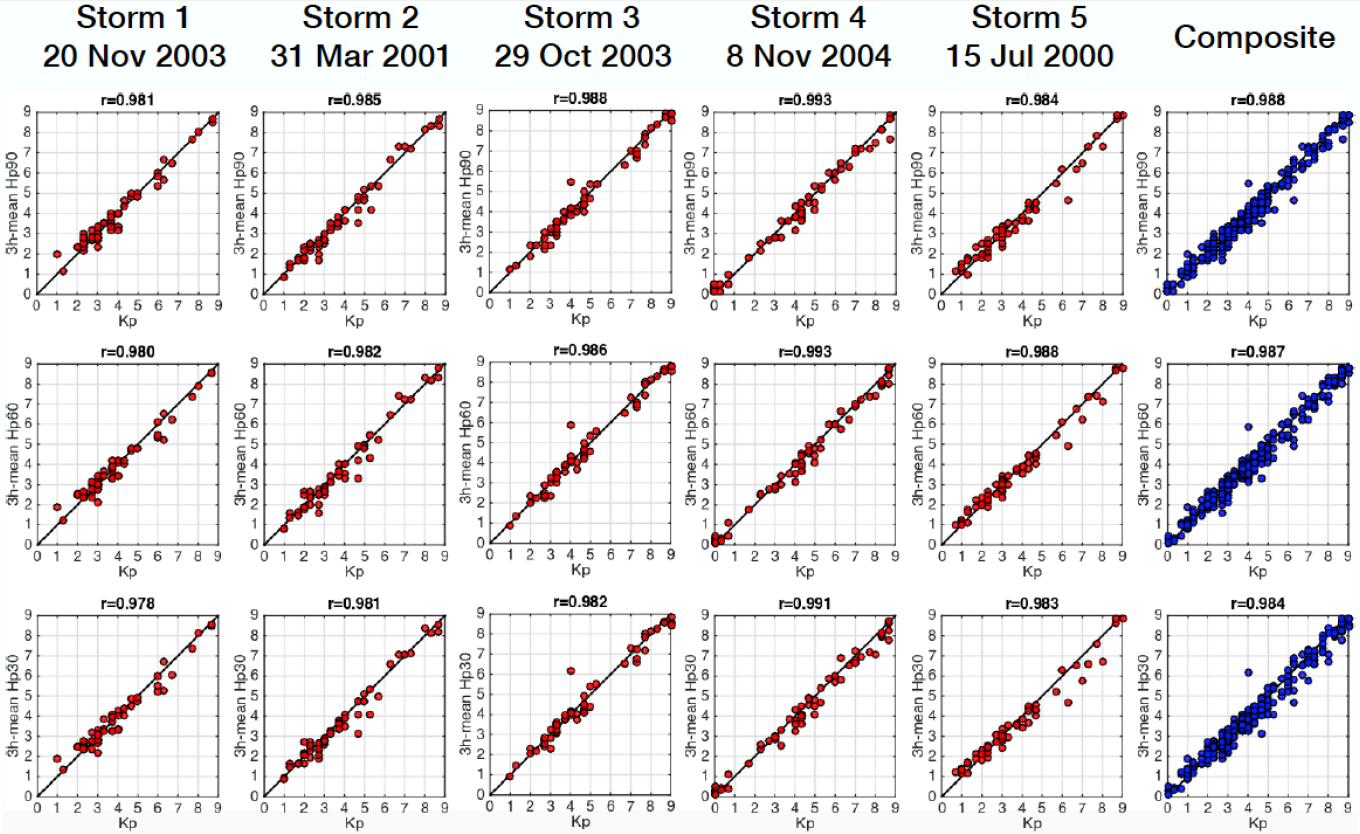
Take away: Relationship of *Kp* and Hp30 to other space physics parameters is similar, even for 30 minutes resolution.

Comparing Hp and *Kp* for five storms (Dst < -300nT)



※ 7 days around the storm (the 3rd day corresponds to the storm main phase)

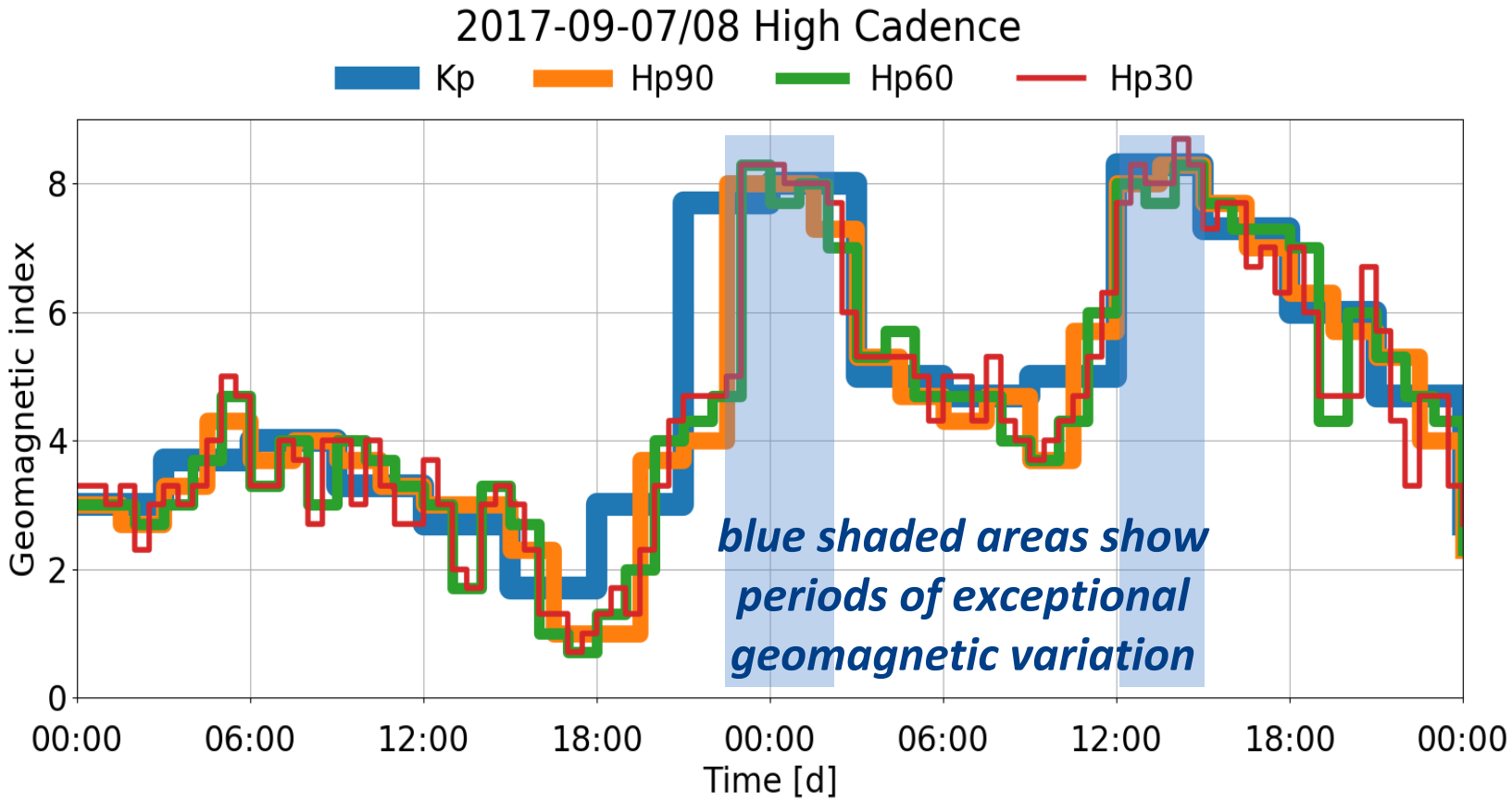
Comparing Hp and *Kp* for five storms (Dst < -300nT)



Take away: Frequency distribution (previous slide) are very similar and overall agreement of *Kp* and Hp90, Hp60, and Hp30 is very good (R^2>95%) during the 5 strongest storms from 1995 to 2017.

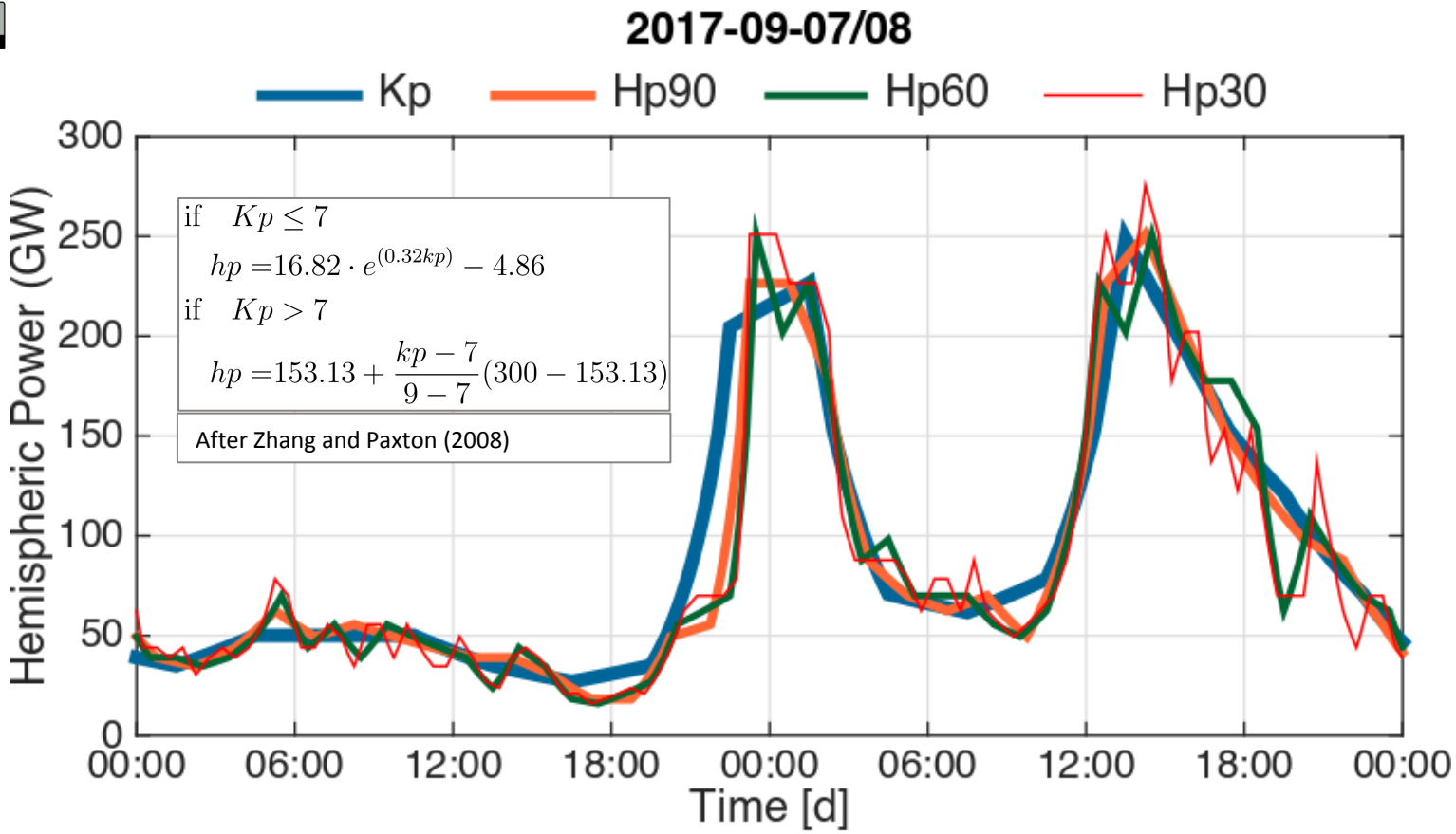
Example:
Storm of Sept. 7 & 8, 2017 and hemispheric power, an input parameter for TIE-GCM modeling (open-ended comes later)

Kp, Hp90, Hp60, Hp30 indices

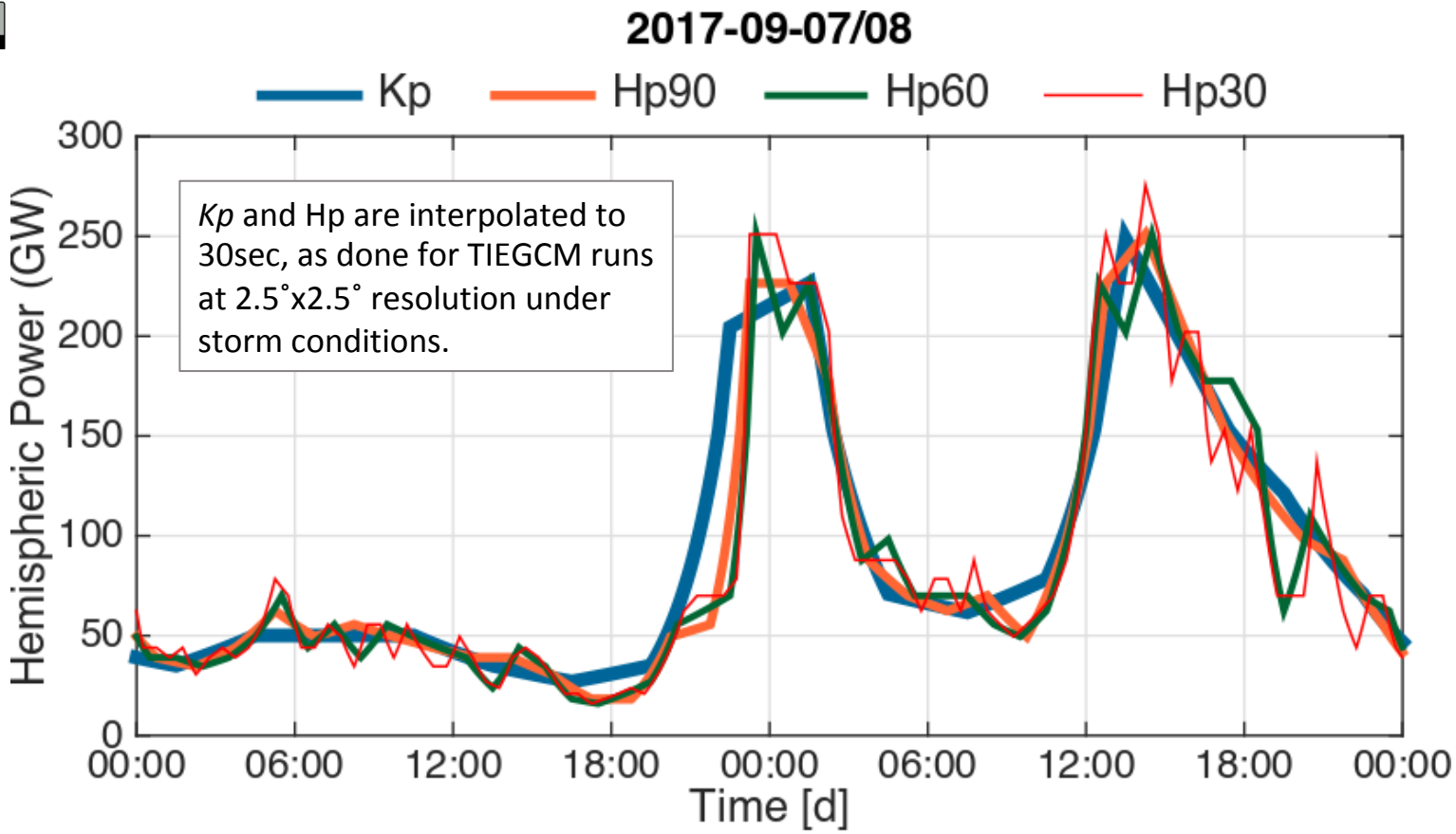


Take away: Hp indicates more precisely than *Kp* the onset of exceptional geomagnetic activity on Sept. 7.

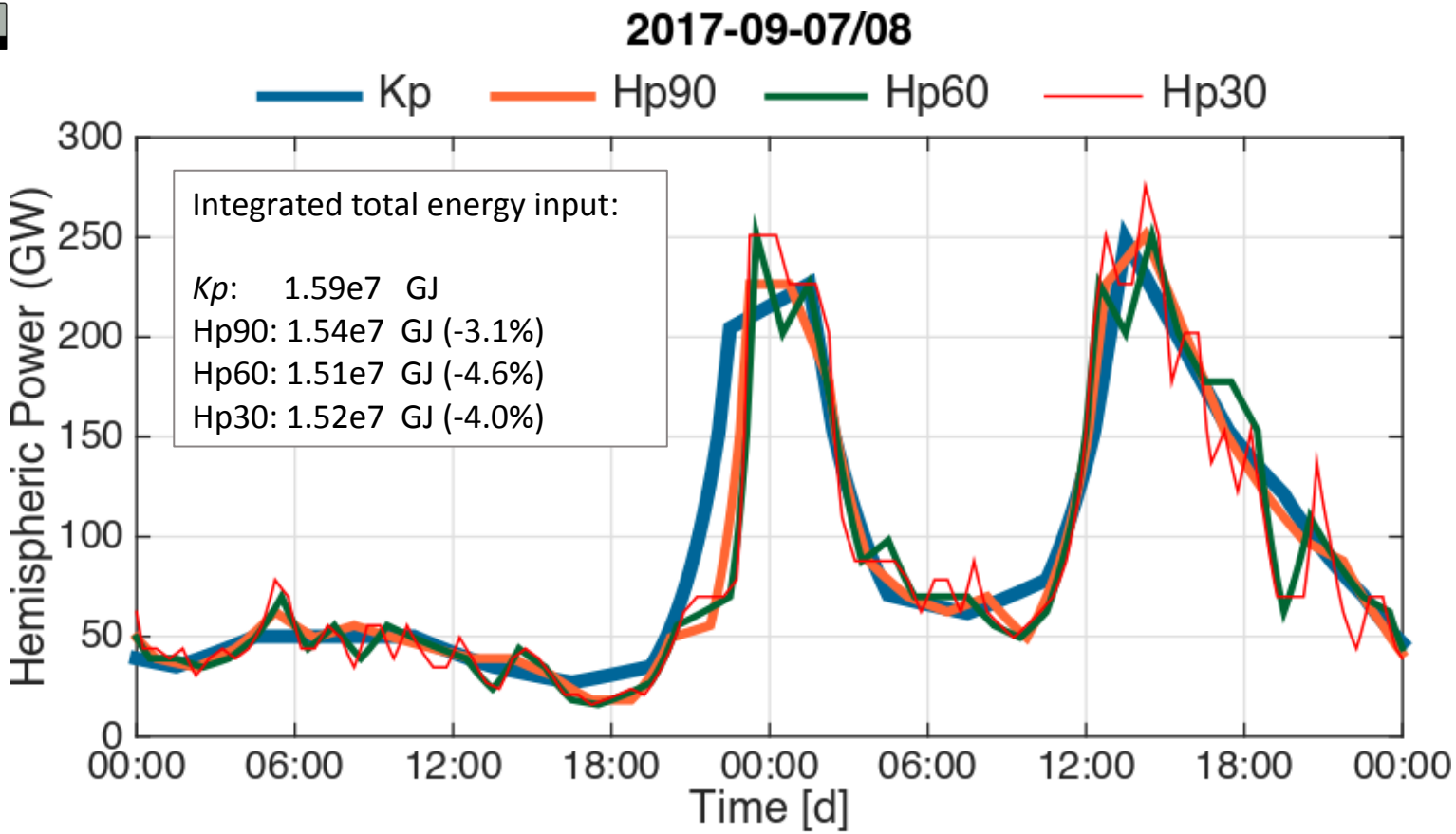
Hemispheric power determined from *Kp* and Hp90, Hp60, Hp30



Hemispheric power determined from *Kp* and Hp90, Hp60, Hp30



Hemispheric power determined from *Kp* and Hp90, Hp60, Hp30



Take away: Hp gives similar, but slightly smaller (and possibly more realistic) hemispheric power than *Kp*

Conclusion on high cadence Hp indices

- Hp90, Hp60, Hp30 work similarly well as *Kp*-like index.
- No systematic degradation of the high cadence index properties with decreasing time resolution of the indices is observed.
- Therefore, development and production of Hp90 with the lowest time resolution is discontinued.
- Hp60 and Hp30 are further developed towards an open-ended indices.

Developing the open-ended, high cadence Hp30 and Hp60

Note:
We evaluated two versions of an open-ended Hp30 and Hp60. The first version (Scale A) is designed to give lower Hp values than the second version (Scale B) for the same event of severe geomagnetic disturbance.

Developing open-ended, high cadence Hp30, Hp60

- The station specific scales for mapping geomagnetic variation ranges to H values are extended to H = 10, 11, 12, etc. This results in open-ended H indices.
- Two different scales are used and will be evaluated:
  - Scale A increases the range limits by a factor of approx. 1.4 to get the lower limits for H = 10, 11, …
  - Scale B increases the range limits by a factor of 1.35 to get the lower limit for H = 10, 1.30 to get the lower limit of H = 11, and 1.2 to get the lower limits of H = 12, 13, 14, etc.
- The open-ended Hp index is calculated according to the following rules:
  - open-ended Hp < 9 is calculated from H capped to 9
  - open-ended Hp ≥ 9 is calculated from H according to the new, extended scale
- In this way, the open-ended Hp is identical to the normal Hp up to Hp = 9-.
- Number of events Hp ≥ 9 for 1995 to 2017:

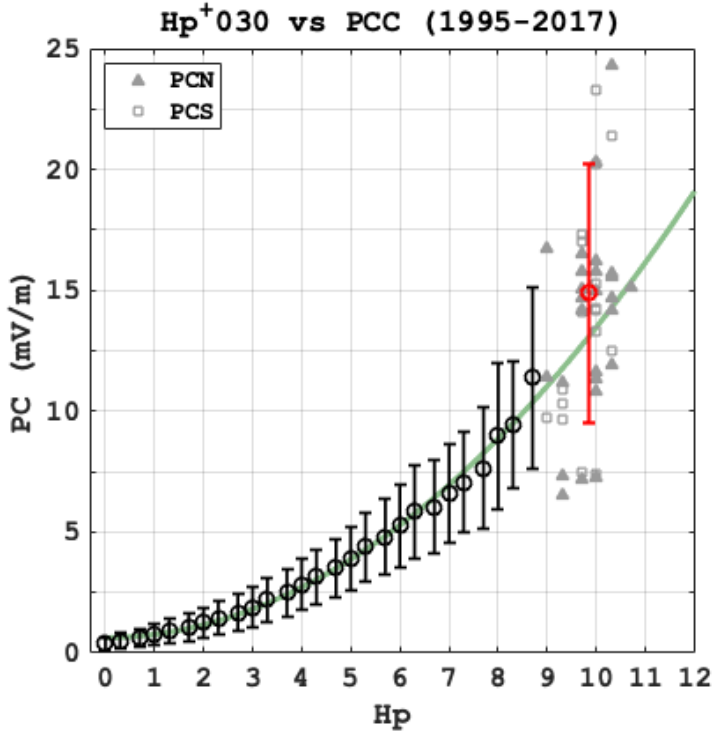
number \ Hp =	9.0	9.3	9.7	10.0	10.3	10.7	11.0	11.3	11.7	sum
scale A, Hp60	-	4	6	2	1	1	1	-	-	15
scale A, Hp30	2	5	6	10	7	1	1	-	-	32
scale B, Hp60	-	2	1	7	2	1	1	-	1	15
scale B, Hp30	-	3	5	5	5	8	4	-	2	32

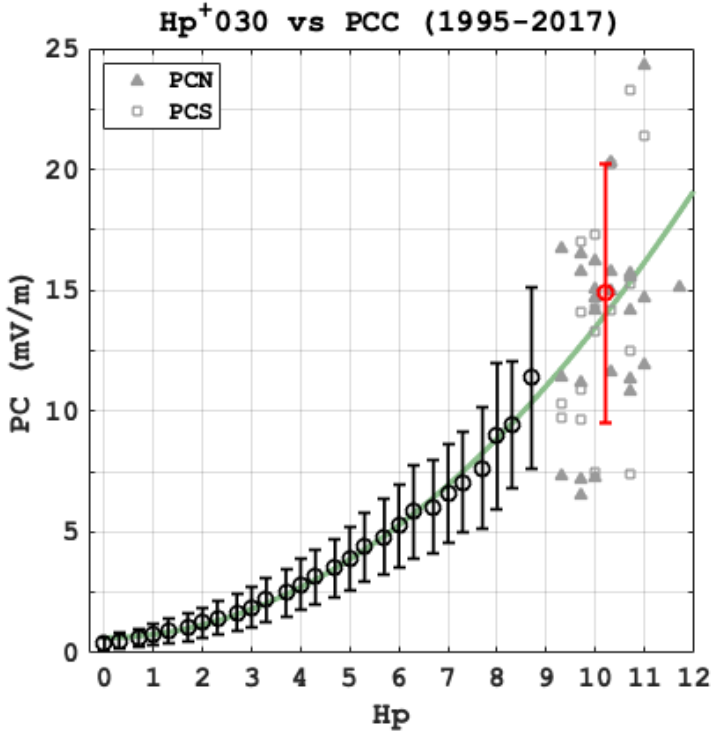
Comparing the open-ended, high cadence Hp with the PC index and solar wind parameters

Evaluating open-ended high cadence Hp

- For evaluation of the open-ended index versions, other open-ended, related parameters are needed to compare with. These are:
  - The composite polar cap index PCC = [(PCN if PCN>0 or else zero) + (PCS if PCS>0 or else zero)]/2, where PCN is the polar cap index in the northern and PCS in the southern hemisphere.
  - Merging electric field E_N after Newell (2007)
  - Merging electric field E_{KL} after Kan and Lee (1979)
- Data from 1995 to 2017
- E_N and E_{KL} are time shifted by 20 minutes (propagation from magnetosphere bow-shock nose to ionosphere)
- PCC, E_N and E_{KL} are averaged over the time interval of Hp (30 or 60 minutes).
- Relation between PCC (or E_N or E_{KL}) and Hp is evaluated for Hp<9 and expressed as third-order polynomial

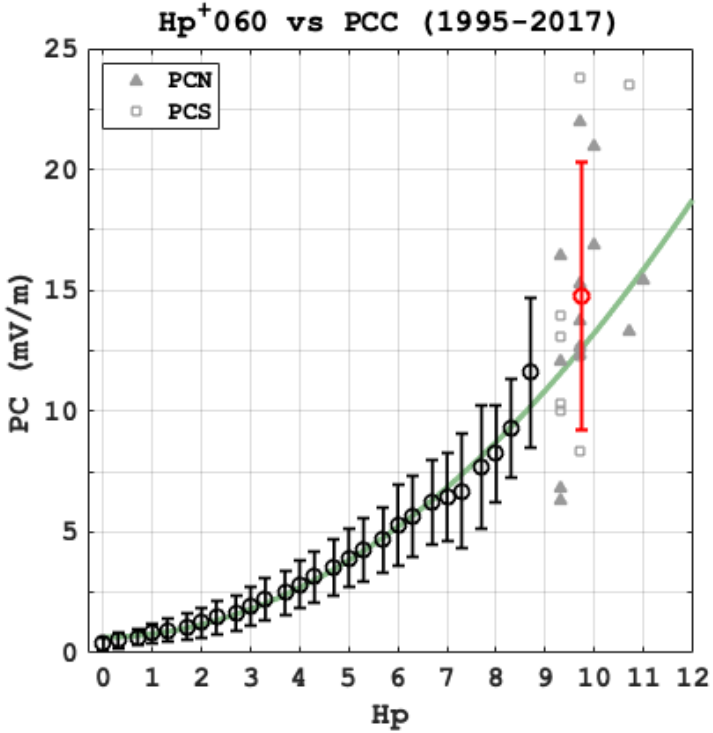
Open-ended Hp30 versus PCC (Scale A left, Scale B right)

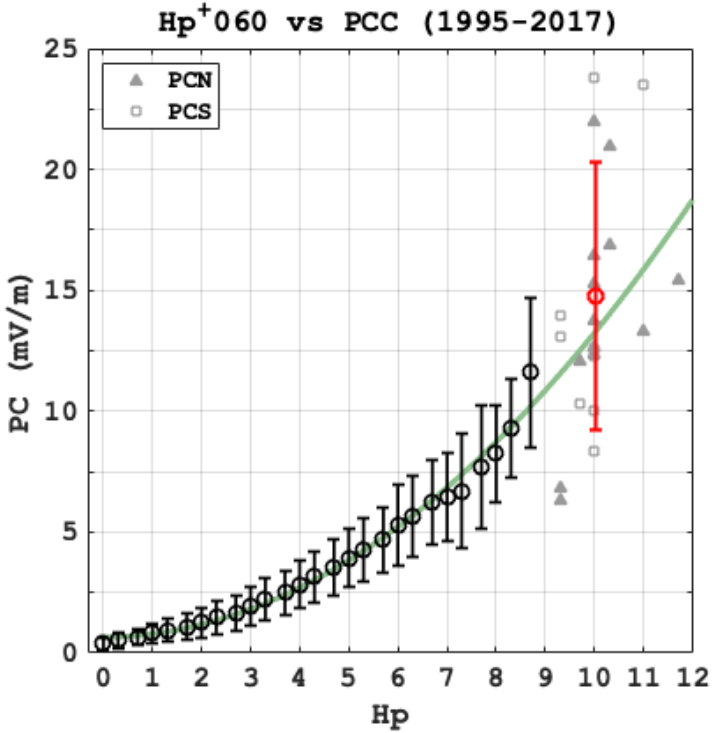




Take away: Scale B fits polynomial prediction of H30p vs. PCC better than Scale A.

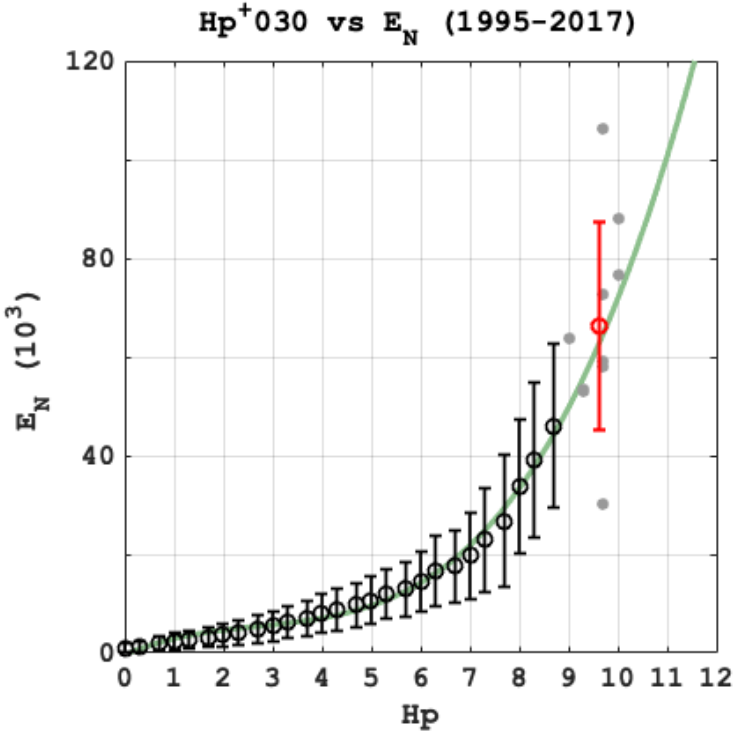
Open-ended Hp60 versus PCC (Scale A left, Scale B right)

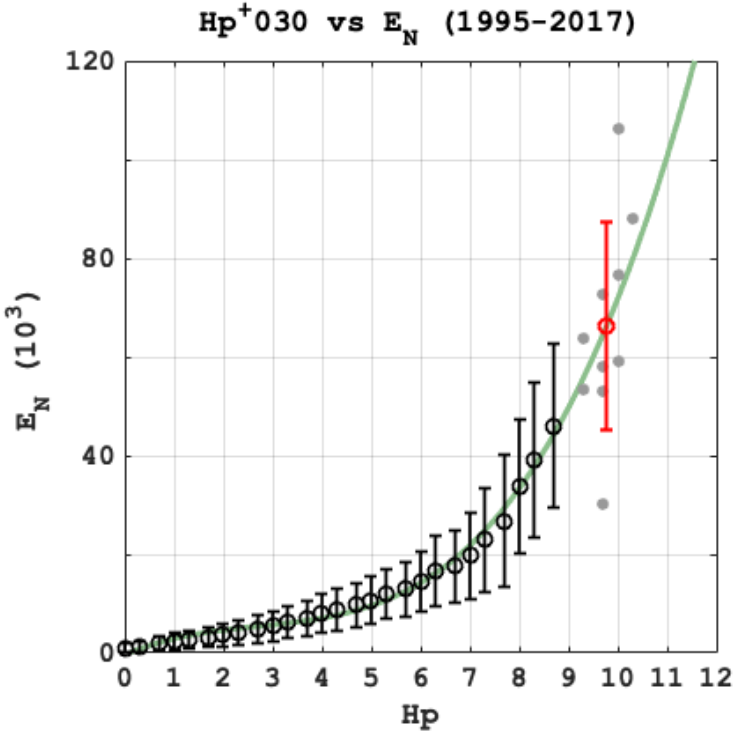




Take away: Scale B fits polynomial prediction of Hp60 vs. PCC better than Scale A.

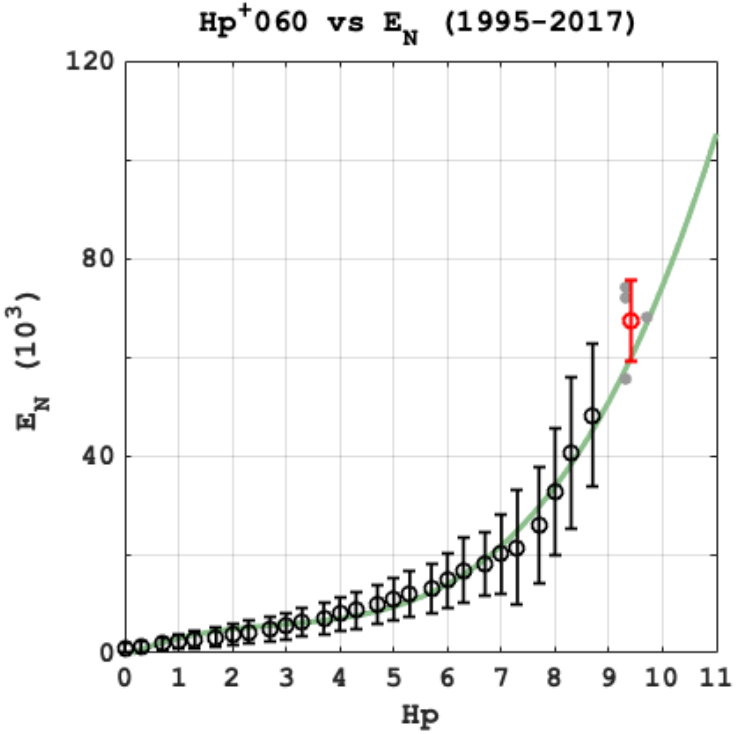
Open-ended Hp30 versus E_N (Scale A left, Scale B right)

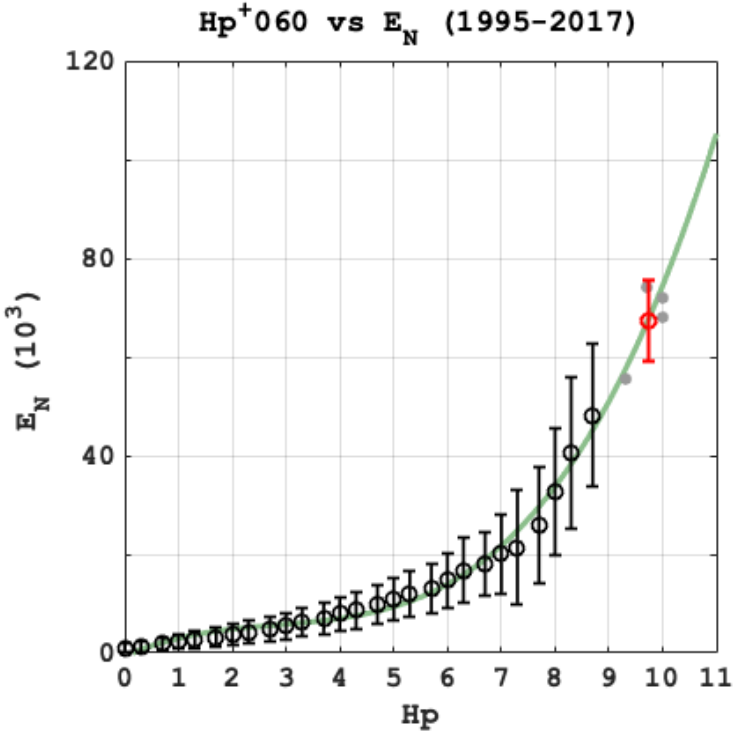




Take away: Scale B fits polynomial prediction of Hp30 vs. E_N marginally better than Scale A.

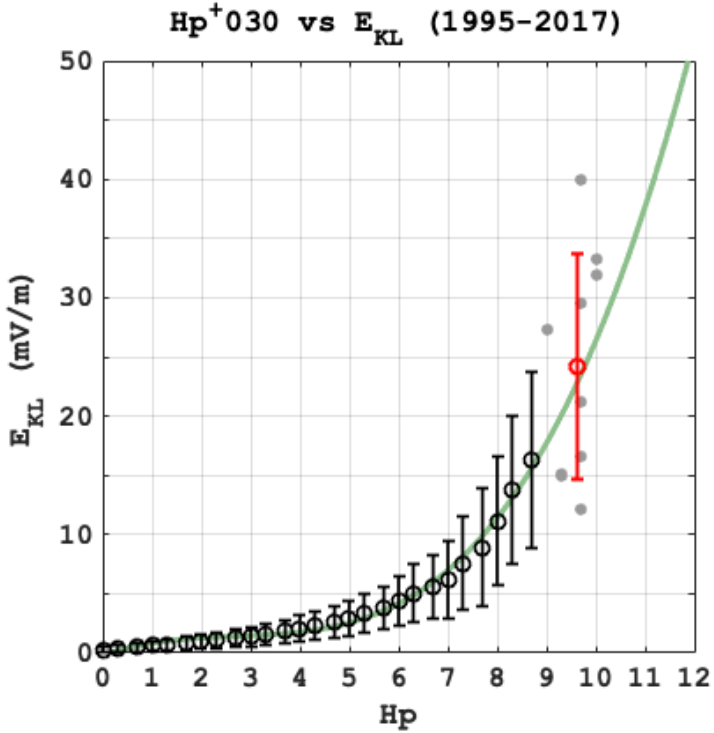
Open-ended Hp60 versus E_N (Scale A left, Scale B right)

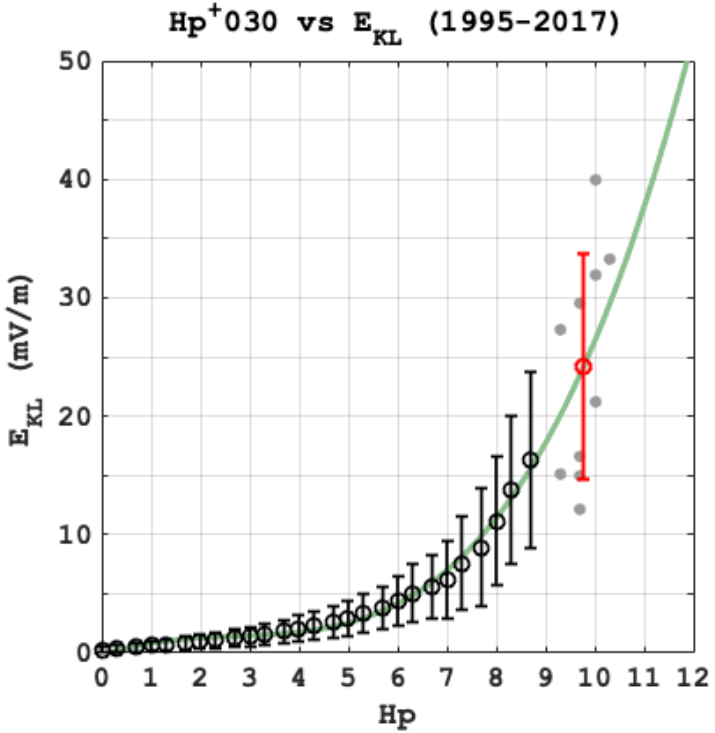




Take away: Scale B fits polynomial prediction of Hp60 vs. E_N better than Scale A.

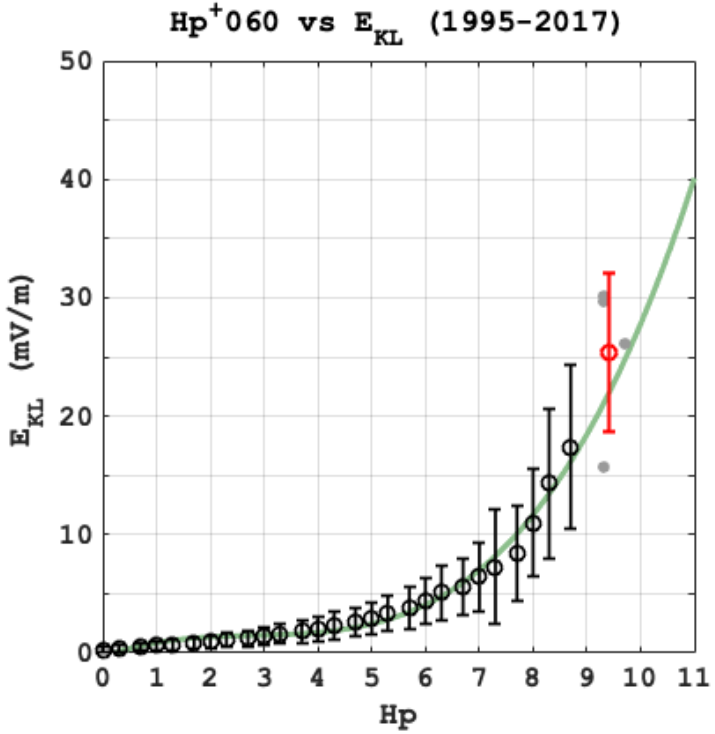
Open-ended Hp30 versus E_{KL} (Scale A left, Scale B right)

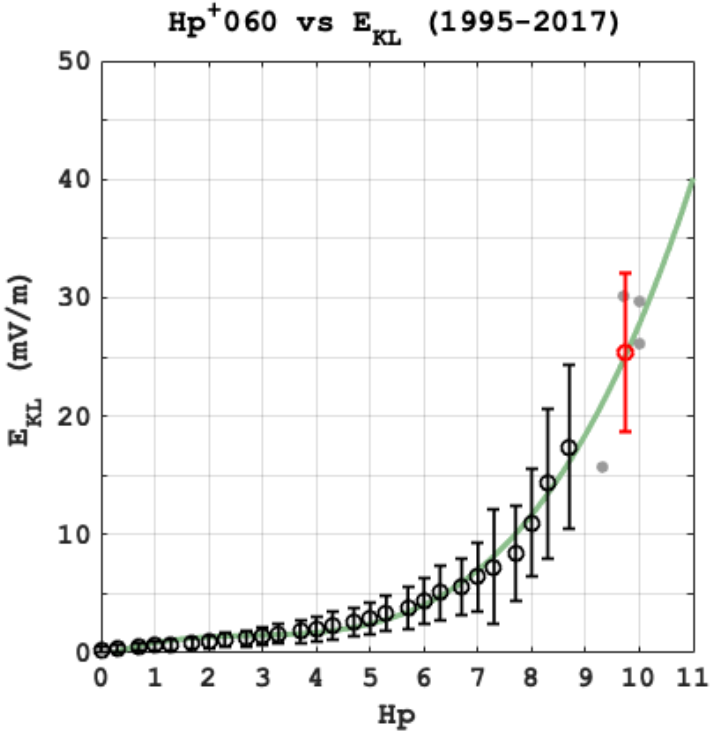




Take away: Scale B fits polynomial prediction of H30p vs. E_{KL} marginally better than Scale A.

Open-ended Hp60 versus E_{KL} (Scale A left, Scale B right)





Take away: Scale B fits polynomial prediction of Hp60 vs. E_{KL} better than Scale A.

Conclusions on open-ended high cadence Hp30 and Hp60

- Scale B gave better agreement with the composite polar cap index PCC as well as with merging electric field by Newell (2007) and Kan and Lee (1979) than Scale A , for both Hp30 and Hp60.
- The highest value observed in 1995 to 2017 for Scale B was Hp30 and Hp60 = 11.7.
- All our high cadence indices will be distributed in an open-ended version in the future, **utilizing Scale B.**
- The open-ended indices are identical to the previous version of the high cadence indices for $0 \leq Hp < 9$.

Index Distribution

Test dataset available from GFZ since June 2019, see link on:

http://swami-h2020.eu/

Feedback welcome!

Content:

- Years 2003,2004,2005,2017
- Hp90, Hp60, Hp30, ap90, ap60, ap30
- Technical note
- DOI: 10.5880/GFZ.2.3.2019.002
- CC-BY 4.0
- This is NOT the open ended version.

Disclaimer to users of the Hp indices test dataset:

Please carefully test and validate all your model output and services for which you use the Hp indices (including the ap90, ap60, ap30) as input parameter. This is especially true when these models and services were originally derived or parameterized with the *Kp* index.

Further years of the data set can be requested from the authors.

Archive back to 1995 and **nowcast** of the index as well as a publication **describing** the index are in preparation.

We acknowledge INTERMAGNET and the contributing observatories for providing high quality geomagnetic data.