Geomagnetic indices and their use in operational space weather monitoring services

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Outline

There is an ongoing demand for services that can provide real-time assessment of the (global and local) geomagnetic activity. Such services depend largely on the reduction of solar, geomagnetic and ionospheric observations to generate activity indices. The presentation will review the most frequently used geomagnetic indices – definition, derivation, and the opportunities for their real time estimation. The focus however will be on the recently-developed nowcast system for local operational geomagnetic index K calculation (K-LOGIC). The system is based on a fully automated computer procedure for real-time digital magnetogram data acquisition, screening the dataset and removing the outliers, establishing the solar regular (Sr) variation of the geomagnetic field, calculating the K index, and issuing an alert if storm-level activity is indicated. This is a time-controlled (rather than event-driven) system delivering as regular output (time resolution set to 1 hour) the K value, the estimated quality flag, and eventually, an alert. The system is now operational at the RMI Geophysical Centre in Dourbes (50.1N, 4.6E).

- Introduction
- Geomagnetic indices (most frequently used)
- K-LOGIC (Local Operational Geomagnetic Index K Calculation)
- LIEDR (Local Ionospheric Electron Density Profile Reconstruction)
- Summary and Outlook

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Geomagnetic Observatory - Dourbes

Geofysisch Centrum van het KMI * Centre de Physique du Globe de l'IRM

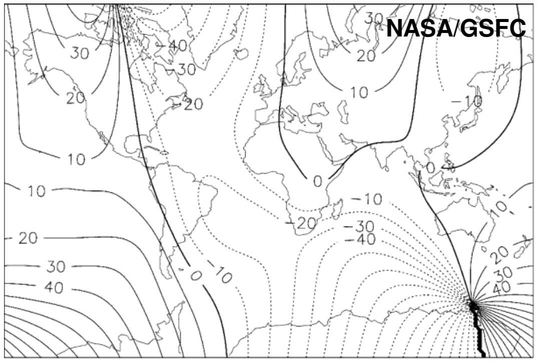
• Geomagnetic observatory, by definition, is a place where the geomagnetic field vector is observed for an extended period of time (duration of at least 1 full year).

• As only the natural geomagnetic field is of interest here, the observatory should be protected from artificial magnetic signals, and its surroundings and facilities should be amagnetic, that is, should not modify the direction or amplitude of the geomagnetic vector.

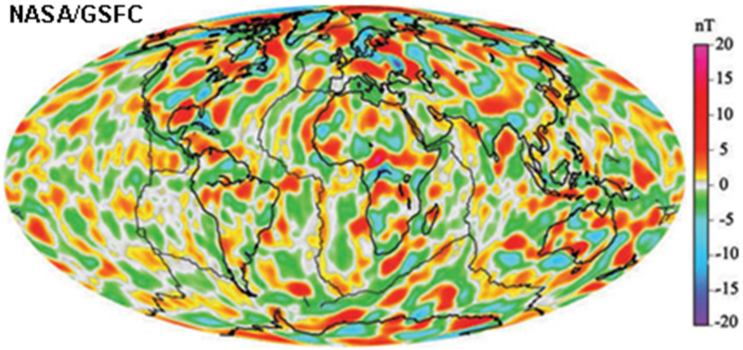
• The sampling of the field should be 1/hour or faster, with 1/minute the standard now.

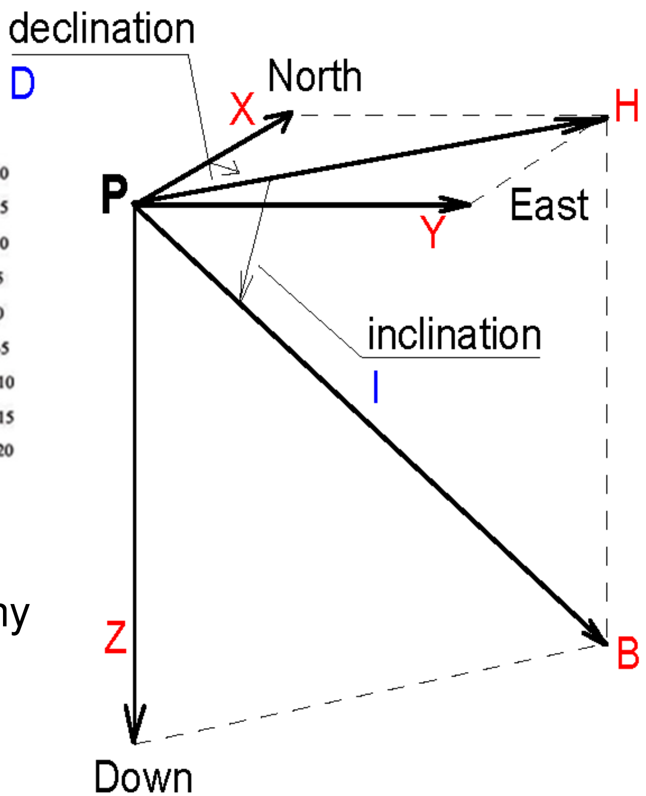
Geomagnetic field – components and measurements

Declination (deg, East), IGRF 2000



Modeled image of Earth's magnetic field variations based on MAGSAT data (2004). Colour bar – positive and negative field areas.





Magnetometer orientations:

- Cartesian: **X , Y , Z**
- Cylindrical: **D , H , Z**
- Spherical: **D , I , F**

The geomagnetic field is a vector field which intensity **B** (alternatively, **F** – the magnetic field modulus) specified by any three of the following independent components:

$B^2 = X^2+Y^2+Z^2 = H^2+Z^2$
$H^2 = X^2+Y^2$
$H = B.\cos(I)$
$X = H.\cos(D)$
$Y = H.\sin(D) = X.\tan(D)$
$Z = B.\sin(I) = H.\tan(I)$
$D = \arctan(Y/X)$
$I = \arctan(Z/H)$

B – the total magnetic field intensity;
H – the horizontal vector component of the field intensity **B**;
X – the northward horizontal component of **B**;
Y - the eastward horizontal component of **B**;
Z – vertical component of **B** (positive when downward);
D – declination, the deviation of **H** from the northward horizontal direction (positive when eastward);
I – inclination (dip), the deviation of **B** from **H** (positive when downward).

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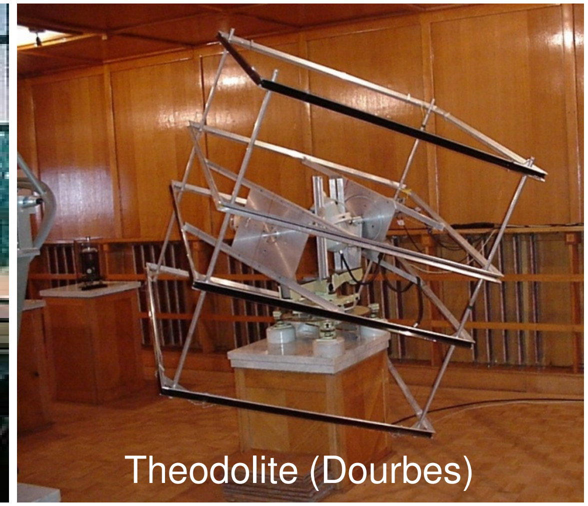
Geomagnetic activity - monitoring service

STCE

Measurements:
• Variation of the field components about baseline values (Variometers, 2 systems currently in operation: fluxgate 3-axial and proton vector magnetometers).
• Absolute measurements to establish the values of the baselines with adequate instrumentation (DIfluxes, proton magnetometers).


Proton Magnetometer

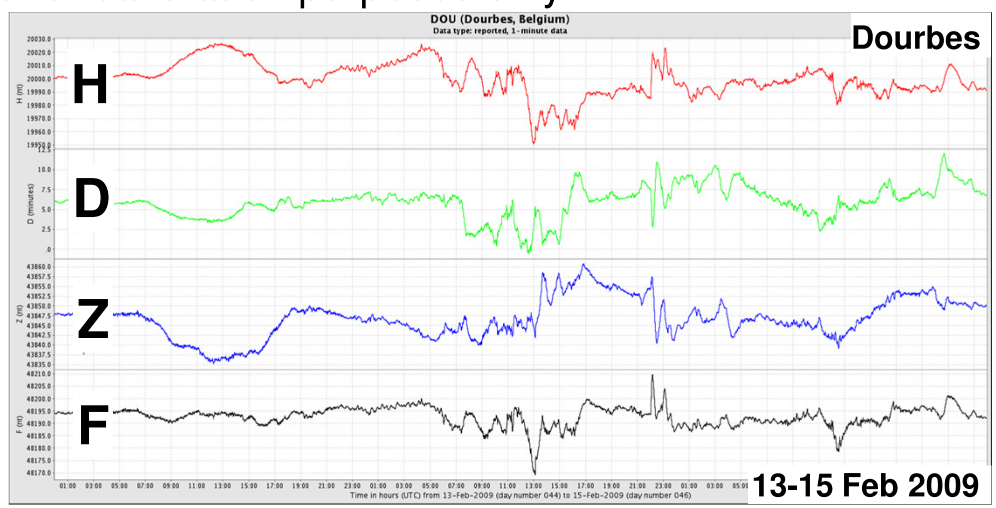

Theodolite (Dourbes)

Instrumentation (Dourbes):
• Fluxgate (3-axial) magnetometers
• Proton vector magnetometers
• Theodolite / DIflux magnetometers => absolute measurements of the declination (D) and inclination (I)
• Overhauser proton magnetometer => induction (B), for the total length measurements
• Optical pumping Potassium magnetometers, now used for calibration purposes only

Precision:
• Time: 1 sec (w/ Optically pumped Potassium magnetometer)
• Induction: 0.1 nT
• Declination: 0.001 °

Requirements:
• Angular measurements: 1 sec of arc, should be referenced to the Vertical and to the geographic North
• H deduced from the total field (B) and inclination (I)

Output: magnetogram (digital)



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Geomagnetic field variations – secular/transient, regular/irregular

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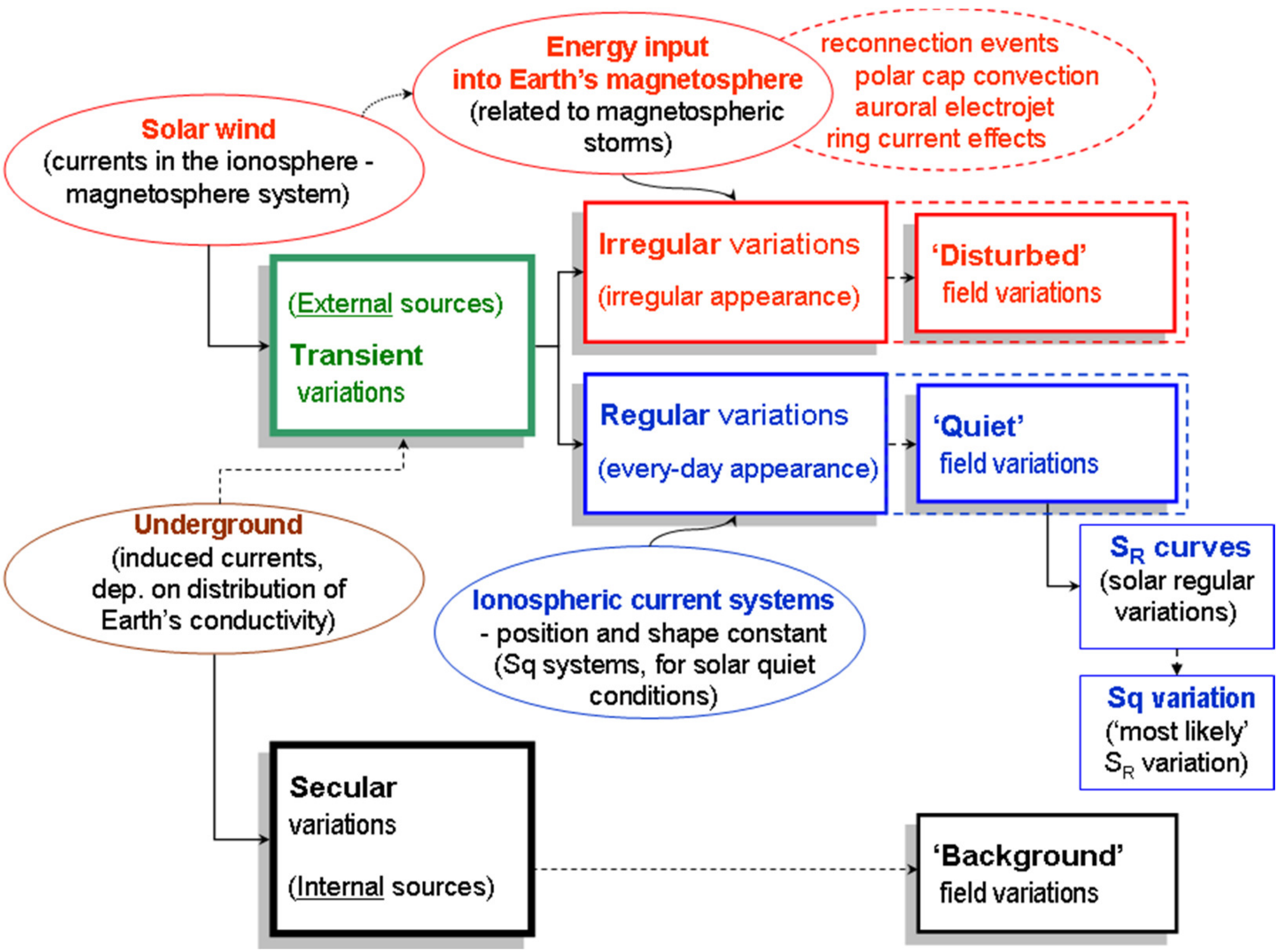

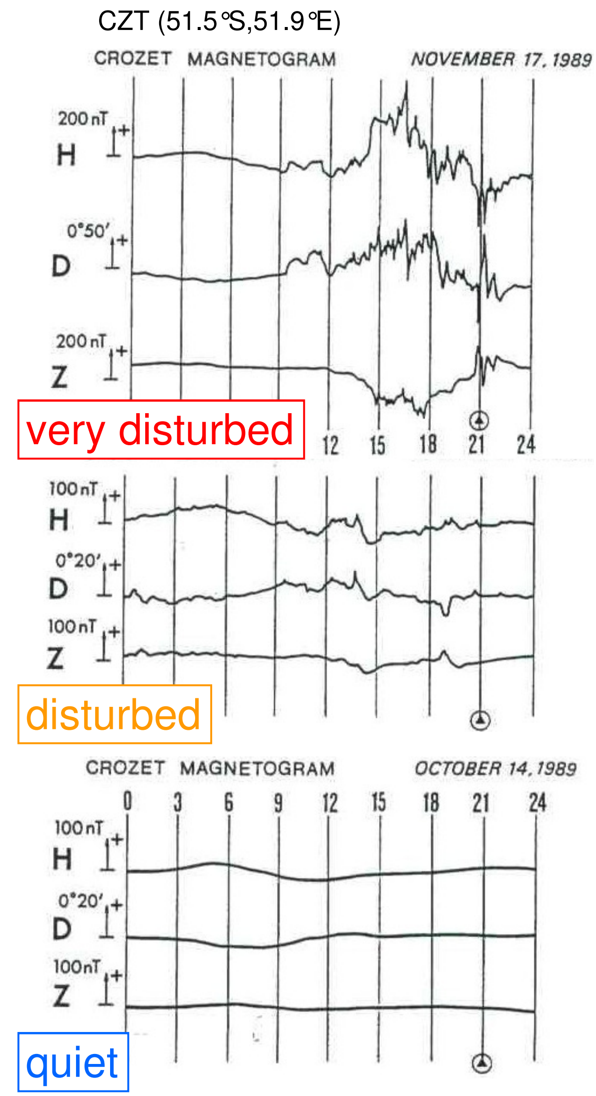

Source: Menvielle et al. (1991): Rev. Geophysics, 29(3), 415-432.

Source: Jacobs, J.A. (1987): Geomagnetism. Academic Press Ltd.

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Geomagnetic field measurements - Dourbes

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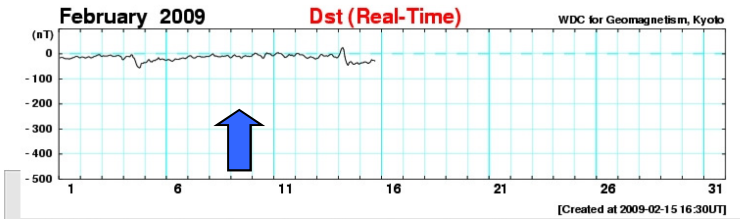
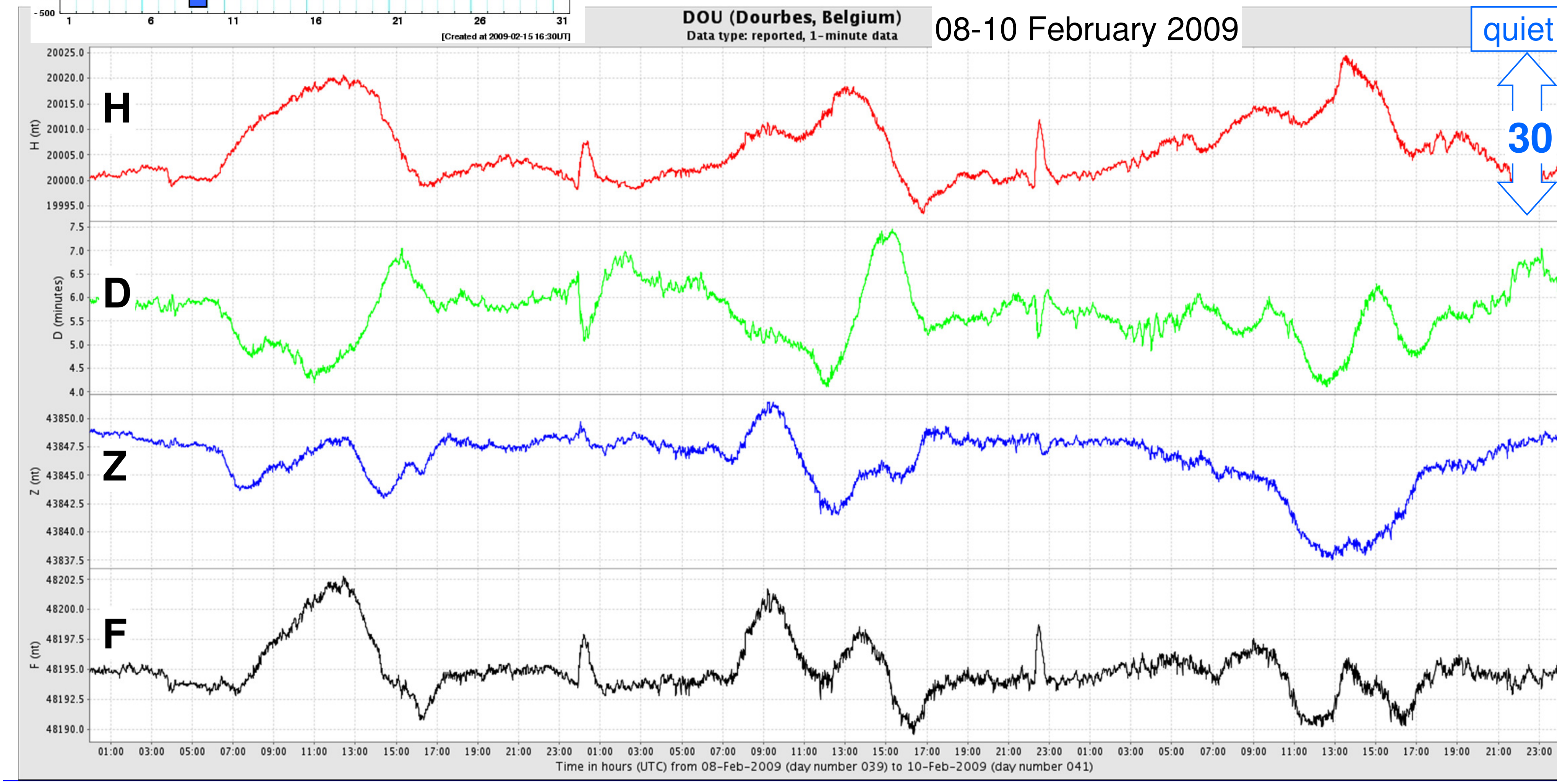
Regular / non-disturbed field





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Geomagnetic field measurements - Dourbes

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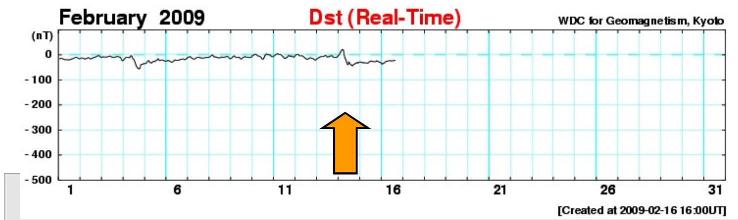
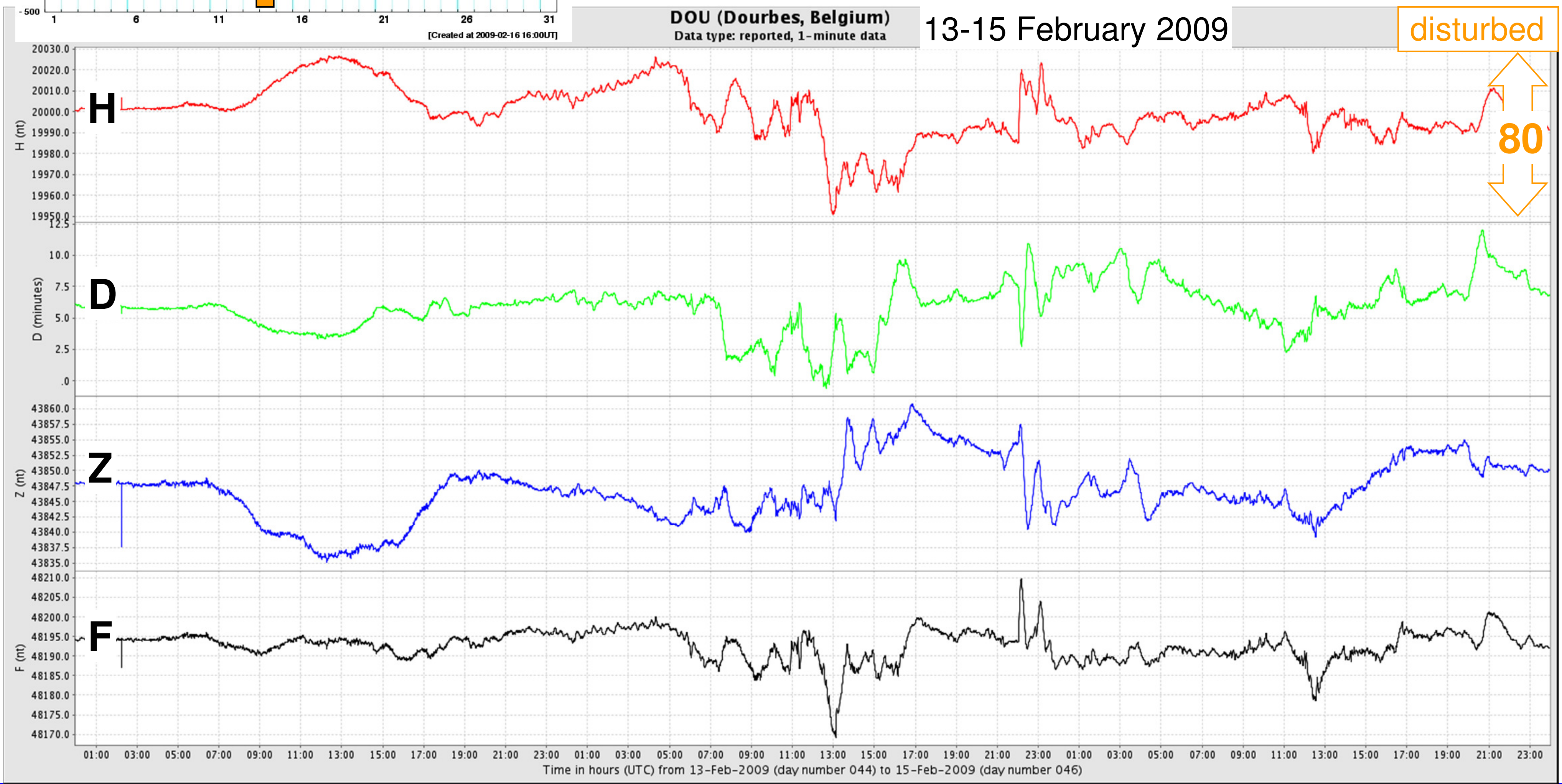
Irregular / disturbed field

(a boundary case – minor geomagnetic storm)

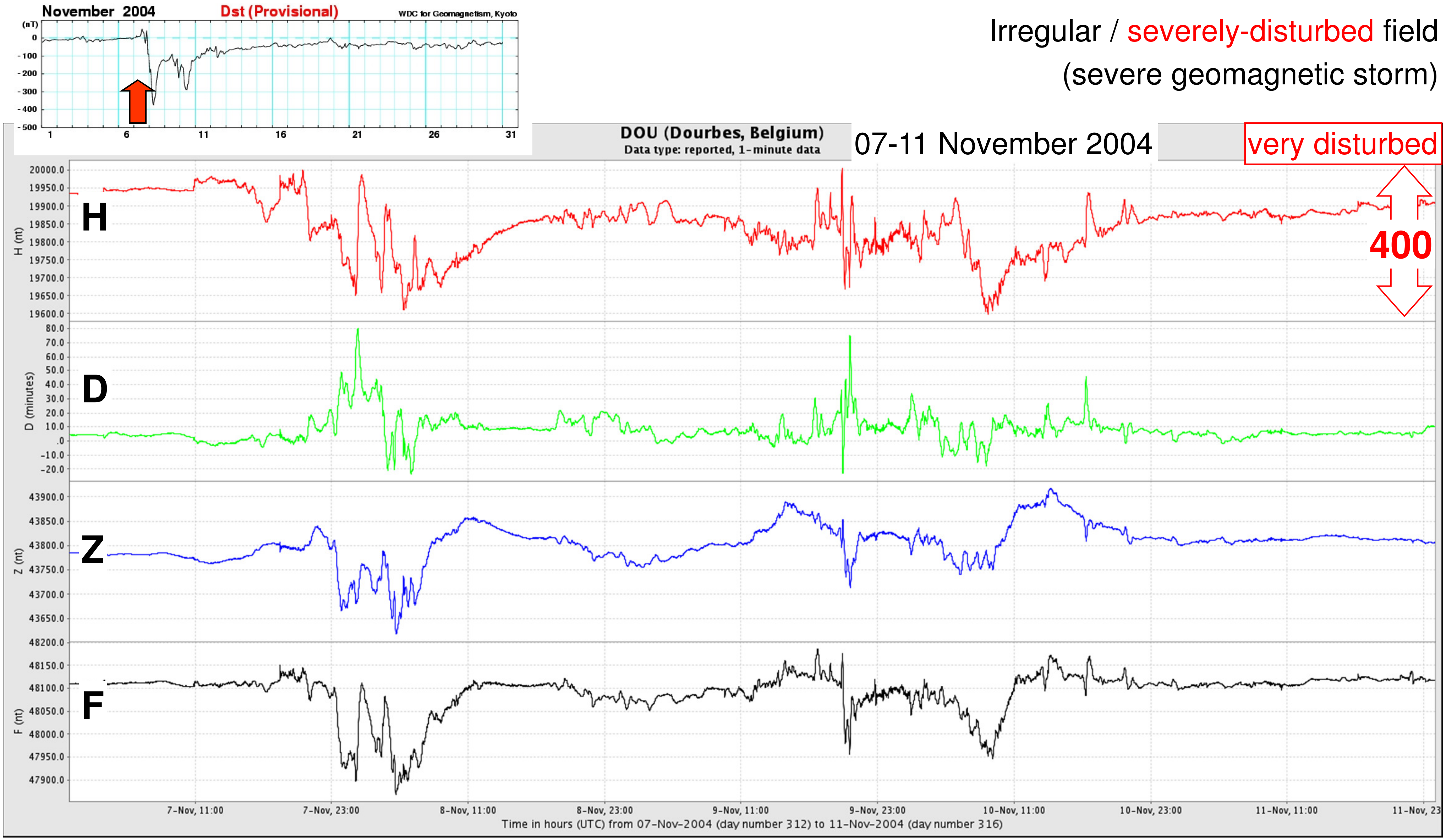


13-15 February 2009



Geomagnetic field measurements - Dourbes

Irregular / severely-disturbed field
(severe geomagnetic storm)



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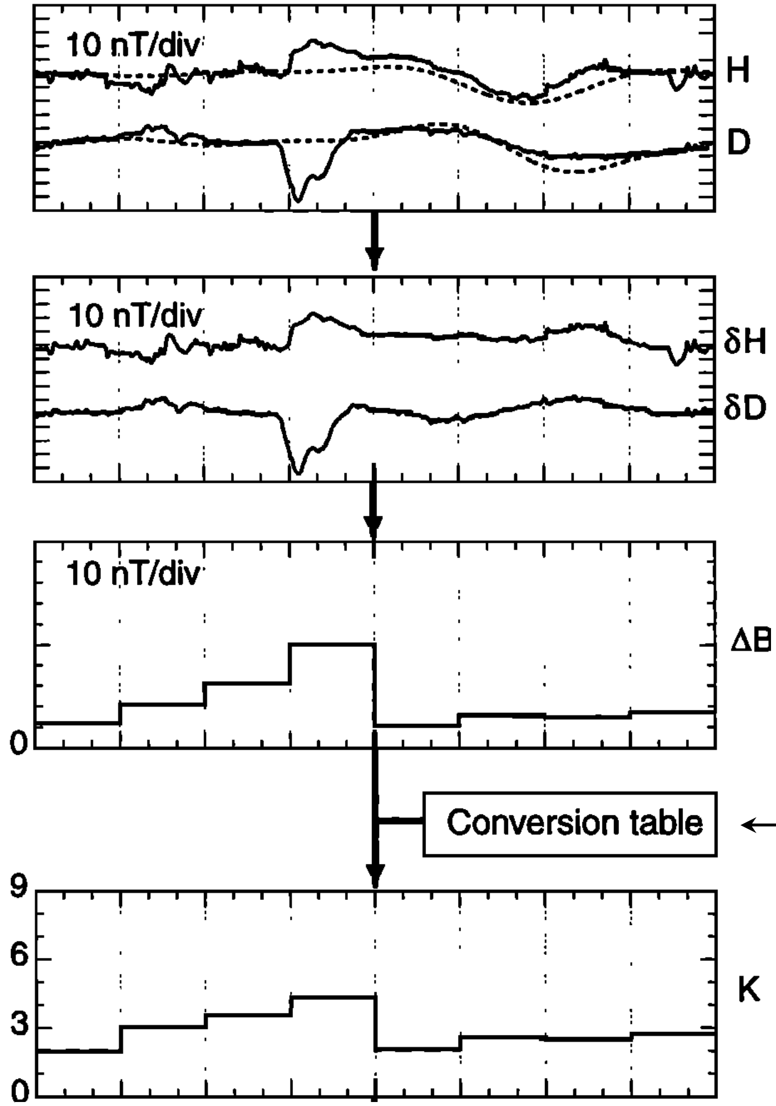
K index (local)



K index determination

Definition:

• An individual K index characterizes the geomagnetic activity during a 3-hour interval (UT). It is based on the amplitude of the variations of the observed horizontal components after subtracting the solar regular (S_R) variation of the day.

• The K index is an integer between 0 and 9 corresponding to the larger of the 2 ranges measured in the horizontal components.

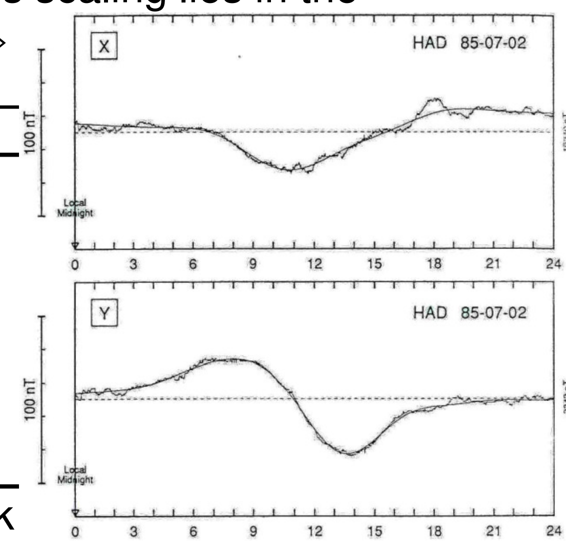
Purpose:

- Providing information on the geomagnetic activity level (when analysing phenomena linked to this activity)
- Objective monitoring of the irregular variations at a location

Note: Main difficulty in the K-indices scaling lies in the identification of the S_R curves ⇨

K	Δ*B*, nT	Δ*B* in Fraction of *K9*
0	0-5	0.00-0.01
1	5-10	0.01-0.02
2	10-20	0.02-0.04
3	20-40	0.04-0.08
4	40-70	0.08-0.14
5	70-120	0.14-0.24
6	120-200	0.24-0.40
7	200-330	0.40-0.66
8	330-500	0.66-1.00
9	500-	1.00-

Limits of range classes (nT), Niemegk



Source: Takahashi et al. (1995): J. Geophys. Res., 106(A10), 21017-21032.

Source: Menvielle et al. (1995): Geophys. J. Int., 123, 866-886.

K index estimation (the linear elimination method)

Preliminary estimate:

• **Preliminary K values determined**: for each of the horizontal components' variations (the difference between the component's maximum and minimum within a predefined time period, e.g. 3 hours), K – the larger of the 2 components' estimates

• **Calculation of the mean hourly values of K** (all data inside the hour and $m+n$ minutes on both sides of this hour):

m depends on LT (0 for 06-18LT, 60 for 03-06LT and 18-21LT, 120 for 21-03LT),
n depends on geomagnetic activity ($n = K^{3.3}$ minutes, where K is the preliminary value)

• **S_R curve produced** by a fifth degree harmonic fit to the means (middle points for each hour)

Corrective estimate:

• ***n* calculation** using the preliminary K values

• **S_R curve produced** by a fifth degree harmonic fit to the means

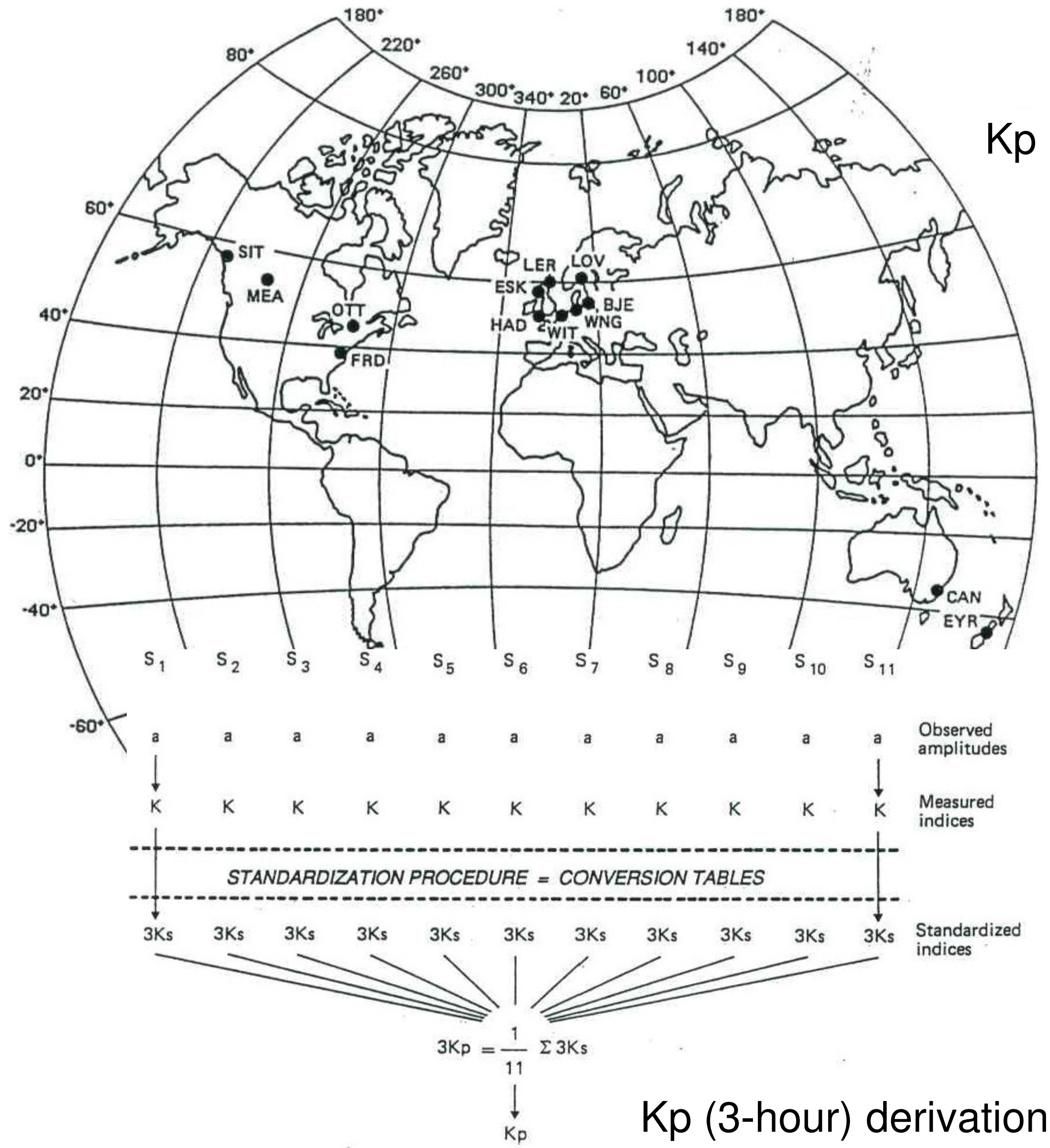
Source: Sucksdorff et al. (1991): Computer production of K-indices based on linear elimination. Geophysical Transactions, 36(3-4), 335-345.

K index (planetary)

Observatory	Code	Corrected Geomagnetic Latitude
Northern Hemisphere		
Meanook	MEA	62.5°
Sitka	SIT	60.0°
Lerwick	LER	58.9°
Ottawa	OTT	58.9°
Lovö*	LOV	56.5°
Eskdalemuir	ESK	54.3°
Brorfelde	BJE	52.7°
Fredericksburg	FRD	51.8°
Wingst	WNG	50.9°
Witteveen	WIT	50.2°
Hartland	HAD	50.0°
Southern Hemisphere		
Eyrewell	EYR	50.2°
Canberra†	CAN	45.2°

*Observatory added to the network in 1954.
†Observatory added to the network in 1970.

Kp network



Kp (3-hour) derivation scheme

Source: Menvielle et al. (1991): Rev. Geophysics, 29(3), 415-432.

Geomagnetic activity – storm level scales

NOAA Space Weather Scales

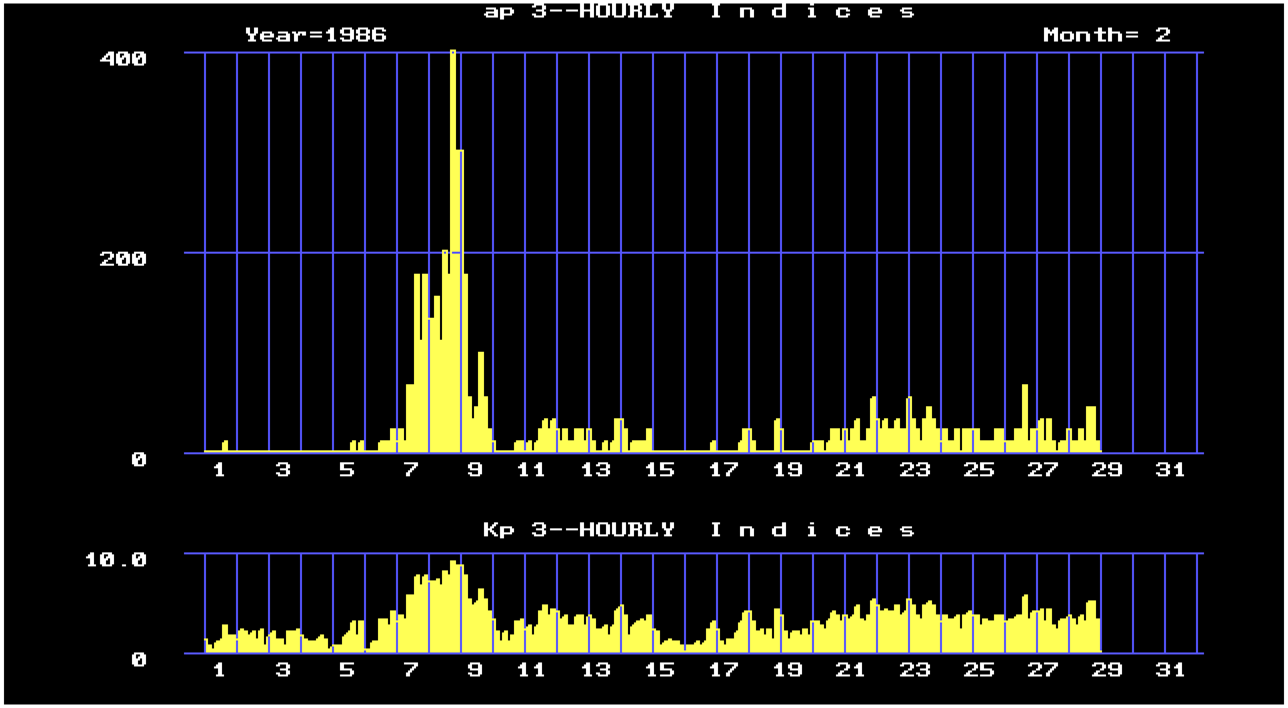
Category: Scale	Category: Descriptor	Effect (Duration of event will influence severity of effects)	Physical measure	Average Frequency (1 cycle = 11 years)
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	Power systems: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**.	Kp=9	4 per cycle (4 days per cycle)
G 4	Severe	Power systems: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. Spacecraft operations: may experience surface charging and tracking problems, corrections may be needed for orientation problems. Other systems: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.)**.	Kp=8, including a 9-	100 per cycle (60 days per cycle)
G 3	Strong	Power systems: voltage corrections may be required, false alarms triggered on some protection devices. Spacecraft operations: surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. Other systems: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.)**.	Kp=7	200 per cycle (130 days per cycle)
G 2	Moderate	Power systems: high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. Spacecraft operations: corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. Other systems: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.)**.	Kp=6	600 per cycle (360 days per cycle)
G 1	Minor	Power systems: weak power grid fluctuations can occur. Spacecraft operations: minor impact on satellite operations possible. Other systems: migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**.	Kp=5	1700 per cycle (900 days per cycle)

* Based on this measure, but other physical measures are also considered.
** For specific locations around the globe, use geomagnetic latitude to determine likely sightings (see www.sec.noaa.gov/Aurora)

ap , Ap , aa , AA indices

The 3-hourly **ap** (equivalent range) index is derived from the Kp index as follows:

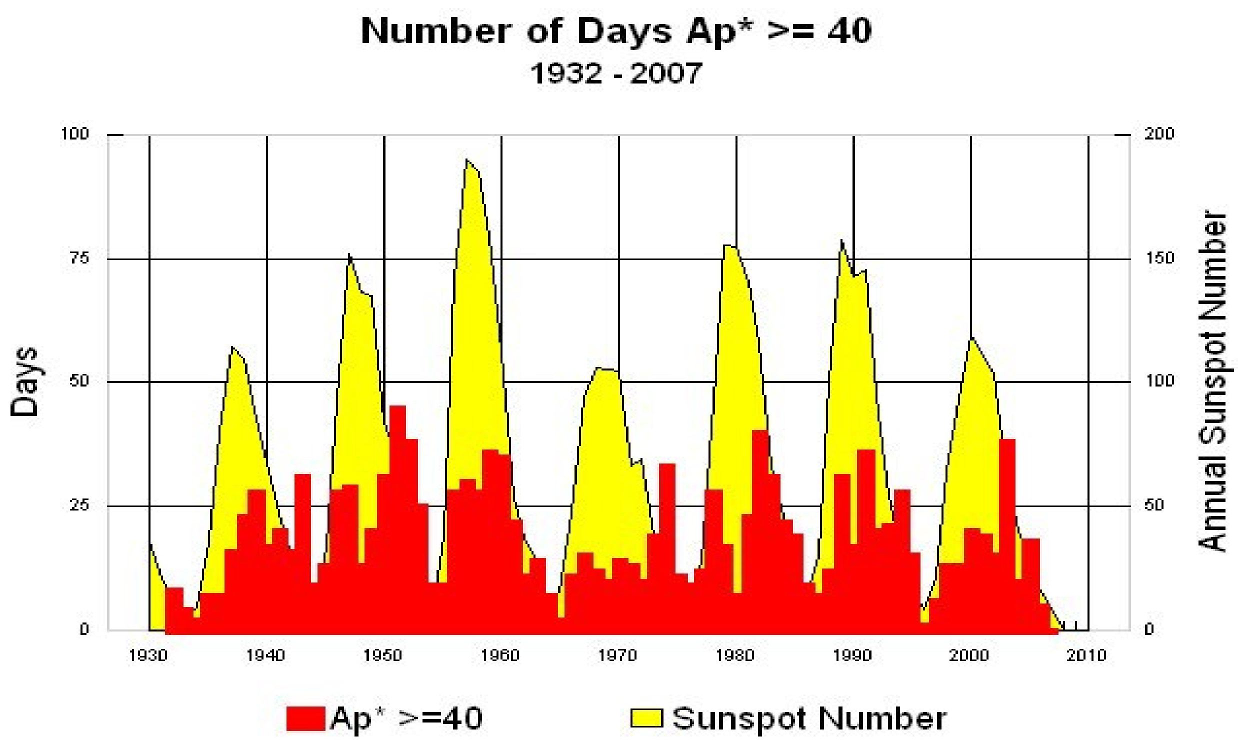
Kp =	0o	0+	1-	1o	1+	2-	2o	2+	3-	3o	3+	4-	4o	4+	5-	5o	5+	6-	6o	6+	7-	7o	7+	8-	8o	8+	9-	9o
ap =	0	2	3	4	5	6	7	9	12	15	18	22	27	32	39	48	56	67	80	94	111	132	154	179	207	236	300	400



Source: NOAA

ap , Ap , aa , AA indices

- **Ap** is defined as the earliest occurring maximum 24-hour value obtained by computing an **8-point running average of successive 3-hour ap indices** during a geomagnetic storm event without regard to the starting and ending times of the UT-day.
- Ap is uniquely associated with a storm event.
- Ap values provide a maximum disturbance measure useful to identify major geomagnetic storms chronologically (by date and start time) and by amplitude from largest to smallest.

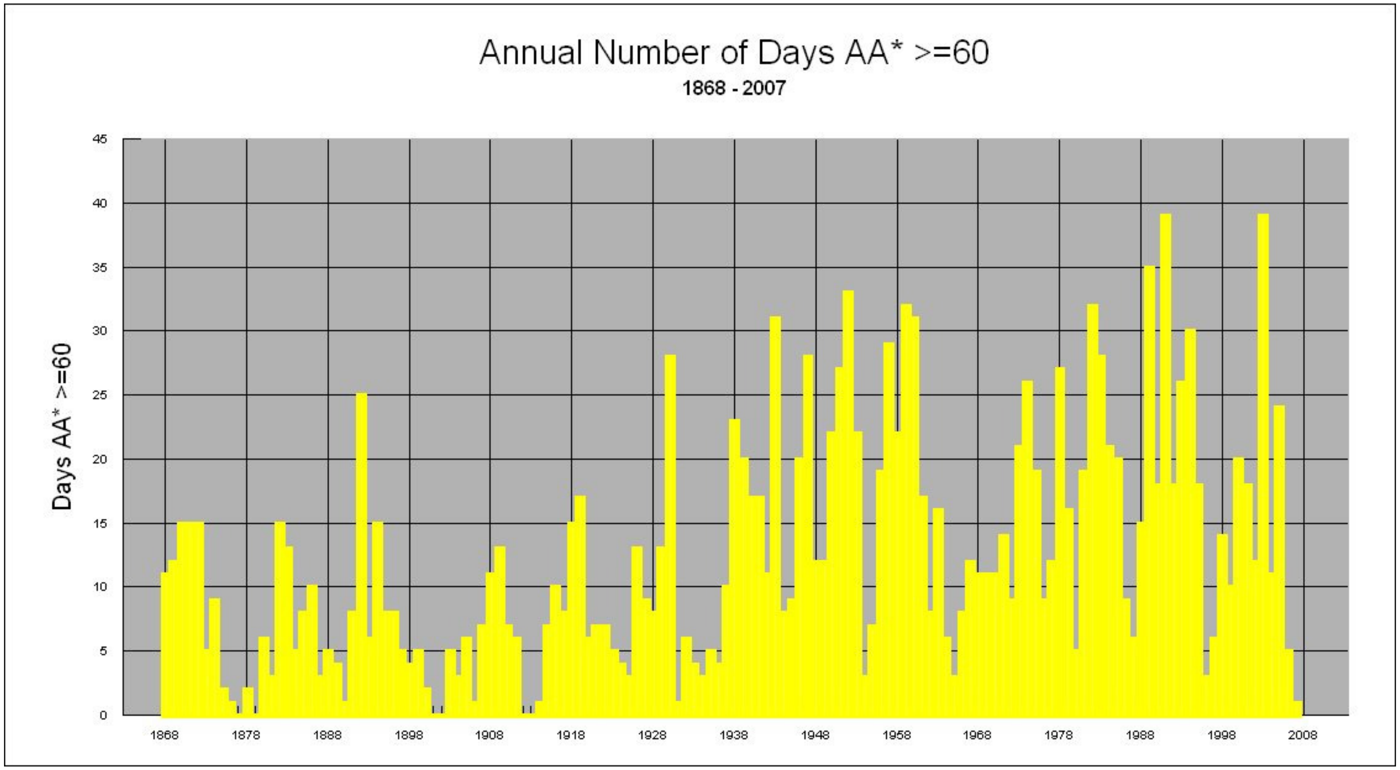


Source: NOAA

ap , Ap , aa , AA indices

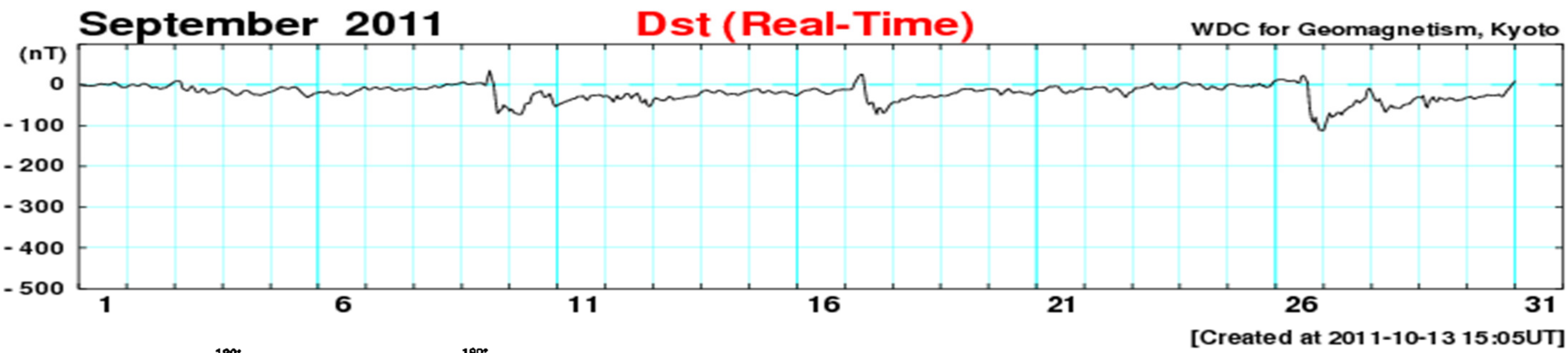
The **aa** index is a 3-hourly equivalent amplitude antipodal index. It is a simple global index of magnetic activity, produced in France, from the K indices of two nearly antipodal magnetic observatories in England and Australia.

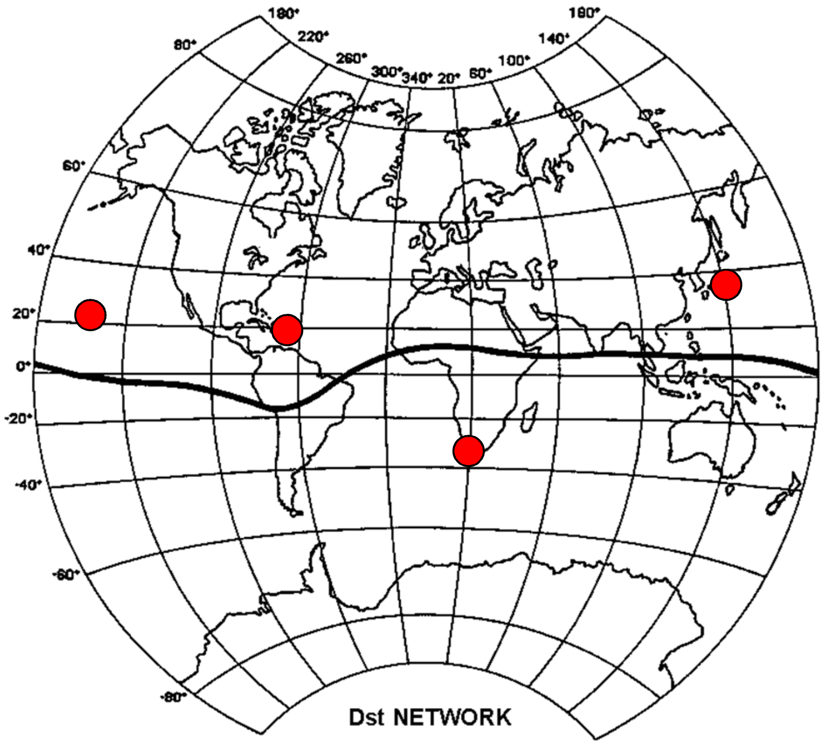
The **AA** index is a daily average index derived similarly to Ap. However, the AA index is derived from indices from only two magnetic observatories whereas Ap incorporates indices from more observatories.



Source: NOAA

Dst index





The **Dst index** gives the average (in longitude) **depression of the horisontal component in low latitudes (due to the ring current)**, which is proportional to the total kinetic energy of the particles injected and trapped in the Van Allen (electron) belt.

Observatory		Geographic Longitude (E)	Geographic Latitude	Geomagnetic Dipole latitude
Hermanus		19.22°	-34.40°	-33.3°
Kakioka		140.18°	36.23°	26.0°
Honolulu	to April 1960	201.90°	21.30°	21.0°
	after April 1960	201.98°	21.32°	21.1°
San Juan	to January 1965	293.88°	18.38°	29.9°
	after January 1965	293.88°	18.11°	28.0°

Dst index

- The **baseline** for H is defined for each observatory in a manner that takes into account the secular variation. For each observatory, the annual mean values of H, calculated from the "five quietest day" for each month, form the database for the baseline. Final Dst values are determined after each calendar year.

$$H_{base}(\tau) = A + B\tau + C\tau^2 \qquad \tau - \text{time in years, from a reference epoch}$$

- The **deviation** for H is defined as the difference between the observed and the base value:

$$\Delta H(T) = H_{obs} - H_{base}(T) \qquad T - \text{time, universal}$$

- The **average solar quiet daily variation** (Sq) **for each month** is determined from the values of H(T) for the internationally selected five quietest days of the month. The 12 sets of the monthly average Sq , determined for the whole year, are expanded in a double Fourier series with local time, t, and month number, s, as two variables:

$$S_q(t,s) = \sum_m \sum_n A_{mn} \cos(mt + \alpha_m) \cos(ns + \beta_n)$$

- The disturbance variation (for each observatory): $D(T) = \Delta H(T) - S_q(T)$

- The Hourly Equatorial Dst Index (averaged disturbance variations): $Dst(T) = D(T) / \cos\varphi$

φ - dipole latitude

Dst index

Interpretation:

The Dst index, which is regarded as a function of storm time, represents the axially symmetric disturbance magnetic field at the dipole equator on the Earth's surface.

Major disturbances in Dst are negative, namely decreases in the geomagnetic field. These field decreases are produced mainly by the equatorial current system in the magnetosphere, usually referred to as the ring current. The neutral sheet current flowing across the magnetospheric tail makes a small contribution to the field decreases near the Earth.

Positive variations in Dst are mostly caused by the compression of the magnetosphere from solar wind pressure increases.

Dst advantages:

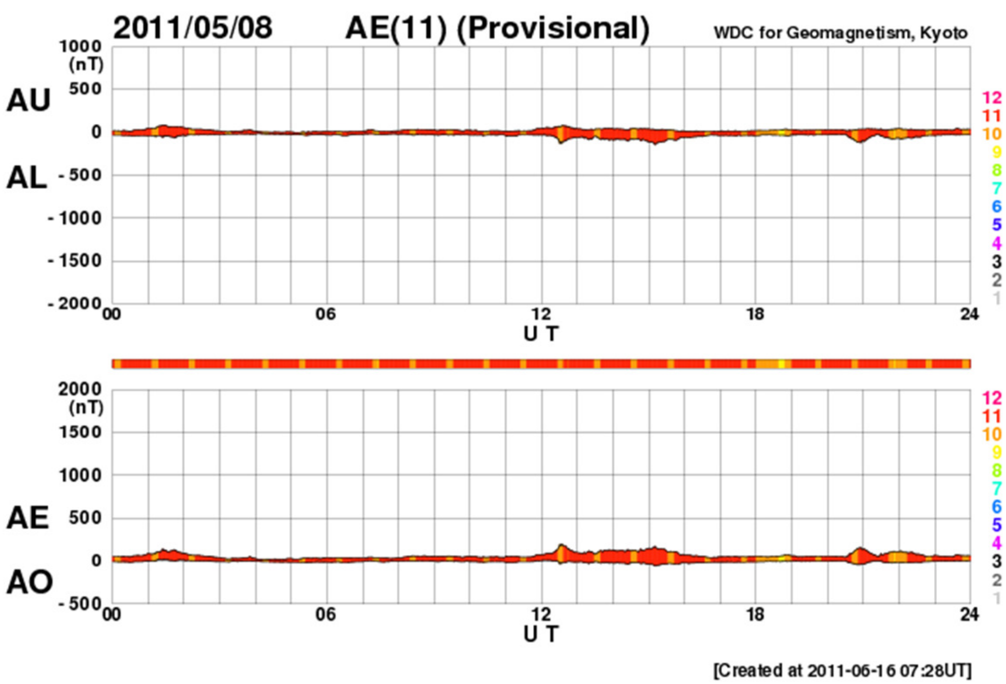
• Dst is derived continuously as a function of UT and its variation will clearly indicate the occurrence of a magnetic storm - start, intensity, and duration.

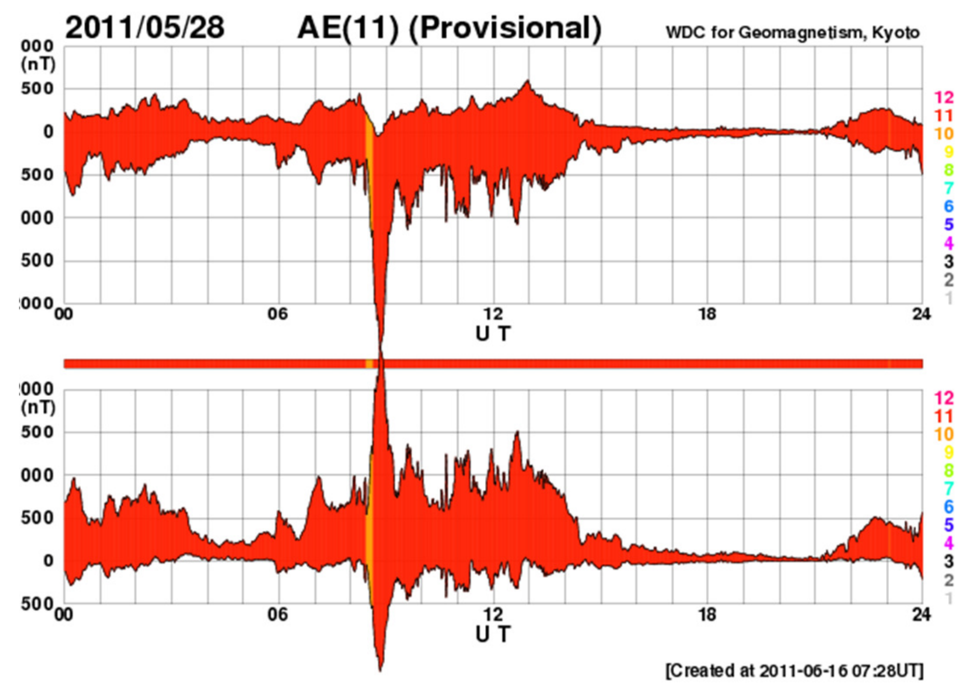
• Dst can be derived on an instantaneous basis.

AE indices

The **Auroral Electrojet Index**, **AE**, is designed (Davis and Sugiura, 1966) to provide a global, quantitative measure of the auroral zone magnetic activity produced by enhanced ionospheric currents flowing below and within the auroral oval.

AE is **the total range of deviation at an instant of time from quiet day values of the horizontal magnetic field (H) around the auroral oval**.



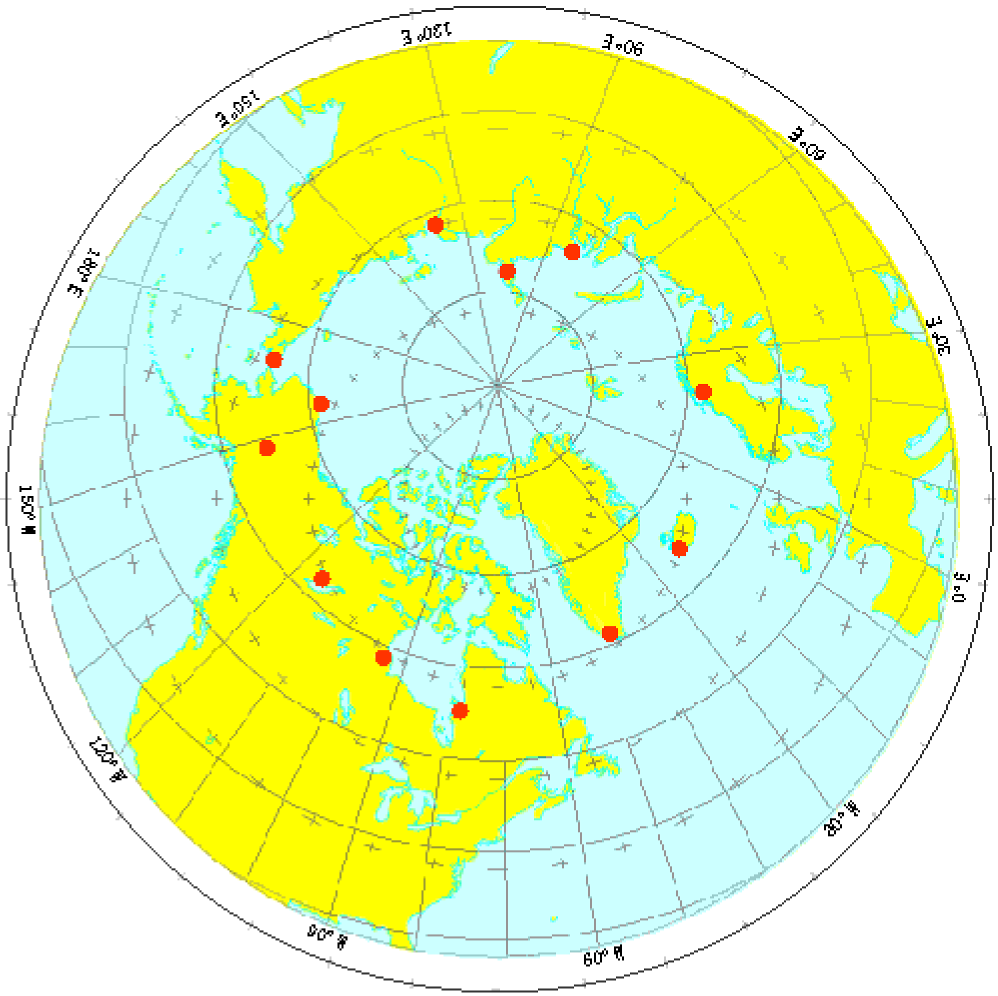


Note: The number of stations used to derive the index is shown in the color scale on the right.

AU index – the upper envelope of the superposed plots
AL index – the lower envelope of the superposed plots

AE index = AU - AL
AO index = (AU + AL) / 2

AE index



Observatory	IAGA Code	Geographic Coord. Lat.(°N)	Geographic Coord. Long.(°E)	Geomagnetic Coord. Lat.(°N)	Geomagnetic Coord. Long.(°E)
Abisko	ABK	68.36	18.82	66.04	115.08
Dixon Island	DIK	73.55	80.57	63.02	161.57
Cape Chelyuskin	CCS	77.72	104.28	66.26	176.46
Tixie Bay	TIK	71.58	129.00	60.44	191.41
Cape Wellen	CWE	66.17	190.17	61.79	237.10
Barrow	BRW	71.30	203.25	68.54	241.15
College	CMO	64.87	212.17	64.63	256.52
Yellowknife	YKC	62.40	245.60	69.00	292.80
Fort Churchill	FCC	58.80	265.90	68.70	322.77
Poste-de-la-Baleine	PBQ	55.27	282.22	66.58	347.36
Narsarsuaq (Narssarssuaq)	NAQ	61.20	314.16	71.21	36.79
Leirvogur	LRV	64.18	338.30	70.22	71.04

AE index

AE advantages:

- it can be **derived on an instantaneous basis** or from averages of variations computed over any selected interval
- it is a quantitative index which, in general, is **directly related to the processes producing the observed magnetic variations**
- its **method of derivation is relatively simple, digital, and objective** and is well suited to present computer processing techniques
- it may be used **to study either individual events of statistical aggregates**

AE disadvantages:

- the distribution of the **observatories in operation is not uniform** along the auroral zone
- a loss of only one station could lead to **omission of significant disturbance events**

AE has been usefully employed, both qualitatively and quantitatively, as a correlative index in studies of substorm morphology, the behavior of communication satellites, radio propagation, radio scintillation, and the coupling between the interplanetary magnetic field and the earth's magnetosphere.

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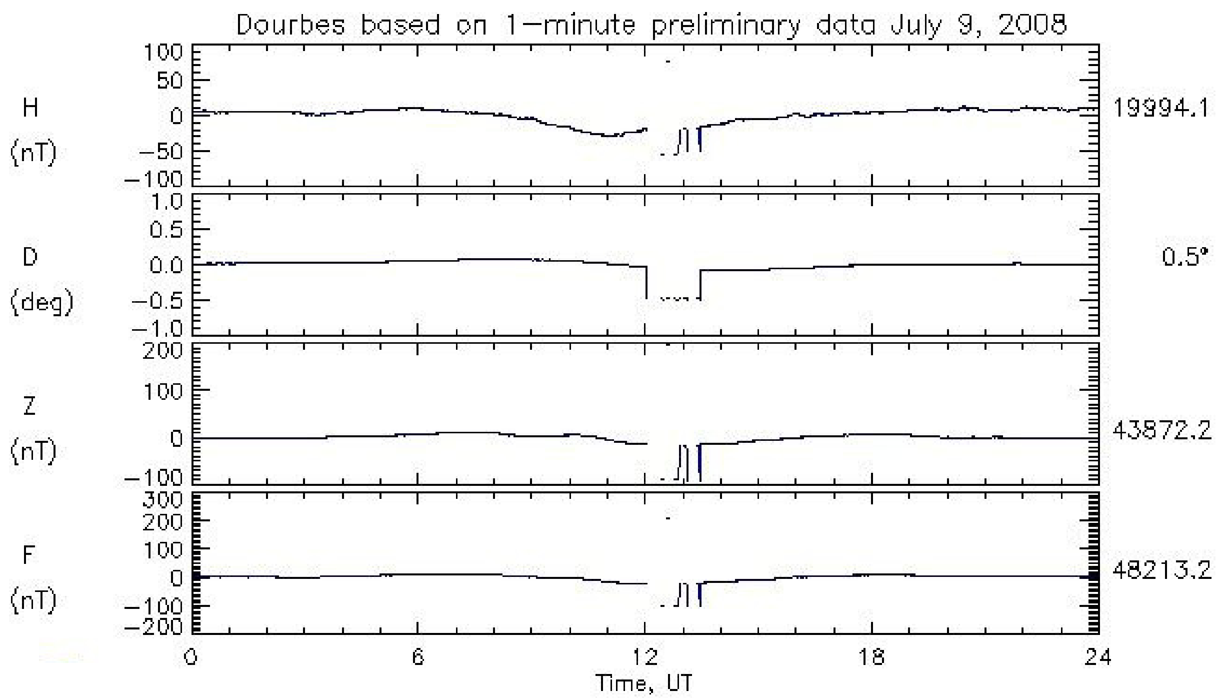
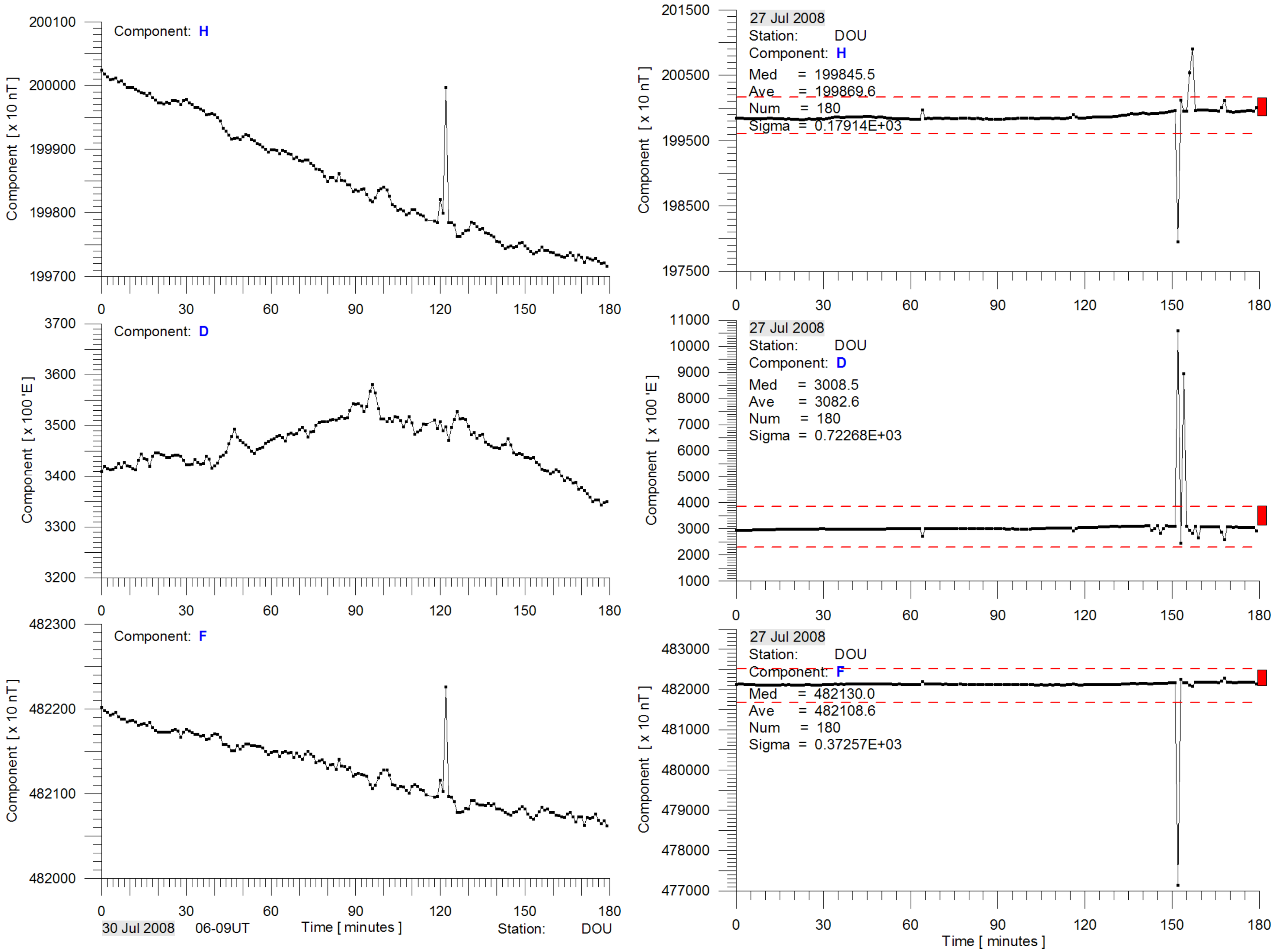
Nowcast – K index (challenges)

- **Existing techniques not designed for real-time applications**: gaps and outliers handled in post-processing mode, data required far beyond the UT interval for K
- **Input data quality**: raw magnetometer data may contain gaps and ‘bad’ records, i.e. outliers
- **Determination of the S_R (solar regular variation) curves**: for example, if K=6, *n* should be 370 minutes, i.e. more than 6 hours in future data needed



Source: Sucksdorff et al. (1991): Computer production of K-indices based on linear elimination. Geophysical Transactions, 36(3-4), 335-345.

Nowcast – K index (challenges)

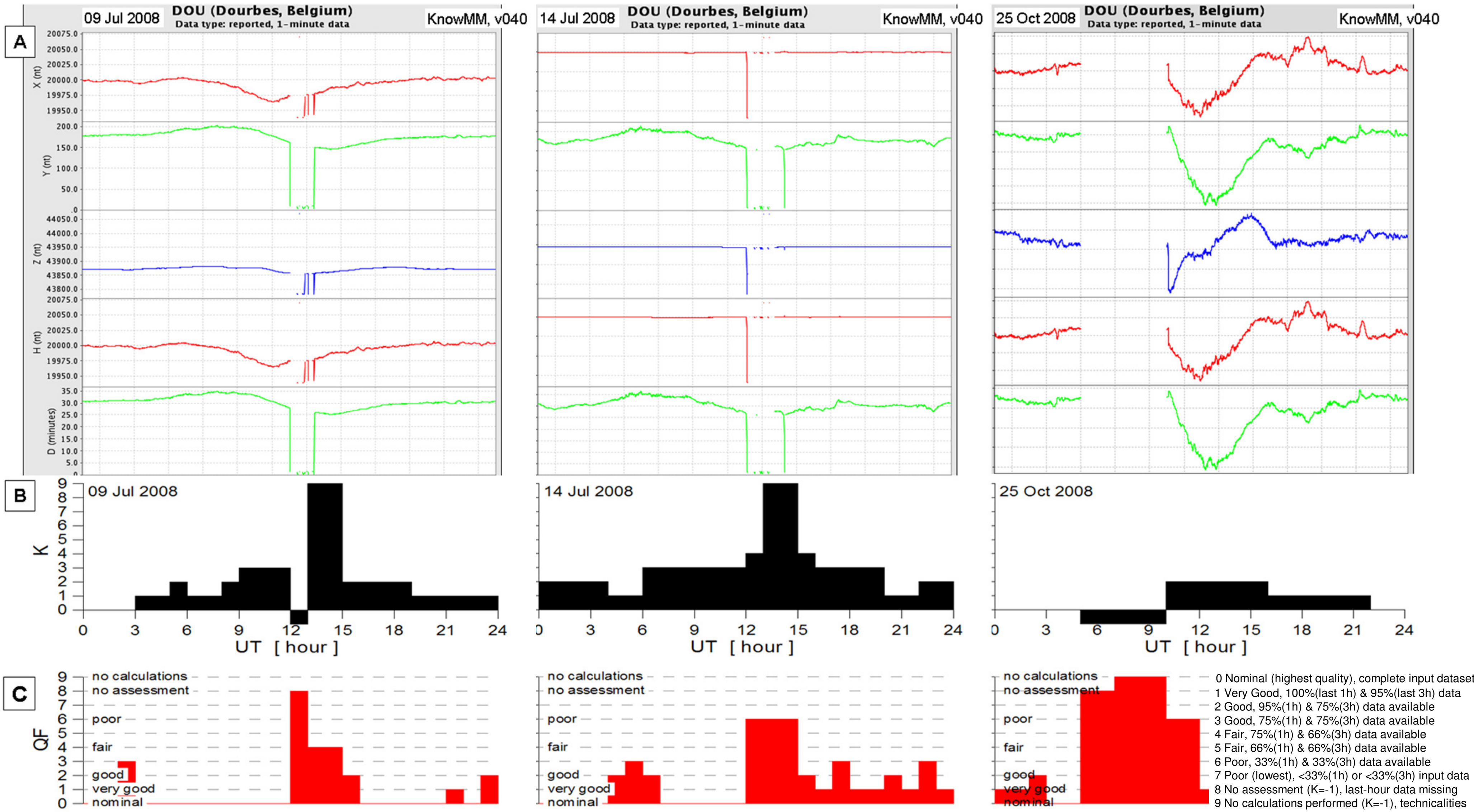


Max number of <u>consequtive data points</u> considered a single spike event set to **5** minutes.

Hard flag threshold for the <u>max number of spikes</u> set to **10.0**%

The number of standard deviation from the local meanthe define a spike set to **2.50**

Nowcast (ground measurements) - Developments



Motivation:

• The enhanced geomagnetic activity and especially the *geomagnetic storms often lead to substantial ionospheric plasma fluctuations/disturbances* among many other space weather effects.

• There is an *ongoing demand for services* that can provide real-time assessment of the (global and local) geomagnetic activity -- and *being of importance to*:

- exploration geophysics,
- radio communications and precise position/navigation practices,
- space weather research and modelling, etc.

Objective:

• To *develop service/s* that can promptly evaluate the current level of the local geomagnetic activity and to estimate in advance the activity index K.

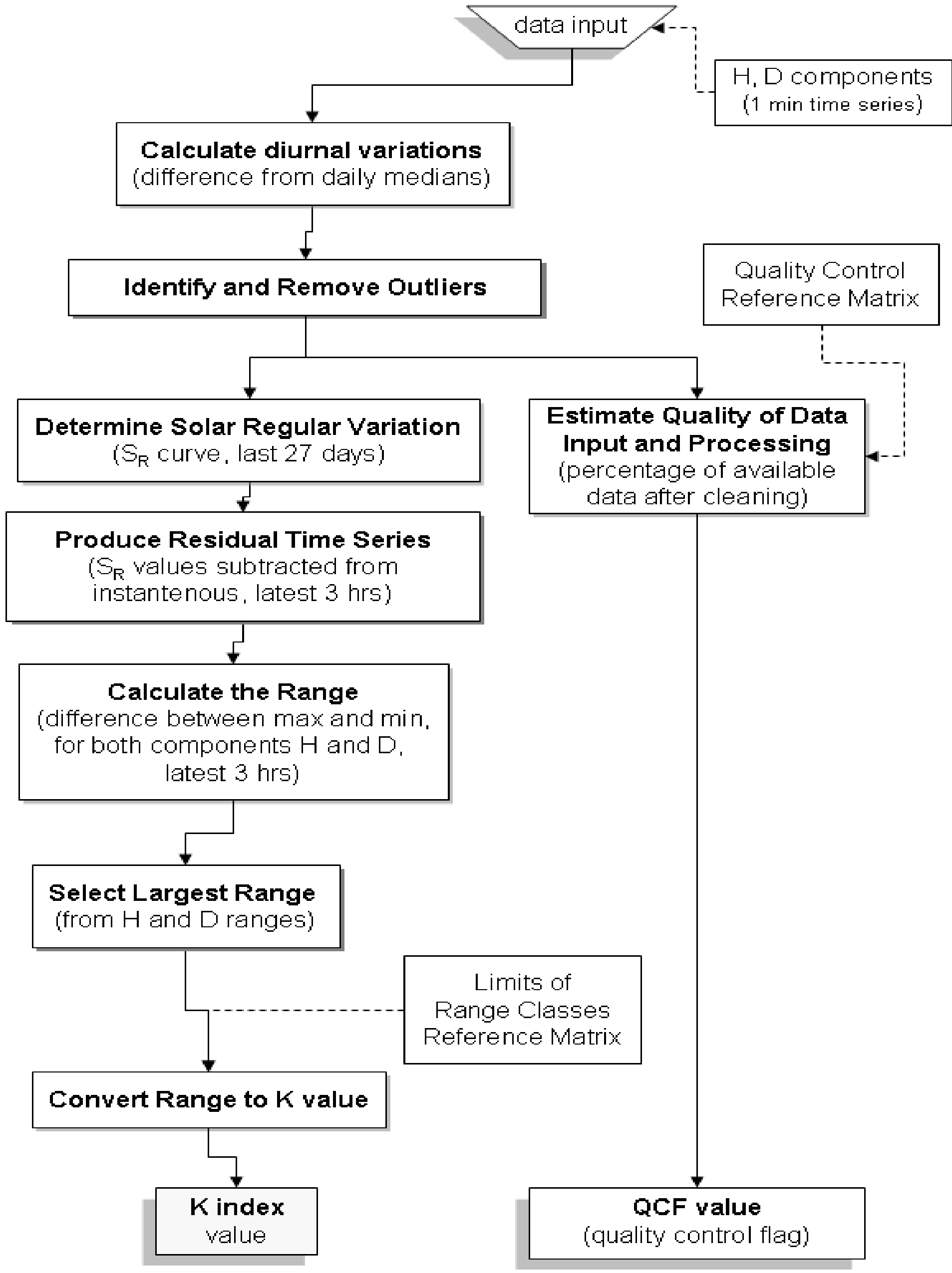
Stankov et al. (2010): On the local operational geomagnetic index K calculation.
Geophysical Research Abstracts, Vol.12, EGU2010-7228, EGU General Assembly, 2-7 May 2010, Vienna.

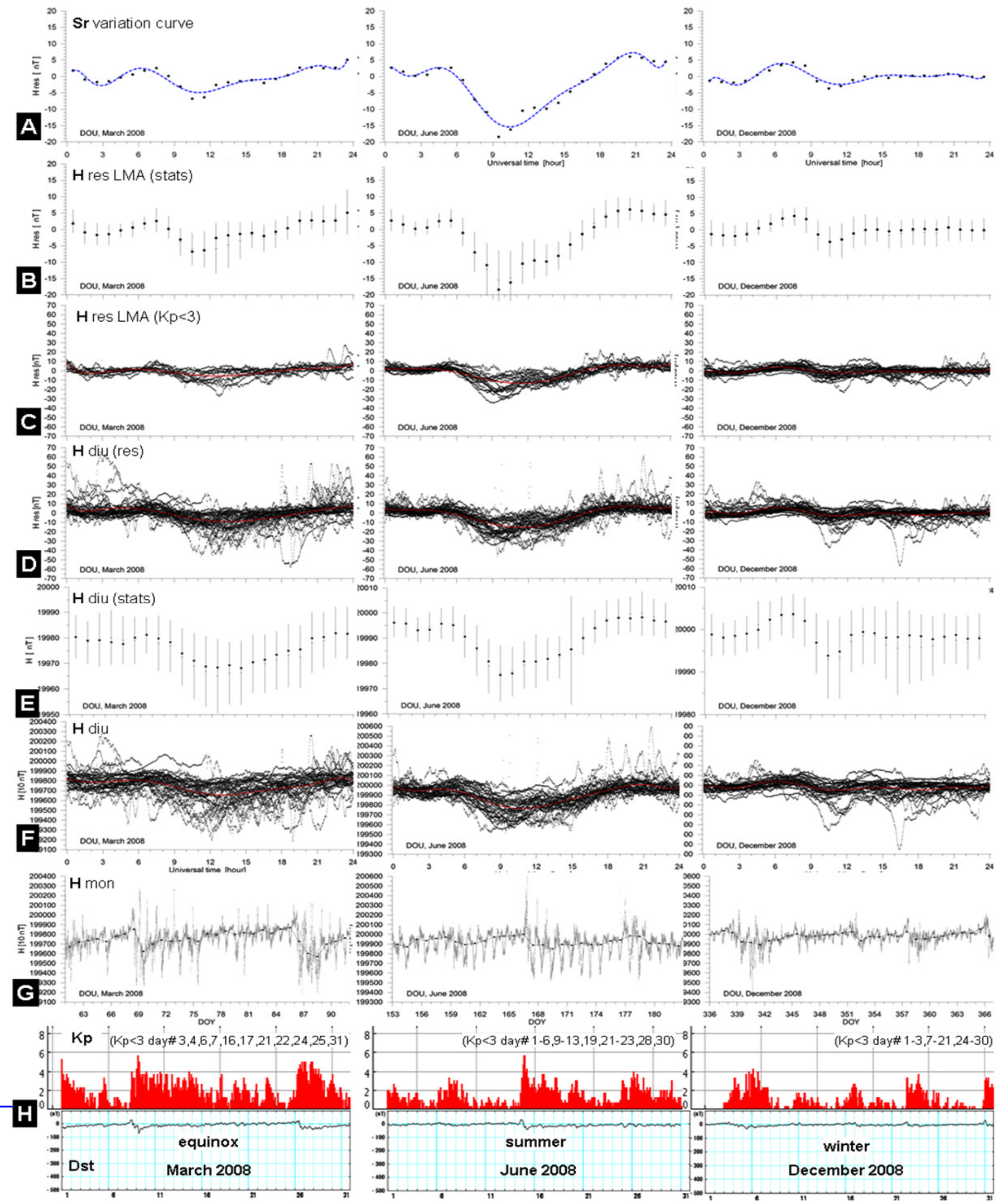
Royal Meteorological Institute

RMI

Nowcast (ground-based measurements)

STCE

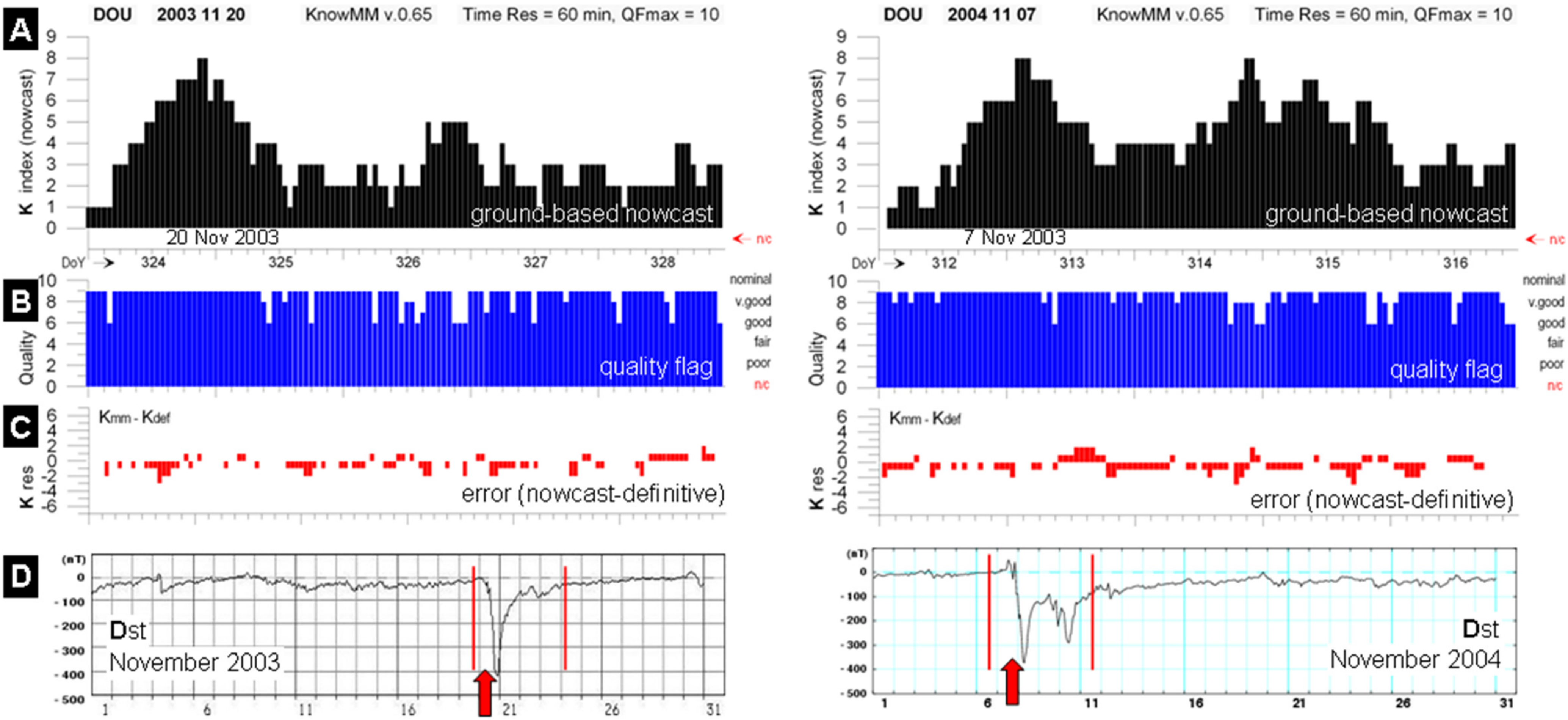




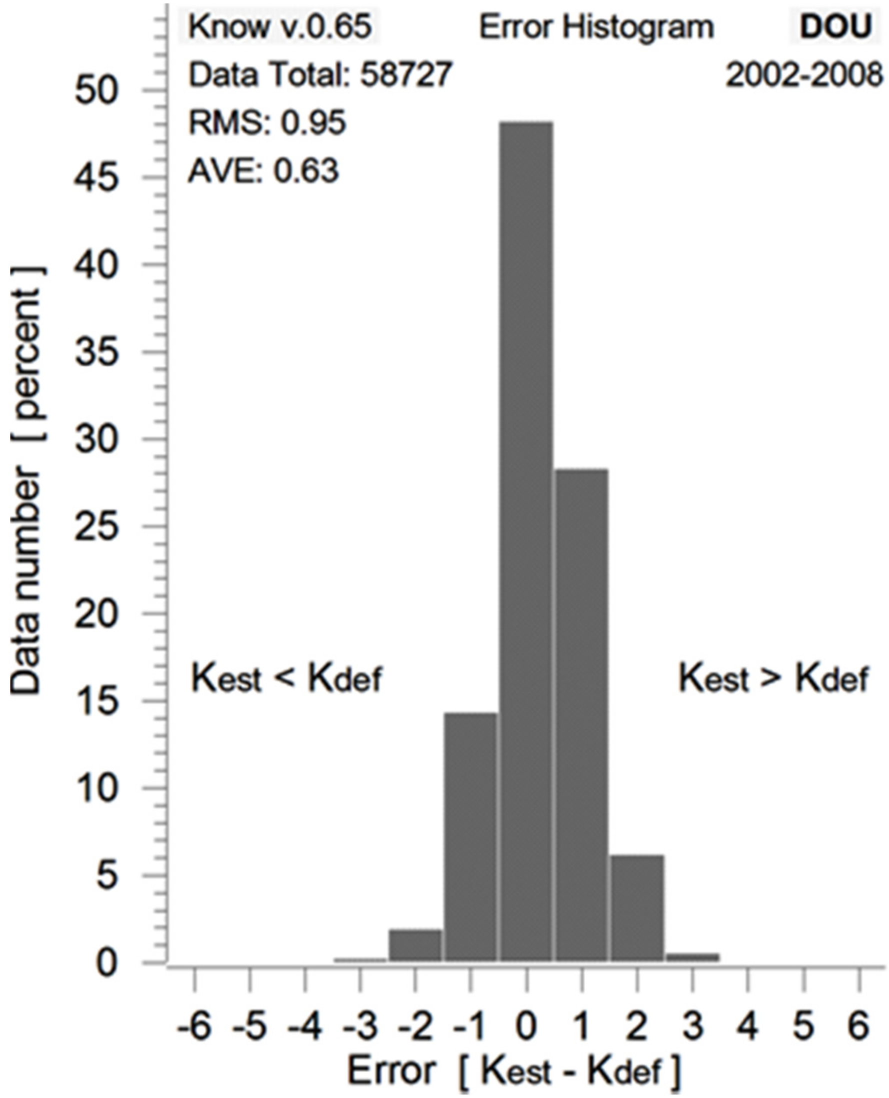
Royal Meteorological Institute

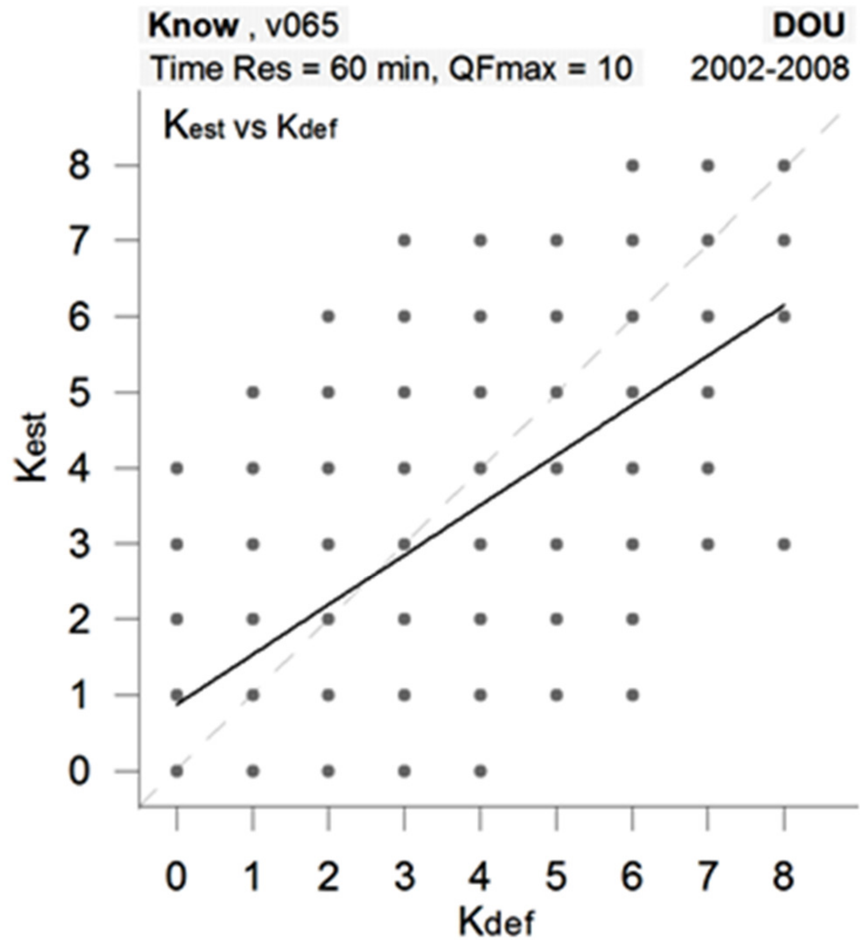
Nowcast (ground-based measurements)

STCE



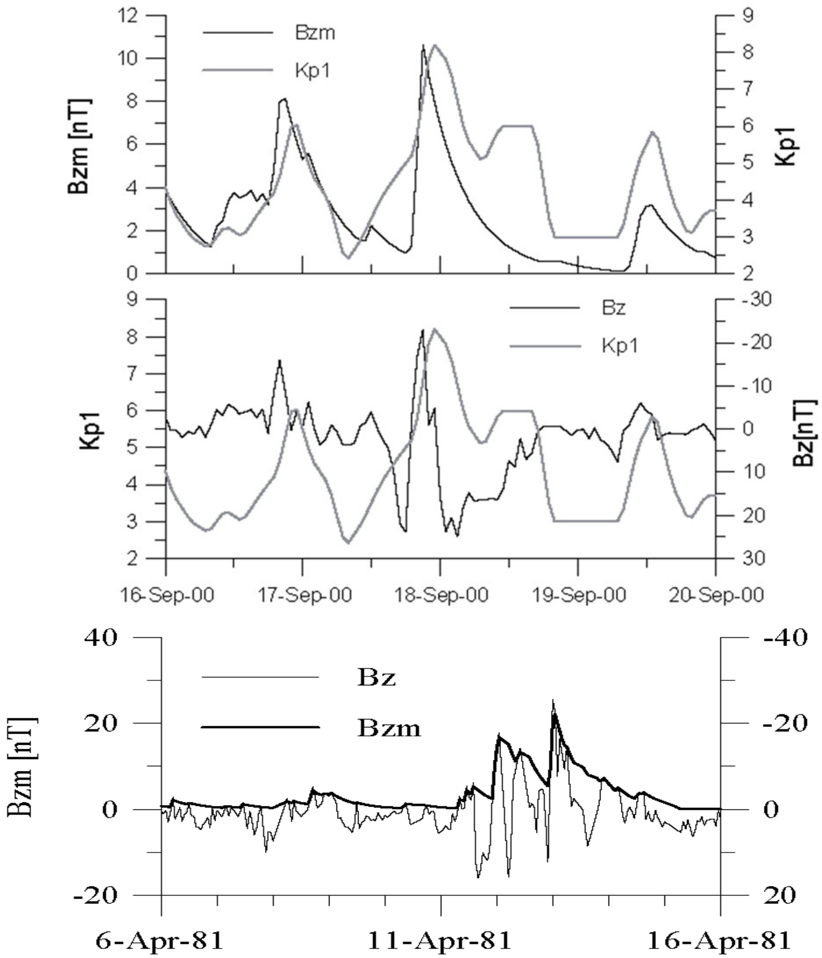
Nowcast (ground-based measurements)





A new (<u>space-based</u> observ's) algorithm for modelling & predicting the geomagnetic activity index

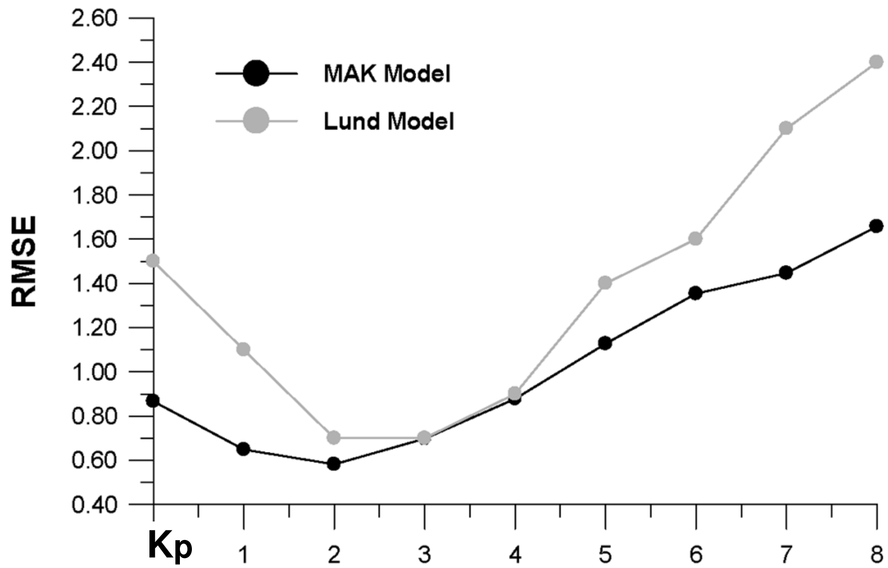
The **concept** is based on the assumption that the geomagnetic index K (also, Kp) can be presented as a **delayed reaction of the auroral ionosphere** to the solar wind-magnetosphere interaction.



A proxy index **Ksw** proposed, correlated with the ground-based K (Kp) index

$$Ksw = a_o + a_1 Bzm + a_2 P + a_3 V + a_4 Bzm^2 + a_5 P^2$$

Bzm – IMF Bz modified function
P – solar wind dynamic pressure
V – solar wind velocity



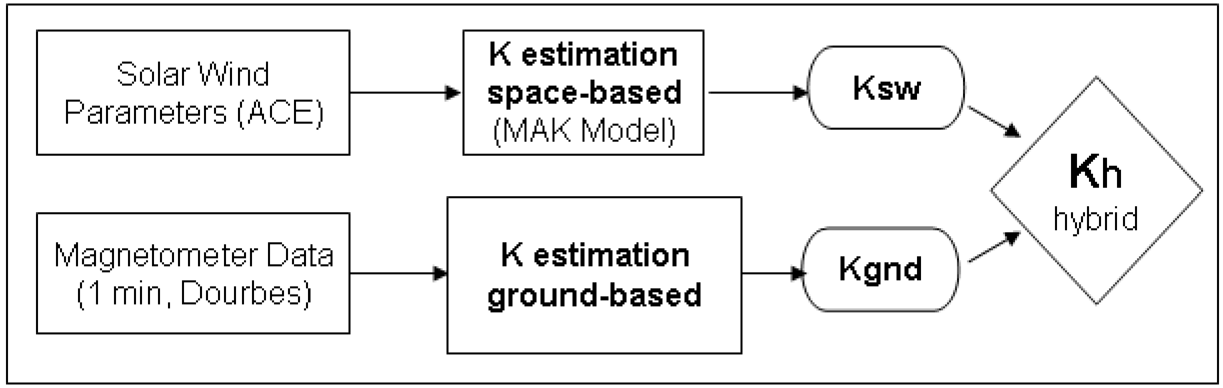
Andonov et al. (2004): Analogue model, relating Kp index to solar wind parameters. J. Atm. Terr. Physics, 66(11), 927-932.

Nowcast & Forecast (hybrid approach)

A new algorithm for modelling and predicting the geomagnetic activity index

The space-based estimate (Ksw) uses Advanced Composition Explorer (ACE) satellite data and an analogue model (MAK) relating the planetary geomagnetic index to solar wind parameters.

The ground-based estimate (Kgnd) uses magnetometer measurement data from the station in Dourbes to estimate the local geomagnetic index in real time.



Bzm – IMF Bz modified function
P – solar wind dynamic pressure
V – solar wind velocity

(space-based) **Nowcast** → $Ksw = a_o + a_1 B_{zm} + a_2 P + a_3 V + a_4 B_{zm}^2 + a_5 P^2$

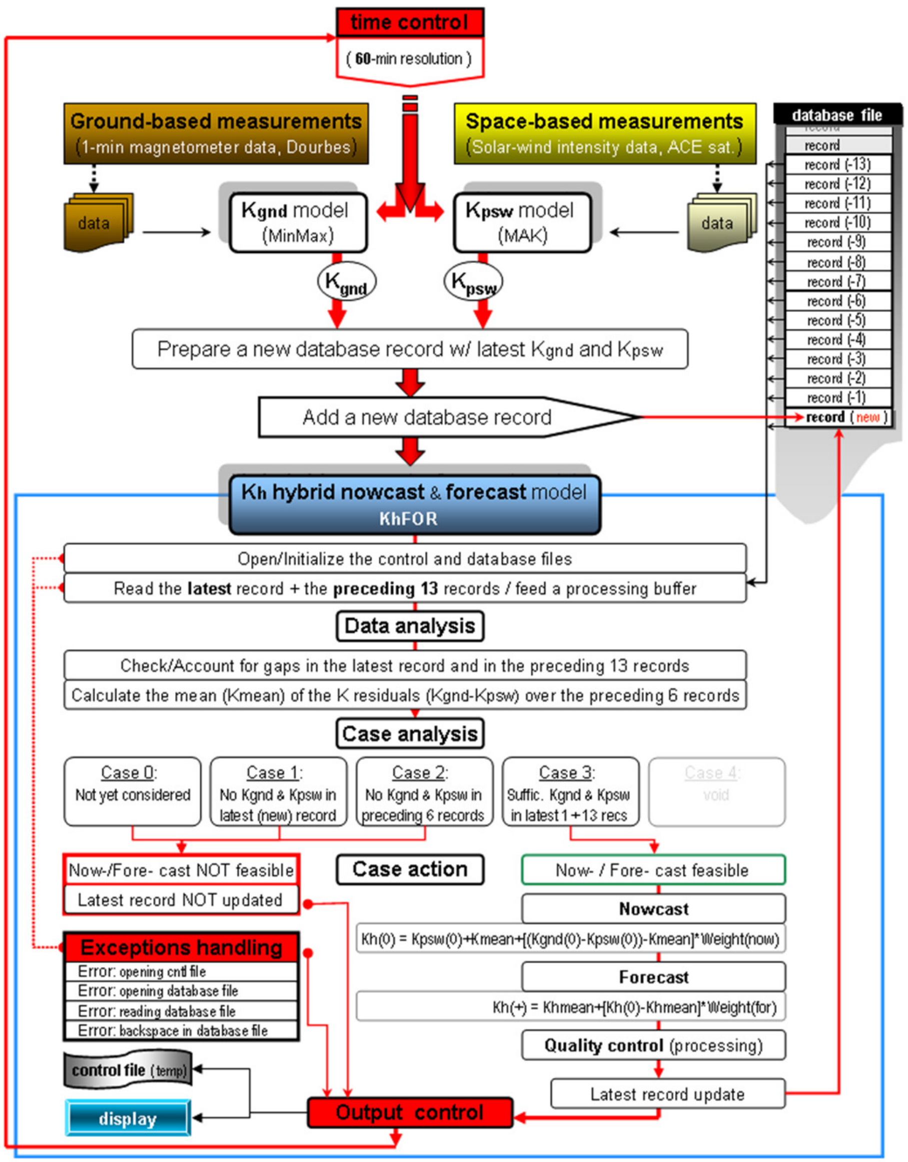
(hybrid) **Nowcast** → $Kh(0) = Ksw(0) + K_{mean} + [Kgnd(0) - Ksw(0) - K_{mean}] * \exp(-1/6)$

(hybrid) **Forecast** → $Kh(+\tau) = Kh_{mean} + [\, Kh(0) - Kh_{mean} \,] * \exp(-\tau/13)$

Note: The hybrid approach inherits the advantages of the space based concept with the robustness of the ground-based estimation of K

Source: Kutiev et al. (2009): Hybrid model for nowcasting and forecasting the K index J. Atm. Terr. Physics, 71, 589-596.

Nowcast & Forecast (hybrid approach) - Algorithm



Database Record Description / Legend:

1. CCYY - year (incl. century digits), integer [2001-unlimted) e.g. 2008
2. MM - month of year, integer [1-12]
3. DD - day of month, integer [1-31]
4. DOY - day of year, integer [1-366]
5. HH - hour of day, integer [0-23], Universal Time (UT)
6. MN - minute of hour, integer [0-59]
7. hhmin - time = HH+MN/60, real [0.00-23.99], Universal Time (UT)
8. Kgnd - K estimate (current-time) from ground-based (magnetogram) measurements
9. Kpsw - Kp estimate (current-time) from space-based (solar wind) measurements
10. Kh#0 - Kh (K hybrid) estimate for the current time UT
11. Kh#1 - Kh (K hybrid) estimate for the current time UT +1 hour ahead
12. Kh#2 - Kh (K hybrid) estimate for the current time UT +2 hours ahead
13. Kh#3 - Kh (K hybrid) estimate for the current time UT +3 hours ahead
14. Kh#4 - Kh (K hybrid) estimate for the current time UT +4 hours ahead
15. Kh#5 - Kh (K hybrid) estimate for the current time UT +5 hours ahead
16. Kh#6 - Kh (K hybrid) estimate for the current time UT +6 hours ahead
17. Q - quality of the estimates, integer [1-9], 1-highest, 9-lowest

Quality control (processing) :

0 Nominal (highest quality), complete input dataset
1 Very Good, 100%(last 1h) & 95%(last 3h) data available
2 Good, 95%(1h) & 75%(3h) data available
3 Good, 75%(1h) & 75%(3h) data available
4 Fair, 75%(1h) & 66%(3h) data available
5 Fair, 66%(1h) & 66%(3h) data available
6 Poor, 33%(1h) & 33%(3h) data available
7 Poor (lowest), <33%(1h) or <33%(3h) input data available
8 No quality assessment (K=-1), eg. last-hour data missing
9 No calculations performed (K=-1), technicalities

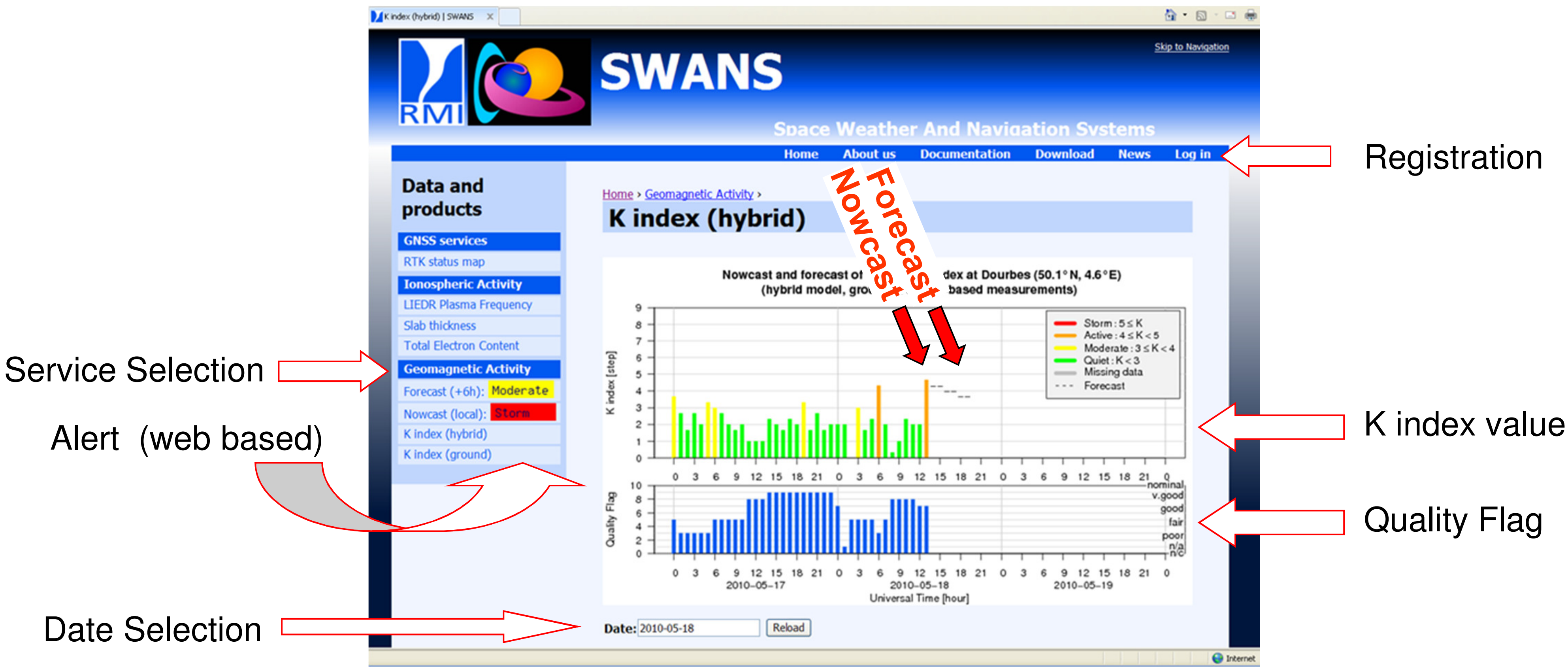
K-LOGIC - Local Operational Geomagnetic Index K Calculation

Service Type:

- Nowcast: update – every 60 min, latency less than 3 min after the hour mark
- Forecast: update – every 60 min, forecast time horizon – up to 6 hours ahead

Service Output:

- K index value - data files (ASCII), plots
- Quality Flag (QF) – data acquisition and processing quality assessment
- Alerts – web (verbose & colour code), email



http://swans.meteo.be/geomagnetism

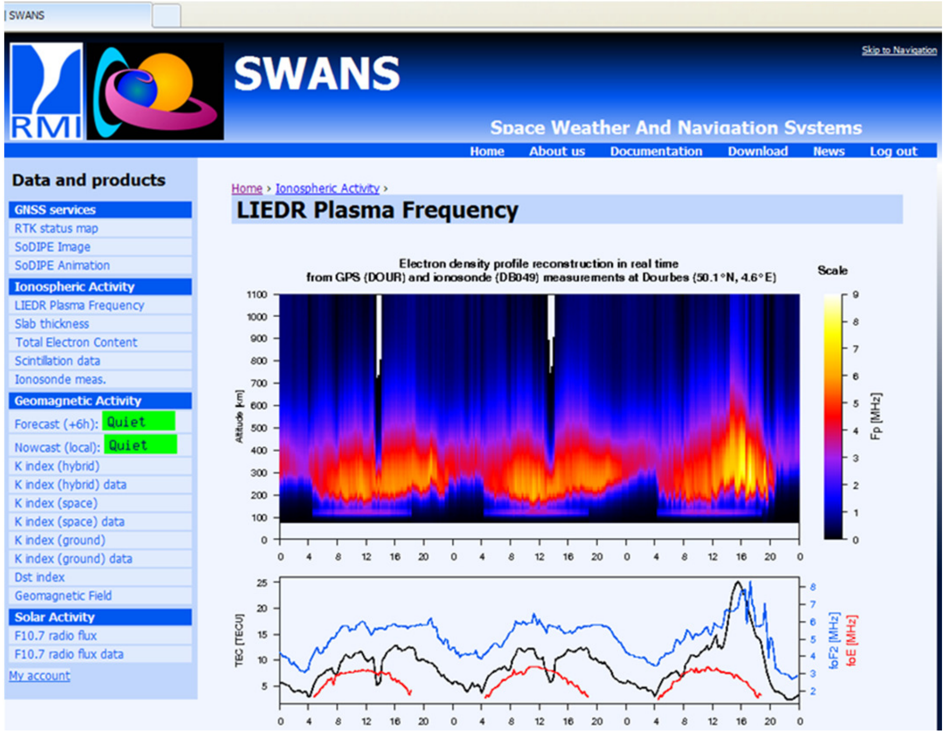
Outline

- Introduction
- Geomagnetic indices (most frequently used)
- K-LOGIC (Local Operational Geomagnetic Index K Calculation)
- LIEDR (Local Ionospheric Electron Density Profile Reconstruction)
- Summary and Outlook

LIEDR – Local Ionospheric Electron Density Reconstruction

Objective: **Ionospheric plasma density specification in real time**

Development of operational procedure for reconstruction of the local ionospheric electron density distribution on a real-time basis using GNSS and vertical incidence sounding measurements.



Developments – procedure and service:

Type – operational nowcast
Output – ionospheric plasma density/frequency
Altitude range – from 90 to 1100 km
Time resolution – 15 min
Latency – less then 3 min

Applications:

Research, verification of ionospheric models, ionospheric tomography, etc.

Stankov et al. (2003): A new method for reconstruction of the vertical electron density distribution in the upper ionosphere and plasmasphere. Journal of Geophysical Research, 108(A5), 1164, doi:10.1029/2002JA009570.

Ionospheric plasma density specification in real time

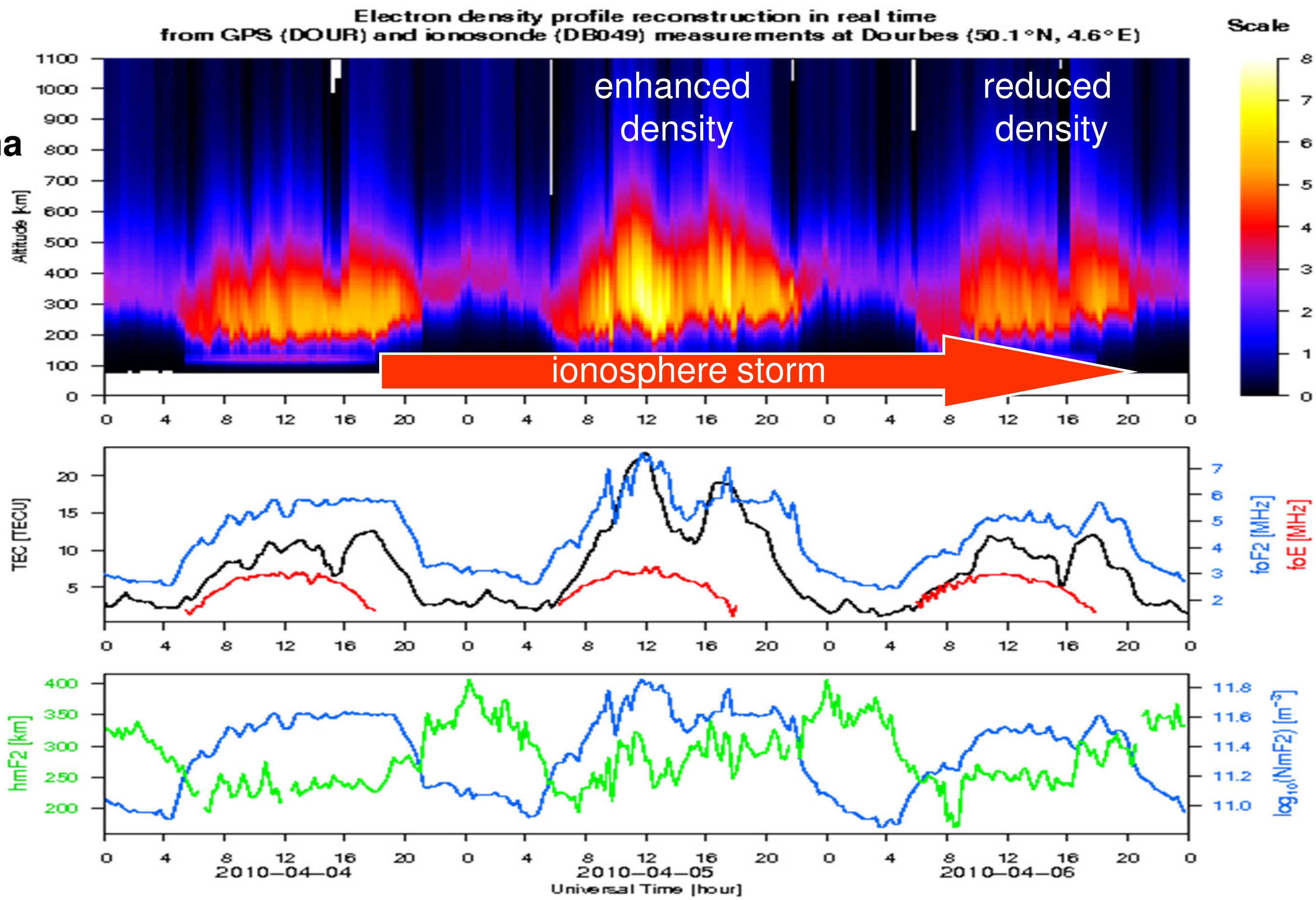
Development:

Type – operational nowcast, Output – ionospheric plasma density/frequency, Altitude range – from 90 to 1100 km, Time resolution – 15 min, Latency – less then 3 min.

Ionosphere Plasma Frequency

Ionosphere Total Electron Content (TEC)

Ionosphere peak density altitude (hmF2)



$$f_p[MHz] \approx c_p\, N_e^{0.5}[el/m^3]$$

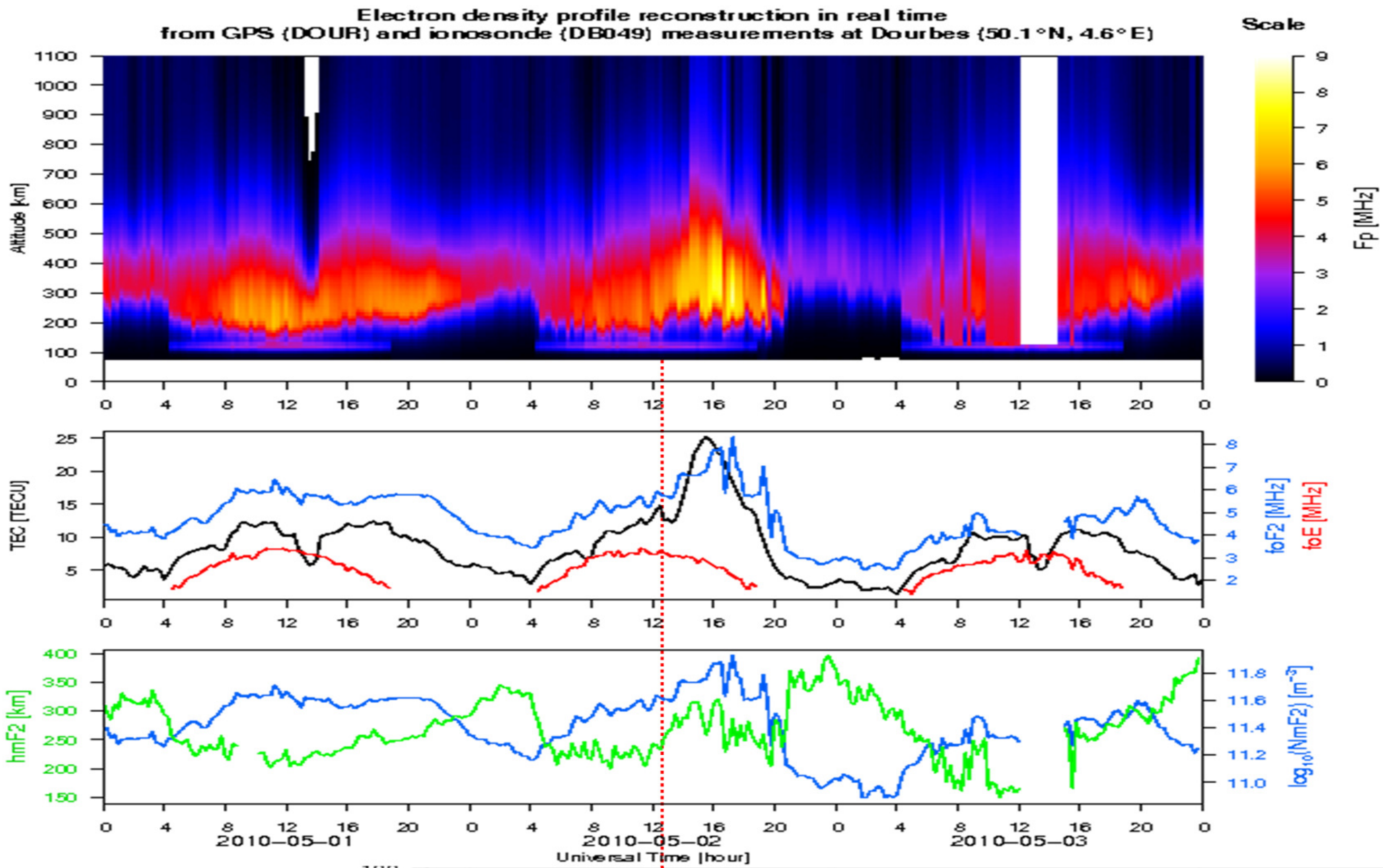
$$c_p = 0.898 \times 10^{-5}$$

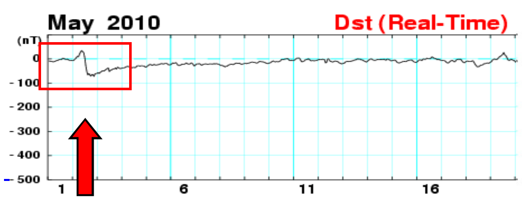
Ionosphere Critical Frequencies (F2 layer - foF2 , E layer - foE)

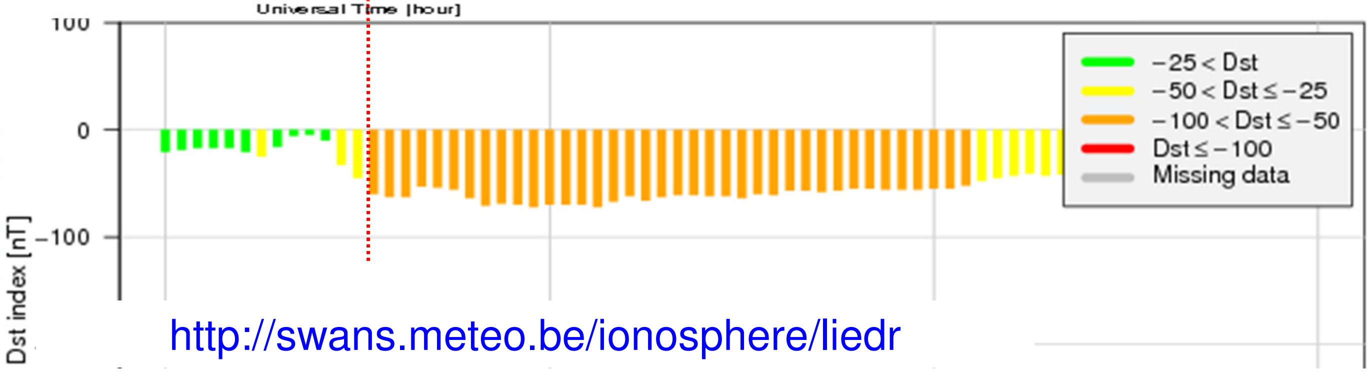
Ionosphere Peak Density (NmF2)

http://swans.meteo.be/ionosphere/liedr

LIEDR – Local Ionospheric Electron Density Reconstruction







http://swans.meteo.be/ionosphere/liedr

Outline

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Summary

- Geomagnetic activity specification and availability - important for geomagnetic and ionospheric research
- K-indices are relatively good representatives of large-scale ionospheric disturbances, particularly at middle latitudes
- However, the 3-hour time scale is much too large for the characteristic time of small-scale ionospheric variations/phenomena
- Local K index derivation from magnetogram records is specific for each magnetic station (e.g. differences b/w stations in the limits of classes)
- Kp index is not the optimal index for geomagnetic storm description -- storm effects on technological systems depend predominantly on location, time, and system configuration
- Local K index specification, nowcast and forecast is crucial for high-end GNSS-based applications.

Outlook

- New, local K estimation procedure w/ ground-based measurements implemented -- quality improved
- New, space-based measurements utilized for proxy K index specification -- implemented
- New, hybrid (ground & space based measurements) forecast technique developed -- implemented
- New, Alerts - should be issued / based on high-quality K estimates only -- developed

- Further work – to test various approaches for estimating the S_R variations, implement if better
- Further work – to improve service integrity, research, tests, comparisons, validations (incl. determination of the extent of the geographic area to be serviced)
- Further work – to improve time resolution (5-15 min now considered optimal)
- Further work – to improve the alert system (flexibility, user specific, dissemination)